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# Nutrient availability as the key regulator of global forest carbon balance

**Authors:** M. Fernández-Martínez*[1,2], S. Vicca[3], I. A. Janssens[3], J. Sardans[1,2], S. Luyssaert[4], M. Campioli[3], F.S. Chapin III[5], P. Ciais[4], Y. Malhi[6], M. Obersteiner[7], D. Papale[8], S.L. Piao[9,10], M. Reichstein[11], F. Rodà[2,12], J. Peñuelas[1,2]

**Affiliations:**

[1] CSIC, Global Ecology Unit, CREAF-CSIC-UAB, Cerdanyola del Vallès, 08193 Barcelona, Catalonia, Spain

[2] CREAF, Cerdanyola del Vallès, 08193 Barcelona, Catalonia, Spain

[3] Research Group of Plant and Vegetation Ecology, Department of Biology, University of Antwerp, 2610 Wilrijk, Belgium.

[4] LSCE CEA-CNRS-UVSQ, Orme des Merisiers, F-91191 Gif-sur-Yvette, France

[5] Institute of Arctic Biology, University of Alaska Fairbanks, Fairbanks, AK 99775, USA

[6] Environmental Change Institute, School of Geography and the Environment, University of Oxford, Oxford OX1 3QY, UK

[7] International Institute for Applied Systems Analysis, Schlossplatz 1, 2361 Laxenburg, Austria

[8] DIBAF, University of Tuscia, 01100 Viterbo, Italy

[9] College of Urban and Environmental Sciences, Peking University, Beijing 100871, China

[10] Institute of Tibetan Plateau Research, Chinese Academy of Sciences, Beijing 100085, China

[11] Max Planck Institute for Biogeochemistry, Jena, German

[12] Department of Animal Biology, Plant Biology and Ecology, Universitat Autònoma de Barcelona, 08193 Barcelona, Catalonia, Spain

*Correspondence to: M. Fernández-Martínez, m.fernandez@creaf.uab.cat

## Summary paragraph

Forests strongly affect climate through the exchange of large amounts of atmospheric $CO_2$[1]. The main drivers of spatial variability in net ecosystem production (NEP) on a global scale are, however, poorly known. Since increasing nutrient availability increases the production of biomass per unit of photosynthesis[2] and reduces heterotrophic[3] respiration in forests, we expected nutrients to determine carbon sequestration in forests. Our synthesis study of 92 forests in different climate zones revealed that nutrient availability indeed plays a crucial role in determining NEP and ecosystem carbon-use efficiency [CUEe, i.e. the ratio of NEP to gross primary production (GPP)]. Forests with high GPP exhibited high NEP only in nutrient-rich forests (CUEe = 33 ± 4%; mean ± SE). In nutrient-poor forests, a much larger proportion of GPP was released through ecosystem respiration, resulting in lower CUEe (6 ± 4%). Our finding that nutrient availability exerts a stronger control on NEP than on carbon input (GPP) conflicts with assumptions of nearly all global coupled carbon cycle-climate models, which assume that carbon inputs through photosynthesis drive biomass production and carbon sequestration. An improved global understanding of nutrient availability would therefore greatly improve carbon cycle modeling and should become a critical focus for future research.

## Main Text

The net ecosystem production (NEP) of an ecosystem represents its C balance at daily to decadal scales. Despite considerable study, the main drivers of NEP are still unclear. Climate [4,5], climatic trends [6], nitrogen deposition [7,8], disturbance and management [8,9] have been suggested to influence NEP. These studies, however, were either unable to explain a substantial percentage of the spatial variability in NEP or collected data in a restricted subset of climatic space, indicating that it is not yet known what factor(s) most strongly govern NEP, one of the critical pathways by which terrestrial ecosystems feedback to climate.

At the ecosystem scale, nitrogen deposition has been suggested to enhance the NEP of forests [3,7]. Nutrient availability is indeed a key variable explaining patterns of carbon allocation in forests; nutrient-rich forests exhibit higher biomass production (BP), biomass production efficiency (BPE, defined as BP-to-GPP ratio) and shoot-to-root biomass production ratio [2]. By converting a larger fraction of GPP to woody biomass and thereby increasing the residence time of the assimilated carbon (C), forests growing on more fertile soils can be expected to exhibit higher NEP. Carbon-use efficiency at the ecosystem level (CUEe), defined as NEP of an ecosystem per unit of GPP, measures the proficiency of an ecosystem to store C absorbed from the atmosphere. We thus hypothesize that both NEP and CUEe increase with increasing nutrient availability in forest ecosystems.

To test this hypothesis, we updated and analyzed a global forest data set of mean annual carbon flux [GPP, ecosystem respiration (Re) and NEP], stand biomass, stand age and information on management. The resulting data set of 92 forests included scattered data from 1990 to 2010 from boreal, temperate, Mediterranean and tropical forests [9] (Supplementary Fig. 1). We added all published information on the nutrient status of these forests and we classified them as forests with high nutrient availability (without apparent nutrient limitation) and low nutrient availability (apparently strongly nutrient-limited, sensu Vicca et al. [2], considering a holistic combination of availability of nutrients and soil characteristics). We based the nutrient availability classification on a multivariate factor analysis containing information about soil type, soil and foliar nutrient concentrations (N, P), soil pH, soil C:N ratio, nitrogen deposition and mineralization, history of the stand, specific reports of nutrient availability and an assessment by the principal investigator of the site (Supplementary Table 1). This analysis clearly separated nutrient-rich from nutrient-poor forests (Supplementary Fig. 2). We also established a medium category that was used for additional testing; it contained forests with information indicating moderate availability of nutrients or with few information about their nutrient status. Mean annual temperature and precipitation (MAT, MAP) from the WorldClim database[10] and water deficit (WD) derived from MODIS evapotranspiration time series (MOD15A2 product) were used as climatic predictors. We then used generalized linear models to disentangle the effects of climate, management and stand age from those of nutrient availability on NEP and CUEe (see Methods for details on datasets and methodology).

NEP in nutrient-rich forests averaged 33 ± 4% (mean ± SE) of GPP, whereas nutrient-poor forests only accumulated 6 ± 4% of the photosynthesized carbon (CUEe in Fig. 1, difference = 27 ± 7% , ANOVA $P < 0.001$). Only nutrient-rich forests showed a clear positive relationship between GPP and NEP (Fig. 1). In contrast, nutrient-poor forests channelled a larger proportion of GPP into Re (Fig. 2), with NEP being almost independent of GPP. Higher nutrient availability thus appears to channel C fixed by GPP toward storage in biomass and soils, rather than being respired back to the atmosphere.

A common protocol in eddy covariance $CO_2$ flux studies is to estimate GPP by adding Re (e.g. extrapolated from nocturnal measurements) to the measured net ecosystem exchange (NEE, a proxy for short-term NEP). In this protocol any error in Re would therefore be directly propagated into a biased estimation of GPP, potentially imposing a spurious correlation between GPP and Re [11,12]. This correlation, however, in addition to being irrelevant on an annual scale [13], was present in nutrient-poor forests but not in nutrient-rich forests (Fig. 2). The correlation between GPP and Re observed across nutrient-poor forests is thus unlikely an artefact from the processing of eddy-covariance data for separating these gross fluxes. We instead hypothesize that the positive relationship between Re and GPP only in nutrient-poor forests is due to different patterns of ecosystem functioning in nutrient-poor versus nutrient-rich forests.

Our statistical analyses using generalized linear models, including GPP, nutrient availability and stand age, explained 74, 93 and 43% of the variance in NEP, Re (Table 1) and CUEe across sites, respectively (Supplementary Table 2). Nutrient availability alone explained 19% of the variance in NEP. When summed with its interactions with GPP (15%) and age (1%), nutrient availability accounted for 35% of the variance in NEP. GPP alone explained 18% of the cross-site variability in NEP. When additional interactions with nutrient availability and age (9%) were included, GPP explained 42% of the variability in NEP. The relationship between NEP and stand age, however, was only significant when GPP was previously included in the models, which emphasises the smaller effect of stand age on NEP as compared to GPP (Supplementary Figs. 3 and 4). Finally, MAT was positively correlated with NEP and explained 9% of its variance. In contrast to NEP, GPP alone explained 64% of the variance in Re, with nutrient availability and its interactions explaining 9% and age and its interactions explaining only 5%. For CUEe, nutrient availability explained 12%, and GPP 14% of the variance in CUEe. Stand age also played an important role, interacting with GPP (reducing the positive effect of GPP on CUEe as forests matured) and explaining 17% of the variance in CUEe.

The relative contribution of explanatory variables thus differed among the NEP, Re and CUEe models, but the key and robust result is that nutrient status was a key factor for NEP and CUEe (Fig. 3, Table 1 and Supplementary Table 2), despite the use of nutrient status as a binary variable (high vs. low nutrient availability). Other possible predictors such as management and climate (MAP and WD), were not selected to enter in the general model by the stepwise model selection procedure, i.e., they did not significantly affect neither NEP nor Re (Table 1). Model-averaging techniques (see Supplementary Information) also indicated little importance of climate or management on NEP and Re. In contrast to NEP and Re, GPP was clearly climatically driven, being positively correlated with MAT and negatively correlated with WD, which accounted for 65% and 10%, respectively, of the variance in GPP.

The significant positive effect of nutrient availability on NEP proved to be robust in weighted models (Supplementary Fig. 5) and when controlling for effects of potentially confounding factors, for example: i) when using only data derived from eddy covariance measurements (Table 1), ii) when excluding forests with GPPs > 2500 gC $m^{-2}$ $year^{-1}$ (i.e. mostly tropical forests) from the analyses (no nutrient-rich forests were available for comparison at GPP higher than this threshold, Figs. 1 and 2), iii) when using only managed forests (Supplementary Figs. 6 and 7), iv) when using an alternative classification of nutrient status to analyse sensitivity to possible classification errors (Tables 1 and Supplementary Table 2) and v) when using the first factor of the factor analysis for nutrient classification as a nutrient richness covariate (Table 1, *nutrient richness factor*). Furthermore, when including the moderate nutrient availability forests, this group showed an intermediate behaviour between the nutrient-rich and the nutrient-poor forests (Supplementary Fig. 8). On the other hand, when nutrient status was excluded from the analyses, management played the role of nutrients in our models, albeit the models explained less of the variance than did the models containing nutrient availability (Table 1), and the second-order Akaike information criterion (AICc) increased considerably (by 18.6 and 17.2 points for NEP and Re, respectively). These results were expected because managed forests are mostly nutrient-rich forests (Supplementary Fig. 7) for the generation of profits from fertile lands.

The positive effect of nutrient availability on a more efficient use of photosynthates and a larger sequestration of carbon at the ecosystem level is likely not driven by a single mechanism or a single compartment of the ecosystem but rather by a combination of autotrophic and heterotrophic processes. Autotrophic processes are mainly related to different patterns of carbon allocation in nutrient-rich and nutrient-poor forests [2,14], whereas mechanisms related to heterotrophic processes involve primarily changes in substrate quality and the composition of the community of decomposers (mainly fungal and bacterial) [3,15].

For the autotrophic compartment, we detected two differences in the distribution of biomass across different organs between the different nutrient classes, despite also considering other factors such as climate and management. 1) Although only marginally significant, the ratio of fine-root biomass to total biomass was almost three times higher in nutrient-poor forests than in nutrient-rich forests ($P$ = 0.06, N = 17; Supplementary Fig. 9A), indicating a higher proportional investment of GPP into fine roots for increasing access to nutrients [16,17]. 2) The leaf area index per unit of fine-root biomass was twice as large in nutrient-rich forests ($P$ = 0.013, N = 19; Supplementary Fig. 9B), indicating a shift in carbon allocation towards photosynthetic tissues when nutrients are not limiting growth and trees need to invest less in nutrient-acquiring structures. Accordingly, an earlier study, using a subset of our database, pointed out that nutrient-rich forests allocate larger proportions of their photosynthates to wood production compared to nutrient-poor forests at the cost of producing less root biomass [2]. These changes in allocation patterns thus suggest enhanced carbon fixation in nutrient-rich forests.

An increase in the production of leaves in nutrient-rich forests, at the expense of producing less fine roots, could decrease the benefit of increasing aboveground allocation in terms of CUEe if that aboveground carbon is not stabilised. On the other hand, although some studies have reported higher root respiration per unit mass at high root nutrient concentrations [18,19], a substantial decrease in root biomass may counterbalance this increase in autotrophic respiration and even reduce it at the ecosystem level [3]. In addition, when soil nutrients are poorly available, plants engage in active nutrient transport through the cell to increase nutrient uptake, spending energy for nutrient acquisition and therefore reducing energy available for plant growth[20]. The net effect of root physiological adjustments to nutrient supply is unclear.

Changes in patterns of photosynthate allocation are also relevant for the heterotrophic compartment. For example, the higher proportion of GPP in nutrient-rich forests partitioned to tissues with long turnover times such as wood [2,14] may decrease heterotrophic respiration, because wood is generally composed of rather recalcitrant molecules that decompose slowly [21]. Furthermore, numerous studies suggest that under high nutrient availability, forests allocate less C to fungal root symbionts [2], and to exudation that stimulates heterotrophic respiration in the rhizosphere [3]. Together, these nutrient effects would reduce microbial biomass and respiration, relative to nutrient-poor forests. In addition, communities of microbes and detritivores that consume nutrient-rich organic matter have higher growth efficiencies (less respiration per unit of organic matter decomposed) than do communities that decompose nutrient-poor organic matter[15,22]. This difference could reduce heterotrophic respiration in nutrient-rich forests [3,15] and potentially enhance carbon sequestration and accumulation in nutrient-rich forests.

Our results indicate a key effect of nutrient availability on forest carbon balance and particularly on the capacity of forests to sequester carbon. Only when nutrient availability is high can forests sequester large amounts of carbon. This knowledge is crucial, especially given the human-induced alterations of nutrient availability and stoichiometry in many regions of the planet [23,24]. Earth system models should evolve from considering only the effects of nitrogen on plant growth[25,26] to considering the interactions of nitrogen as well as other nutrients with the entire carbon cycle[27]. The relationship between GPP and NEP appears to be strongly controlled by the nutrient status of the forest, which implies that Earth system models will be unable to accurately predict the carbon balance of forest ecosystems without information on both background (pre-industrial) and regional changes in nutrient availability [28] resulting from direct human activities (e.g. nitrogen deposition) and from indirect human activities (e.g. climate change and elevated $CO_2$ altering soil and plant nutrient cycling). Moreover, because GPP and surrogates are widely available from remotely sensed data, the assessment of nutrient status could allow estimation of NEP with remote sensing of GPP and ground based measurements of CUEe. This way, estimates of global terrestrial carbon sequestration could be improved, and guidance for improved management of forest carbon could be provided. Finally, experimental research and environmental monitoring would benefit substantially by considering nutrient availability as carefully as climate.

## References and Notes:


1. Dixon, R. K. *et al.* Carbon pools and flux of global forest ecosystems. *Science (80-. ).* **263,** 185–90 (1994).

2. Vicca, S. *et al.* Fertile forests produce biomass more efficiently. *Ecol. Lett.* **15,** 520–6 (2012).

3. Janssens, I. a. *et al.* Reduction of forest soil respiration in response to nitrogen deposition. *Nat. Geosci.* **3,** 315–322 (2010).

4. Valentini, R. *et al.* Respiration as the main determinant of carbon balance in European forests. *Nature* **404,** 861–5 (2000).

5. Kato, T. & Tang, Y. Spatial variability and major controlling factors of CO 2 sink strength in Asian terrestrial ecosystems: evidence from eddy covariance data. *Glob. Chang. Biol.* **14,** 2333–2348 (2008).

6. Piao, S. *et al.* Footprint of temperature changes in the temperate and boreal forest carbon balance. *Geophys. Res. Lett.* **36,** L07404 (2009).

7. De Vries, W. *et al.* The impact of nitrogen deposition on carbon sequestration by European forests and heathlands. *For. Ecol. Manage.* **258,** 1814–1823 (2009).

8. Fernández-Martínez, M. *et al.* Spatial variability and controls over biomass stocks, carbon fluxes and resource-use efficiencies in forest ecosystems. *Trees, Struct. Funct.* **28,** 1–15 (2014).

9. Luyssaert, S. *et al.* CO 2 balance of boreal, temperate, and tropical forests derived from a global database. *Glob. Chang. Biol.* **13,** 2509–2537 (2007).

10. Hijmans, R. J., Cameron, S. E., Parra, J. L., Jones, P. G. & Jarvis, A. Very high resolution interpolated climate surfaces for global land areas. *Int. J. Climatol.* **25,** 1965–1978 (2005).

11. Reichstein, M. *et al.* On the separation of net ecosystem exchange into assimilation and ecosystem respiration: review and improved algorithm. *Glob. Chang. Biol.* **11,** 1424–1439 (2005).

12. Vickers, D., Thomas, C. K., Martin, J. G. & Law, B. Self-correlation between assimilation and respiration resulting from flux partitioning of eddy-covariance CO2 fluxes. *Agric. For. Meteorol.* **149,** 1552–1555 (2009).

13. Lasslop, G., Reichstein, M., Detto, M., Richardson, A. D. & Baldocchi, D. D. Comment on Vickers et al.: Self-correlation between assimilation and respiration resulting from flux partitioning of eddy-covariance CO2 fluxes. *Agric. For. Meteorol.* **150,** 312–314 (2010).

14. Litton, C. M., Raich, J. W. & Ryan, M. G. Carbon allocation in forest ecosystems. *Glob. Chang. Biol.* **13,** 2089–2109 (2007).

15. Manzoni, S., Taylor, P., Richter, A., Porporato, A. & Agren, G. I. Environmental and stoichiometric controls on microbial carbon-use efficiency in soils. *New Phytol.* **196,** 79–91 (2012).

16. Shan, J., Morris, L. a. & Hendrick, R. L. The effects of management on soil and plant carbon sequestration in slash pine plantations. *J. Appl. Ecol.* **38,** 932–941 (2002).

17. Goulden, M. L. *et al.* Patterns of NPP, GPP, respiration, and NEP during boreal forest succession. *Glob. Chang. Biol.* **17,** 855–871 (2011).

18. Chapin, F. S. The mineral nutrition of wild plants. *Annu. Rev. Ecol. Syst.* **11,** 233–260 (1980).

19. Burton, A., Pregitzer, K., Ruess, R., Hendrick, R. & Allen, M. Root respiration in North American forests: effects of nitrogen concentration and temperature across biomes. *Oecologia* **131,** 559–568 (2002).

20. Lee, S. C. *et al.* A protein phosphorylation/dephosphorylation network regulates a plant potassium channel. *Proc. Natl. Acad. Sci. U. S. A.* **104,** 15959–64 (2007).

21. Keith, H., Mackey, B. G. & Lindenmayer, D. B. Re-evaluation of forest biomass carbon stocks and lessons from the world's most carbon-dense forests. *Proc. Natl. Acad. Sci.* **106,** 11635–11640 (2009).

22. Cotrufo, M. F., Wallenstein, M. D., Boot, C. M., Denef, K. & Paul, E. The Microbial Efficiency-Matrix Stabilization (MEMS) framework integrates plant litter decomposition with soil organic matter stabilization: do labile plant inputs form stable soil organic matter? *Glob. Chang. Biol.* **19,** 988–95 (2013).

23. Peñuelas, J., Sardans, J., Rivas-ubach, A. & Janssens, I. a. The human-induced imbalance between C, N and P in Earth's life system. *Glob. Chang. Biol.* **18,** 3–6 (2012).

24. Peñuelas, J. *et al.* Human-induced nitrogen-phosphorus imbalances alter natural and managed ecosystems across the globe. *Nat. Commun.* **4,** 2934 (2013).

25. Zaehle, S. & Friend, A. D. Carbon and nitrogen cycle dynamics in the O-CN land surface model: 1. Model description, site-scale evaluation, and sensitivity to parameter estimates. *Global Biogeochem. Cycles* **24,** n/a–n/a (2010).

26. Zaehle, S., Friedlingstein, P. & Friend, A. D. Terrestrial nitrogen feedbacks may accelerate future climate change. *Geophys. Res. Lett.* **37,** n/a–n/a (2010).

27. De Vries, W. & Posch, M. Modelling the impact of nitrogen deposition, climate change and nutrient limitations on tree carbon sequestration in Europe for the period 1900–2050. *Environ. Pollut.* **159,** 2289–2299 (2011).

28. Piao, S. *et al.* Evaluation of terrestrial carbon cycle models for their response to climate variability and to CO2 trends. *Glob. Chang. Biol.* **19,** 2117–32 (2013).

29. R Core Team. R: A Language and Environment for Statistical Computing. *R Found. Stat. Comput.* **1,** 409 (2013).

30. Grömping, U. Relative importance for linear regression in R: the package relaimpo. *J. Stat. Softw.* **17,** 1–27 (2006).

31. Chevan, A. & Sutherland, M. Hierarchical Partitioning. *Am. Stat.* **45,** 90–96 (1991).

32. Barton, K. MuMIn: Multi-model inference. R package version 1.7.2. http://CRAN.R-project.org/package=MuMIn. (2012). at <http://cran.r-project.org/package=MuMIn>

33. Burnham, K. P. & Anderson, D. R. *Model Selection and Multimodel Inference: A Practical Information-Theoretic Approach*. (Springer, 2004).

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## Figure captions

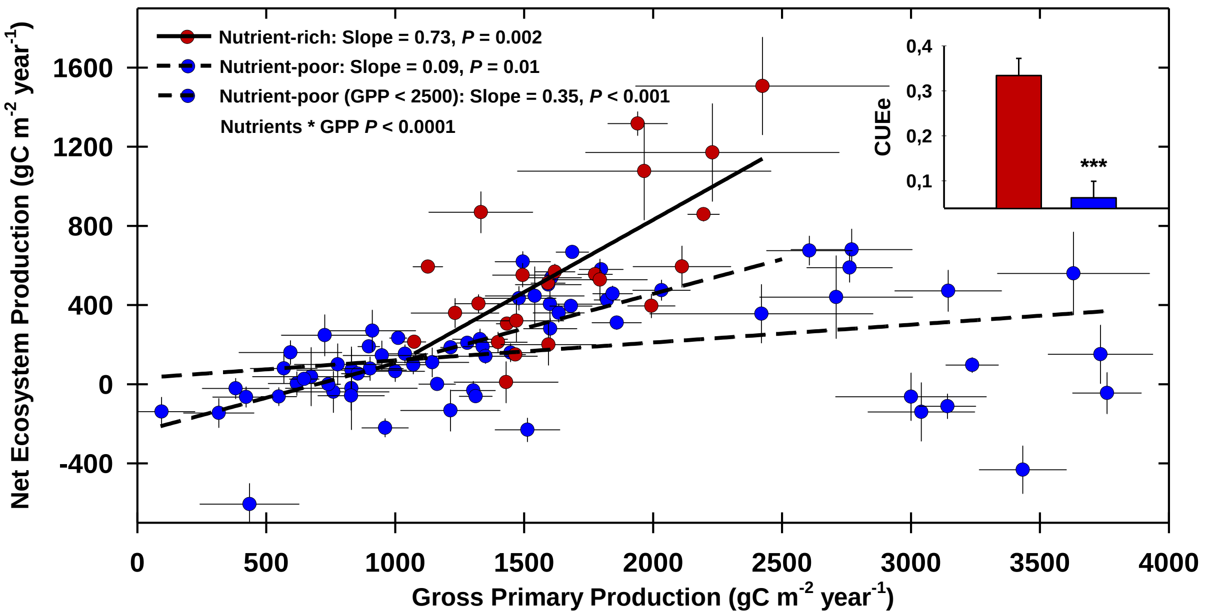
**Fig. 1. Only nutrient-rich forests substantially increase carbon sequestration with increasing carbon uptake.** The bar chart inside the main graph shows that CUEe (NEP to GPP ratio) in nutrient-rich forests is more than five times higher than in nutrient-poor forests. We also present results for forests with GPP < 2500 gC $m^{-2}$ $year^{-1}$, because values of GPP > 2500 gC $m^{-2}$ $year^{-1}$ were only available for nutrient-poor forests. When considering only forests with GPP < 2500 gC $m^{-2}$ $year^{-1}$, the Nutrients*GPP (where Nutrients = nutrient availability) interaction was significant at the 0.006 level.

**Fig. 2. The coupling between Re and GPP is weak in nutrient-rich forests and very strong in nutrient-poor forests.** Nutrient-rich forests decouple Re from GPP, resulting in an increase in carbon accumulation with increasing GPP. When considering only forests with GPP < 2500 gC $m^{-2}$ $year^{-1}$, the Nutrients*GPP (where Nutrients = nutrient availability) interaction is significant at the 0.005 level. Error bars indicate the uncertainty of the estimate on both the x- and y-axes (SE).

