Modelling tropical forest responses to elevated CO_2 in a nutrient-limited environment: JULES simulations at the AmazonFACE site

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The AmazonFACE Experiment

- Increased levels of atmospheric CO_2 are expected to have a fertilising effect on vegetation, increasing productivity from photosynthesis, and reducing transpiration so plants are less limited by water availability
- However, the size of this fertilising effect needs to be measured since vegetation productivity is also limited by nutrient availability so that the effect may not be as great as expected
- The AmazonFACE experiment, set up near Manaus, will subject small areas (30 x 30m) of old growth rainforest to enriched CO_2 (+200 ppmv) to determine the response of vegetation
- In areas such as Manaus the soil is known to be poor in Phosphorus
- This experiment joins BIFoRFACE in the UK and EucFACE in Australia, all examining the responses of vegetation to enriched CO_2

The AmazonFACE site near to Manaus

Brazil Ministry of Science, Technology and Innovation

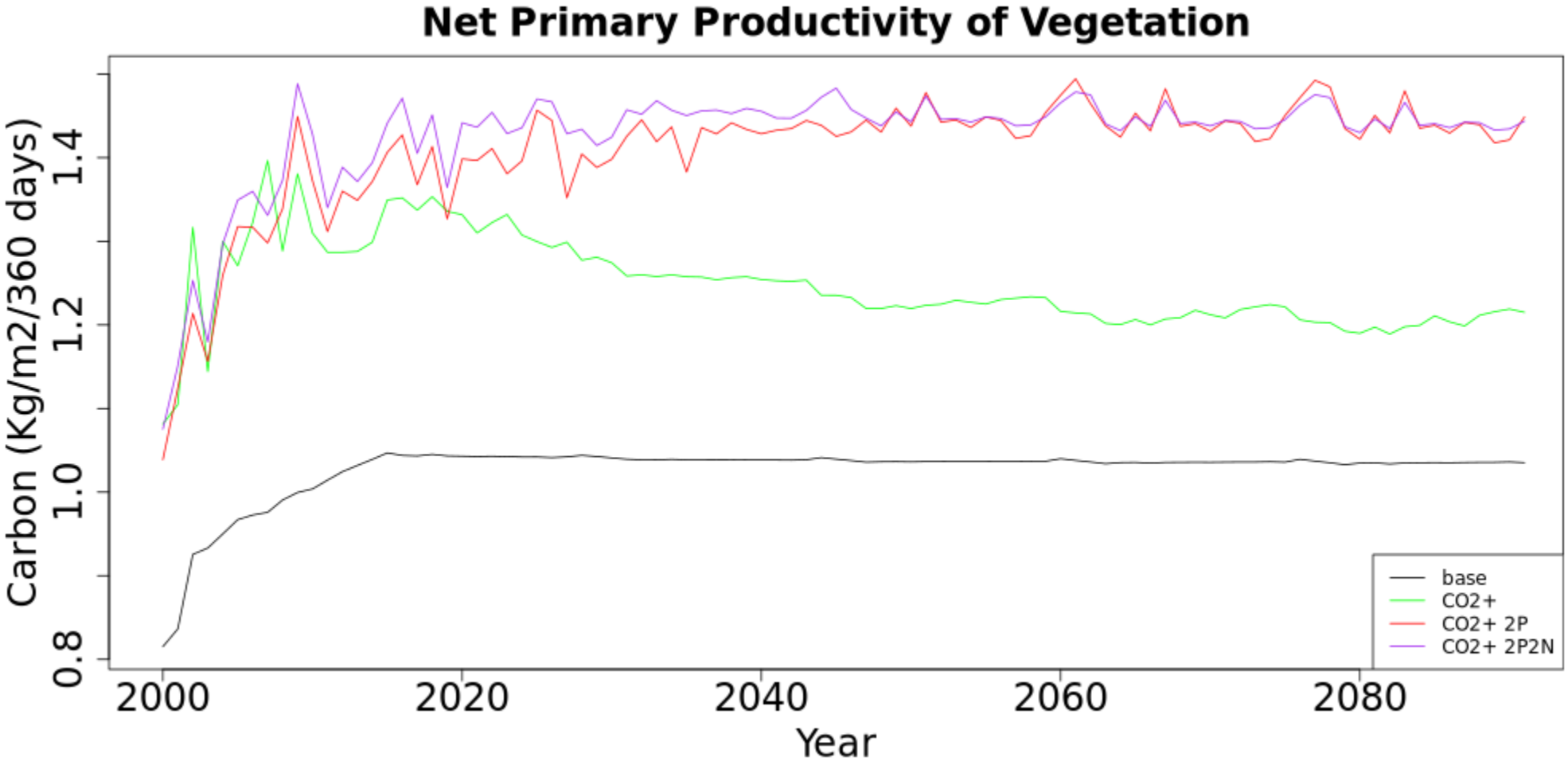
The JULES-CNP Land Surface Model

- A new version of JULES, the land surface scheme of the UK Earth System Model, has been developed to include Phosphorus chemistry connected to the previously developed Carbon and Nitrogen chemistry (Navhavali et al. 2022, and the code is now in JULES suite dk173)
- Vegetation growth is limited by Phosphorus availability, taking inorganic Phosphorus from the soil and losing organic Phosphorus to plant litter
- JULES-CNP is presently set up to examine vegetation near Manaus, and uses the measured soil properties and quantities of Phosphorus and Nitrogen obtained from a nearby project in the Amazon
- Fleischer et al. 2019 has already employed a number of land surface models with CNP chemistry to examine Phosphorus limitations on CO_2 fertilization for AmazonFACE, but JULES-CNP was not available then

