Modelling integrated Carbon-Nitrogen-Phosphorus cycling in natural and agricultural systems – the sustainability of long-term agriculture

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Abstract

The cycling of carbon within the earth system is intrinsically linked with major nutrients, notably nitrogen and phosphorus, due to the tendency of these elements to limit the productivity of terrestrial ecosystems. To understand the response of the carbon cycle to global change pressures, models must integrate Carbon-Nitrogen-Phosphorus cycles. Whilst such models exist, to-date these have focused on natural and semi-natural ecosystems. Agriculture results in significant modification to natural biogeochemical cycling, and currently represents approximately 37% of land-use. With the projected increase in global food demand over the 21st century, this area is expected to increase. It is therefore critical to understand and simulate biogeochemical cycling in both natural and agricultural systems, and the transition between these, to estimate ecosystem response to environmental change. In this study we present an integrated C-N-P model including both natural and agricultural temperate ecosystems. The N14CP model has been developed to include representation of both arable and grassland systems, with the inclusion of agricultural management practices such as fertilizer application, crop removal, grazing and yield estimation. The model has been tested both spatially and temporally using a range of long-term experimental sites across Northern-Europe, and applied at both local and national scales. We use the model to assess impacts of land-use change and management on long-term nutrient cycling, and discuss the implications of this for sustainable agriculture and ecosystem functioning.

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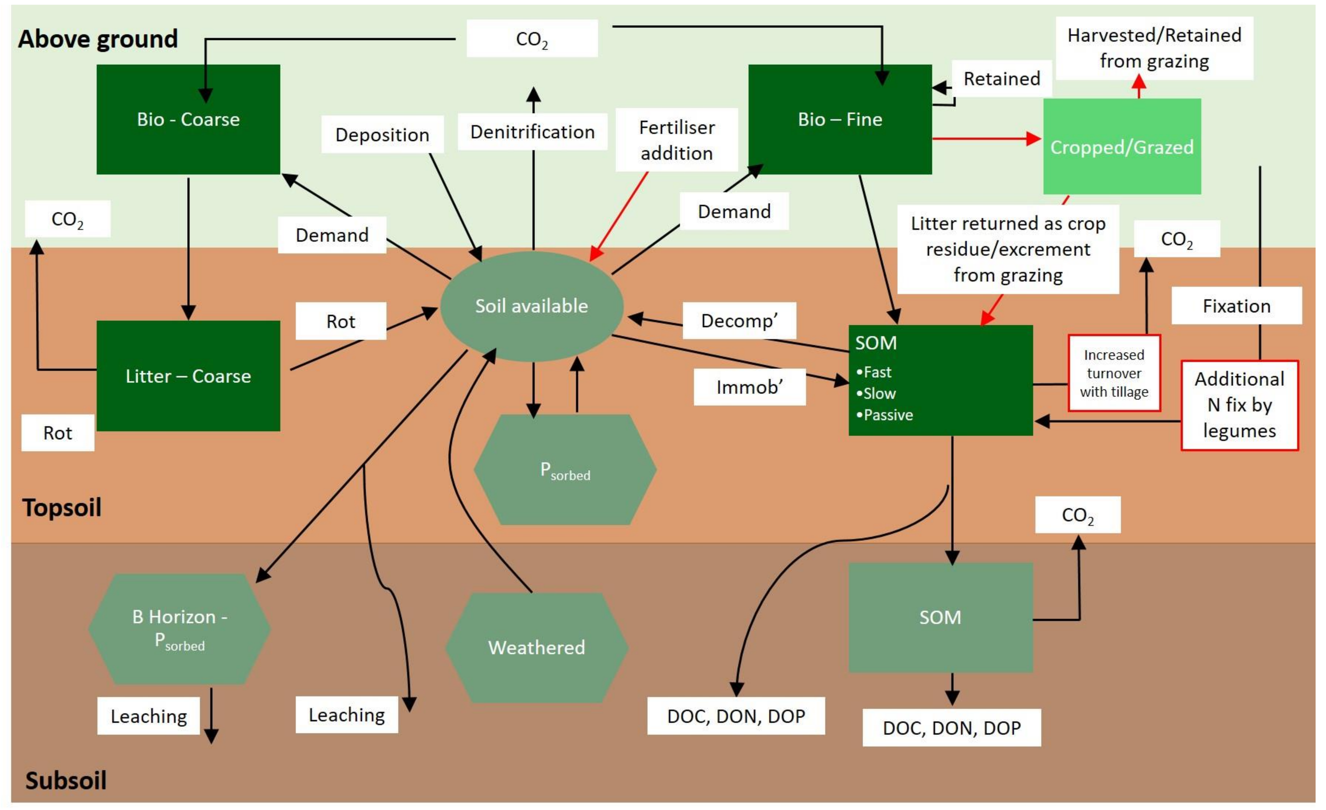
Introduction

Biogeochemical cycles of carbon, nitrogen and phosphorus (C, N and P) are tightly coupled, and have been significantly altered during the Anthropocene through atmospheric pollution, land use change and management practices. These changes have significant implications for food security, climate change, water quality and biodiversity.