**Fig. 3. Relative contribution of predictor variables in the model explaining variability in NEP.** Letters indicate significant differences according to the bootstrapped confidence intervals computed for the differences among variables [relaimpo R package (23)]. Nutrients = nutrient availability. All variables and interactions shown were statistically significant (*P* < 0.05).

**Table 1. Summary of the percentage of variance explained by the significant variables of the models relating NEP and Re with GPP, nutrient availability (NA), management (MNG) and stand age and their second-order interactions.** The β coefficients of the models are shown in brackets. For NA, MNG or their interactions with covariates, the β coefficients of the factors and the interactions indicate differences from the reference level (e.g. the slope of nutrient-rich forests of the general model is 1.8, and the slope, β, of the nutrient-poor forests is 1.8 – 1.9 = -0.1). The model "Nutrient richness factor" shows the model including the factors used in the nutrient classification (see Methods, *information on nutrient availability*, and Fig. S2) as a nutrient richness covariate instead of the binary variable nutrient availability. For this model, NA indicates the effect of the first factor extracted.

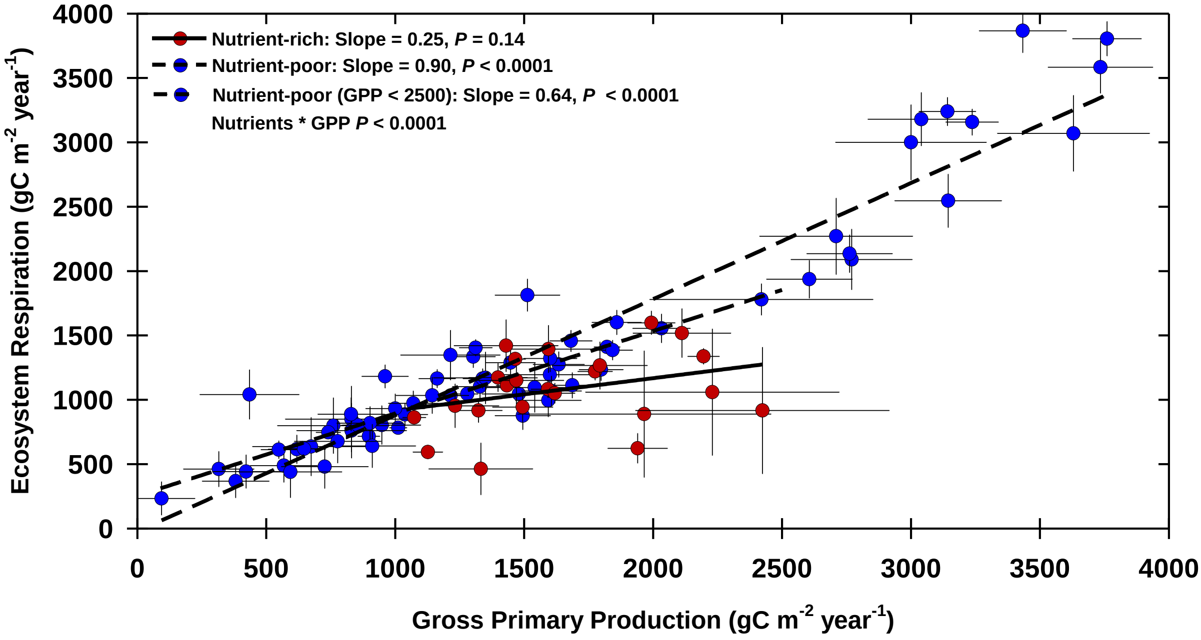
329 **Fig. 1**.



Nutrient-rich: Slope = 0.73, P = 0.002
Nutrient-poor: Slope = 0.09, P = 0.01
Nutrient-poor (GPP < 2500): Slope = 0.35, P < 0.001
Nutrients * GPP P < 0.0001
CUEe
0,4
0,3
0,2
0,1
***
Net Ecosystem Production (gC m-2 year-1)
1600
1200
800
400
0
-400
0
500
1000
1500
2000
2500
3000
3500
4000
Gross Primary Production (gC m-2 year-1)

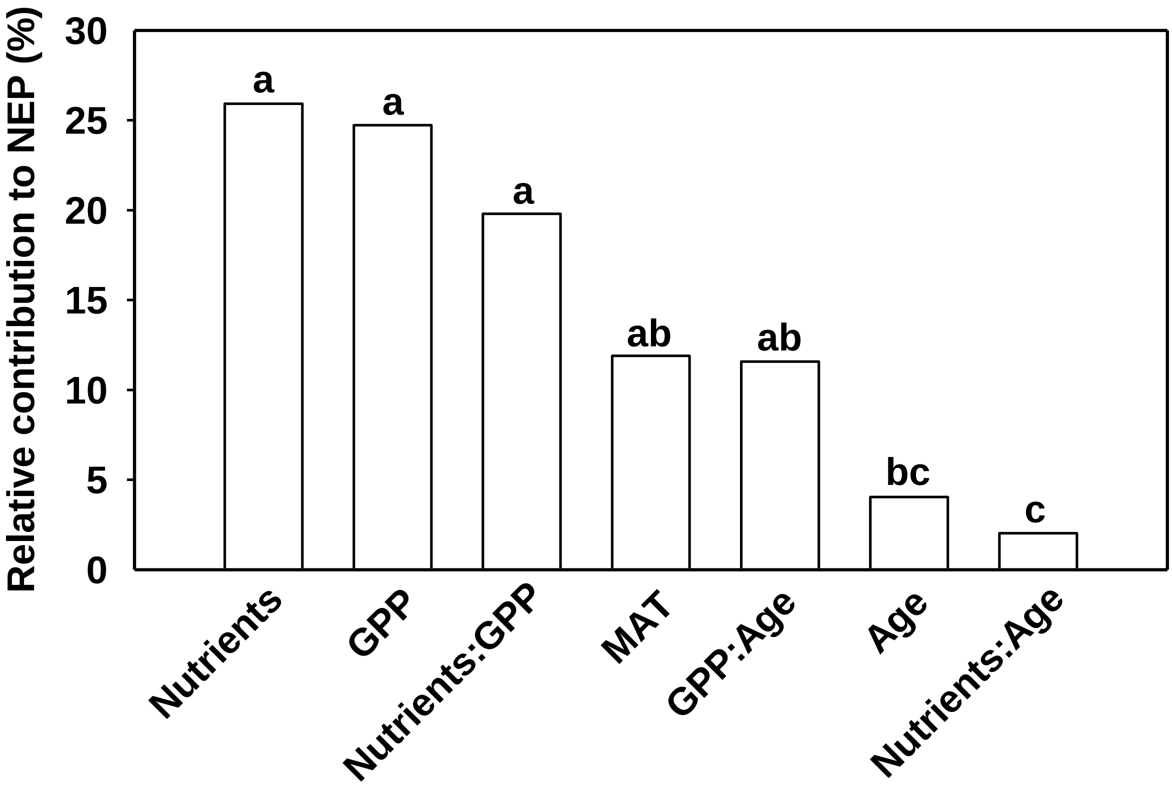

330

**Fig. 2.**



Nutrient-rich: Slope = 0.25, P = 0.14
Nutrient-poor: Slope = 0.90, P < 0.0001
Nutrient-poor (GPP < 2500): Slope = 0.64, P < 0.0001
Nutrients * GPP P < 0.0001
Ecosystem Respiration (gC m-2 year-1)
Gross Primary Production (gC m-2 year-1)
0
500
1000
1500
2000
2500
3000
3500
4000

**Fig. 3.**


Relative contribution to NEP (%)
30
25
20
15
10
5
0
a
a
a
ab
ab
bc
c
Nutrients
GPP
Nutrients:GPP
MAT
GPP:Age
Age
Nutrients:Age

## Table 1.

| Models | GPP | NA | GPP:NA | MAT | GPP:Age | Age | Age:NA | MNG | WD | GPP:MNG | Model $R^2$ (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **General** | | | | | | | | | | | |
| NEP (Fig. 1) | 18 (1.8) | 19 (1.3) | 15 (-1.9) | 9 (0.5) | 9 (-1.0) | 3 (1.1) | 1 (-0.4) | | | | **74** |
| Re (Fig. 2) | 64 (0.1) | 3 (-0.7) | 5 (1.1) | 16 (-0.2) | 3 (0.5) | 1 (-0.6) | 1 (0.2) | | | | **93** |
| CUEe | 14 (0.9) | 12 (-0.3) | | | 17 (-1.2) | 0 (1.1) | | | | | **43** |
| **Weighted** (Supl. Fig. 2) | | | | | | | | | | | |
| NEP | 20 (1.6) | 14 (1.0) | 8 (-1.4) | 8 (0.4) | 6 (-1.0) | 2 (1.2) | 3 (-0.5) | | | | **61** |
| Re | 65 (0.3) | 2 (-0.5) | 3 (0.8) | 15 (-0.2) | 2 (0.5) | 0 (-0.6) | 1 (0.3) | | | | **88** |
| CUEe | 1 (0.5) | 16 (-0.1) | | | 9 (-0.8) | 3 (0.9) | 5 (-0.4) | | | | **34** |
| **Eddy covariance data only** | | | | | | | | | | | |
| NEP | 18 (1.5) | 11 (0.8) | 6 (-1.5) | 9 (0.5) | | | | 4 (0.6) | | 11 (-0.8) | **59** |
| Re | 67 (0.4) | 1 (-0.4) | 1 (0.7) | 19 (-0.2) | | | | 1 (-0.2) | | 2 (0.4) | **92** |
| CUEe | 12 (0.9) | 9 (-0.3) | | | 15 (-1.2) | 2 (1.2) | | | | | **38** |
| **Without nutrient availability** | | | | | | | | | | | |
| NEP | 31 (1.1) | | | | | | | 8 (0.6) | 5 (0.3) | 15 (-1.8) | **59** |
| Re | 70 (0.6) | | | | | | | 2 (-0.3) | 11 (-0.2) | 4 (0.5) | **87** |
| CUEe | 15 (0.9) | | | | | | | 0 (0.8) | | 2 (-1.1) | **46** |
| **GPP < 2500 gC $m^{-2}$ $year^{-1}$** | | | | | | | | | | | |
| NEP (Fig. 1) | 44 (1.2) | 17 (0.6) | 6 (-0.9) | | | | | | 5 (0.2) | | **72** |
| Re (Fig. 2) | 55 (0.3) | 3 (-0.6) | 6 (0.8) | | | | | | 10 (-0.2) | | **74** |
| CUEe | 38 (0.8) | | | | 7 (-0.8) | 1 (0.9) | | | | | **46** |
| **GPP < 2500 gC $m^{-2}$ $year^{-1}$ weighted** (Supl. Fig. 2) | | | | | | | | | | | |
| NEP | 34 (0.9) | 11 (0.7) | 5 (-0.9) | 12 (0.3) | | | | | | | **62** |
| Re | 58 (0.9) | 3 (0.2) | | | | | | | 11 (-0.2) | | **72** |
| CUEe | | 15 (-0.2) | | 19 (0.3) | | | | | | | **34** |
| **Managed Forests** (Supl. Fig. 6) | | | | | | | | | | | |
| NEP | 52 (1.1) | 14 (0.3) | 4 (-0.7) | | | | | | 9 (0.3) | | **79** |
| Re | 57 (0.4) | 3 (-0.4) | 5 (0.7) | | | | | | 17 (-0.3) | | **82** |
| CUEe | 37 (0.7) | 9 (-0.3) | | | 5 (-0.6) | 3 (0.8) | | | | | **54** |
| **Alternative classification** | | | | | | | | | | | |
| NEP | 25 (1.6) | 12 (1.2) | 11 (-1.5) | 11 (0.5) | 1 (-1.1) | 4 (1.2) | 2 (-0.4) | | | | **75** |
| Re | 67 (0.3) | 2 (-0.8) | 4 (0.9) | 13 (-0.3) | 4 (0.6) | 1 (-0.7) | 1 (0.2) | | | | **92** |
| CUEe | 12 (0.6) | 7 (-0.3) | | 6 (0.4) | 18 (-1.2) | 0 (1.2) | | | | | **43** |
| **Nutrient richness factor** | | | | | | | | | | | |
| NEP | 25 (0.9) | 23 (-0.4) | 5 (0.8) | | | | | 5 (0.4) | | 9 (-0.7) | **67** |
| Re | 79 (0.7) | 4 (-0.2) | | | | | | 1 (-0.3) | | 3 (0.4) | **87** |
| CUEe | 14 (0.8) | 10 (0.2) | | | | | | 0 (0.8) | | 17 (-1.0) | **41** |

# Methods

### ***Sources of data***

We used data of mean annual carbon flux from a global forest database [9]. This data set contains complete measurements of carbon balance and uncertainties of gross primary production (GPP), ecosystem respiration (Re) and net ecosystem production (NEP) of forests around the world. The WorldClim database[10] (resolution ~ 1km at the equator) and MODIS evapotranspiration time series (MOD15A2 product) provided climatic data [mean annual temperature (MAT) and mean annual precipitation (MAP) from WorldClim and potential and actual evapotranspiration (PET, AET) from MODIS]. The reliability of the data from the WorldClim database was tested with the available observed climatic values from the forests (N=123). Results indicated a strong correlation between observed and WorldClim values for annual temperature and precipitation ($R^2$ = 0.96, $P$ < 0.001 and $R^2$ = 0.84, $P$ < 0.001 respectively).

All continents were represented in our analyses (Supplementary Fig. 1), although most of the forests were located in Europe and North America. Boreal (N = 31) and especially temperate (N = 68) sites outnumbered Mediterranean (N = 14) and tropical (N = 16) sites. 61 forests were coniferous, 57 were broadleaved and 11 were mixed.

### ***Information on nutrient availability***

For each forest, we compiled all available information from the published literature (carbon, nitrogen and phosphorus concentrations of soil and/or leaves, soil type, soil texture, soil C:N ratio, soil pH, measures of nutrients, etc.) related to nutrient availability. Then we followed the criteria shown in Supplementary Table 3 to code these variables as three-level factors indicating high, medium or low nutrient availability. Next, we transformed these factors into dummy variables and performed a factor analysis. The first factor extracted explained 14.8% of the variance in the dataset and was related to nutrient-rich dummy variables whereas the second factor explained 8.7% of the variance and was related to nutrient-poor dummy variables (Supplementary Fig. 2A). Then, based on the aggregations across the two main factors extracted (Supplementary Fig. 2B) we classified the forests as having clearly high or clearly low nutrient availabilities. The remaining forests, for which empirical evidence was insufficient to classify them as nutrient-rich or nutrient-poor or indicated moderate nutrient availability were classified as medium nutrient availability. To maximize robustness, we included only the forests with clearly high (N = 23) and clearly low (N = 69) nutrient availabilities in the main analysis, discarding data from the 37 remaining forests with medium nutrient availability. We also present the analysis with all the available data (including the medium nutrient availability category) in Supplementary Fig. 8 and in the Supplementary Models.

### *Statistical analyses*

We ran generalized linear models (GLM) to test for differences in CUEe, NEP, Re and GPP between forests of high and low nutrient availability, accounting for the possible effects of GPP, mean stand age, management (as a binary variable: managed or unmanaged) and climate [MAT, MAP and water deficit (WD) = 1 – (AET/PET)*100]. That is, NEP ~ GPP + nutrient availability + Age + Management + MAT + MAP + WD. We tested for interactions up to the second order among GPP, nutrient availability, age and management. The significant variables of the final model (minimum adequate model) were selected using stepwise backward variable selection and the AIC of the respective regression models. To evaluate the variance explained by each predictor variable, we used the *averaged over orderings* method (the *lmg* metric, similar to hierarchical partitioning) to decompose $R^2$ from $R$ [29] with the package relaimpo [Relative Importance for Linear Regression [30]]. Finally, we tested whether nutrient status, management, age and climatic variables could lead to changes in patterns of biomass allocation with stepwise forward regressions. Model residuals met the assumptions required in all analyses (i.e., normality and homoscedasticity).

The robustness of our analyses was tested by five different methods: i) running weighted models using the inverse of the uncertainty of the estimates as a weighting factor, ii) using only data derived from eddy covariance towers, iii) restricting comparison of nutrient-rich and nutrient-poor forests to a common rank of GPP (GPP < 2500 gC $m^{-2}$ $year^{-1}$ in Figs. 1 and 2, thus excluding most of the tropical forests and using forests presenting GPPs above 1000 and below 2500 gC $m^{-2}$ $year^{-1}$ in Supplementary Fig. 10), iv) using an alternative classification of nutrient availability (the second most plausible classification) as an analysis of sensitivity and v) using the factors extracted for the classification of nutrients as nutrient richness covariates instead of using the binary factor nutrient availability. Detailed information about the methods used in this paper is presented in Supplementary Information.

**Supplementary Information:**

**Detailed and extended information on methods**

***Sources of data***

We used data of mean annual carbon flux from a global forest database [9]. This data set contains complete measurements of carbon balance and uncertainties of gross primary production (GPP), ecosystem respiration (Re) and net ecosystem production (NEP) of forests around the world. Of these forests, we excluded those that had been disturbed less than one year before measurement and those for which we found no information on nutrient availability. The carbon balance of the remaining 129 forests was estimated by eddy covariance (N = 124) or by modelling with site-specific parameterization (N = 5). During the processing of eddy covariance data, any error in estimating Re from nighttime measurements would be translated into biased GPP, and a spurious correlation between Re and GPP would then be the consequence. However, problems related to the calculation of Re and GPP were previously shown important at shorter timescales, but irrelevant at annual time scale [13]. Carbon fluxes not captured by net ecosystem exchange (NEE), such as fluxes of volatile organic compounds, dissolved carbon or lateral fluxes (exportations), were assumed to be similar (and negligible) across forest sites.

The WorldClim database[10] (resolution ~ 1km at the equator) and MODIS evapotranspiration time series (MOD15A2 product) provided climatic data [mean annual temperature (MAT) and mean annual precipitation (MAP) from WorldClim and potential and actual evapotranspiration (PET, AET) from MODIS]. The reliability of the data from the WorldClim database was tested with the available observed climatic values from the forests. Results indicated a strong correlation between observed and WorldClim values for annual temperature and precipitation (R = 0.98, $P < 0.001$ and R = 0.91, $P < 0.001$ respectively).

All continents were represented in our analyses (Supplementary Fig. 1), although most of the forests studied were in Europe and North America. Boreal (N = 31) and especially temperate (N = 68) sites outnumbered Mediterranean (N = 14) and tropical (N = 16) sites, and 61 forests were coniferous, 57 were broadleaved and 11 were mixed.

***Information on nutrient availability***

For each forest, we compiled all available information from the published literature (carbon, nitrogen and phosphorus concentrations of soil and/or leaves, soil type, soil texture, soil C:N ratio, soil pH, measures of nutrients, see Supplementary Table 1) related to nutrient availability. Then we followed the criteria shown in Supplementary Table 3 to code these variables as three-level factors indicating high, medium or low nutrient availability. Next, we transformed these factors into dummy variables (e.g. 3 binary variables for pH indicating high, medium or low nutrient availability) and performed a factor analysis in which we only included those dummy variables indicating high and low nutrient availability. Those indicating medium nutrient availability were excluded from the factor analysis (as well as from all other analyses) to reduce the number of variables in the multivariate analysis and to ensure a clear separation into two groups. The first factor extracted explained 14.8% of the variance in the dataset and was related to nutrient-rich dummy variables whereas the second factor explained 8.7% of the variance and was related to nutrient-poor dummy variables (Supplementary Fig. 2A). Then, based on the aggregations across the two main factors extracted (Supplementary Fig. 2B) we classified the forests as having clearly high or clearly low nutrient availabilities. Those forests located near the threshold nutrient-rich/poor were further analyzed, checking in detail all the information available for classification. The remaining forests whose empirical evidence was not strong enough to be clearly classified into the high or the low nutrient availability groups (due to lack of data, contradictory information or simply presenting data indicating moderate nutrient availability) were classified as medium nutrient availability.

To maximize robustness, we included only the forests with clearly high (N = 23) and clearly low (N = 69) nutrient availabilities for the main analysis, discarding data from the 37 remaining forests of medium nutrient availability from the main analyses. In a second analysis, those forests whose nutrient status was not completely certain were assigned an alternative nutrient classification (the second most plausible nutrient availability level, e.g. if a nutrient-rich forest did not present very strong evidence of belonging to the high category, we assigned it to the medium category: the nutrient status changed in the direction that would go against our main finding; thus potentially offsetting the observed increase of CUEe with increasing nutrient availability), to perform a sensitivity analysis to test the robustness of our results to possible misclassifications (Supplementary Table 2). This sensitivity analysis supported the robustness of our results.

We further tested the objectiveness of our nutrient classification using logit models, in which the response variable was the nutrient status of the forests (high or low availability), and the predictor variables were those contained in Supplementary Table 1). Given the lack of data for all variables for all forests, we categorized the predictor variables into four-level factors (following the criteria shown in Supplementary Table 3), where na indicated that data was not available, and high, medium and low indicated values or indications that suggested high, medium or low nutrient availability.

From the saturated model (i.e. nutrient status [high or low] ~ all variables in Supplementary Table S1), we constructed the minimum adequate model selecting the predictor variables using stepwise backward selection and the Akaike information criterion (AIC). We then cross-validated the saturated and the minimum adequate models using the repeated random sub-sampling validation technique: 78 forests were randomly selected as the training set for our nutrient classification models and were tested by predicting the 14 remaining forests for which the models were not previously fitted. This procedure was repeated 1000 times. Both the saturated and stepwise-selected models performed well in the classification of the nutrient status with the available data (100% and 99% of the cases were correctly classified in the saturated and the stepwise model, respectively; see Supplementary Table 4). To further test our classification, we tested the reports on nutrient availability ("Report" column in Supplementary Table 1) available in the literature, considering them the most objective classification, with the other predictor variables, except for the assessments by the principal investigators because these assessments would mostly agree with those in the publications. We applied the same model selection and cross-validation procedures to these models predicting the reports from literature as to the models predicting our nutrient classification. With all the available data, the saturated and stepwise models correctly classified 95% and 93% of the forests, respectively (Supplementary Table 4).

***Statistical analyses***

We ran generalized linear models (GLM) to test for differences in CUEe, NEP, Re and GPP between forests of high and low nutrient availability, accounting for the possible effects of GPP, mean age of the stand (as a covariate), management (as a binary variable: managed or unmanaged) and climate [MAT, MAP and water deficit (WD) = 1 – (AET/PET)*100]. In addition, we tested for interactions up to the second order among GPP, nutrient availability, age and management. Thus, the saturated model (e.g. for NEP) was: NEP ~ (GPP + nutrient availability + Age + Management) + MAT + MAP + WD, where variables between brackets where those for which we tested for interactions up to the second order. The significant variables of the final model (minimum adequate model, al terms significant at the 0.05 level) were selected using stepwise backward variable selection and the AIC of the respective regression models. To evaluate the variance explained by each predictor variable, we used the *averaged over orderings* method (the *lmg* metric, similar to hierarchical partitioning [31]) to decompose $R^2$ from the *R* [29] package relaimpo [Relative Importance for Linear Regression [30]]. We further tested our results with model averaging [MuMIn R Package [32]]. Model averaging is a procedure based on multimodel inference techniques that computes an average model from the estimates of the best models predicting the data and weighting their relative importance according to the difference of the second-order AIC between each model and the best model [33]. Finally, we tested whether nutrient status, management, age and climatic variables could lead to changes in patterns of biomass allocation with stepwise forward regressions. Model residuals met the assumptions required in all analyses.

The robustness of our analyses was tested by five different methods: i) running weighted models using the inverse of the uncertainty of the estimates as a weighting factor, ii) using only data derived from eddy covariance towers, iii) restricting comparison of nutrient-rich and nutrient-poor forests to a common rank of GPP (GPP < 2500 gC $m^{-2}$ $year^{-1}$, thus excluding most of the tropical forests), iv) using an alternative classification of nutrient availability (the second most plausible classification) as an analysis of sensitivity and v) using the factors extracted for the classification of nutrients as nutrient richness covariates instead of using the binary factor nutrient availability. We also present the analysis with all the data available (including the medium nutrient availability category) in Supplementary Fig. 8 and in the Supplementary Models. All analyses revealed very similar results.

## Captions

**Fig. S1. Global map of the forests used in this study.** Forests have been coded according to their nutrient status: red indicates nutrient-rich forests whereas blue indicates nutrient-poor forests.