Simulations using JULES-CNP in this study

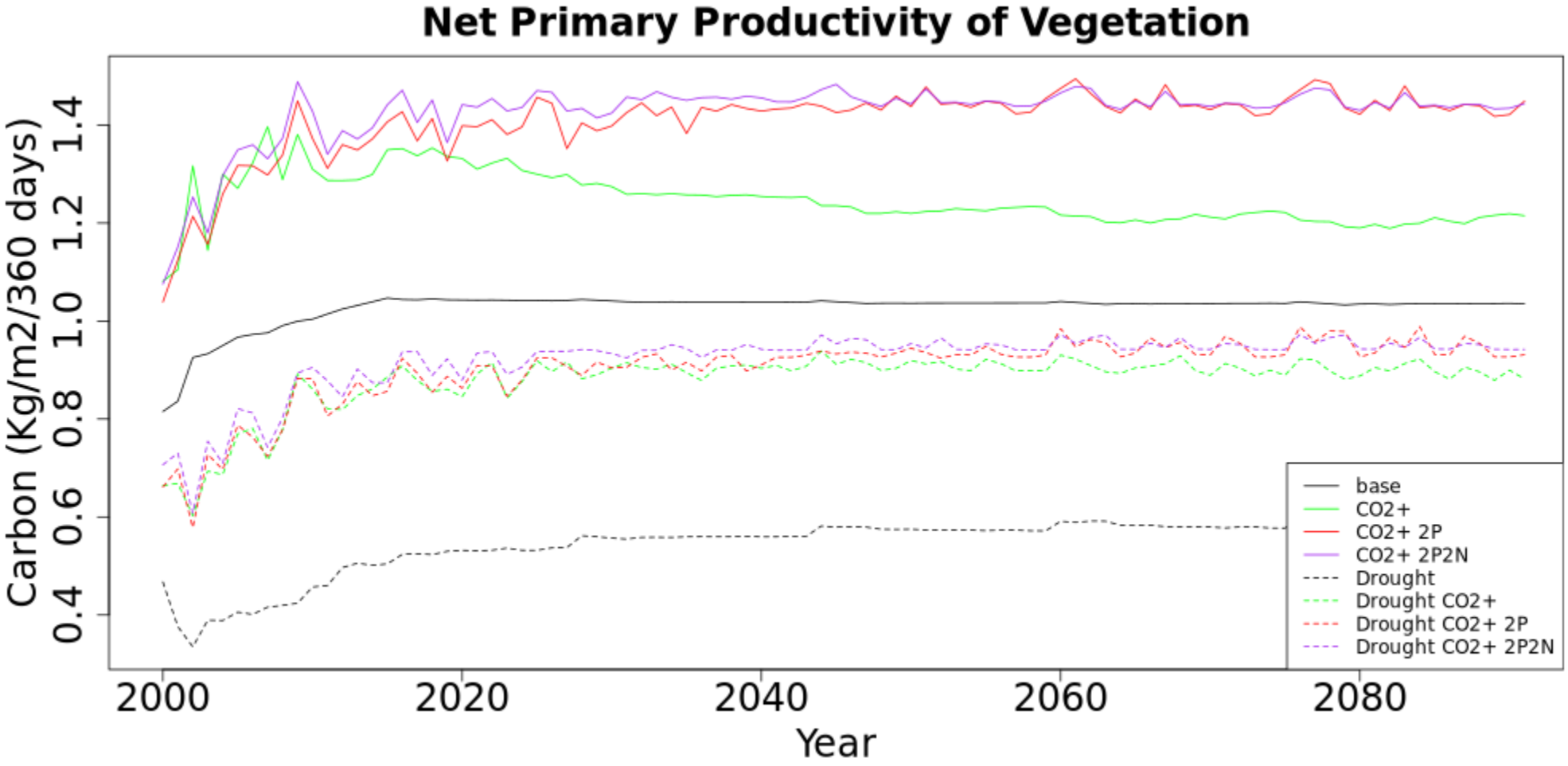
- JULES-CNP was driven by 16 years of meteorological data (2000-2015) measured near Manaus by the K34 flux tower
- Use measured CO_2 (370 ppmv in 2000 to 403 ppmv in 2015) or use enriched CO_2 (measured values +200 ppmv)
- Simulations for 2000-2090 by looping over the meteorological data and having constant CO_2 after 2015 (not examining climate change)
- Use the measured values of Phosphorus and Nitrogen in the soil, or use doubled Phosphorus and/or doubled Nitrogen (so no nutrient limitations) to determine how the model vegetation is nutrient limited
- Use the precipitation values in the driving data, or simulate drought conditions by reducing precipitation by half, though with enriched CO_2 plants can conserve water and reduce the effects of drought