Here we present a plant-soil model of integrated C-N-P cycling in both natural and agricultural environments, with the ability to simulate long-term nutrient change at large spatial scales.

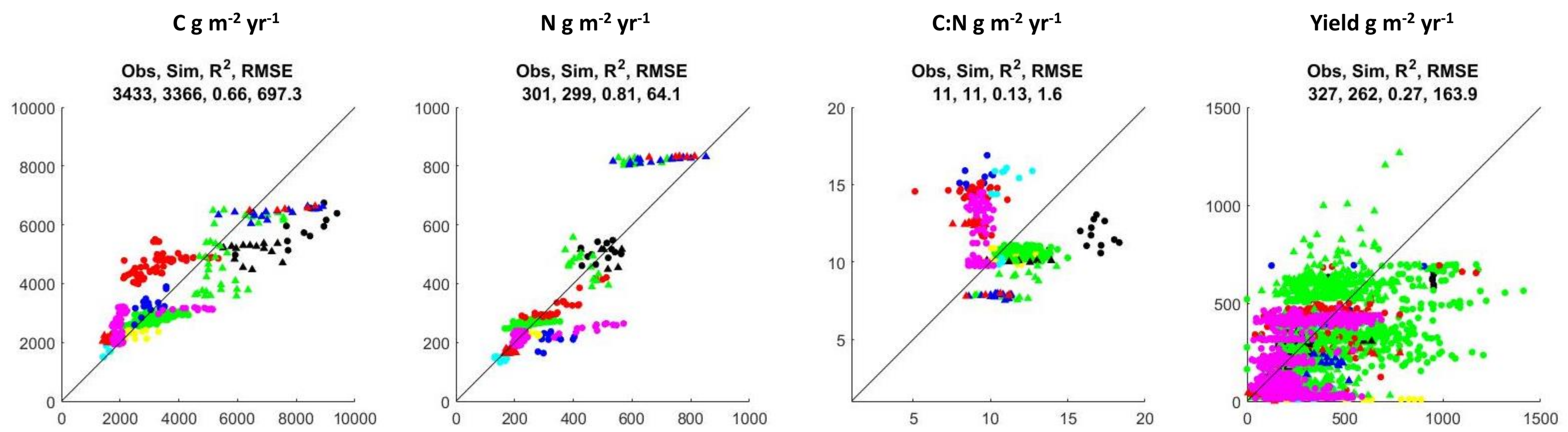
N14CP model

Existing C-N-P models mainly focus on natural ecosystems. Here we developed the N14CP model[1] to simulate both natural and agricultural land uses and transitioning between these. The new N14CP-Agri model[2] includes crop yield estimation, N fixation by legumes, and representation of practices such as fertilizer input, cropping, tillage, grazing. Plant types cereal, legume, root, and oilseed have been incorporated within the model. The model uses widely available input data and does not require site specific calibration.