**Fig. S2. Summary of the factor analysis performed to evaluate nutrient availability.** Graph A shows the factor loadings of the variables used in the analysis following the criteria presented in Supplementary Table S3. A clear separation can be seen between those indicating high (correlated with Factor 1, F1) and low (correlated with Factor 2, F2) nutrient availability. Graph B shows the factor scores of the studied forests aggregated according to the nutrient status. Note that in graph A FP is missing because no forest presented high values of FP. Note also that in graph B some forests might present equal factor scores, resulting in fewer points than expected. Abbreviations: ASI (additional soil information), CEC (cation exchange capacity), CN (soil C:N ratio), FN (foliar nitrogen concentration), FP (foliar phosphorus concentration), H (history of the stand), NDM (nitrogen deposition or mineralization), ST (soil type), ON (other soil nutrients), PI (assessment by the principal investigator of the forest), R (report about nutrient availability), SN (soil nitrogen concentration).

**Fig. S3. Influence of stand age and nutrient availability on NEP.** Nutrient availability clearly influences NEP ($P < 0.0001$), but stand age has no significant effect ($P = 0.14$) when GPP is not considered. Neither interaction between nutrient availability and stand age is significant ($P = 0.50$).

**Fig. S4. Relationships of NEP (A) and Re (B) with GPP in nutrient-rich and nutrient-poor forests indicating the age category of each stand.** The age of the stand did not affect the relationships of NEP (graphs **A**, **C**, **E**) and Re (graphs **B**, **D**, **F**) with GPP. The bar charts inside the NEP graphs show the average CUEe of nutrient-rich and nutrient-poor forests. Graphs **C** and **D** show forests older than 50 years old and graphs **E** and **F** show forests younger than 50 years old. Red-like points indicate nutrient-rich forests and blue-like points represent the nutrient-poor ones.

**Fig. S5. Relationships of NEP (A) and Re (B) with GPP in nutrient-rich and nutrient-poor forests weighted using the inverse of the uncertainty as a weighting factor.** The uncertainty of the estimates did not change the results. Thus, as in Fig. 1, nutrient-poor forests do not increase NEP when rates of carbon uptake increase. The bar chart inside graph **A** shows the average CUEe of nutrient-rich and nutrient-poor forests. Error bars indicate the uncertainty of the estimate on both the x- and y-axes (SE). In forests with GPP < 2500, Nutrients*GPP (where Nutrients = nutrient availability) interactions are not significant at the 0.05 level.

**Fig. S6. Relationships of NEP (A) and Re (B) with GPP in nutrient-rich and nutrient-poor managed forests.** The general pattern for NEP and Re versus GPP shown for nutrient-rich forests was also evident here. Nutrients = nutrient availability.

**Fig. S7. NEP to GPP ratio (CUEe) is influenced by nutrient availability but not by management.** Different letters indicate significant differences between groups (Tukey's HSD). The numbers beside the letters indicate the number of forest sites in the data base.

**Fig. S8. Relationships of NEP (A) and Re (B) with GPP showing also the medium nutrient availability category.** The general pattern for NEP and Re versus GPP in medium nutrient availability forests fits between the patterns shown by the nutrient-rich and the nutrient-poor forests. Nutrients = nutrient availability.

**Fig. S9. Nutrient-rich forests have a lower fine-root to total biomass ratio and a higher ratio of leaf area index (LAI) per unit of fine-root biomass.** Error bars indicate standard errors. The numbers above the bars indicate the number of forest sites in the data base. Significance was tested with ANOVA.

**Fig. S10. Relationships of NEP (A) and Re (B) with GPP showing only forests presenting 1000 < GPP < 2500.** The results for this range of GPP indicate that the interaction between GPP*nutrient availability is not significant neither for NEP nor for Re. However, nutrient availability significantly increases the mean in NEP and reduces Re ($P$ = 0.0026 and $P$ = 0.0036 respectively). On the other hand, differences in CUEe between nutrient-rich and nutrient-poor forests remained significant at the < 0.001 level (CUEe nutrient-rich = 0.33, nutrient-poor = 0.17). Nutrients = nutrient availability.

**Table S1: Information on the nutrient availability of the forests studied.** The term id indicates the number of the site, referenced at the bottom of the table. NA indicates our classification of nutrient status according to the provided information [high (H), medium (M) or low (L) nutrient availability]. PI indicates the nutrient status suggested by the principal investigators of the forests. The other columns provide information on nutrient availability as follows: soil type, additional soil information, soil pH, soil carbon content (kg $m^{-2}$) or concentration (per dry mass %), soil nitrogen content or concentration, carbon-to-nitrogen ratio (C:N), information on other soil nutrients, cation exchange capacity (CEC), nitrogen deposition (D) or mineralisation (M), foliar nutrient concentration (N: nitrogen, P: phosphorus), history of the forest and reports in the published literature on soil or forest nutrient availability. Units: Carbon (C) and nitrogen (N) in percentage of dry mass (when indicated by %) or in kg $m^{-2}$; CEC in meq 100 $g^{-1}$; nitrogen deposition and mineralization in kg $ha^{-1}$ $year^{-1}$; foliar nutrient concentration in percentage of dry mass. Additional abbreviations: L (lower soil horizons), Lt (litterfall), U (upper soil horizons).

**Table S2. Analysis of sensitivity to a possible misclassification of nutrient availability.** The table contains those forests for which information assessing nutrient status could lead to a wrong classification. Each shows its values for CUEe, the uncertainty of this estimate (SE), the original and most plausible classification of nutrient status and an alternative nutrient classification. The *P*-values of the significant variables and the β weights of the covariates, using the original and the alternative nutrient classification with stepwise backward regressions, are shown at the bottom of the table. Possible predictors were GPP, nutrient availability, stand age and management, including their interactions up to the second order, MAT, MAP and WD. Significance levels: * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$. H high, M medium and L low nutrient availability.

**Table S3: Followed criteria for evaluating nutrient availability.** The table shows the code assigned to the forests according to the values of the variables used for the nutrient availability assessment.

**Table S4. Validation of the nutrient classification.** Summary of the percentage of successfully classified forests of the different logit models used to validate the nutrient classification. In general terms, our nutrient classification was successfully predicted with the available data for nutrient status that, in turn, achieved a good percentage of successful predictions of the reports found in the literature on the nutrient status of the forests.

**Fig. S1.**

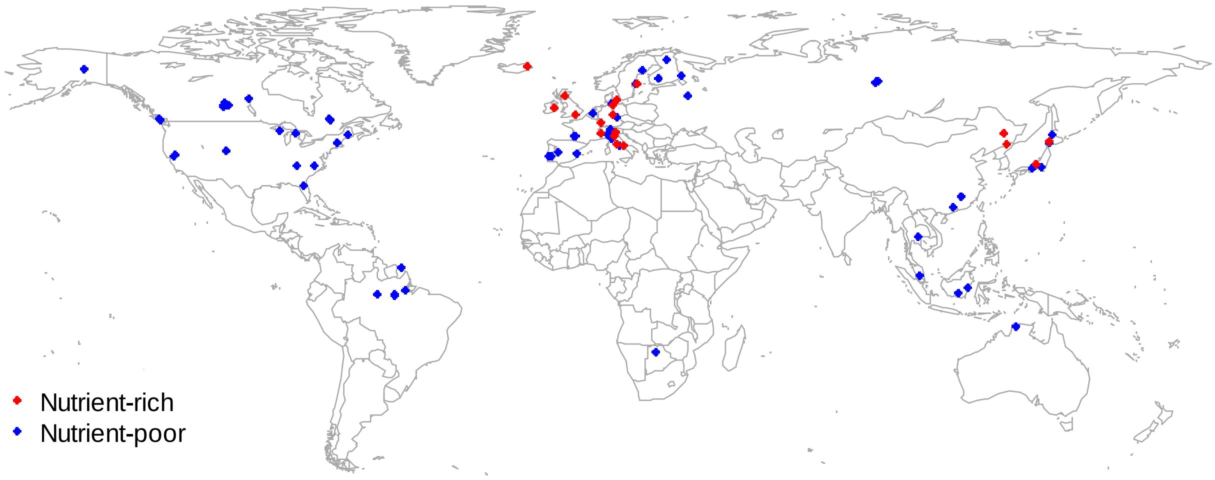


**Fig. S2.**

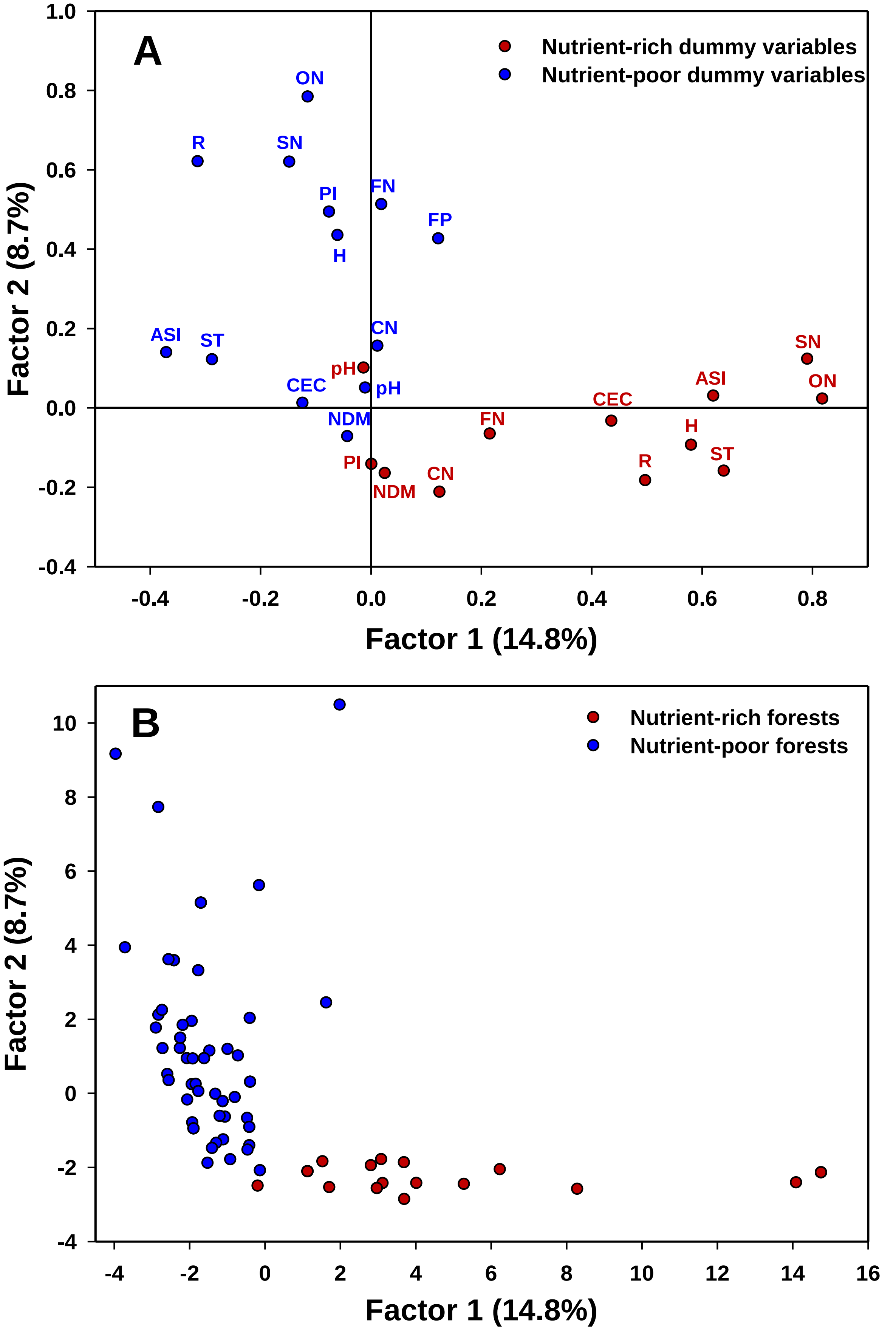
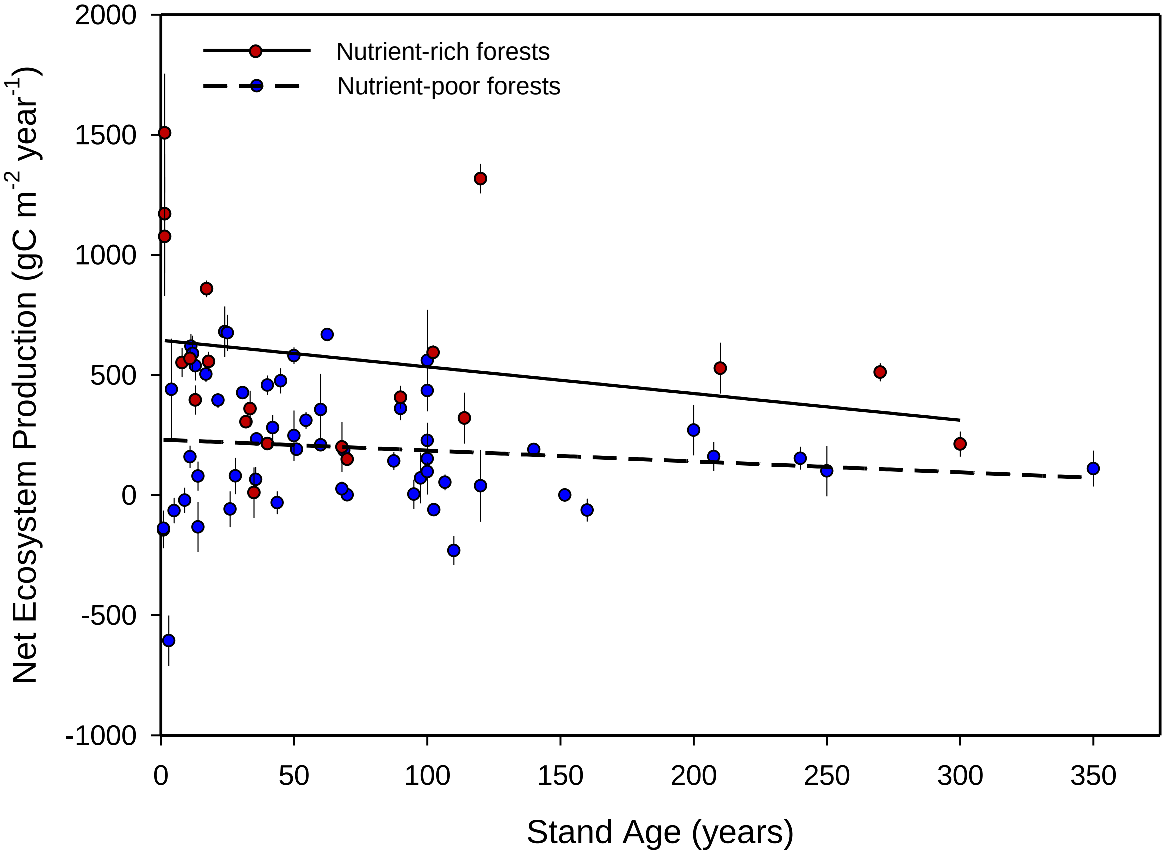
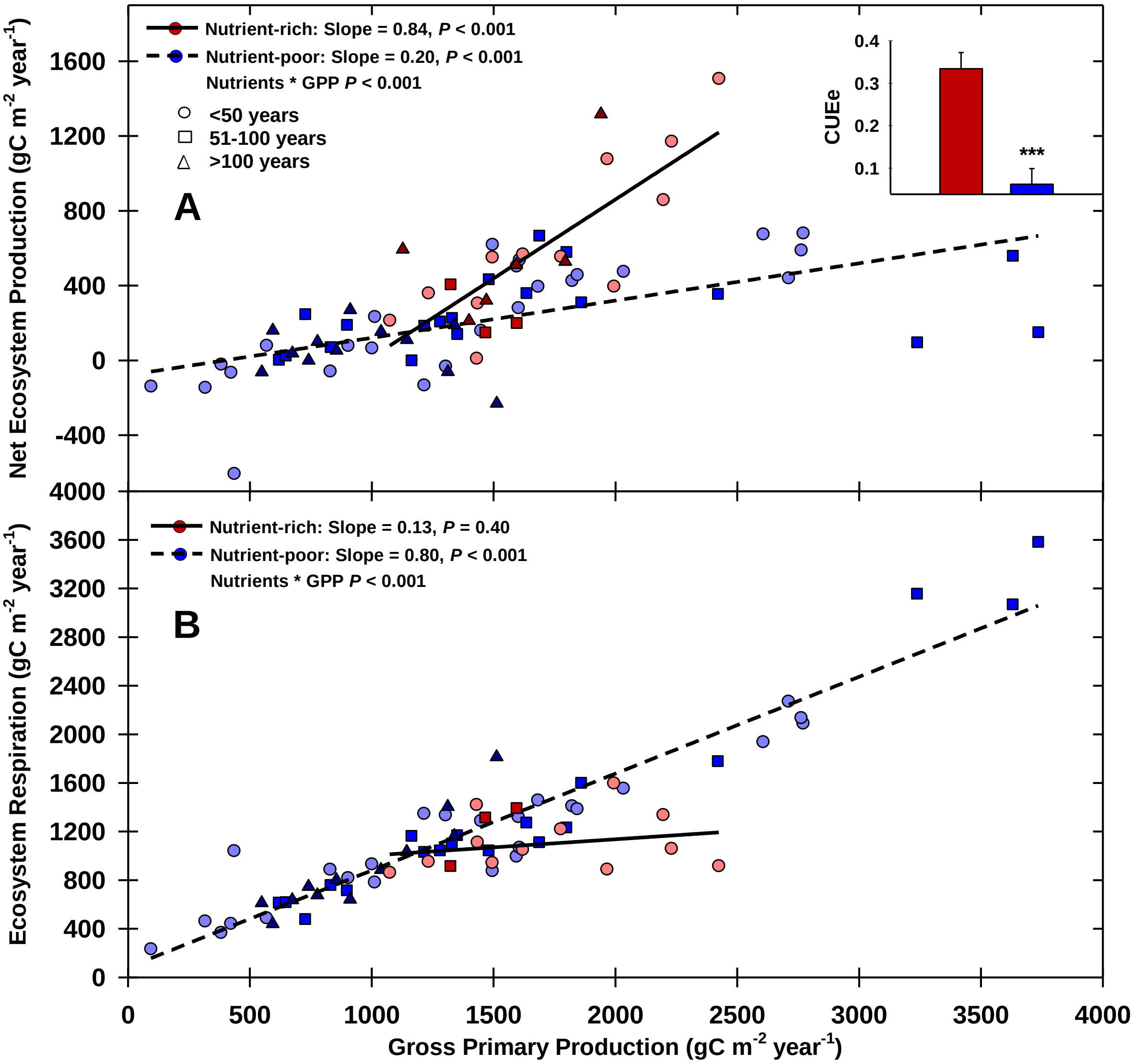

A
Nutrient-rich dummy variables
Nutrient-poor dummy variables
ON
R
SN
PI
FN
H
FP
ASI
ST
CN
pH
CEC
NDM
FN
CEC
ASI
SN
ON
H
R
ST
PI
NDM
CN
Factor 2 (8.7%)
Factor 1 (14.8%)
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.4
-0.2
0.0
0.2
0.4
0.6
0.8
B
Nutrient-rich forests
Nutrient-poor forests
Factor 2 (8.7%)
Factor 1 (14.8%)
10
8
6
4
2
0
-2
-4
-4
-2
0
2
4
6
8
10
12
14
16

**Fig. S3.**

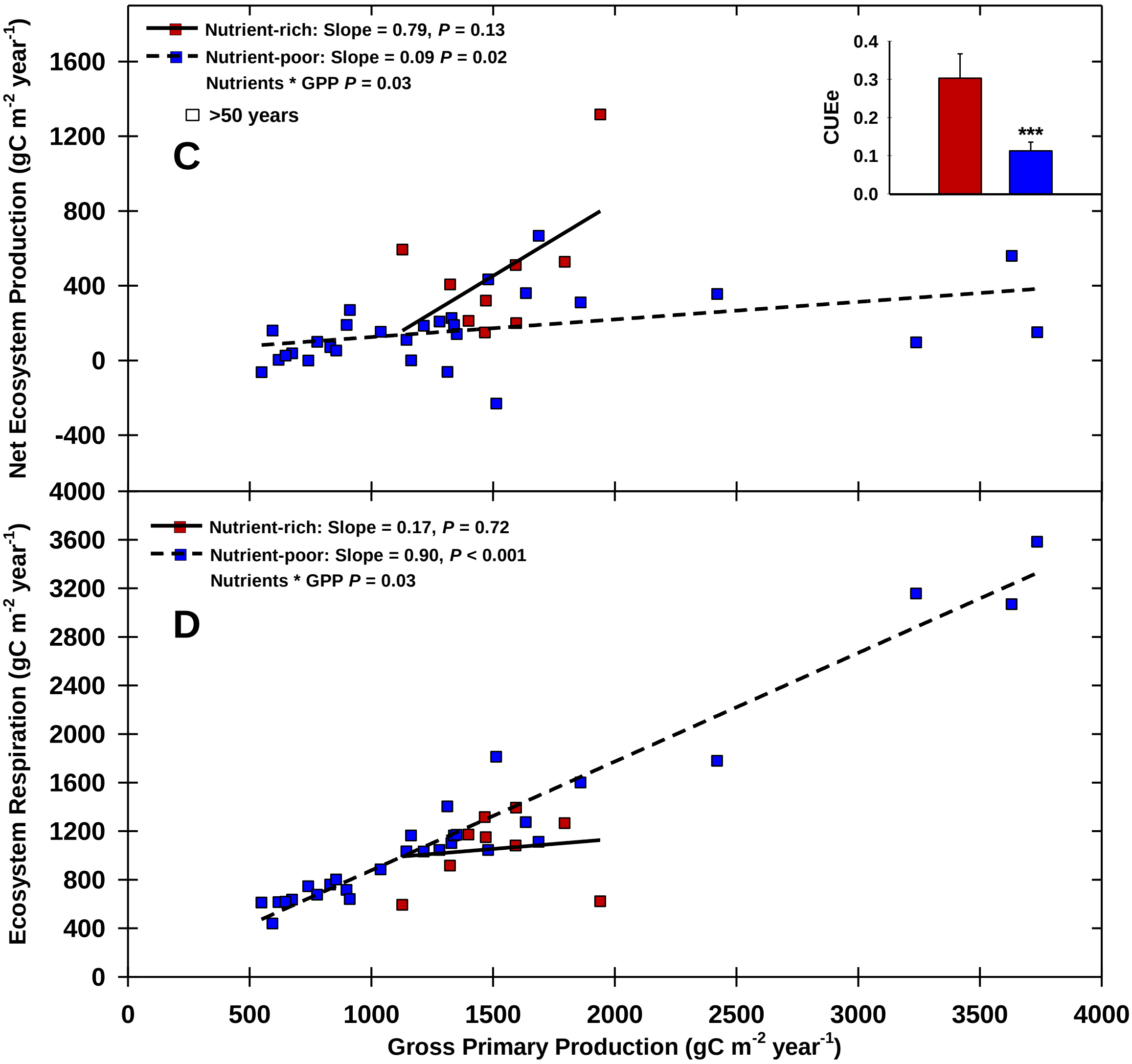


Nutrient-rich forests
Nutrient-poor forests
Net Ecosystem Production (gC m-2 year-1)
Stand Age (years)
2000
1500
1000
500
0
-500
-1000
0
50
100
150
200
250
300
350