Vegetation Productivity in Different Simulations



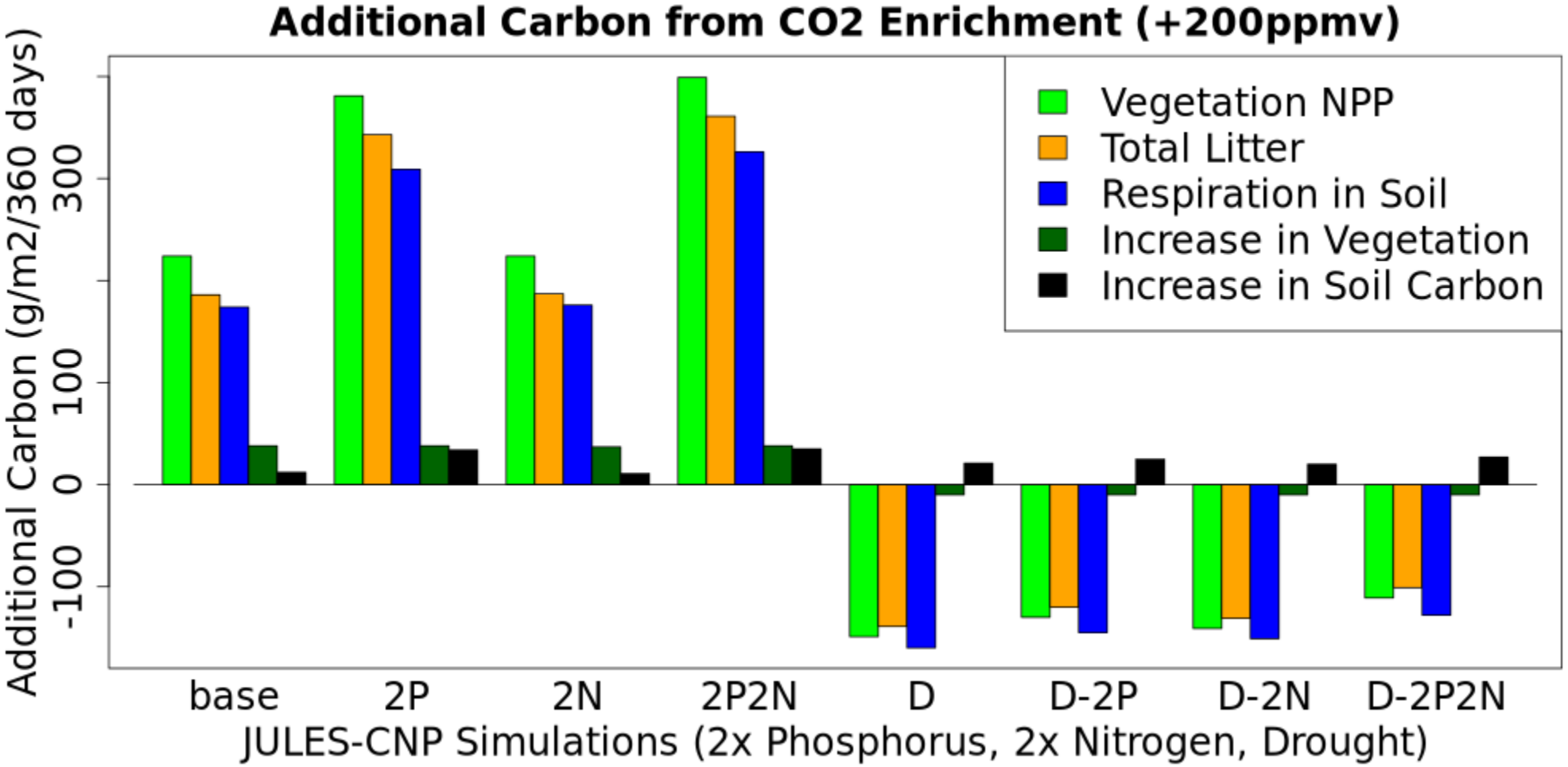
With enriched CO_2 productivity is increased but then declines over time as Phosphorus in the soil is depleted unless the Phosphorus is increased

