Keeping the grasslands growing

Grasslands are among the most extensive and heavily exploited environments in the world. The work of **Professor Mark Ritchie** of Syracuse University, New York, USA, explores how plants, animals and microbes interact within these complex ecosystems, and how they can be managed sustainably for local stakeholders and to mitigate global climate change.

Grasslands are thought to cover up to 40% of the earth's terrestrial surface and contribute to the livelihoods of some 800 million people – over ten percent of the world's population. They are also key carbon sinks (able to absorb carbon dioxide from the atmosphere), which could be harnessed to help mitigate climate change. Indiscriminate grazing of livestock on grasslands may degrade supplies of soil carbon and nitrogen, causing spiralling losses of biodiversity and productivity. Prof Ritchie's research seeks to prevent this by exploring the network of interactions between plants, animals, humans and other organisms in grassland ecosystems, and by finding ways in which they can best work together.

Grasslands – including steppe, savanna and pampas – may look like relatively simple communities but their appearance belies the complexity beneath the soil surface. Many occur on poor soils, low in essential nutrients, but support higher-than-expected rates of productivity. Prof Ritchie's latest project focuses on how carbon and nitrogen from the atmosphere are fixed into the soil by plants and microorganisms, contributing to grasslands' extraordinary plant growth and more fertile soils.

Focusing on the Serengeti National Park in Tanzania, East Africa – and building on a long history of ecological research there – his three-year, National Science Foundation-funded project aims to elucidate how wild and domesticated grazing animals, rainfall, and the chemical composition of grassland soils all interact to shape the key processes of nitrogen fixation and carbon storage.

NUTRIENTS FROM THE AIR

Nitrogen is a key component of amino acids, the building blocks of life. This relatively inert molecule enters the web of life when it is 'fixed' by bacteria, living freely in the soil or associated with plant roots, into usable, soluble compounds such as ammonia. In many ecosystems, plant productivity is effectively limited by nitrogen availability and the activity of these nitrogen 'fixers'.

Nitrogen-fixing bacteria have long been linked with certain groups of plants, particularly legumes (Fabaceae, the pea and bean family), with which they form a mutually-beneficial ('symbiotic') relationship. However, Prof Ritchie's recent research has shown that nitrogen-fixing bacteria may also form symbiotic relationships with grass roots in the Serengeti.

By measuring the activity of bacteria that possess the particular gene that facilitates nitrogen fixation, Prof Ritchie showed that nitrogen fixation by the dominant grass species of the Serengeti, *Themeda triandra*, was often similar or even greater than that of the dominant legume species, *Indigofera volkensii*. He concluded that grasses host 'abundant, active bacteria that can fix large amounts of nitrogen' – potentially far more significant than previously recognised.

A COMPLEX SYSTEM

Prof Ritchie believes that grassland soils harbour a complex community of plants, fungi, multiple types of nitrogen-fixing bacteria and other soil microbes, that in turn are modified by grazing, rainfall and the availability of other soil nutrients. His latest project aims, for the first time, to tease out the interactions between all these factors, in order to design management systems that maximise

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the sustainability and productivity of fragile grassland ecosystems. The project will achieve this, firstly, by gathering more detailed information on the rate of nitrogen fixation by bacteria associated with multiple grass species in large scale field plots covering a range of natural conditions.

Crucially, grass-associated nitrogen-fixing bacteria may be affected differently by environmental factors than legume-associated and free-living bacteria, which may have important implications for the sustainable management of grassland ecosystems. Therefore, the second aim of the project is to test experimentally how grass- and legume-associated bacteria respond to grazing, water, and soil chemical composition.