625 **Fig. S4.**

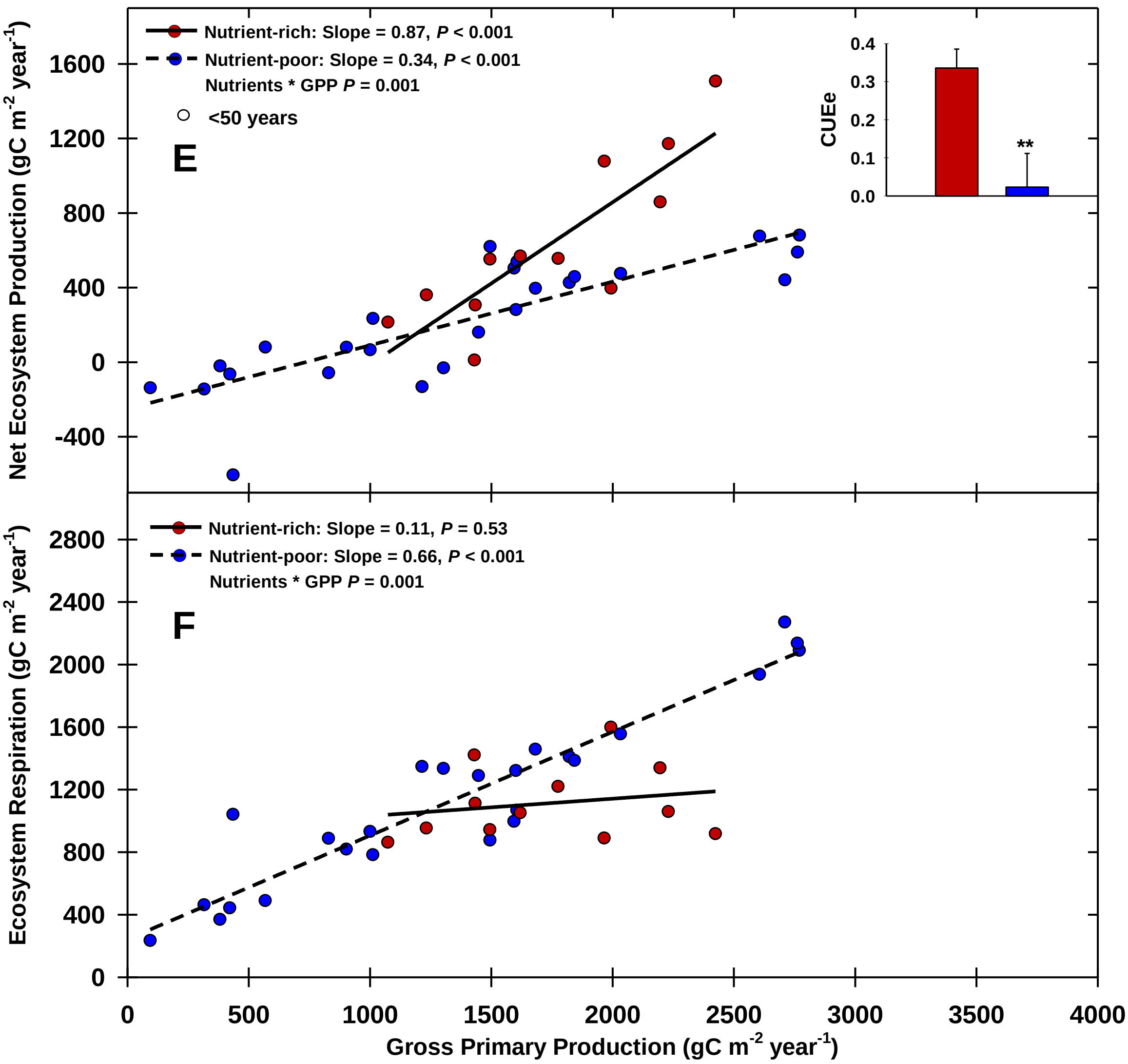



626


Nutrient-rich: Slope = 0.79, P = 0.13
Nutrient-poor: Slope = 0.09 P = 0.02
Nutrients * GPP P = 0.03
>50 years
C
CUEe
***
Net Ecosystem Production (gC m-2 year-1)
Nutrient-rich: Slope = 0.17, P = 0.72
Nutrient-poor: Slope = 0.90, P < 0.001
Nutrients * GPP P = 0.03
D
Ecosystem Respiration (gC m-2 year-1)
Gross Primary Production (gC m-2 year-1)

627

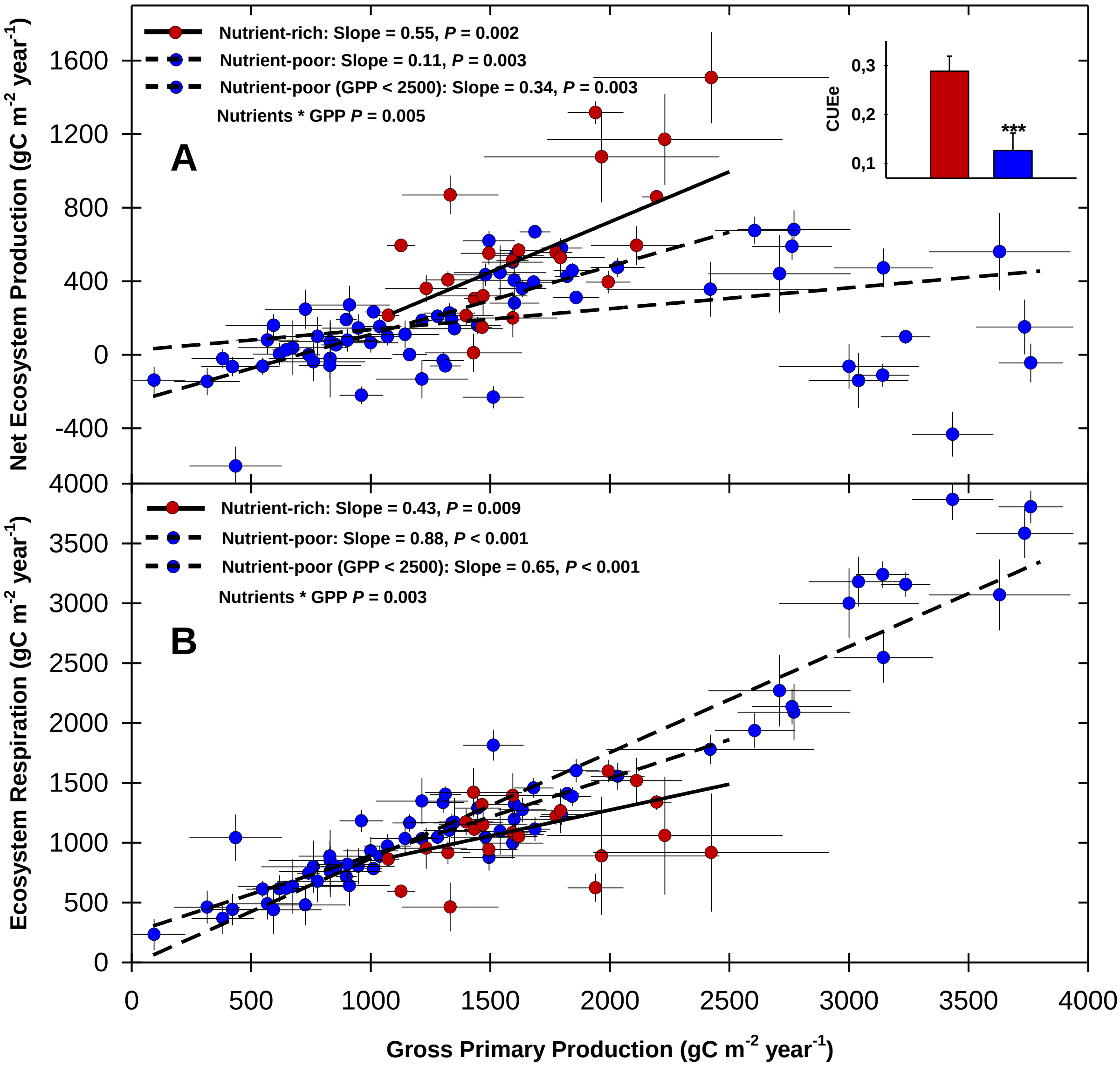
628



Nutrient-rich: Slope = 0.87, P < 0.001
Nutrient-poor: Slope = 0.34, P < 0.001
Nutrients * GPP P = 0.001
<50 years
E
CUEe
**
Net Ecosystem Production (gC m-2 year-1)
Nutrient-rich: Slope = 0.11, P = 0.53
Nutrient-poor: Slope = 0.66, P < 0.001
Nutrients * GPP P = 0.001
F
Ecosystem Respiration (gC m-2 year-1)
Gross Primary Production (gC m-2 year-1)

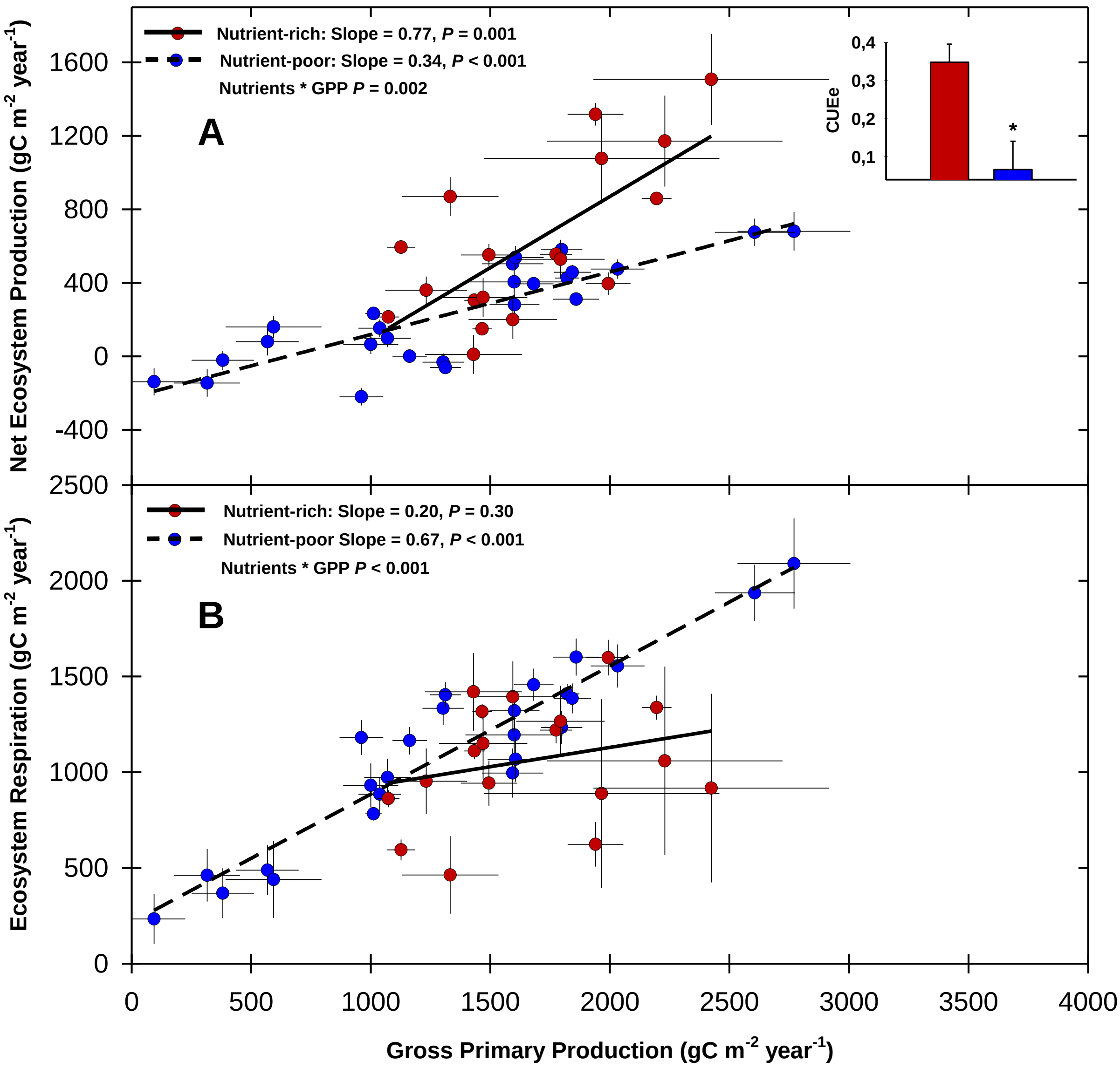

629

**Fig. S5.**



Nutrient-rich: Slope = 0.55, P = 0.002
Nutrient-poor: Slope = 0.11, P = 0.003
Nutrient-poor (GPP < 2500): Slope = 0.34, P = 0.003
Nutrients * GPP P = 0.005
A
CUEe
0,3
0,2
0,1
***
Net Ecosystem Production (gC m-2 year-1)
1600
1200
800
400
0
-400
Nutrient-rich: Slope = 0.43, P = 0.009
Nutrient-poor: Slope = 0.88, P < 0.001
Nutrient-poor (GPP < 2500): Slope = 0.65, P < 0.001
Nutrients * GPP P = 0.003
B
Ecosystem Respiration (gC m-2 year-1)
4000
3500
3000
2500
2000
1500
1000
500
0
0
500
1000
1500
2000
2500
3000
3500
4000
Gross Primary Production (gC m-2 year-1)

633 **Fig. S6.**




634

635

**Fig. S7.**

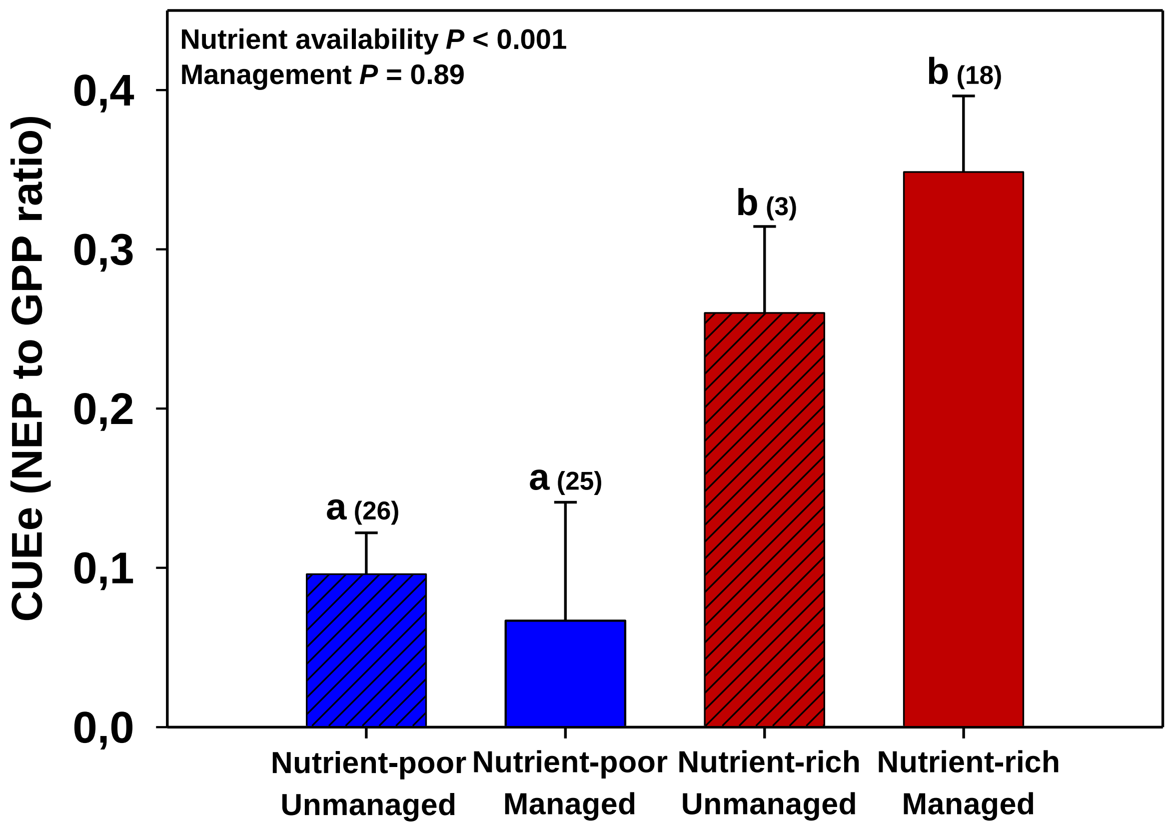
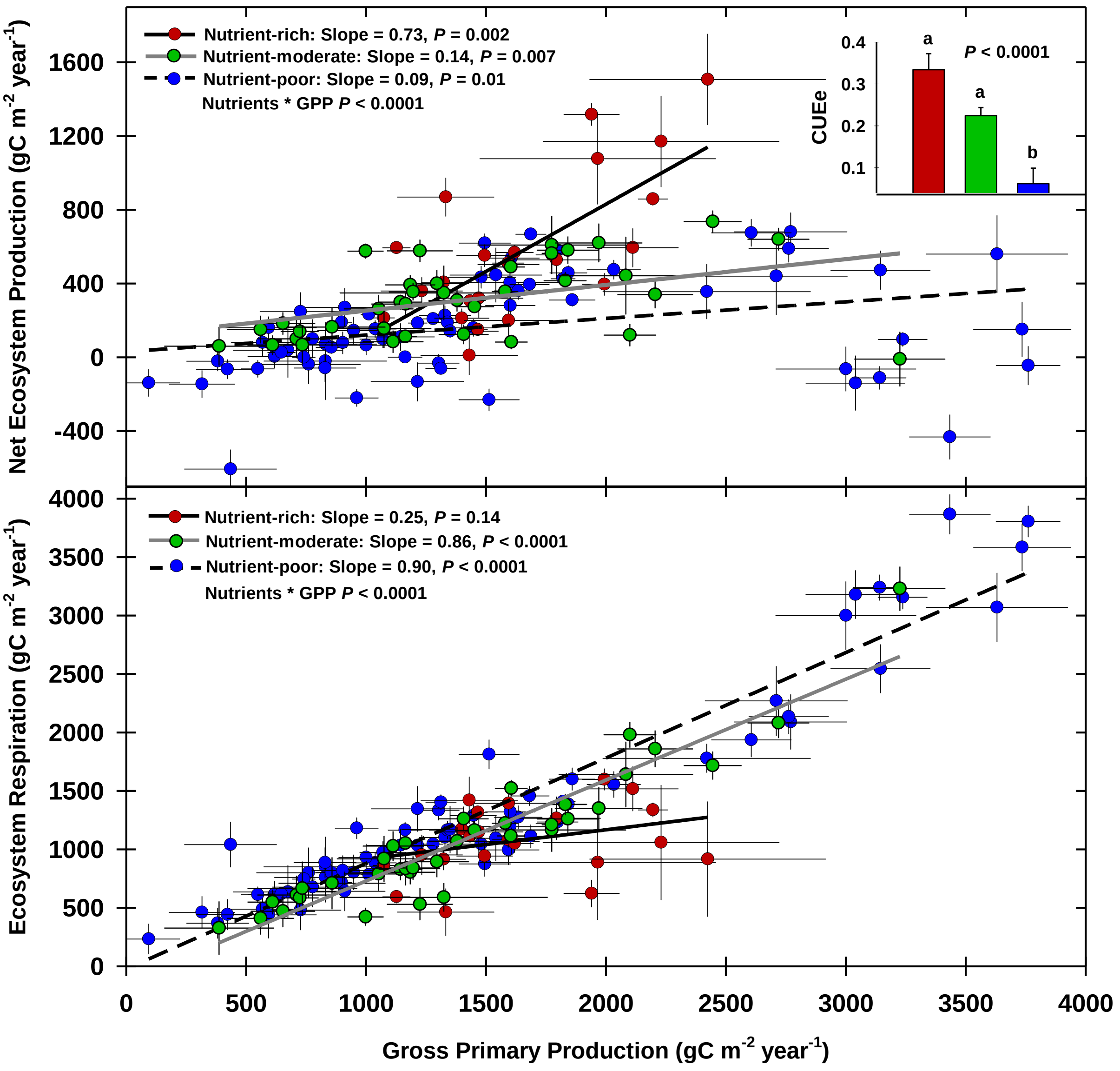
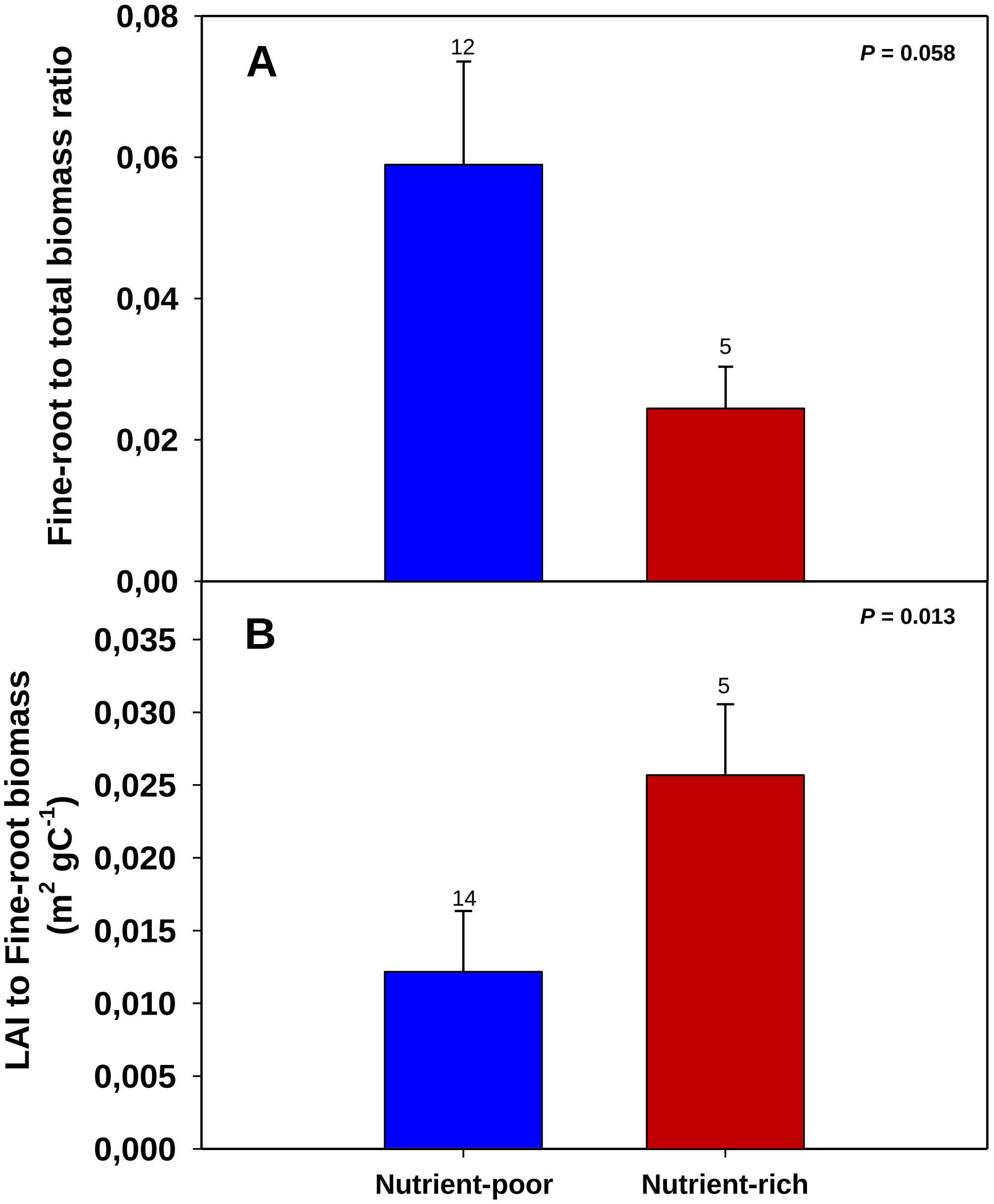

Nutrient availability *P* < 0.001
Management *P* = 0.89
CUEe (NEP to GPP ratio)
0,0
0,1
0,2
0,3
0,4
a (26)
a (25)
b (3)
b (18)
Nutrient-poor Unmanaged
Nutrient-poor Managed
Nutrient-rich Unmanaged
Nutrient-rich Managed