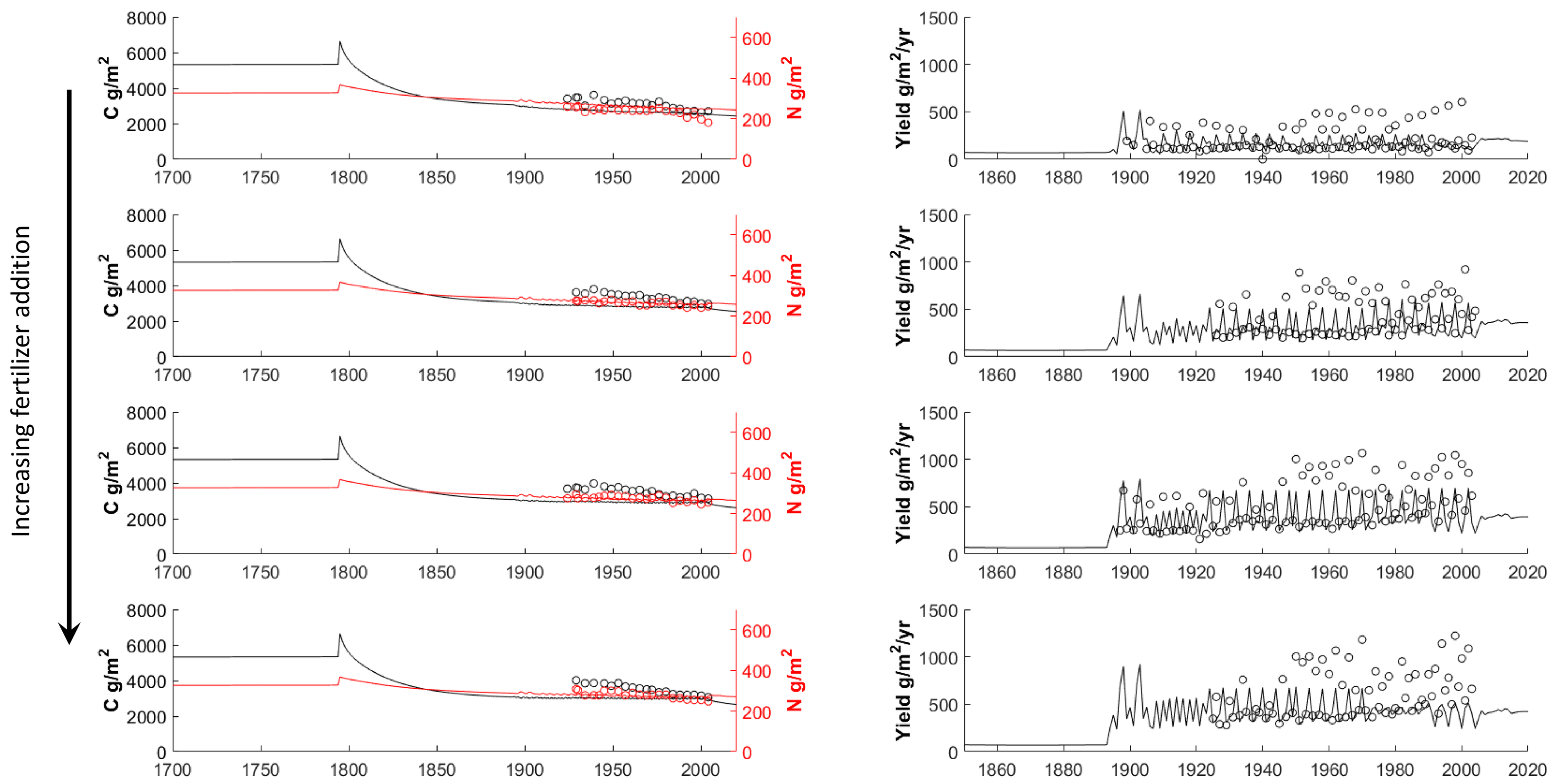


Model Performance

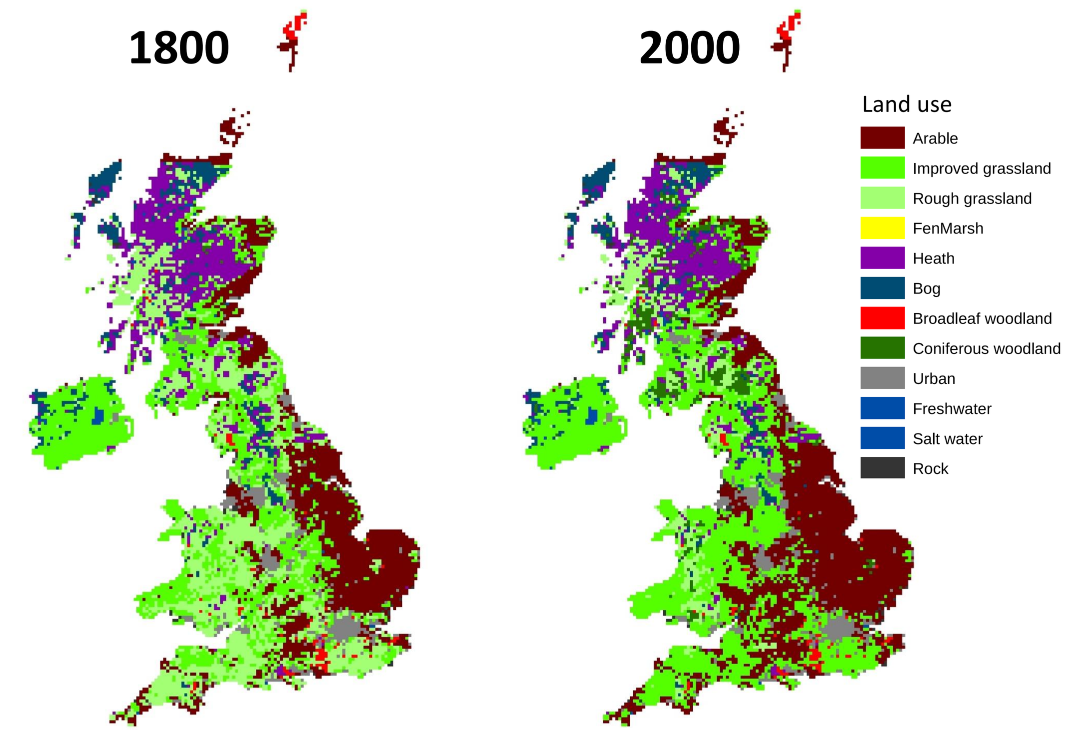
Model outputs were compared with observational data from 62 plots at 11 long-term agricultural experimental sites covering a range of management practices. Key output variables (topsoil C, N, and dry matter yield) show statistically significant (p<0.001) relationships between observed and simulated values.