Vegetation Productivity in Different Simulations



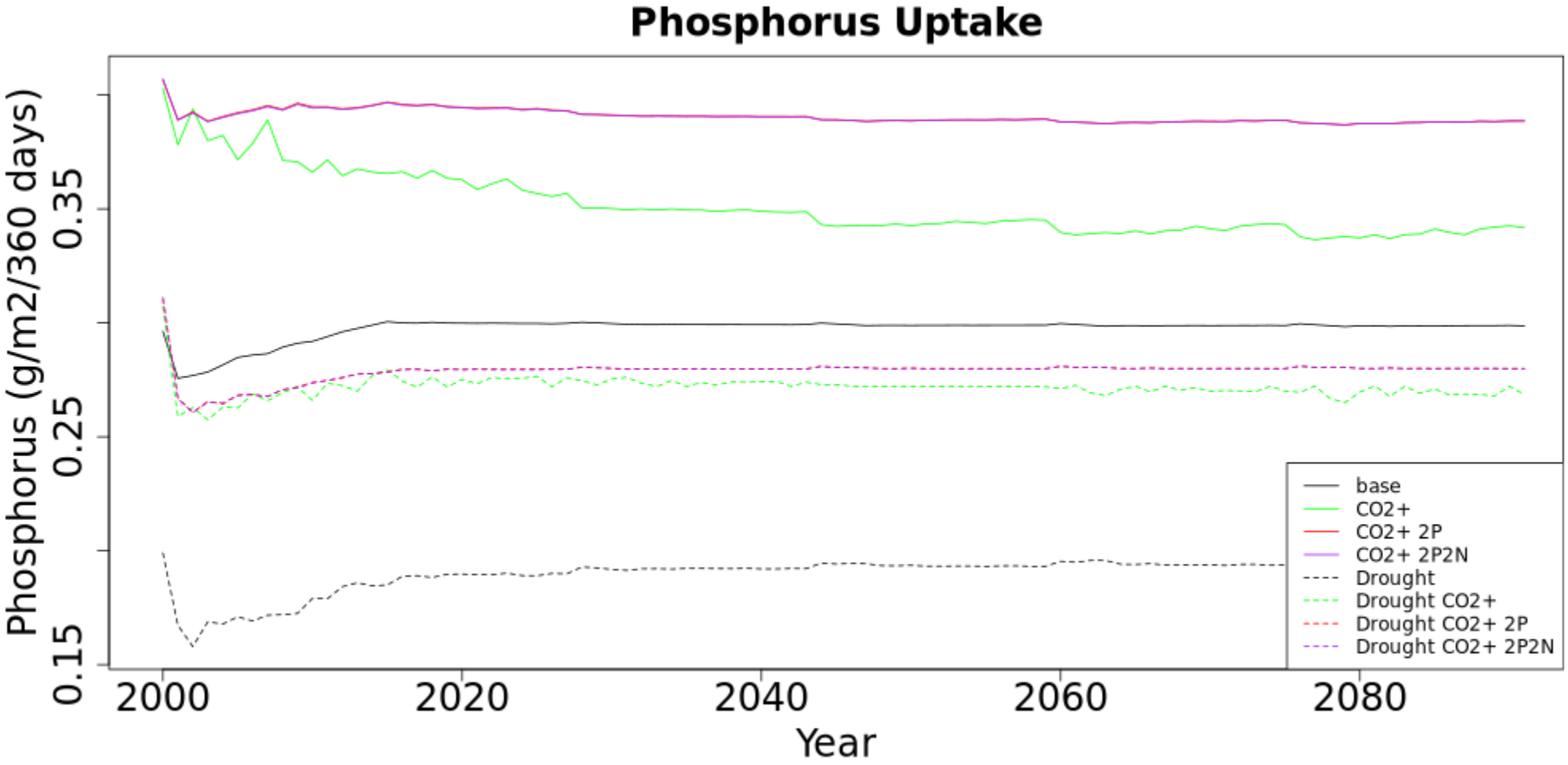
The effects of drought are reduced by enriched CO_2 reducing transpiration