**Fig. S8**

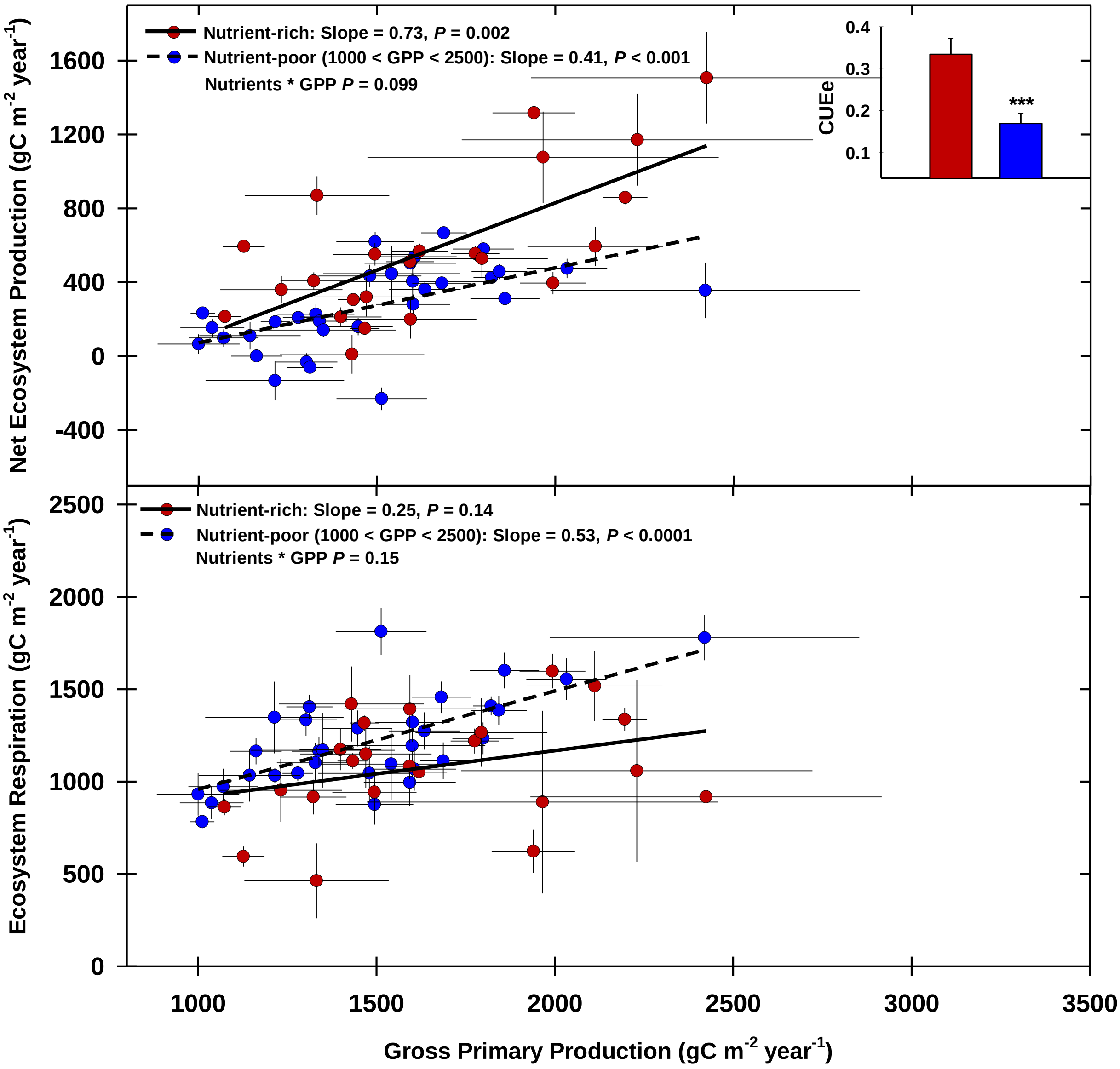

Nutrient-rich: Slope = 0.73, P = 0.002
Nutrient-moderate: Slope = 0.14, P = 0.007
Nutrient-poor: Slope = 0.09, P = 0.01
Nutrients * GPP P < 0.0001
CUEe
P < 0.0001
a
a
b
Net Ecosystem Production (gC m-2 year-1)
Nutrient-rich: Slope = 0.25, P = 0.14
Nutrient-moderate: Slope = 0.86, P < 0.0001
Nutrient-poor: Slope = 0.90, P < 0.0001
Nutrients * GPP P < 0.0001
Ecosystem Respiration (gC m-2 year-1)
Gross Primary Production (gC m-2 year-1)

642 **Fig. S9.**




643

644 **Fig. S10**




645

## Table S1.

| Site id | NA | PI | Soil type | Additional soil info | pH | C | N | C:N | Other Nutrients | CEC | N D/M | Fol N | History | Report |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | H | | | | | | | | | | D:10 | | Fertilized with 350 kg urea $ha^{-1}$, 46% N | |
| 2 | L | L | Spodosol (ultic alaquods) | Poorly drained, argilic horizon | | | | | | | | | | Nutrient limited |
| 3 | M | | | Stony sandy loam | | | | | | | | | | Adequate nutrient supply |
| 4 | M | | | | | | | 24 | | | M:65 | | | |
| 5 | L | | Dystric, podzolic brown soils or Gleysols | Sandy to loamy sandy texture, organic layer mod/moder | 3 to 5 | | | | | Low (Ca, Mg) | D: high | | | |
| 6 | L | | Hydromorphic podzol | Sandy, surface water table in winter | | | | | | | | | | |
| 7 | M | M | Haplic and Entic podzols | | | | U: 1.53%<br>L: 0.13% | U: 30<br>L: 21 | | | | | | |
| 8 | L | | Mixed, mesic, ultic haploxeralf (Cohasset series) | Fine-loamy, clay-loam | 5.5 | U: 6.9% | U: 0.17% | U: 41 | | | | | | |
| 9 | L | | Fibric Histosol | Very wet, waterlogged | | | | | | | | | | Nutrient-poor |
| 10 | M | | Dystri-cambic Arenosol, near id 10 | Not waterlogged | | | | | | | D: high | | | |
| 11 | L | | Haplic podzol | wet sandy soil with humus and/or iron B horizon (Al buffer region). | 4 | | | | | Low | D: 35 | | | Poor in Mg and P foliar concentrations. Good N foliar concentration. |
| 12 | L | | Ultisol | | | | | | | | | | | |
| 13 | M | M | Brown podzolic | well drained, stone free, fine sandy loam materials | | | | | | | | | | Good potato production when fertilized. |
| 14 | L | | | Sandy, hummus rich in calcium carbonate | 5.8 | U: 1.9%<br>L: 0.7% | | U: 66<br>L: 100 | | | | | | |
| 15 | L | | | | | | | | Low P | Low | | | | Extremely nutrient limited |
| 16 | H | | Brown forest earth | Deep and nutrient-rich soil layer | | | | | | | | | | |
| 17 | L | | Ferro-humic or humic podzols | Good drainage | | | 0.01% | 135 | | | | N:0.79% | | |
| 18 | L | | | | | | | | | | | | | Similar to id 17 |

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 19 | M | | Histosol (Belhaven series) | Loamy mixed dysis thermic terric Haplosaprists (peat soils) | <4.5 | | | | | | | | Previously farmed; F at planting: 28–50 kg $ha^{-1}$ (N and P); F mid-rotation: 140–195 kg $ha^{-1}$ N and 28 kg $ha^{-1}$P | |
| 20 | H | | Humic alfisol | Silty loam-silty clay | 5.2 | | Very high | | | Very high | D: high | | | |
| 21 | L | | Oxisol | 80% clay, high porosity (50-80%), low water capacity, highly weathered | 4.3 | | | | | | | | | Low nutrient content |
| 22 | L | | Rustic podsol, Chromic cambisol | Reddish soils | 4 | | | U: 29 | | | D: 13 | | | |
| 23 | L | | Lateritic red or yellow soil | 63% clay, 19% silt | 3.8 | | | | | | | | | |
| 24 | H | | | | | | | | | | | | Former agricultural land regularly fertilized | Nutrient rich |
| 25 | L | | Ultic alfisol | Mixed clay mineralogy, poorly drained from fall to spring | 5.8 | | | | | | | | | |
| 26 | L | | Arenosol | Dune system | | | | | | | | | | |
| 27 | L | | Dystric cambisols | | 4.8 | 0.35% | 0.03% | | P: 9 ppm | | | N: 1.17% P: 0.07% | | |
| 28 | L | | Gelisol | Loamy sand to loam, thick organic horizon (30cm) | | U: 40% L: 3% | U: 0.7% L: 0.17% | U: 50 L: 20 | | | | N: 0.84% | | |
| 29 | L | | | | | | | | | | | | | Strongly nutrient limited |
| 30 | L | | | | | | Low | | | | D: 5.7 | | | Immature and nutrient-rich lava soil (64% N deficit) |
| 31 | L | | | Peat soil | <4.7 | | | | | | | | | Nutrient limited |
| 32 | M | | Orthic Gleysol | | | | | | | | | N: 0.7 - 2.1% | | |
| 33 | M | | Andosol | Silty loam | 5.8 | U: 2.1% | Low | | | 19 | | | | Nitrogen limited |
| 34 | L | L | Acrisol and ultisols | Sandy | | | | | | | | | | Nutrient-poor |
| 35 | M | | Brown alfisol | Sandy loam or loam | | | | | | | | | | |
| 36 | H | | Cambisol | 4% sand, 56% lime, 44% clay | | | | | | | | | | Nutrient-rich |
| 37 | H | H | Gleysol | | | | U: 1.3% | U: 19 L: 30 | | | | | | |
| 38 | M | | Gleysol | Peaty, seasonally waterlogged, black organic horizon | | | | | | | | | Fertilized 40 ago. | N increased after clear cutting |

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 39 | M | | Gleysol | Peaty, seasonally waterlogged, black organic horizon | | | | | | | | | Fertilized 40 ago. | N increased after clear cutting |
| 40 | L | | | well drained, acidic sandy loam with some poorly drained peat soils | | | | | | | M: 34 | | | Nutrient-poor |
| 41 | H | | Luvisol or Stagnic luvisol | | | | | | | | | | | Typically very nutrient-rich soils |
| 42 | L | L | | Well drained lateritic red and yellow earth soils with highly weathered sands | 5.5 | | 0.10% | | | | | | | Nutrient-poor |
| 43 | L | L | | | 3.5 | | | 35 | | | | N: 1.06% | | |
| 44 | L | M<br>L | Haplic podzol | | | | Low | | | | M: low<br>D: low | | | >99.9% soil N is unavailable for plants. Nitrogen limitation. |
| 45 | L | | | Sandy loam with limited water capacity | acid | | Low | | Low P | | | | | Bogs and peatland poor in N and very P limited |
| 46 | L | L | Lithic haploxerepts | Very rocky silt loam | | 1.1% | 0.11% | 10 | | | | | | |
| 47 | L | | | Heavily leached | | | | | Low P | Low | | | | Nutrient-poor |
| 48 | H | | | | | | | | | | | | | Very nutrient-rich soil |
| 49 | H | | | | | | | | | | | | | Very nutrient-rich soil |
| 50 | H | | | | | | | | | | | | | Very nutrient-rich soil |
| 51 | M | | Spodosol (or cryosol) | Coarse texture, highly leached, gray | | 2.2% | 0.50% | 4.4 | | | | | | |
| 52 | L | | Entisol | | | | | | | | | | | |
| 53 | L | | Dystric cambisol | 90 cm depth, low water capacity, rocky and sandy (80%) | 5.6 | 2.6% | | 14 | | | | | | |
| 54 | H | M | Typic Fragiudalf (Alfisol) | fine-silty | U: 3.7<br>L: 6.7 | U: 6.2% | U: 0.5% | U: 12.6 | | | | | | |
| 55 | M | | Haplic cambisol and rendzic leptosols (rendzina) | Very shallow | 4 to 7.5 | 6.5 | 0.47 | U: 15 | | | D: 26 | | | |
| 56 | H | | Alfisol | Dark-brown | | | | | | | | | | |
| 57 | H | H | Humic Umbrisol | | 6.1 | | | 15.8 | | | | | | |
| 58 | L | | Hydromorphic podzol | Sandy, waterlogged in winter | | | | 26 | | | | | | |
| 59 | M | | | Sand dunes. | | | | | | | D: high | | | Nutrient-poor under natural conditions |

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 60 | M | | Kandiustalfs | | 6.5 | | | | | | | | | Relatively nutrient rich |
| 61 | L | L<br>M | Kalahari sands | Presents a calcrete duricrust | | | | | | | | N: 1 to 3% | | Nutrient-poor |
| 62 | M | | | Sandy soils | | | Low | | | | | | | N-fixing shrubs increase N availability |
| 63 | M | | | Sandy soils | | | Low | | | | | | | N-fixing shrubs increase N availability |
| 64 | L | L | | 83% sand, 9% silt and 8% clay | 5.6 | 1.6% | 0.12% | 133 | | | | | | |
| 65 | M | | Typic Dystrochrept | | | | | | | | M: 122 | | | |
| 66 | M | M | Mollic Eutroboralf and Typic Argiboroll | Loam | 5.3 | 2.5% | 0.14 | 17.9 | High P | | | | | Although N might be limiting, P is highly available |
| 67 | L | M<br>L | | | | | | | | | | N: 0.95% | | |
| 68 | H | | Eutric Vertisol | 60% clay | | 5.6% | 3.80% | 8.5 | P: 98ppm | 27 | | N: 3% | Former fertilized agricultural land | |
| 69 | L | | Podzolic glacial till | Sandy | | | | | | | | | | Nutrient-poor |
| 70 | L | L | Ombrotrophic peat dome | | <3 | 39% | 1.30% | 30 | Low | | | P: very low<br>N: low | | Low availability of essential nutrients |
| 71 | L | L | | 58% sand, 32% silt, 10% clay | U: 6.4<br>L: 6.3 | U: 1.2<br>L: 1.6 | U: 0.08<br>L: 0.08 | U: 15<br>L: 20 | | | | N: 0.71% | | |
| 72 | L | | Durian Series | Band of laterite, highly leached | 3.5 to 4.8 | | | | Low P | Low | | | | |
| 73 | H | | Xeric Alfisol | Loam texture | | | High | | High | | | | Former agricultural land | Characterized by its high nutrient availability |
| 74 | H | | Xeric Alfisol | Loam texture | | | High | | High | | | | Former agricultural land | Characterized by its high nutrient availability |
| 75 | H | | Xeric Alfisol | Loam texture | | | High | | High | | | | Former agricultural land | Characterized by its high nutrient availability |
| 76 | L | | | Waterlogged | | | | | | | | | | Nutrient availability restricted by slow decomposition rates |
| 77 | L | | | Waterlogged | | | | | | | | | | Nutrient availability restricted by slow decomposition rates |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 78 | L | | | Waterlogged | | | | | | | | | Nutrient availability restricted by slow decomposition rates |
| 79 | M | H | | 75% rocks, stone-free fraction is silty-clay loam (39% clay, 35% silt, 26% sand) | | 7.40% | 0.48% | U: 15<br>L: 11 | | | N: 1.26% | | |
| 80 | L | | Red earth | | | | Low | | Low | | | | Very poor nutrient status |
| 81 | M | | | | U: 3.9<br>L: 4.1 | U: 27%<br>L: 9% | U: 1.3%<br>L: 0.4% | U: 20<br>L: 24 | U: 0.08% L: 0.03% | | N Lt: 1%<br>P lt: 0.07% | | |
| 82 | H | | Luvisol | 100 cm depth, 52% sand, 12% silt, 35% clay | 5.7 | | | 12.6 | | | | | |
| 83 | L | | Utisol | Stony | 5.1 | | Low | | Low | Low | | | Nutrient-poor, especially P |
| 84 | L | L | | 93% sand, 3% silt, 4% clay | 6.5 to<br>>7.9 | U: 0.9<br>L: 0.4 | U: 0.03<br>L: 0.03 | U: 30<br>L: 14 | Low | | N: 0.70% | | Poor sandy soil |
| 85 | H | | | Loam, from volcanic ashes. | | | | | | | N: 2.30% | | |
| 86 | M | M | | | | U: 4.2% | U: 0.4% | 10.5 | | | | | |
| 87 | L | | | Sandy to sandy loam | | 3.1 | 0.14 | 22.0 | | | N: 0.95% | | |
| 88 | L | | | Sandy to sandy loam | | 2.3 | 0.19 | 12.1 | | | N:1.07% | | |
| 89 | L | | | Sandy to sandy loam | | 3.3 | 0.17 | 19.4 | | | N:1.35% | | |
| 90 | L | | | Sandy to sandy loam | | 1.7 | 0.08 | 21.3 | | | N:1.36% | | |
| 91 | L | | | Sandy | | 1.8 | 0.1 | 18.0 | | | N:1.20% | | HJP75 could be more nutrient limited due to higher tree competition |
| 92 | L | | | Sandy to sandy loam | | 1.4 | 0.1 | 14.0 | | | N:1.55% | | |
| 93 | M | M | | | | | | | | | | | |
| 94 | M | M | | | | | | | | | | | |
| 95 | H | | | | | | | | | | | | Fertilized |
| 96 | L | L | Ultic alaquods | Sandy, siliceous, thermic | | Low | Low | | Low | | | Trees responded drastically to fertilization experiment | Low in available nutrients |
| 97 | L | L | Ultic alaquods | Sandy, siliceous, thermic | | Low | Low | | Low | | | Trees responded drastically to fertilization experiment | Low in available nutrients |
| 98 | L | | Haplic podzol | | | | Low | | Low | | | | Nutrient-poor soil |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 99 | M | | | | Low | | | | | Low | | | Nutrients are sufficiently available in this forest |
| 100 | H | | Luvisol | | | | High | | | | | | Very nutrient rich |
| 101 | L | M | | 57% sand, 36% silt and 6% clay | | | 0.18% | | | | M: 4.4 | | |
| 102 | H | | Brown soil | | | | | | | | | | Very nutrient rich |
| 103 | M | | Dystric Cambisol | Clay loam, from volcanic ash deposit | | | | | | | | | |
| 104 | L | | Belterra clay Ferralsols | | | | Low | | Low | | | | Nutrient-poor |
| 105 | L | | Belterra clay Ferralsols | | | | Low | | Low | | | | Nutrient-poor |
| 106 | L | | Gleyic Cambisol | | | | | | | | D: 5 | | Stream water chemistry revealed very low N concentrations |
| 107 | M | | Dystric Cambisol | | | | | | | | | | Less nutrient rich than a eutric Cambisol |
| 108 | L | | | Drained, peat-rich | | | Low | | Low | | | | Severely nutrient limited |
| 109 | L | | Volcanogenous regosol | Well drained | | | Low | | Low | | | | Nutrient-poor |
| 110 | M | M | Brunicolic grey brown luvisol | Sandy to loamy sand soil, low-to-moderate water-holding capacity | 6.3 | 0.56% | U: 0.06% | L: 11.4 | | | D: 7.5 | Planted on former agricultural land | Have higher amounts of soil macronutrients (i.e. P, K, Ca, Mg) than id 111 and 112 |
| 111 | M | M | Gleyed brunisolic luvisol | Sandy to loamy sand soil, low-to-moderate water-holding capacity | 4.1 | 0.61% | U: 0.05% | L: 15.4 | | | D: 7.5 | Planted on cleared oak-savannah land | |
| 112 | M | M | Brunicolic grey brown luvisol | Sandy to loamy sand soil, low-to-moderate water-holding capacity | 3.7 | 0.60% | U: 0.06% | L: 19.4 | | | D: 7.5 | Planted on cleared oak-savannah land | |
| 113 | M | M | Gleyed brunisolic luvisol | Sandy to loamy sand soil, low-to-moderate water-holding capacity | 4.3 | 0.51% | U: 0.07% | L: 14.2 | | | D: 7.5 | Planted on former agricultural land | Same as id 110 |
| 114 | L | | Entic Haplothod | Sandy, well drained | | | Low | | | | | | Nitrogen limited |
| 115 | H | | Brown Andosol | | | U: 8.1%<br>L: 3.0% | U: 0.4%<br>L: 0.2%. | U: 20<br>L: 15 | | | | Grazed heathland pasture prior to afforestation | |
| 116 | L | L<br>M | | Gravelly loamy sand, 19 cm depth | | U: 39%<br>L: 4.6% | U: 0.9%<br>L: 0.3% | U: 43<br>L: 15 | | | | | Presents low nitrogen availability |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 117 | L | L<br>M | | Gravelly loamy sand to sand, 19 cm depth | U: 45%<br>L: 6.9% | U: 1%<br>L: 0.2% | U: 45<br>L: 35 | | | | | |
| 118 | L | L<br>M | | Gravelly loamy sand, 19 cm depth | U: 46%<br>L: 18% | U: 1%<br>L: 0.8% | U: 46<br>L: 23 | | | | | |
| 119 | M | M | | | | | | | | | | Fertilization stimulated tree growth |
| 120 | L | | Typic Paleudult | Highly weathered, acidic | | Low | | low P | Low | | | |
| 121 | M | | Podzols and Cambisols | | | | | | | | | Moderately nutrient-rich soils |
| 122 | M | | Enthic Haplorthod | | | | | | | M: > id 114 | | Nutrient-poor soil similar to id 114 |
| 123 | M | | Stagni-vertic Cambisol | Some areas of arenihaplic Luvisols and calcaric Cambisols | | | | | | | | Vegetation is typical for relatively nutrient-rich soils |
| 124 | M | | Rendzina | Above chalk and limestone | | | 11 | | | | | Poor soil conditions |
| 125 | M | | Brown | Loam | | Low | | Low | | | | Nutrient limitations |
| 126 | L | | Cambisols | Sandy silt | | Low | | Low | | | see report | Nutrient limited: extremely low nutrient concentrations were reported in *Pinus* and *Larix* trees |
| 127 | L | | Cambisols | Sandy silt | | Low | | Low | | | Idem id 126 | Nutrient limited |
| 128 | L | | Cambisols | Sandy silt | | Low | | Low | | | Idem id 126 | Nutrient limited |
| 129 | L | | Cambisols | Sandy silt | | Low | | Low | | | Idem id 126 | Nutrient limited |

**Site id: 1.** Aberfeldy/Griffins; **2.** Austin; 3. Balmoral; 4. Barlett; 5. Bayreuth/Weiden Brunnen; **6.** Bilos; **7.** Bily Kriz Forest; **8.** Blodgett Forest; **9.** Bornhoved Alder; **10.** Bornhoved Beech; **11.** Brasschaat; **12.** Bukit Soeharto; **13.** Camp Borden; **14.** Castelporziano; **15.** Caxiuana; **16.** Changbai Mountains; **17.** Chibougamau EOBS; **18.** Chibougamau HBS00; **19.** Coastal plain North Carolina; **20.** Collelongo; **21.** Cuieiras/C14; **22.** Davos; **23.** Dinghushan DHS; **24.** Dooary; **25.** Duke Forest; **26.** El Saler; **27.** Espirra; **28.** Fairbanks; **29.** Flakaliden C; **30.** Fujiyoshida; **31.** Fyedorovskoye; **32.** Groundhog; **33.** Gunnarsholt; **34.** Guyaflux; **35.** Gwangneung; **36.** Hainich; **37.** Hampshire; **38.** Hardwood; **39.** Hardwood_21; **40.** Harvard; **41.** Hesse; **42.** Howards spring; **43.** Howland; **44.** Hyytiala; **45.** Ilomantsi Mekrijärvi; **46.** Ione; **47.** Jacaranda/K34; **48.** Kannenbruch Alder/Ash; **49.** Kannenbruch Beech; **50.** Kannenbruch Oak; **51.** Khentei Taiga; **52.** Kiryu; **53.** La Majadas del Tietar; **54.** La Mandria; **55.** Lägeren; **56.** Laoshan;

**57.** Lavarone; **58.** Le Bray; **59.** Loobos; **60.** Mae Klong; **61.** Maun Mopane; **62.** Metolius; **63.** Metolius young; **64.** Mitra; **65.** Morgan Monroe; **66.** NAU Centennial; **67.** Niwot Ridge; **68.** Nonantola; **69.** Norunda; **70.** Palangkaraya; **71.** Parco Ticino; **72.** Pasoh; **73.** Popface alba; **74.** Popface euamericana; **75.** Popface nigra; **76.** Prince Albert SSA (SOAS); **77.** Prince Albert SSA (SOBS); **78.** Prince Albert SSA (SOJP); **79.** Puechabon; **80.** Qianyanzhou Ecological Station; **81.** Renon; **82.** Roccarespampami 2; **83.** Sakaerat; **84.** San Rossore; **85.** Sapporo; **86.** Sardinilla; **87.** Saskatchewan F77; **88.** Saskatchewan F89; **89.** Saskatchewan F98; **90.** Saskatchewan HJP02; **91.** Saskatchewan HJP75; **92.** Saskatchewan HJP94; **93.** Sky Oaks old; **94.** Sky Oaks young; **95.** Skyttorp2; **96.** Slash pine Florida Mid; **97.** Slash pine Florida old; **98.** Sodankylä; **99.** Solling; **100.** Soroe; **101.** Sylvania; **102.** Takayama; **103.** Takayama 2; **104.** Tapajos 67; **105.** Tapajos 83; **106.** Teshio CC-LaG; **107.** Tharandt; **108.** Thompson NSA (NOBS); **109.** Tomakomai; **110.** Turkey Point TP02; **111.** Turkey Point TP39; **112.** Turkey Point TP74; **113.** Turkey Point TP89; **114.** University of Michigan; **115.** Vallanes; **116.** Vancouver Island DF49; **117.** Vancouver Island HDF00; **118.** Vancouver Island HDF88; **119.** Vielsalm; **120.** Walker Branch; **121.** Wet-T-57; **122.** Willow Creek; **123.** Wytham Woods; **124.** Yatir; **125.** Yellow River Xiaolangdi; **126.** Yenisey Abies; **127.** Yenisey Betula; **128.** Yenisey Mixed; **129.** Yenisey/Zotino.