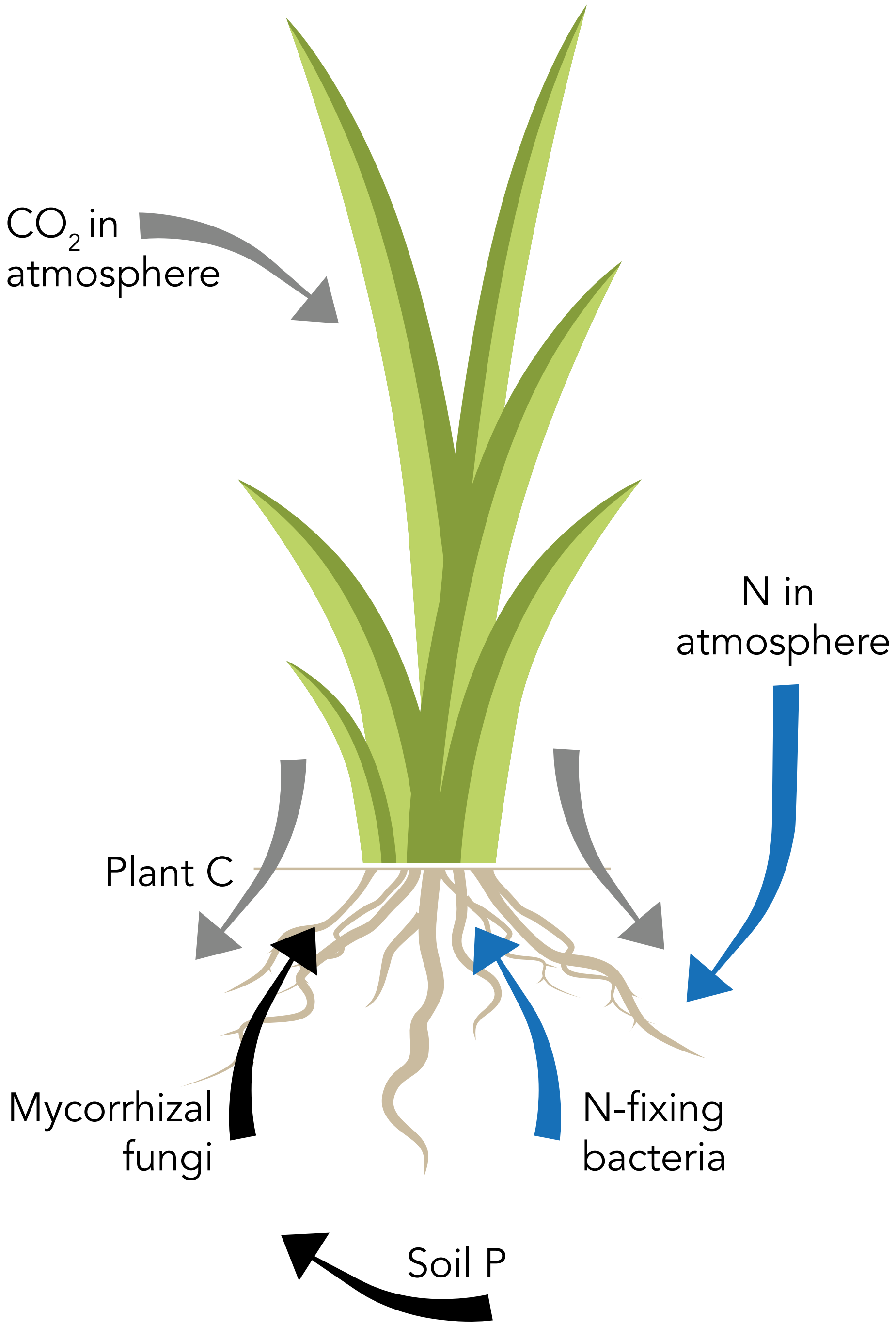
The team will also conduct experiments to test for competition between bacteria and widespread plant root-associated fungi known as 'mycorrhiza'. Prof Ritchie believes it is possible that these otherwise beneficial fungi compete with nitrogen-fixing bacteria for nutrients supplied by their host plants and thus impact negatively on bacterial nitrogen-fixation.

Based on these empirical data, the team will then develop a computer model to integrate the effects of rainfall, grazing, competition with mycorrhizal fungi, and nutrient limitation on nitrogen-fixation, carbon storage and grass productivity. The model will show how nitrogen-fixing bacteria and fungi can affect the role of grasslands as carbon sinks, and how this could be manipulated by changes in grazing regime and vegetation management.

MANAGING FOR SUSTAINABILITY

Preliminary results from the study suggest that plant growth in the Serengeti grasslands is limited by both water and nutrients, including nitrogen. Prof Ritchie proposes that the bacteria associated with grass roots may be the most important source of nitrogen in many tropical and subtropical grassland ecosystems, and therefore may be crucial to productivity, ecosystem services, and the human livelihoods that depend on these ecosystems. He also suggests that the fixation associated with grass species is less susceptible to interference by grazing mammals than that associated with legume species.