Mean increases in Carbon between simulations



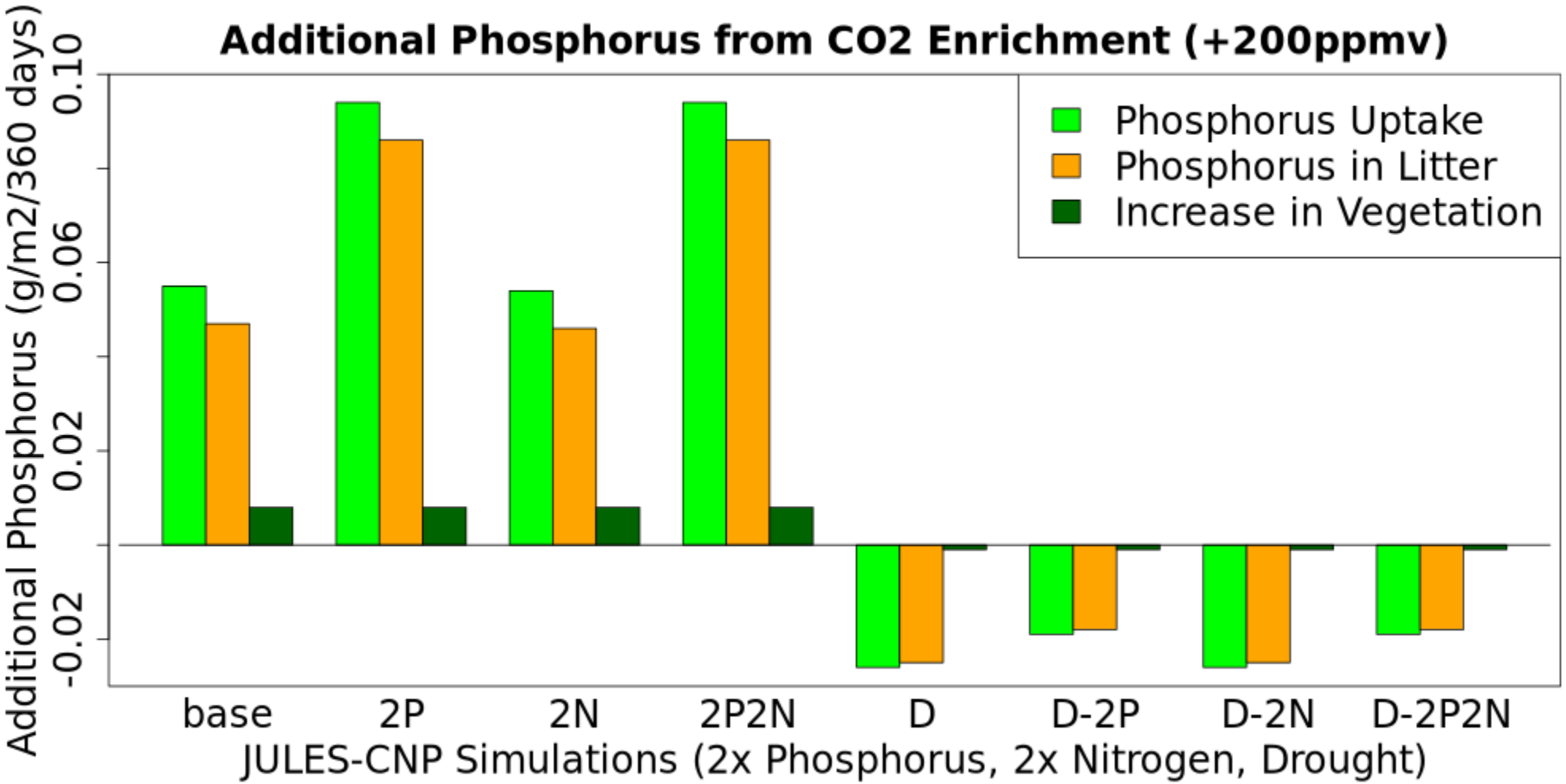
Mean additional productivity from CO_2 enrichment is increased significantly when Phosphorus is doubled (so not limited), it is increased slightly more when Nitrogen is also doubled but otherwise is not Nitrogen limited

Phosphorus Uptake in Different Simulations



With enriched CO_2 Phosphorus uptake is increased but then declines over time as Phosphorus in the soil is depleted unless the Phosphorus is increased, the effects of drought are reduced by enriched CO_2 reducing transpiration

Mean increases in Phosphorus uptake and loss



Mean additional Phosphorus uptake from the soil and loss to litter from CO_2 enrichment is increased significantly when Phosphorus is doubled, in drought productivity is less and Phosphorus uptake is also sensitive to soil moisture

Summary

- The new JULES-CNP code works well
- Enriched CO_2 results in significantly greater productivity of vegetation, but this declines over time as Phosphorus in the soil is depleted
- With increased Phosphorus the greater productivity from enriched CO_2 is not limited and remains high
- Increased Nitrogen has little effect by itself, but coupled with increased Phosphorus there is an even greater productivity of vegetation
- In drought conditions (precipitation reduced by half) there's a significant drop in productivity, but coupled with enriched CO_2 the plants are able to conserve water and reduce the effects of drought so there's a much smaller drop in productivity