**Table S2.**

| Forest name | CUEe | SE | Original Classification | | Alternative Classification | |
|---|---|---|---|---|---|---|
| Bayreuth/Weiden Brunnen | -0.02 | 0.04 | L | | M | |
| Bilos | 0.25 | 0.07 | L | | M | |
| Blodgett Forest | 0.11 | 0.03 | L | | M | |
| Bornhoved Alder | 0.15 | 0.07 | L | | M | |
| Brasschaat | 0.00 | 0.02 | L | | M | |
| Camp Borden | 0.12 | 0.05 | M | | L | |
| Castelporziano | 0.32 | 0.02 | L | | M | |
| Guyaflux | 0.04 | 0.04 | L | | M | |
| Hampshire | 0.28 | 0.06 | H | | M | |
| Hardwood | 0.32 | 0.05 | M | | H | |
| Hardwood_21 | 0.31 | 0.06 | M | | H | |
| Lägeren | 0.23 | 0.03 | M | | H | |
| Lavarone | 0.68 | 0.05 | H | | M | |
| Loobos | 0.23 | 0.02 | M | | L | |
| Maun Mopane | -0.03 | 0.25 | L | | M | |
| Prince Albert SSA (SOAS) | 0.15 | 0.02 | L | | M | |
| Prince Albert SSA (SOBS) | 0.06 | 0.06 | L | | M | |
| Prince Albert SSA (SOJP) | 0.05 | 0.08 | L | | M | |
| Sylvania | 0.10 | 0.07 | L | | M | |
| Teshio CC-LaG | 0.05 | 0.08 | L | | M | |
| Vielsalm | 0.31 | 0.02 | M | | L | |
| Wet-T-57 | -0.03 | 0.04 | M | | H | |
| Willow Creek | 0.25 | 0.06 | M | | H | |
| Yatir | 0.28 | 0.11 | M | | L | |
| Yellow River Xiaolangdi | 0.30 | 0.05 | M | | L | |
| | | | **Effect (β)** | ***$R^2$*** | **Effect (β)** | ***$R^2$*** |
| **Nutrient availability** | | | H>L; -0.32** | 0.12 | H>L; -0.29** | 0.07 |
| **GPP** | | | 0.91*** | 0.14 | 0.59** | 0.12 |
| **Age** | | | 1.13*** | <0.01 | 1.22*** | 0.01 |
| **GPP*Age** | | | -1.17*** | 0.17 | -1.18*** | 0.18 |
| **MAT** | | | - | - | 0.39* | 0.06 |
| **Adjusted *$R^2$*** | | | **0.40** | | **0.39** | |

**NOTE:** Depending on the classification, the number of replicates varies (because the number of forests of medium nutrient availability changes).

## Table S3.

| Variable | Code | Variable | Code |
|---|---|---|---|
| **Soil Additional Info** | | **Soil type** | |
| Poorly drained, argilic horizon | Low | Acrisol and ultisols | Low |
| 100 cm depth, 52% sand, 12% silt, 35% clay | Medium | Alfisol | High |
| 4% sand, 56% lime, 44% clay | Medium | Andosol | Medium |
| 57% sand, 36% silt and 6% clay | Low | Arenosol | Low |
| 58% sand, 32% silt, 10% clay | Medium | Belterra clay Ferralsols | Low |
| 60% clay | Medium | Brown Andosol | High |
| 63% clay, 19% silt | Low | Brown podzolic | Low |
| 75% rocks, stone free fraction is silty-clay loam (39% clay, 35% silt, 26% sand) | Medium | Brown soil | High |
| 80% clay, high porosity (50-80%), low water capacity, highly weathered | Low | Brunicolic grey brown luvisol | High |
| 83% sand, 9% silt and 8% clay | Low | Cambisol | Medium |
| 90 cm depth, low water capacity, roky and sandy (80%) | Low | Dystric cambisol | Medium |
| 93% sand, 3% silt, 4% clay | Low | Enthic Haplorthod | Low |
| Above chalk and limestone | Low | Entisol | Low |
| Band of laterite, highly leached | Low | Eutric Vertisol | Low |
| Clay loam, from volcanic ash deposit | Medium | Fibric Histosol | Low |
| Coarse texture, highly leached, gray | Low | Gleyed brunisolic luvisol | High |
| Dark-brown | High | Gleyic Cambisol | Medium |
| Deep and fertile soil layer | High | Gleysol | Medium |
| Drained, peat-rich | Low | Haplic cambisol and rendzic leptosols | Medium |
| Dune system | Low | Histosol | Low |
| Fine-loamy, clay-loam | Medium | Humic umbrisol | Medium |
| Fine-silty | Medium | Kalahari sands | Low |
| Good drainage | High | Kandiustalfs | Medium |
| Gravelly loamy sand to sand, 19 cm depth | Medium | Lateritic red or yellow soil | Low |
| Gravelly loamy sand, 19 cm depth | Medium | Lithic haploxerepts | Low |
| Heavily leached | Low | Luvisols | High |
| Highly weathered, acidic | Low | Mixed mesic ultic haploxeralf | Low |
| Loam | High | Mollic Eutroboralf and Typic Argiboroll | Medium |
| Loam, from volcanic ashes. | High | Ombrotrophic peat dome | Low |
| Loamy mixed dysis thermic terric Haplosaprists (peat soils) | Low | Orthic Gleysol | Medium |
| Loamy sand to loam, thick organiz horizon (30cm) | Medium | Oxisol | Low |
| Mixed clay mineralogy, poorly drained from fall to spring | Low | Podzol | Low |
| Not waterlogged | Medium | Red earths | Low |
| Peat soil | Low | Spodosol | Low |
| Peaty, seasonally waterlogged, black organic horizon | Low | Stagni-vertic Cambisol | Medium |
| Peaty, seasonally waterlogged, black organic horizon | Low | Typic Dystrochrept | Medium |
| Presents a calcrete duricrust | Low | Typic Paleudult | Low |
| Sand dunes | Low | Ultic alaquods | Low |
| Sandy | Low | Ultic alfisol | Low |
| Sandy loam or loam | Medium | Ultisol | Low |
| Sandy loam with limited water capacity | Low | Volcanogenous regosol | Medium |
| Sandy silt | Medium | | |

| | |
|---|---|
| Sandy to loamy sand soil, low-to-moderate water holding capacity | Medium |
| Sandy to loamy sandy texture, organic layer mod/moder | Medium |
| Sandy to sandy loam | Medium |
| Sandy, hummus rich in calcium carbonate | Low |
| Sandy, siliceous, thermic | Low |
| Sandy, surface water table in winter | Low |
| Sandy, waterlogged in winter | Low |
| Sandy, well drained | Low |
| Silty loam | Medium |
| Silty loam-silty clay | Medium |
| Some areas of arenihaplic Luvisols and calcaric Cambisols | Medium |
| Stony | Low |
| Stony sandy loam | Medium |
| Very rocky silt loam | Low |
| Very shallow | Low |
| Very wet, waterlogged | Low |
| Waterlogged | Low |
| Well drained | Medium |
| Well drained lateritic red and yellow earth soils with highly weathered sands | Low |
| Well drained, acidic sandy loam with some poorly drained peat soils | Low |
| Well drained, stonefree, fine sandy loam materials | Medium |
| Wet sandy soil with humus and/or iron B horizon (Al buffer region). | Medium |

**Soil pH**

| | |
|---|---|
| 0 - 5 | Low |
| 5.1 - 6 | Medium |
| 6.1 - 8 | High |

**Soil N%**

| | |
|---|---|
| >0.8% | High |
| >0.1% | Medium |
| <0.1% | Low |

**Other Nutrients (soil P)**

| | |
|---|---|
| 9 ppm | Low |
| 98 ppm | High |
| 0.08-0.03% | Medium |

**C:N ratio**

| | |
|---|---|
| > 30 | Low |
| 30 - 20 | Medium |
| <20 | High |

**CEC (meq $L^{-1}$)**

| | |
|---|---|
| >20 | High |
| >10 | Medium |
| <10 | Low |

**N deposition (kg $ha^{-1}$ $year^{-1}$)**

| | |
|---|---|
| >20 | High |
| 20 - 10 | Medium |
| <10 | Low |

**N mineralization (kg $ha^{-1}$ $year^{-1}$)**

| | |
|---|---|
| 4.4 | Low |
| 34 | Low |
| 65 | Medium |
| 122 | High |

**Foliar N%**

| | |
|---|---|
| >2% | High |
| 2 - 1% | Medium |
| <1% | Low |

**Foliar P%**

| | |
|---|---|
| 0.07% | Low |

667

**Table S4.**

| Dependent variable | Model selection | AIC | Correct cases | Failed cases | Success (%) |
|---|---|---|---|---|---|
| Nutrient status | Saturated | 110 | 92 | 0 | 100% |
| Nutrient status | Stepwise | 37 | 91 | 1 | 99% |
| Report | Saturated | 130 | 55 | 3 | 95% |
| Report | Stepwise | 37 | 54 | 4 | 93% |

## List of Models

Here, we present the minimum adequate models exposed in Table 1 followed by its homologous final model achieved by the model averaging procedure. Predictor variables were: GPP, Nutrient availability (NA), Age, Management (MNG), and its interactions up to second order, MAT, MAP and WD. Forests whose category of management was not managed or unmanaged were excluded. In model averaging summaries, R imp indicates the relative importance of the variables in the final model.

## General Model

## NEP (Fig. 1)

| | Estimate | Std.Err | t value | Pr(>\|t\|) | |
|---|---|---|---|---|---|
| **Intercept** | -1056 | 219.8 | -4.803 | 0.0000124 | *** |
| **gpp** | 0.8679 | 0.1235 | 7.029 | 3.38E-09 | *** |
| **age** | 4.76 | 1.319 | 3.609 | 0.000664 | *** |
| **nutrient.classLOW** | 934.9 | 229.4 | 4.076 | 0.000149 | *** |
| **mat** | 20.67 | 6.186 | 3.342 | 0.001502 | ** |
| **gpp:age** | -0.00293 | 0.0007656 | -3.828 | 0.000333 | *** |
| **gpp:nutrient.classLOW** | -0.6802 | 0.1318 | -5.162 | 0.00000346 | *** |
| **age:nutrient.classLOW** | -1.862 | 0.7679 | -2.425 | 0.018614 | * |

**$R^2$=** 0.7356 **adj $R^2$=** 0.702

**ANOVA table (type III)**

| | SumSq | DF | F value | Pr(>F) | | $R^2$ |
|---|---|---|---|---|---|---|
| **(Intercept)** | 809163 | 1 | 23.0691 | 0.00001244 | *** | |
| **gpp** | 1732864 | 1 | 49.4036 | 3.384E-09 | *** | 0.18 |
| **age** | 456867 | 1 | 13.0252 | 0.0006645 | *** | 0.03 |
| **nutrient.class** | 582787 | 1 | 16.6151 | 0.0001486 | *** | 0.19 |
| **mat** | 391717 | 1 | 11.1678 | 0.0015015 | ** | 0.09 |
| **gpp:age** | 513890 | 1 | 14.6509 | 0.0003332 | *** | 0.09 |
| **gpp:nutrient.class** | 934745 | 1 | 26.6494 | 3.465E-06 | *** | 0.15 |
| **age:nutrient.class** | 206289 | 1 | 5.8813 | 0.0186138 | * | 0.01 |
| **Residuals** | 1929161 | 55 | | | | |

## NEP model averaging

| | Estimate | SE | Adj SE | z val | Pr(>\|z\|) | | Variables | R Imp |
|---|---|---|---|---|---|---|---|---|
| **(Intercept)** | -935.8 | 239.8 | 244.1 | 3.833 | 0.00013 | *** | (Intercept) | 1.00 |
| **age** | 3.947 | 2.058 | 2.075 | 1.902 | 0.05715 | . | gpp | 1.00 |
| **gpp** | 0.7856 | 0.1379 | 0.1404 | 5.597 | <0.00001 | *** | gpp:NA | 1.00 |
| **mat** | 18.69 | 6.871 | 7.011 | 2.667 | 0.00766 | ** | NA | 1.00 |
| **NA.LOW** | 731.9 | 287.5 | 291.9 | 2.507 | 0.01217 | * | mat | 0.97 |
| **age:gpp** | -0.00284 | 0.00081 | 0.000824 | 3.445 | 0.00057 | *** | MNG | 0.62 |
| **age:NA.LOW** | -1.865 | 0.7762 | 0.7939 | 2.349 | 0.01881 | * | gpp:MNG | 0.55 |
| **gpp:NA.LOW** | -0.5897 | 0.164 | 0.1668 | 3.536 | 0.00041 | *** | age | 0.53 |
| **MNG.UM** | 280.4 | 156.1 | 158.2 | 1.773 | 0.07628 | . | wd | 0.50 |
| **wd** | 2.738 | 1.733 | 1.768 | 1.549 | 0.12146 | | age:gpp | 0.45 |
| **gpp:MNG.UM** | -0.2451 | 0.0736 | 0.07525 | 3.257 | 0.00112 | ** | age:NA | 0.42 |
| **MNG.UM:NA.LOW** | -72.39 | 136 | 139.1 | 0.52 | 0.60276 | | map | 0.15 |
| **map** | -0.0281 | 0.09175 | 0.0938 | 0.3 | 0.76454 | | MNG:NA | 0.08 |
| | | | | | | | age:MNG | 0.00 |

**16 models Δ < 4**

## Re (Fig. 2)

| | Estimate | Std.Err | t value | Pr(>\|t\|) | |
|---|---|---|---|---|---|
| **(Intercept)** | 1097 | 228.8 | 4.794 | 0.0000129 | *** |
| **gpp** | 0.09329 | 0.1285 | 0.726 | 0.471097 | |
| **age** | -4.788 | 1.373 | -3.487 | 0.000968 | *** |
| **nutrient.classLOW** | -955.6 | 238.8 | -4.002 | 0.00019 | *** |
| **mat** | -17.02 | 6.44 | -2.643 | 0.010676 | * |
| **gpp:age** | 0.00294 | 0.000797 | 3.688 | 0.000519 | *** |
| **gpp:nutrient.classLOW** | 0.6805 | 0.1372 | 4.961 | 0.00000712 | *** |
| **age:nutrient.classLOW** | 1.967 | 0.7995 | 2.46 | 0.017077 | * |

**$R^2$=** 0.9108 **adj $R^2$=** 0.8995

**ANOVA table (type III)**

| | SumSq | DF | F value | Pr(>F) | | $R^2$ |
|---|---|---|---|---|---|---|
| **(Intercept)** | 873556 | 1 | 22.9785 | 0.00001286 | *** | |
| **gpp** | 20021 | 1 | 0.5266 | 0.4710968 | | 0.64 |
| **age** | 462225 | 1 | 12.1587 | 0.0009684 | *** | 0.01 |
| **nutrient.class** | 608864 | 1 | 16.0159 | 0.0001896 | *** | 0.03 |
| **mat** | 265614 | 1 | 6.9869 | 0.0106758 | * | 0.16 |
| **gpp:age** | 517154 | 1 | 13.6035 | 0.0005186 | *** | 0.03 |
| **gpp:nutrient.class** | 935495 | 1 | 24.6078 | 7.125E-06 | *** | 0.05 |
| **age:nutrient.class** | 230005 | 1 | 6.0502 | 0.0170767 | * | 0.01 |
| **Residuals** | 2090888 | 55 | | | | |

## Re model averaging

| | Estimate | SE | Adj SE | z val | Pr(>\|z\|) | | Variables | R Imp |
|---|---|---|---|---|---|---|---|---|
| **(Intercept)** | 1028 | 252.1 | 256.7 | 4.004 | 6.2E-05 | *** | (Intercept) | 1.00 |
| **age** | -4.61 | 1.463 | 1.492 | 3.089 | 0.00201 | ** | gpp | 1.00 |
| **gpp** | 0.1505 | 0.1434 | 0.146 | 1.031 | 0.30247 | | NA | 1.00 |
| **mat** | -15.27 | 7.095 | 7.242 | 2.108 | 0.03502 | * | gpp:NA | 1.00 |
| **NA.LOW** | -765.2 | 303.2 | 307.8 | 2.486 | 0.01293 | * | mat | 0.85 |
| **age:gpp** | 0.00283 | 0.00083 | 0.00085 | 3.332 | 0.00086 | *** | age | 0.71 |
| **age:NA.LOW** | 1.971 | 0.8094 | 0.8277 | 2.382 | 0.01723 | * | age:gpp | 0.71 |
| **gpp:NA.LOW** | 0.5838 | 0.1719 | 0.1747 | 3.342 | 0.00083 | *** | age:NA | 0.68 |
| **wd** | -3.12 | 1.809 | 1.845 | 1.691 | 0.09077 | . | wd | 0.59 |
| **MNG.UM** | -214.4 | 164.1 | 165.9 | 1.292 | 0.1963 | | MNG | 0.39 |
| **gpp:MNG.UM** | 0.2253 | 0.07724 | 0.07896 | 2.853 | 0.00434 | ** | gpp:MNG | 0.29 |
| **map** | 0.05755 | 0.09505 | 0.09721 | 0.592 | 0.55382 | | map | 0.15 |
| **MNG.UM:NA.LOW** | 76.51 | 142 | 145.3 | 0.527 | 0.59841 | | MNG:NA | 0.03 |
| | | | | | | | age:MNG | 0.00 |

**13 models Δ < 4**

## Models weighted by the uncertainty of the estimates (Supplementary Fig. 5)

## NEP

| | Estimate | Std.Err | t value | Pr(>\|t\|) | |
|---|---|---|---|---|---|
| **(Intercept)** | -848.4 | 226.4 | -3.747 | 0.000431 | *** |
| **gpp** | 0.7368 | 0.1328 | 5.548 | 8.53E-07 | *** |
| **age** | 5.099 | 1.522 | 3.349 | 0.001468 | ** |
| **nutrient.classLOW** | 719.1 | 240.9 | 2.985 | 0.004221 | ** |
| **mat** | 17.79 | 6.842 | 2.6 | 0.011953 | * |
| **gpp:age** | -0.00308 | 0.0009198 | -3.346 | 0.001484 | ** |
| **gpp:nutrient.classLOW** | -0.515 | 0.1536 | -3.352 | 0.001457 | ** |
| **age:nutrient.classLOW** | -2.288 | 0.8235 | -2.778 | 0.007462 | ** |

**$R^2$=** 0.614 **adj $R^2$=** 0.5648

**ANOVA table (type III)**

| | SumSq | DF | F value | Pr(>F) | | $R^2$ |
|---|---|---|---|---|---|---|
| **(Intercept)** | 15401 | 1 | 14.0377 | 0.0004313 | *** | |
| **gpp** | 33773 | 1 | 30.783 | 8.532E-07 | *** | 0.20 |
| **age** | 12308 | 1 | 11.2187 | 0.0014678 | ** | 0.02 |
| **nutrient.class** | 9778 | 1 | 8.9126 | 0.0042208 | ** | 0.14 |
| **mat** | 7416 | 1 | 6.7591 | 0.011953 | * | 0.08 |
| **gpp:age** | 12281 | 1 | 11.1935 | 0.0014844 | ** | 0.06 |
| **gpp:nutrient.class** | 12327 | 1 | 11.2351 | 0.001457 | ** | 0.08 |
| **age:nutrient.class** | 8469 | 1 | 7.7187 | 0.0074616 | ** | 0.03 |
| **Residuals** | 60343 | 55 | | | | |

## NEP model averaging

| | Estimate | SE | Adj SE | z val | Pr(>\|z\|) | | Variables | R Imp |
|---|---|---|---|---|---|---|---|---|
| **(Intercept)** | 1028 | 252.1 | 256.7 | 4.004 | 6.2E-05 | *** | (Intercept) | 1.00 |
| **age** | -4.61 | 1.463 | 1.492 | 3.089 | 0.00201 | ** | gpp | 1.00 |
| **gpp** | 0.1505 | 0.1434 | 0.146 | 1.031 | 0.30247 | | NA | 1.00 |
| **mat** | -15.27 | 7.095 | 7.242 | 2.108 | 0.03502 | * | gpp:NA | 1.00 |
| **NA.LOW** | -765.2 | 303.2 | 307.8 | 2.486 | 0.01293 | * | mat | 0.85 |
| **age:gpp** | 0.002829 | 0.00083 | 0.000849 | 3.332 | 0.00086 | *** | age | 0.71 |
| **age:NA.LOW** | 1.971 | 0.8094 | 0.8277 | 2.382 | 0.01723 | * | age:gpp | 0.71 |
| **gpp:NA.LOW** | 0.5838 | 0.1719 | 0.1747 | 3.342 | 0.00083 | *** | age:NA | 0.68 |
| **wd** | -3.12 | 1.809 | 1.845 | 1.691 | 0.09077 | . | wd | 0.59 |
| **MNG.UM** | -214.4 | 164.1 | 165.9 | 1.292 | 0.1963 | | MNG | 0.39 |
| **gpp:MNG.UM** | 0.2253 | 0.07724 | 0.07896 | 2.853 | 0.00434 | ** | gpp:MNG | 0.29 |
| **map** | 0.05755 | 0.09505 | 0.09721 | 0.592 | 0.55382 | | map | 0.15 |
| **MNG.UM:NA.LOW** | 76.51 | 142 | 145.3 | 0.527 | 0.59841 | | MNG:NA | 0.03 |
| | | | | | | | age:MNG | 0.00 |

**13 models Δ < 4**

## Re

| | Estimate | Std.Err | t value | Pr(>\|t\|) | |
|---|---|---|---|---|---|
| **(Intercept)** | 843.6 | 226 | 3.733 | 0.000451 | *** |
| **gpp** | 0.257 | 0.1309 | 1.963 | 0.054717 | . |
| **age** | -4.752 | 1.544 | -3.078 | 0.003249 | ** |
| **nutrient.classLOW** | -710.6 | 240.3 | -2.957 | 0.004569 | ** |
| **mat** | -14.44 | 6.942 | -2.08 | 0.042228 | * |
| **gpp:age** | 0.002832 | 0.0009312 | 3.041 | 0.003608 | ** |
| **gpp:nutrient.classLOW** | 0.5055 | 0.1522 | 3.321 | 0.001596 | ** |
| **age:nutrient.classLOW** | 2.252 | 0.8341 | 2.7 | 0.009199 | ** |

**$R^2$=** 0.8781 **adj $R^2$=** 0.8626

**ANOVA table (type III)**

| | SumSq | DF | F value | Pr(>F) | | $R^2$ |
|---|---|---|---|---|---|---|
| **(Intercept)** | 10232 | 1 | 13.9334 | 0.0004507 | *** | |
| **gpp** | 2830 | 1 | 3.8532 | 0.0547171 | . | 0.65 |
| **age** | 6956 | 1 | 9.4726 | 0.0032495 | ** | 0.00 |
| **nutrient.class** | 6421 | 1 | 8.7445 | 0.0045687 | ** | 0.02 |
| **mat** | 3176 | 1 | 4.3251 | 0.0422277 | * | 0.15 |
| **gpp:age** | 6791 | 1 | 9.2477 | 0.0036078 | ** | 0.02 |
| **gpp:nutrient.class** | 8101 | 1 | 11.032 | 0.0015956 | ** | 0.03 |
| **age:nutrient.class** | 5353 | 1 | 7.2893 | 0.009199 | ** | 0.01 |
| **Residuals** | 40389 | 55 | | | | |

## Re model averaging

| | Estimate | SE | Adj SE | z val | Pr(>\|z\|) | | Variables | R Imp |
|---|---|---|---|---|---|---|---|---|
| **(Intercept)** | 787.1 | 271 | 275.3 | 2.858 | 0.00426 | ** | (Intercept) | 1.00 |
| **age** | -4.66 | 1.566 | 1.602 | 2.91 | 0.00362 | ** | gpp | 1.00 |
| **gpp** | 0.2976 | 0.1511 | 0.1536 | 1.937 | 0.05273 | . | NA | 1.00 |
| **mat** | -13.85 | 7.181 | 7.34 | 1.887 | 0.05921 | . | gpp:NA | 0.97 |
| **NA.LOW** | -557 | 302.8 | 307 | 1.814 | 0.06964 | . | mat | 0.73 |
| **age:gpp** | 0.00279 | 0.00094 | 0.00097 | 2.889 | 0.00387 | ** | age | 0.70 |
| **age:NA.LOW** | 2.252 | 0.8484 | 0.8675 | 2.596 | 0.00942 | ** | age:gpp | 0.70 |
| **gpp:NA.LOW** | 0.4508 | 0.1705 | 0.1735 | 2.598 | 0.00938 | ** | age:NA | 0.70 |
| **wd** | -2.856 | 1.872 | 1.913 | 1.493 | 0.1354 | | wd | 0.51 |
| **MNG.UM** | -185.5 | 162 | 163.9 | 1.132 | 0.25761 | | MNG | 0.30 |
| **gpp:MNG.UM** | 0.2135 | 0.09021 | 0.09213 | 2.317 | 0.02049 | * | gpp:MNG | 0.22 |
| **map** | -0.03157 | 0.08994 | 0.09188 | 0.344 | 0.73117 | | map | 0.11 |
| | | | | | | | age:MNG | 0.00 |
| | | | | | | | MNG:NA | 0.00 |