However, the impact of grazing herbivores is complex, including both negative (destruction of plant material) and positive (fertilisation via dung) impacts on grassland productivity, soil



carbon storage and sustainability. Results thus far extrapolated from sites in the USA and Europe suggest that maintaining a diverse community of grazing species may enhance plant diversity, depending on their natural impact. Systems of migrating domestic herbivores, mimicking the natural grazers of the Serengeti, also promote the health of grasslands in terms of plant diversity, soil carbon storage and soil fertility.

Prof Ritchie's overarching aim is to translate his empirical research and theoretical models into real practices for protecting and enhancing grassland communities, supporting the human livelihoods that depend upon them, and mitigating climate change by restoring carbon sinks. He is already working with over 40 local human communities in Tanzania and Kenya, supported by The Nature Conservancy and other non-governmental organisations, to introduce new livestock and fire management practices. This will not only improve sustainable livestock production, but will also help retain soil carbon and potentially generate income for communities from the sale of 'carbon credits'. Working with the natural characteristics of grassland ecosystems in this way can be of benefit to plants, animals and humans, and Prof Ritchie's work is helping to uncover those characteristics.

Q&A

How did you come across the novel idea that there may be nitrogen-fixing bacteria associated with grass species as well as the more widely-known legumes?

My collaborator Nancy Johnson pointed out that rice and grasses grown for biofuel production had recently been shown to harbour nitrogen-fixing bacteria, so we thought we would check to see if such bacteria were abundant and active in a natural grassland ecosystem.

How do you manage to tease apart the influences of so many factors (plants, animals, humans, microbes, climate, soil composition, etc.)?

First, we begin with experiments to eliminate some factors, such as fences to exclude grazing animals and sterilising soil to exclude microorganisms. Then we do these experiments across a range of soil, fire frequency, rainfall and intensity of grazing conditions. These comparisons are made possible by the tremendous natural laboratory that is the Serengeti, which features extremely nitrogen-poor and phosphorus-rich to extremely phosphorus-poor soils, climates from near-deserts to wet enough to support forests, and a range of fire histories. Then we make predictions about how human-dominated systems might work and compare these with actual data from outside the park.

How can computer modelling help us to understand and manage real ecosystems such as grasslands?

When multiple factors affect important measures like productivity and carbon storage, computer models with as much real-world data as possible help understand how these factors compare in their importance. We can also make predictions about nitrogen and carbon in plants and soils under different conditions, such as under sustainable livestock grazing, which currently do not exist. Agreement between models and data, such as happened for soil carbon in pastoralist livestock-dominated grasslands in Kenya, encourages people that they can achieve healthier lands if they change their management.

How do the grasslands of the Serengeti differ from those you have studied elsewhere in temperate climes? Can your results be extrapolated or does each system have to be studied individually?

90% of what humans know about grasslands has come from intensive studies in the Great Plains of North America, pastures in Europe, and livestock-dominated grasslands in China and Mongolia. Tropical grasslands are severely understudied and are dominated by very different grass and other plant species than are found in cooler climates. The Serengeti and other African grasslands I've studied appear to have higher densities of soil microorganisms and much lower mineral nutrient content, so plants may be more likely to benefit from associating with these microorganisms.

Do you think it is possible to develop sustainable management regimes that are easily translated into practice in the field?

Absolutely, this is already happening in northern Kenya, where degraded rangelands have very slowly started to recover after three years of a Serengeti-inspired plan of moving and migrating livestock to allow grass to rest from grazing when soil moisture is available. These changes in management were motivated by a model of changes in soil carbon developed from our Serengeti research.

Our experiments and comparisons are made possible by the tremendous natural laboratory that is the Serengeti

Detail

RESEARCH OBJECTIVES

Dr Ritchie's research focuses on biodiversity, plant–herbivore interactions, and environmental science. His latest research investigates the contributing factors behind nitrogen fixation in areas of poor quality grasslands, such as the Serengeti National Park.

FUNDING

National Science Foundation (NSF)

COLLABORATORS

- Dr Nancy Johnson, Northern Arizona University
- Dr Geofrey Soka, Sokoine University of Agriculture, Tanzania

BIO

Dr Ritchie is an ecologist with worldwide experience. He grew up in Texas, USA where he developed a keen interest in grassland and savanna ecosystems, and later learned the power of mathematics in understanding nature. His research now is focused on ecosystem function and sustainable grazing in East Africa.

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