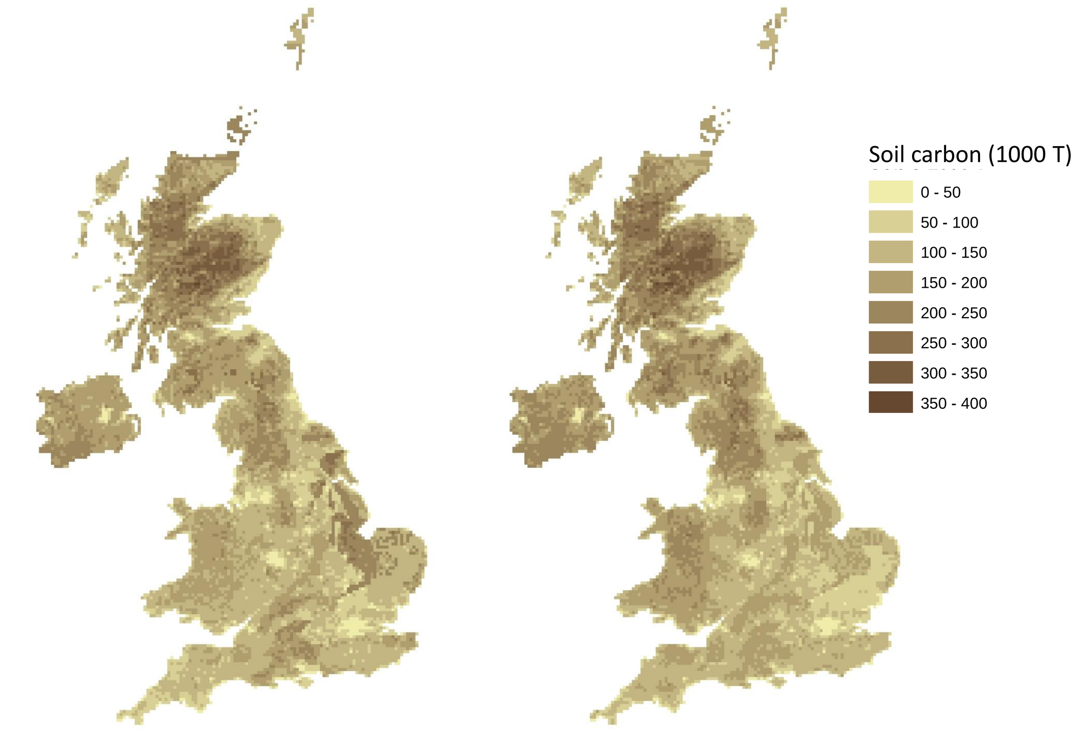


The model was also evaluated temporally; the figure shows an example of time series performance at an arable site with a crop rotation. The model simulates the magnitude of soil C and N, temporal trends, and the impacts of the fertilizer treatments on soil C and N pools with reasonable accuracy.



Long-term nutrient change - UK soils





The model has been applied across the UK at a 5km x 5km grid scale to simulate the Anthropocene using historical reconstructions of climate and land use. Since 1800 arable and improved grassland areas in the UK have increased by 45 and 15% respectively.

Results indicate a decrease in topsoil soil carbon in arable areas, (average -13%) and improved grasslands (-2%). Nitrogen deposition and increased NPP has increased topsoil carbon across natural land uses (+13%) as has been observed previously[3]. Total UK topsoil carbon stocks have increased by approximately 32,000 kT (+2.4%).

Conclusions

The results demonstrate the combined effects of atmospheric pollution and land use change on soil C storage at a national scale; whilst agriculture has resulted in a loss of soil C, to-date this is mitigated by N deposition. The results further support the need for integrated nutrient cycling within models.

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