**15 models $\Delta < 4$**

## Models forests Eddy Covariance data

## NEP

| | Estimate | Std.Err | t value | Pr(>\|t\|) | |
|---|---|---|---|---|---|
| **(Intercept)** | -575.607 | 257.70547 | -2.234 | 0.029924 | * |
| **gpp** | 0.58016 | 0.1567 | 3.702 | 0.000525 | *** |
| **nutrient.classLOW** | 468.7595 | 281.1306 | 1.667 | 0.101563 | |
| **managementUM** | 321.0978 | 119.82562 | 2.68 | 0.009896 | ** |
| **mat** | 18.41545 | 7.09241 | 2.597 | 0.012274 | * |
| **gpp:nutrient.classLOW** | -0.43306 | 0.18555 | -2.334 | 0.02358 | * |
| **gpp:managementUM** | -0.25613 | 0.07463 | -3.432 | 0.001197 | ** |

**$R^2$=** 0.58 **adj $R^2$=** 0.5306

**ANOVA table (type III)**

| | SumSq | DF | F value | Pr(>F) | | $R^2$ |
|---|---|---|---|---|---|---|
| **(Intercept)** | 181821 | 1 | 4.9889 | 0.029924 | * | |
| **gpp** | 499578 | 1 | 13.7077 | 0.000525 | *** | 0.18 |
| **nutrient.class** | 101326 | 1 | 2.7803 | 0.101563 | | 0.11 |
| **management** | 261706 | 1 | 7.1808 | 0.009896 | ** | 0.04 |
| **mat** | 245706 | 1 | 6.7418 | 0.012274 | * | 0.09 |
| **gpp:nutrient.class** | 198516 | 1 | 5.447 | 0.02358 | * | 0.06 |
| **gpp:management** | 429267 | 1 | 11.7785 | 0.001197 | ** | 0.11 |
| **Residuals** | 1858698 | 51 | | | | |

## NEP model averaging

| | Estimate | SE | Adj SE | z val | Pr(>\|z\|) | | Variables | R Imp |
|---|---|---|---|---|---|---|---|---|
| **(Intercept)** | -541.6 | 328.6 | 333.1 | 1.626 | 0.10396 | | (Intercept) | 1.00 |
| **gpp** | 0.5573 | 0.1879 | 0.1907 | 2.922 | 0.00348 | ** | gpp | 1.00 |
| **MNG.UM** | 328.7 | 130.2 | 133.2 | 2.467 | 0.01361 | * | NA | 1.00 |
| **mat** | 17.67 | 7.436 | 7.606 | 2.323 | 0.02018 | * | MNG | 0.91 |
| **NA.LOW** | 391.7 | 370.2 | 374.8 | 1.045 | 0.29596 | | gpp:MNG | 0.91 |
| **gpp:MNG.UM** | -0.2623 | 0.07625 | 0.07807 | 3.36 | 0.00078 | *** | mat | 0.90 |
| **gpp:NA.LOW** | -0.4468 | 0.1904 | 0.1948 | 2.293 | 0.02183 | * | gpp:NA | 0.83 |
| **wd** | 1.995 | 1.977 | 2.023 | 0.986 | 0.32403 | | age | 0.18 |
| **MNG.UM:NA.LOW** | -91.61 | 138.1 | 141.5 | 0.648 | 0.51729 | | wd | 0.18 |
| **age** | 2.343 | 2.424 | 2.434 | 0.963 | 0.33564 | | MNG:NA | 0.11 |
| **age:gpp** | -0.00275 | 0.0008 | 0.000822 | 3.341 | 0.00083 | *** | age:gpp | 0.09 |
| **age:NA.LOW** | -1.928 | 0.799 | 0.8188 | 2.354 | 0.01855 | * | age:NA | 0.09 |
| **map** | 0.02251 | 0.09908 | 0.1015 | 0.222 | 0.82458 | | map | 0.08 |
| | | | | | | | age:MNG | 0.00 |

**9 models $\Delta < 4$**

## Re

| | Estimate | Std.Err | t value | Pr(>\|t\|) | |
|---|---|---|---|---|---|
| **(Intercept)** | 627.57583 | 260.16476 | 2.412 | 0.01949 | * |
| **gpp** | 0.38836 | 0.1582 | 2.455 | 0.01754 | * |
| **nutrient.classLOW** | -522.60114 | 283.81343 | -1.841 | 0.07139 | . |
| **managementUM** | -314.55694 | 120.96911 | -2.6 | 0.01215 | * |
| **mat** | -17.83373 | 7.16009 | -2.491 | 0.01605 | * |
| **gpp:nutrient.classLOW** | 0.46899 | 0.18732 | 2.504 | 0.01554 | * |
| **gpp:managementUM** | 0.2495 | 0.07534 | 3.311 | 0.00171 | ** |

**$R^2$=** 0.9163 **adj $R^2$=** 0.9065

**ANOVA table (type III)**

| | SumSq | DF | F value | Pr(>F) | | $R^2$ |
|---|---|---|---|---|---|---|
| **(Intercept)** | 216134 | 1 | 5.8188 | 0.01949 | * | |
| **gpp** | 223853 | 1 | 6.0266 | 0.01754 | * | 0.67 |
| **nutrient.class** | 125940 | 1 | 3.3906 | 0.07139 | . | 0.01 |
| **management** | 251153 | 1 | 6.7616 | 0.01215 | * | 0.01 |
| **mat** | 230428 | 1 | 6.2036 | 0.01605 | * | 0.19 |
| **gpp:nutrient.class** | 232822 | 1 | 6.2681 | 0.01554 | * | 0.01 |
| **gpp:management** | 407320 | 1 | 10.966 | 0.00171 | ** | 0.02 |
| **Residuals** | 1894342 | 51 | | | | |

## Re model averaging

| | Estimate | SE | Adj SE | z val | Pr(>\|z\|) | | Variables | R Imp |
|---|---|---|---|---|---|---|---|---|
| **(Intercept)** | 643 | 310.3 | 315.7 | 2.037 | 0.04166 | * | (Intercept) | 1.00 |
| **gpp** | 0.3806 | 0.1769 | 0.1803 | 2.111 | 0.03475 | * | gpp | 1.00 |
| **MNG.UM** | -321.6 | 134.1 | 137.2 | 2.344 | 0.01908 | * | NA | 1.00 |
| **mat** | -17.6 | 7.308 | 7.486 | 2.351 | 0.01871 | * | gpp:NA | 0.95 |
| **NA.LOW** | -509.2 | 338.6 | 344.3 | 1.479 | 0.1391 | | mat | 0.90 |
| **gpp:MNG.UM** | 0.2514 | 0.07647 | 0.07833 | 3.21 | 0.00133 | ** | MNG | 0.89 |
| **gpp:NA.LOW** | 0.4727 | 0.1973 | 0.2017 | 2.344 | 0.01908 | * | gpp:MNG | 0.89 |
| **wd** | -1.792 | 1.933 | 1.981 | 0.905 | 0.36569 | | age | 0.20 |
| **MNG.UM:NA.LOW** | 109.1 | 139.1 | 142.6 | 0.765 | 0.44426 | | wd | 0.14 |
| **age** | -2.459 | 2.41 | 2.421 | 1.016 | 0.3098 | | MNG:NA | 0.12 |
| **age:gpp** | 0.00268 | 0.00081 | 0.00083 | 3.236 | 0.00121 | ** | age:gpp | 0.11 |
| **age:NA.LOW** | 1.953 | 0.8048 | 0.8247 | 2.367 | 0.01791 | * | age:NA | 0.11 |
| **map** | -0.01641 | 0.1001 | 0.1025 | 0.16 | 0.87287 | | map | 0.09 |
| | | | | | | | age:MNG | 0.00 |

**8 models Δ < 4**

## Models without nutrient status

## NEP

| | Estimate | Std.Err | t | Pr(>\|t\|) | |
|---|---|---|---|---|---|
| **(Intercept)** | -594.399 | 133.86874 | -4.44 | 4.1E-05 | *** |
| **gpp** | 0.511744 | 0.0616439 | 8.302 | 1.9E-11 | *** |
| **managementUM** | 355.4655 | 131.84313 | 2.696 | 0.00917 | ** |
| **wd** | 5.280222 | 1.6748899 | 3.153 | 0.00256 | ** |
| **gpp:managementUM** | -0.36777 | 0.0796442 | -4.62 | 2.2E-05 | *** |

**$R^2$=** 0.5974 **adj $R^2$=** 0.5697

**ANOVA table (type III)**

| | SumSq | DF | F value | Pr(>F) | | $R^2$ |
|---|---|---|---|---|---|---|
| **(Intercept)** | 998461 | 1 | 19.7151 | 4.09E-05 | *** | |
| **gpp** | 3490265 | 1 | 68.9169 | 1.92E-11 | *** | 0.31 |
| **management** | 368140 | 1 | 7.2691 | 0.009166 | ** | 0.08 |
| **wd** | 503344 | 1 | 9.9388 | 0.002562 | ** | 0.05 |
| **gpp:management** | 1079913 | 1 | 21.3234 | 2.20E-05 | *** | 0.15 |
| **Residuals** | 2937383 | 58 | | | | |

## NEP model averaging

| | Estimate | SE | Adj SE | z val | Pr(>\|z\|) | | Variables | R |
|---|---|---|---|---|---|---|---|---|
| **(Intercept)** | -571.522 | 154.13 | 157.1015 | 3.638 | 0.00028 | *** | (Intercept) | 1.00 |
| **gpp** | 0.51726 | 0.06999 | 0.07143 | 7.241 | 2.0E-16 | *** | gpp | 1.00 |
| **MNG.UM** | 331.4987 | 138.953 | 141.85 | 2.337 | 0.01944 | * | MNG | 1.00 |
| **wd** | 5.23634 | 1.73593 | 1.7725 | 2.954 | 0.00314 | ** | gpp:MNG | 1.00 |
| **gpp:MNG.UM** | -0.3526 | 0.08492 | 0.08666 | 4.069 | 4.7E-05 | *** | wd | 1.00 |
| **map** | -0.11618 | 0.09751 | 0.09959 | 1.167 | 0.24337 | | map | 0.38 |
| **age** | 0.3439 | 0.45327 | 0.46312 | 0.743 | 0.45774 | | age | 0.22 |
| **mat** | 3.80219 | 7.9414 | 8.10027 | 0.469 | 0.63879 | | mat | 0.19 |
| | | | | | | | age:gpp | 0.00 |
| **6 models Δ < 4** | | | | | | | age:MNG | 0.00 |

## Re

| | Estimate | Std.Err | t | Pr(>\|t\|) | |
|---|---|---|---|---|---|
| **(Intercept)** | 608.429056 | 137.84864 | 4.414 | 0.0000448 | *** |
| **gpp** | 0.4893964 | 0.0634765 | 7.71 | 1.88E-10 | *** |
| **managementUM** | -348.463312 | 135.7628 | -2.567 | 0.01287 | * |
| **wd** | -5.4720214 | 1.7246841 | -3.173 | 0.00242 | ** |
| **gpp:managementUM** | 0.3532584 | 0.082012 | 4.307 | 0.0000646 | *** |

**$R^2$=** 0.8672 **adj $R^2$=** 0.858

**ANOVA table (type III)**

| | SumSq | DF | F value | Pr(>F) | | $R^2$ |
|---|---|---|---|---|---|---|
| **(Intercept)** | 1046150 | 1 | 19.481 | 4.48E-05 | *** | |
| **gpp** | 3192086 | 1 | 59.442 | 1.88E-10 | *** | 0.70 |
| **management** | 353779 | 1 | 6.588 | 0.01287 | * | 0.02 |
| **wd** | 540575 | 1 | 10.066 | 0.002415 | ** | 0.11 |
| **gpp:management** | 996345 | 1 | 18.554 | 6.46E-05 | *** | 0.04 |
| **Residuals** | 3114635 | 58 | | | | |

## Re model averaging

| | Estimate | SE | Adj SE | z val | Pr(>\|z\|) | | Variables | R |
|---|---|---|---|---|---|---|---|---|
| **(Intercept)** | 553.652 | 163.49 | 166.527 | 3.325 | 0.00089 | *** | (Intercept) | 1.00 |
| **gpp** | 0.46987 | 0.07201 | 0.07349 | 6.393 | 2.0E-16 | *** | gpp | 1.00 |
| **MNG.UM** | -301.36 | 144.967 | 147.921 | 2.037 | 0.04162 | * | MNG | 1.00 |
| **map** | 0.16497 | 0.09806 | 0.10018 | 1.647 | 0.09961 | . | gpp:MNG | 1.00 |
| **wd** | -5.33181 | 1.77344 | 1.811 | 2.944 | 0.00324 | ** | wd | 1.00 |
| **gpp:MNG.UM** | 0.31923 | 0.0905 | 0.09226 | 3.46 | 0.00054 | *** | map | 0.57 |
| **mat** | -1.60924 | 8.40043 | 8.56236 | 0.188 | 0.85092 | | mat | 0.18 |
| **age** | -0.27027 | 0.46671 | 0.47681 | 0.567 | 0.57084 | | age | 0.20 |
| | | | | | | | age:gpp | 0.00 |
| **6 models Δ < 4** | | | | | | | age:MNG | 0.00 |

## Models excluding forests with GPP>2500

## NEP (Fig. 1)

| | Estimate | Std.Err | t value | Pr(>\|t\|) | |
|---|---|---|---|---|---|
| **Intercept)** | -862.685 | 196.8156 | -4.383 | 0.0000557 | *** |
| **gpp** | 0.7604 | 0.1203 | 6.32 | 5.59E-08 | *** |
| **nutrient.classLOW** | 441.8157 | 226.904 | 1.947 | 0.05682 | . |
| **wd** | 4.2971 | 1.5516 | 2.77 | 0.00772 | ** |
| **gpp:nutrient.classLOW** | -0.4184 | 0.1396 | -2.998 | 0.00413 | ** |

**$R^2$=** 0.7179 **adj $R^2$=** 0.6966

**ANOVA table (type III)**

| | SumSq | DF | F value | Pr(>F) | | $R^2$ |
|---|---|---|---|---|---|---|
| **(Intercept)** | 706098 | 1 | 19.2125 | 0.00005568 | *** | |
| **gpp** | 1467744 | 1 | 39.9365 | 5.592E-08 | *** | 0.44 |
| **nutrient.class** | 139341 | 1 | 3.7914 | 0.056824 | . | 0.17 |
| **wd** | 281899 | 1 | 7.6703 | 0.007721 | ** | 0.05 |
| **gpp:nutrient.class** | 330378 | 1 | 8.9894 | 0.004128 | ** | 0.06 |
| **Residuals** | 1947852 | 53 | | | | |

## NEP model averaging

| | Estimate | SE | Adj SE | z val | Pr(>\|z\|) | | Variables | R Imp |
|---|---|---|---|---|---|---|---|---|
| **(Intercept)** | -869.3 | 197.7 | 202.4 | 4.295 | 1.7E-05 | *** | (Intercept) | 1.00 |
| **gpp** | 0.7416 | 0.1187 | 0.1215 | 6.105 | <0.00001 | *** | gpp | 1.00 |
| **mat** | 17.13 | 6.702 | 6.847 | 2.502 | 0.01233 | * | NA | 1.00 |
| **NA.LOW** | 700.2 | 250.3 | 255.2 | 2.744 | 0.00607 | ** | gpp:NA | 1.00 |
| **wd** | 2.96 | 1.667 | 1.705 | 1.737 | 0.08247 | . | mat | 0.95 |
| **gpp:NA.LOW** | -0.5919 | 0.1571 | 0.1602 | 3.696 | 0.00022 | *** | wd | 0.63 |
| **age** | 0.4008 | 0.6631 | 0.6738 | 0.595 | 0.55191 | | age | 0.20 |
| **MNG.UM** | 28.78 | 57.71 | 59.08 | 0.487 | 0.6262 | | MNG | 0.15 |
| **map** | 0.003563 | 0.09553 | 0.09778 | 0.036 | 0.97093 | | map | 0.13 |
| **age:gpp** | -0.00076 | 0.00076 | 0.000778 | 0.982 | 0.32601 | | age:gpp | 0.04 |
| | | | | | | | age:MNG | 0.00 |
| | | | | | | | age:NA | 0.00 |
| | | | | | | | gpp:MNG | 0.00 |
| **10 models Δ < 4** | | | | | | | MNG:NA | 0.00 |

## Re (Fig. 2)

| | Estimate | Std.Err | t value | Pr(>\|t\|) | |
|---|---|---|---|---|---|
| **(Intercept)** | 904.8063 | 195.6001 | 4.626 | 0.0000244 | *** |
| **gpp** | 0.2193 | 0.1196 | 1.834 | 0.07224 | . |
| **nutrient.classLOW** | -460.8056 | 225.5027 | -2.043 | 0.04599 | * |
| **wd** | -4.3754 | 1.542 | -2.838 | 0.00643 | ** |
| **gpp:nutrient.classLOW** | 0.4221 | 0.1387 | 3.043 | 0.00364 | ** |

**$R^2$=** 0.7411 **adj $R^2$=** 0.7215

**ANOVA table (type III)**

| | SumSq | DF | F value | Pr(>F) | | $R^2$ |
|---|---|---|---|---|---|---|
| **(Intercept)** | 776734 | 1 | 21.398 | 0.00002441 | *** | |
| **gpp** | 122124 | 1 | 3.3644 | 0.072238 | . | 0.55 |
| **nutrient.class** | 151576 | 1 | 4.1757 | 0.045992 | * | 0.03 |
| **wd** | 292264 | 1 | 8.0515 | 0.006429 | ** | 0.10 |
| **gpp:nutrient.class** | 336102 | 1 | 9.2592 | 0.003641 | ** | 0.06 |
| **Residuals** | 1923867 | 53 | | | | |

## Re model averaging

| | Estimate | SE | Adj SE | z val | Pr(>\|z\|) | | Variables | R Imp |
|---|---|---|---|---|---|---|---|---|
| **(Intercept)** | 911.146 | 200.906 | 205.649 | 4.431 | 9.4E-06 | *** | (Intercept) | 1.00 |
| **gpp** | 0.22852 | 0.12099 | 0.12381 | 1.846 | 0.06494 | . | gpp | 1.00 |
| **mat** | -12.4522 | 6.86698 | 7.01552 | 1.775 | 0.07591 | . | NA | 1.00 |
| **NA.LOW** | -586.236 | 259.596 | 264.532 | 2.216 | 0.02668 | * | gpp:NA | 1.00 |
| **wd** | -3.77785 | 1.69819 | 1.73473 | 2.178 | 0.02942 | * | wd | 0.86 |
| **gpp:NA.LOW** | 0.50671 | 0.16353 | 0.16657 | 3.042 | 0.00235 | ** | mat | 0.63 |
| **age** | -0.14644 | 0.34228 | 0.35019 | 0.418 | 0.67582 | | MNG | 0.17 |
| **MNG.UM** | -24.049 | 60.7591 | 62.0809 | 0.387 | 0.69847 | | age | 0.14 |
| **map** | -0.01268 | 0.09794 | 0.10008 | 0.127 | 0.89922 | | map | 0.13 |
| | | | | | | | age:gpp | 0.00 |
| | | | | | | | age:MNG | 0.00 |
| | | | | | | | age:NA | 0.00 |
| | | | | | | | gpp:MNG | 0.00 |
| **10 models Δ < 4** | | | | | | | MNG:NA | 0.00 |

## Weighted models excluding forests with GPP>2500

## NEP

| | Estimate | Std.Err | t value | Pr(>\|t\|) | |
|---|---|---|---|---|---|
| **Intercept)** | -567.832 | 201.3927 | -2.82 | 0.00675 | ** |
| **gpp** | 0.5898 | 0.1245 | 4.737 | 0.0000167 | *** |
| **nutrient.classLOW** | 484.8521 | 235.3754 | 2.06 | 0.04433 | * |
| **mat** | 16.0388 | 6.577 | 2.439 | 0.01813 | * |
| **gpp:nutrient.classLOW** | -0.4356 | 0.1585 | -2.748 | 0.00818 | ** |

**$R^2$=** 0.6143 **adj $R^2$=** 0.5852

**ANOVA table (type III)**

| | SumSq | DF | F value | Pr(>F) | | $R^2$ |
|---|---|---|---|---|---|---|
| **(Intercept)** | 8623 | 1 | 7.9497 | 0.00675 | ** | |
| **gpp** | 24335 | 1 | 22.435 | 0.00001666 | *** | 0.34 |
| **nutrient.class** | 4603 | 1 | 4.2432 | 0.044333 | * | 0.11 |
| **mat** | 6450 | 1 | 5.9468 | 0.018128 | * | 0.12 |
| **gpp:nutrient.class** | 8191 | 1 | 7.5515 | 0.008178 | ** | 0.05 |
| **Residuals** | 57488 | 53 | | | | |

## NEP model averaging

| | Estimate | SE | Adj SE | z val | Pr(>\|z\|) | | Variables | R Imp |
|---|---|---|---|---|---|---|---|---|
| **(Intercept)** | -630.542 | 240.08 | 244.2723 | 2.581 | 0.00984 | ** | (Intercept) | 1.00 |
| **gpp** | 0.58475 | 0.13469 | 0.13717 | 4.263 | 2E-05 | *** | gpp | 1.00 |
| **mat** | 13.9113 | 7.15618 | 7.30633 | 1.904 | 0.05691 | . | NA | 1.00 |
| **NA.LOW** | 313.3486 | 302.626 | 306.4643 | 1.022 | 0.30656 | | gpp:NA | 0.87 |
| **wd** | 3.69658 | 1.81166 | 1.85251 | 1.995 | 0.04599 | * | wd | 0.76 |
| **gpp:NA.LOW** | -0.37807 | 0.17028 | 0.17373 | 2.176 | 0.02954 | * | mat | 0.75 |
| **map** | 0.07223 | 0.08776 | 0.08967 | 0.806 | 0.4205 | | map | 0.19 |
| **MNG.UM** | 29.63878 | 54.6654 | 55.95706 | 0.53 | 0.59634 | | MNG | 0.12 |
| **age** | 0.11882 | 0.35025 | 0.35868 | 0.331 | 0.74045 | | age | 0.10 |
| | | | | | | | age:gpp | 0.00 |
| | | | | | | | age:MNG | 0.00 |
| | | | | | | | age:NA | 0.00 |
| | | | | | | | gpp:MNG | 0.00 |
| **12 models Δ < 4** | | | | | | | MNG:NA | 0.00 |

## Re

| | Estimate | Std.Err | t value | Pr(>\|t\|) | |
|---|---|---|---|---|---|
| **(Intercept)** | 330.71463 | 132.59705 | 2.494 | 0.01572 | * |
| **gpp** | 0.58081 | 0.05895 | 9.852 | 1.16E-13 | *** |
| **nutrient.classLOW** | 170.1716 | 56.38605 | 3.018 | 0.00388 | ** |
| **wd** | -3.91987 | 1.78531 | -2.196 | 0.03243 | * |

**$R^2$=** 0.7128 **adj $R^2$=** 0.6968

**ANOVA table (type III)**

| | SumSq | DF | F value | Pr(>F) | | $R^2$ |
|---|---|---|---|---|---|---|
| **(Intercept)** | 4639 | 1 | 6.2207 | 0.01572 | * | |
| **gpp** | 72381 | 1 | 97.0636 | 1.156E-13 | *** | 0.58 |
| **nutrient.class** | 6792 | 1 | 9.1082 | 0.003878 | ** | 0.03 |
| **wd** | 3595 | 1 | 4.8208 | 0.032435 | * | 0.11 |
| **Residuals** | 40268 | 54 | | | | |

## Re model averaging

| | Estimate | SE | Adj SE | z val | Pr(>\|z\|) | | Variables | R Imp |
|---|---|---|---|---|---|---|---|---|
| **(Intercept)** | 614.725 | 234.124 | 238.326 | 2.579 | 0.0099 | ** | (Intercept) | 1.00 |
| **gpp** | 0.40001 | 0.13299 | 0.13544 | 2.953 | 0.00314 | ** | gpp | 1.00 |
| **mat** | -11.4335 | 7.2117 | 7.36514 | 1.552 | 0.12057 | | NA | 1.00 |
| **NA.LOW** | -303.751 | 284.67 | 288.541 | 1.053 | 0.29247 | | gpp:NA | 0.90 |
| **wd** | -3.46331 | 1.80117 | 1.8424 | 1.88 | 0.06014 | . | wd | 0.72 |
| **gpp:NA.LOW** | 0.35391 | 0.16485 | 0.16807 | 2.106 | 0.03523 | * | mat | 0.56 |
| **map** | -0.04307 | 0.08784 | 0.08976 | 0.48 | 0.63136 | | MNG | 0.14 |
| **MNG.UM** | -19.3384 | 58.1629 | 59.4065 | 0.326 | 0.74478 | | map | 0.14 |
| **age** | -0.05802 | 0.34906 | 0.35716 | 0.162 | 0.87094 | | age | 0.12 |
| | | | | | | | age:gpp | 0.00 |
| | | | | | | | age:MNG | 0.00 |
| | | | | | | | age:NA | 0.00 |
| | | | | | | | gpp:MNG | 0.00 |
| **15 models Δ < 4** | | | | | | | MNG:NA | 0.00 |

## Models using only managed forests

### NEP

| | Estimate | Std.Err | t value | Pr(>\|t\|) | |
|---|---|---|---|---|---|
| **(Intercept)** | -857.573 | 205.9132 | -4.165 | 0.000201 | *** |
| **gpp** | 0.7092 | 0.1253 | 5.661 | 0.00000237 | *** |
| **nutrient.classLOW** | 257.9824 | 249.5965 | 1.034 | 0.308621 | |
| **wd** | 6.39 | 1.8149 | 3.521 | 0.001247 | ** |
| **gpp:nutrient.classLOW** | -0.2955 | 0.1474 | -2.005 | 0.053009 | . |

**$R^2$=** 0.7857 **adj $R^2$=** 0.7605

**ANOVA table (type III)**

| | SumSq | DF | F value | Pr(>F) | | $R^2$ |
|---|---|---|---|---|---|---|
| **(Intercept)** | 619836 | 1 | 17.345 | 0.0002014 | *** | |
| **gpp** | 1145367 | 1 | 32.0511 | 2.372E-06 | *** | 0.52 |
| **nutrient.class** | 38177 | 1 | 1.0683 | 0.3086206 | | 0.14 |
| **wd** | 443006 | 1 | 12.3967 | 0.0012471 | ** | 0.09 |
| **gpp:nutrient.class** | 143617 | 1 | 4.0189 | 0.0530094 | . | 0.04 |
| **Residuals** | 1215014 | 34 | | | | |

### NEP model averaging

| | Estimate | SE | Adj SE | z val | Pr(>\|z\|) | | Variables | R Imp |
|---|---|---|---|---|---|---|---|---|
| **(Intercept)** | -872.4 | 254.7 | 261.1 | 3.341 | 0.00083 | *** | (Intercept) | 1.00 |
| **gpp** | 0.6644 | 0.1388 | 0.1426 | 4.66 | 3.2E-06 | *** | gpp | 1.00 |
| **mat** | 16.51 | 9.362 | 9.723 | 1.698 | 0.08957 | . | NA. | 1.00 |
| **NA.LOW** | 282.1 | 334.3 | 341 | 0.827 | 0.408 | | wd | 1.00 |
| **wd** | 6.396 | 2.165 | 2.229 | 2.869 | 0.00412 | ** | gpp:NA | 0.85 |
| **gpp:NA.LOW** | -0.3741 | 0.172 | 0.1776 | 2.107 | 0.03516 | * | mat | 0.49 |
| **age** | 0.9862 | 0.8297 | 0.8554 | 1.153 | 0.24892 | | age | 0.46 |
| **age:NA.LOW** | -1.362 | 1.124 | 1.168 | 1.166 | 0.24349 | | map | 0.13 |
| **map** | -0.02869 | 0.118 | 0.1222 | 0.235 | 0.81435 | | age:NA | 0.11 |
| **age:gpp** | 0.00027 | 0.00105 | 0.001097 | 0.246 | 0.80581 | | age:gpp | 0.03 |

**13 models Δ < 4**

## Re

| | Estimate | Std.Err | t value | Pr(>\|t\|) | |
|---|---|---|---|---|---|
| **(Intercept)** | 909.3045 | 208.0546 | 4.371 | 0.000111 | *** |
| **gpp** | 0.2617 | 0.1266 | 2.067 | 0.04639 | * |
| **nutrient.classLOW** | -323.2086 | 252.1922 | -1.282 | 0.208656 | |
| **wd** | -6.2747 | 1.8337 | -3.422 | 0.001636 | ** |
| **gpp:nutrient.classLOW** | 0.3361 | 0.1489 | 2.257 | 0.03055 | * |

**$R^2$=** 0.8121 **adj $R^2$=** 0.79

**ANOVA table (type III)**

| | SumSq | DF | F value | Pr(>F) | | $R^2$ |
|---|---|---|---|---|---|---|
| **(Intercept)** | 696872 | 1 | 19.1014 | 0.0001107 | *** | |
| **gpp** | 155911 | 1 | 4.2735 | 0.0463903 | * | 0.57 |
| **nutrient.class** | 59923 | 1 | 1.6425 | 0.2086559 | | 0.03 |
| **wd** | 427173 | 1 | 11.7089 | 0.0016363 | ** | 0.17 |
| **gpp:nutrient.class** | 185837 | 1 | 5.0938 | 0.0305504 | * | 0.05 |
| **Residuals** | 1240417 | 34 | | | | |

## Re model averaging

| | Estimate | SE | Adj SE | z val | Pr(>\|z\|) | | Variables | R Imp |
|---|---|---|---|---|---|---|---|---|
| **(Intercept)** | 928.819 | 249.516 | 256.331 | 3.624 | 0.00029 | *** | (Intercept) | 1.00 |
| **gpp** | 0.29454 | 0.14175 | 0.14572 | 2.021 | 0.04325 | * | gpp | 1.00 |
| **NA.LOW** | -353.056 | 325.228 | 332.658 | 1.061 | 0.28855 | | NA | 1.00 |
| **wd** | -6.27146 | 2.166 | 2.23117 | 2.811 | 0.00494 | ** | wd | 1.00 |
| **gpp:NA.LOW** | 0.3958 | 0.17112 | 0.17674 | 2.239 | 0.02513 | * | gpp:NA | 0.90 |
| **mat** | -15.2377 | 9.50801 | 9.87347 | 1.543 | 0.12276 | | mat | 0.44 |
| **age** | -1.00995 | 0.8149 | 0.83836 | 1.205 | 0.22833 | | age | 0.41 |
| **age:NA.LOW** | 1.42601 | 1.14127 | 1.18605 | 1.202 | 0.22924 | | age:NA | 0.12 |
| **map** | 0.03553 | 0.11456 | 0.11897 | 0.299 | 0.76523 | | map | 0.10 |
| | | | | | | | age:gpp | 0.00 |

**10 models $\Delta < 4$**

**Models using an alternative nutrient availability classification**

## NEP

| | Estimate | Std.Err | t value | Pr(>\|t\|) | |
|---|---|---|---|---|---|
| **Intercept)** | -926.2 | 195.4 | -4.74 | 0.0000165 | *** |
| **gpp** | 0.7644 | 0.1093 | 6.994 | 4.6E-09 | *** |
| **age** | 5.143 | 1.253 | 4.104 | 0.000141 | *** |
| **alternutrLOW** | 769.5 | 203 | 3.79 | 0.000387 | *** |
| **mat** | 20.21 | 5.225 | 3.869 | 0.000302 | *** |
| **gpp:age** | -0.00337 | 0.0007395 | -4.557 | 0.0000309 | *** |
| **gpp:alternutrLOW** | -0.5263 | 0.1166 | -4.515 | 0.0000357 | *** |
| **age:alternutrLOW** | -1.918 | 0.7773 | -2.468 | 0.016854 | * |

**$R^2$=** 0.7553 **adj $R^2$=** 0.723

**ANOVA table (type III)**

| | SumSq | DF | F value | Pr(>F) | | $R^2$ |
|---|---|---|---|---|---|---|
| **Intercept)** | 623153 | 1 | 22.4697 | 0.00001645 | *** | |
| **gpp** | 1356752 | 1 | 48.9219 | 4.604E-09 | *** | 0.25 |
| **age** | 467161 | 1 | 16.8449 | 0.0001407 | *** | 0.04 |
| **alternutr** | 398366 | 1 | 14.3643 | 0.000387 | *** | 0.12 |
| **mat** | 415043 | 1 | 14.9657 | 0.0003016 | *** | 0.11 |
| **gpp:age** | 575924 | 1 | 20.7667 | 0.00003088 | *** | 0.1 |
| **gpp:alternutr** | 565233 | 1 | 20.3812 | 0.0000357 | *** | 0.11 |
| **age:alternutr** | 168904 | 1 | 6.0903 | 0.0168544 | * | 0.02 |
| **Residuals** | 1469850 | 53 | | | | |

## NEP model averaging

| | Estimate | SE | Adj SE | z val | Pr(>\|z\|) | | Variables | R |
|---|---|---|---|---|---|---|---|---|
| **Intercept** | -924.6 | 208.3 | 212.8 | 4.344 | 1.4E-05 | *** | (Intercept) | 1.00 |
| **age** | 5 | 1.387 | 1.413 | 3.539 | 0.0004 | *** | age | 1.00 |
| **alternutrLOW** | 761.1 | 213.8 | 218.6 | 3.482 | 0.0005 | *** | alternutr | 1.00 |
| **gpp** | 0.7599 | 0.1127 | 0.1152 | 6.598 | 2E-16 | *** | gpp | 1.00 |
| **mat** | 20.18 | 5.445 | 5.572 | 3.622 | 0.00029 | *** | mat | 1.00 |
| **age:alternutrLOW** | -1.943 | 0.7858 | 0.8042 | 2.416 | 0.01571 | * | age:gpp | 1.00 |
| **age:gpp** | -0.00331 | 0.0008 | 0.000812 | 4.077 | 4.6E-05 | *** | alternutr:gpp | 1.00 |
| **alternutrLOW:gpp** | -0.5283 | 0.1217 | 0.1245 | 4.244 | 2.2E-05 | *** | age:alternutr | 0.93 |
| **map** | 0.05238 | 0.08533 | 0.08736 | 0.6 | 0.54879 | | map | 0.15 |
| **MNG.UM** | 25.84 | 60.62 | 62.06 | 0.416 | 0.67716 | | MNG | 0.14 |
| **wd** | 0.508 | 1.615 | 1.653 | 0.307 | 0.7586 | | wd | 0.13 |
| | | | | | | | age:MNG | 0.00 |
| | | | | | | | alternutr:MNG | 0.00 |
| **5 models Δ < 4** | | | | | | | gpp:MNG | 0.00 |

## Re

| | Estimate | Std.Err | t value | Pr(>\|t\|) | |
|---|---|---|---|---|---|
| **(Intercept)** | 977.7 | 198 | 4.939 | 0.00000824 | *** |
| **gpp** | 0.2071 | 0.1107 | 1.87 | 0.067002 | . |
| **age** | -5.106 | 1.27 | -4.022 | 0.000184 | *** |
| **alternutrLOW** | -828.8 | 205.7 | -4.029 | 0.00018 | *** |
| **mat** | -19.72 | 5.294 | -3.725 | 0.000475 | *** |
| **gpp:age** | 0.003305 | 0.0007492 | 4.41 | 0.0000508 | *** |
| **gpp:alternutrLOW** | 0.5626 | 0.1181 | 4.763 | 0.0000152 | *** |
| **age:alternutrLOW** | 1.975 | 0.7876 | 2.508 | 0.015246 | * |

**$R^2$=** 0.9122 **adj $R^2$=** 0.9006

**ANOVA table (type III)**

| | SumSq | DF | F value | Pr(>F) | | $R^2$ |
|---|---|---|---|---|---|---|
| **(Intercept)** | 694393 | 1 | 24.3888 | 8.243E-06 | *** | |
| **gpp** | 99570 | 1 | 3.4971 | 0.0670024 | . | 0.67 |
| **age** | 460518 | 1 | 16.1745 | 0.0001841 | *** | 0.01 |
| **alternutr** | 462143 | 1 | 16.2316 | 0.0001799 | *** | 0.02 |
| **mat** | 395084 | 1 | 13.8763 | 0.0004749 | *** | 0.13 |
| **gpp:age** | 553836 | 1 | 19.4521 | 0.0000508 | *** | 0.04 |
| **gpp:alternutr** | 645866 | 1 | 22.6844 | 0.00001521 | *** | 0.04 |
| **age:alternutr** | 179061 | 1 | 6.2891 | 0.0152462 | * | 0.01 |
| **Residuals** | 1509004 | 53 | | | | |

## Re model averaging

| | Estimate | SE | Adj SE | z val | Pr(>\|z\|) | | Variables | R Imp |
|---|---|---|---|---|---|---|---|---|
| **(Intercept)** | 988.9 | 205.1 | 209.8 | 4.713 | 2.4E-06 | *** | (Intercept) | 1.00 |
| **age** | -5.131 | 1.284 | 1.314 | 3.905 | 9.4E-05 | *** | age | 1.00 |
| **alternutrLOW** | -830.8 | 212.8 | 217.7 | 3.815 | 0.00014 | *** | alternutr | 1.00 |
| **gpp** | 0.2053 | 0.1117 | 0.1143 | 1.796 | 0.07251 | . | gpp | 1.00 |
| **mat** | -19.53 | 5.501 | 5.63 | 3.469 | 0.00052 | *** | mat | 1.00 |
| **age:alternutrLOW** | 1.996 | 0.7959 | 0.8146 | 2.451 | 0.01425 | * | age:alternutr | 1.00 |
| **age:gpp** | 0.00332 | 0.00076 | 0.00078 | 4.272 | 1.9E-05 | *** | age:gpp | 1.00 |
| **alternutrLOW:gpp** | 0.5642 | 0.1231 | 0.126 | 4.479 | 7.5E-06 | *** | alternutr:gpp | 1.00 |
| **map** | -0.04651 | **0.08653** | 0.08859 | **0.525** | 0.59959 | | map | 0.16 |
| **MNG.UM** | -24.53 | 61.43 | 62.9 | 0.39 | 0.69654 | | MNG | 0.15 |
| **wd** | -0.5608 | 1.636 | 1.675 | 0.335 | 0.7377 | | wd | 0.14 |
| | | | | | | | age:MNG | 0.00 |
| | | | | | | | alternutr:MNG | 0.00 |
| **4 models Δ < 4** | | | | | | | gpp:MNG | 0.00 |

**Models with the factors extracted from the nutrient classification**

## NEP

| | Estimate | Std.Err | β | β Std.Err | t value | Pr(>\|t\|) | |
|---|---|---|---|---|---|---|---|
| **(Intercept)** | -269.131 | 88.209304 | 0 | 0 | -3.051 | 0.00346 | ** |
| **f1** | -27.8263 | 25.151078 | -0.358 | 0.3235612 | -1.106 | 0.27322 | |
| **gpp** | 0.414041 | 0.0556693 | 0.87959 | 0.1182636 | 7.438 | <.0001 | *** |
| **managementUM** | 269.0477 | 124.50198 | 0.38392 | 0.1776568 | 2.161 | 0.03491 | * |
| **f1:gpp** | 0.030442 | 0.0129536 | 0.7639 | 0.3250582 | 2.35 | 0.02226 | * |
| **gpp:managementUM** | -0.2593 | 0.0770538 | -0.6833 | 0.2030509 | -3.365 | 0.00137 | ** |
| **R2=** | 0.6811 | **adj R2=** | 0.6532 | | | | |

**ANOVA table (type III)**

| | SumSq | DF | F value | Pr(>F) | | R2 |
|---|---|---|---|---|---|---|
| **(Intercept)** | 379989 | 1 | 9.3089 | 0.003459 | ** | |
| **f1** | 49966 | 1 | 1.224 | 0.273216 | | 0.23008 |
| **gpp** | 2258026 | 1 | 55.3167 | 5.93E-10 | *** | 0.25579 |
| **management** | 190625 | 1 | 4.6699 | 0.034912 | * | 0.05029 |
| **f1:gpp** | 225437 | 1 | 5.5227 | 0.022257 | * | 0.05242 |
| **gpp:management** | 462245 | 1 | 11.324 | 0.001374 | ** | 0.09254 |
| **Residuals** | 2326737 | 57 | | | | |

## NEP model averaging

| | Estimate | SE | Adj SE | z val | Pr(>\|z\|) | | Variables | R Imp |
|---|---|---|---|---|---|---|---|---|
| **(Intercept)** | -283.9 | 117.3 | 119.3 | 2.38 | 0.01733 | * | (Intercept) | 1.00 |
| **f1** | -23.95 | 29.63 | 30.08 | 0.796 | 0.42587 | | F1 | 1.00 |
| **gpp** | 0.3949 | 0.0736 | 0.07487 | 5.274 | 1.00E-07 | *** | gpp | 1.00 |
| **managementUM** | 287.8 | 129 | 131.8 | 2.184 | 0.02897 | * | MNG | 1.00 |
| **f1:gpp** | 0.03079 | 0.01348 | 0.01376 | 2.236 | 0.02532 | * | F1:GPP | 0.91 |
| **gpp:managementUM** | -0.2697 | 0.07942 | 0.08109 | 3.326 | 0.00088 | *** | gpp:MNG | 1.00 |
| **mat** | 8.61 | 6.457 | 6.599 | 1.305 | 0.19198 | | mat | 0.40 |
| **wd** | 1.836 | 1.88 | 1.917 | 0.958 | 0.33831 | | wd | 0.23 |
| **f1:managementUM** | 10.99 | 24.14 | 24.68 | 0.445 | 0.65613 | | age | 0.14 |
| **age** | 0.1778 | 0.4022 | 0.411 | 0.433 | 0.66526 | | f1:MNG | 0.11 |
| **map** | -0.00703 | 0.09706 | 0.09907 | 0.071 | 0.94347 | | map | 0.11 |

**13 models Δ < 4**

## Re

| | Estimate | Std.Err | β | β Std.Err | t value | Pr(>\|t\|) | |
|---|---|---|---|---|---|---|---|
| **(Intercept)** | 262.962863 | 95.062739 | 0 | 0 | 2.766 | 0.007595 | ** |
| **f1** | -29.580566 | 6.7969963 | -0.2122776 | 0.04877697 | -4.352 | 5.54E-05 | *** |
| **gpp** | 0.592046 | 0.0600396 | 0.7015992 | 0.0711494 | 9.861 | 5.20E-14 | *** |
| **managementUM** | -354.527459 | 127.54614 | -0.2821977 | 0.10152452 | -2.78 | 0.007325 | ** |
| **gpp:managementUM** | 0.3044804 | 0.0785227 | 0.4475773 | 0.11542614 | 3.878 | 0.000272 | *** |
| **R2=** | 0.8825 | **adj R2=** | 0.8744 | | | | |

**ANOVA table (type III)**

| | SumSq | DF | F value | Pr(>F) | | R2 |
|---|---|---|---|---|---|---|
| **(Intercept)** | 363520 | 1 | 7.6519 | 0.0075953 | ** | |
| **f1** | 899786 | 1 | 18.94 | 5.54E-05 | *** | 0.04064662 |
| **gpp** | 4619512 | 1 | 97.2379 | 5.20E-14 | *** | 0.79499854 |
| **management** | 367050 | 1 | 7.7262 | 0.0073248 | ** | 0.01205423 |
| **gpp:management** | 714312 | 1 | 15.0358 | 0.0002716 | *** | 0.03479453 |
| **Residuals** | 2755424 | 58 | | | | |

## Re model averaging

| | Estimate | SE | Adj SE | z val | Pr(>\|z\|) | | Variables | R Imp |
|---|---|---|---|---|---|---|---|---|
| **(Intercept)** | 304.659 | 129.075 | 131.275 | 2.321 | 0.0203 | * | (Intercept) | 1.00 |
| **f1** | 23.8269 | 30.8621 | 31.3221 | 0.761 | 0.4468 | | F1 | 1.00 |
| **gpp** | 0.5864 | 0.06759 | 0.06894 | 8.506 | <2e-16 | *** | gpp | 1.00 |
| **managementUM** | -269.56 | 134.21 | 137.027 | 1.967 | 0.0492 | * | MNG | 1.00 |
| **f1:gpp** | -0.03089 | 0.01409 | 0.01439 | 2.146 | 0.0319 | * | F1:GPP | 0.89 |
| **gpp:managementUM** | 0.24987 | 0.08332 | 0.08504 | 2.938 | 0.0033 | ** | gpp:MNG | 1.00 |
| **wd** | -2.08056 | 1.89952 | 1.93923 | 1.073 | 0.2833 | | wd | 0.30 |
| **mat** | -5.51703 | 6.9059 | 7.05402 | 0.782 | 0.4341 | | mat | 0.18 |
| **map** | 0.05393 | 0.09743 | 0.09953 | 0.542 | 0.5879 | | map | 0.15 |
| **f1:managementUM** | -10.2502 | 25.1642 | 25.7219 | 0.398 | 0.6903 | | f1:MNG | 0.11 |
| **age** | -0.10723 | 0.41819 | 0.42727 | 0.251 | 0.8018 | | age | 0.11 |

**13 models Δ < 4**

## Models using the “medium” nutrient availability category

### NEP

| | Estimate | Std.Err | β | β Std.Err | t value | Pr(>\|t\|) | |
|---|---|---|---|---|---|---|---|
| **(Intercept)** | -650.147 | 207.74185 | 0 | 0 | -3.13 | 0.00221 | ** |
| **gpp** | 0.689827 | 0.1239448 | 1.68764 | 0.30322786 | 5.566 | 1.66E-07 | *** |
| **nutrient.classLOW** | 258.9967 | 227.36606 | 0.41185 | 0.36154805 | 1.139 | 0.25696 | |
| **nutrient.classMEDIUM** | 391.1855 | 238.17323 | 0.56405 | 0.34342186 | 1.642 | 0.10316 | |
| **managementOTHR** | 110.4697 | 116.18876 | 0.13705 | 0.14414666 | 0.951 | 0.34366 | |
| **managementUM** | 270.503 | 103.77753 | 0.38345 | 0.14710976 | 2.607 | 0.01032 | * |
| **wd** | 3.125687 | 1.1435189 | 0.20683 | 0.07566875 | 2.733 | 0.00723 | ** |
| **gpp:nutrient.classLOW** | -0.32062 | 0.1365047 | -1.0328 | 0.43971008 | -2.349 | 0.0205 | * |
| **gpp:nutrient.classMEDIUM** | -0.37808 | 0.1422941 | -0.8666 | 0.32615306 | -2.657 | 0.00898 | ** |
| **gpp:managementOTHR** | -0.20223 | 0.0766118 | -0.3909 | 0.14808735 | -2.64 | 0.00942 | ** |
| **gpp:managementUM** | -0.3007 | 0.0626977 | -0.8944 | 0.18649016 | -4.796 | 4.77E-06 | *** |
| **R2=** | 0.5834 | **adj R2=** | 0.548 | | | | |

**ANOVA table (type III)**

| | SumSq | DF | F value | Pr(>F) | | R2 |
|---|---|---|---|---|---|---|
| **(Intercept)** | 438923 | 1 | 9.7943 | 2.21E-03 | ** | |
| **gpp** | 1388151 | 1 | 30.9759 | 1.66E-07 | *** | 0.12 |
| **nutrient.class** | 149973 | 2 | 1.6733 | 0.192051 | | 0.17 |
| **management** | 312383 | 2 | 3.4853 | 0.033835 | * | 0.10 |
| **wd** | 334825 | 1 | 7.4714 | 7.23E-03 | ** | 0.03 |
| **gpp:nutrient.class** | 316390 | 2 | 3.53 | 0.032437 | * | 0.05 |
| **gpp:management** | 1030957 | 2 | 11.5026 | 2.73E-05 | *** | 0.10 |
| **Residuals** | 5288049 | 118 | | | | |

## Re

| | Estimate | Std.Err | β | β Std.Err | t | Pr(>\|t\|) | |
|---|---|---|---|---|---|---|---|
| **(Intercept)** | 946.1472 | 225.7538 | 0 | 0 | 4.191 | 6.42E-05 | *** |
| **gpp** | 0.1500605 | 0.1312338 | 0.17799832 | 0.15566652 | 1.143 | 0.255847 | |
| **nutrient.classLOW** | -598.9845 | 238.7771 | - | 0.19726044 | -2.509 | 0.013893 | * |
| **nutrient.classMEDIUM** | -769.0284 | 254.6037 | - | 0.19182404 | -3.02 | 0.003276 | ** |
| **age** | -2.345405 | 0.7963151 | - | 0.08718799 | -2.945 | 0.004096 | ** |
| **managementOTHR** | 112.3993 | 62.51324 | 0.06759027 | 0.03759176 | 1.798 | 0.075492 | . |
| **managementUM** | 171.6502 | 60.24119 | 0.12208751 | 0.04284699 | 2.849 | 0.005417 | ** |
| **wd** | -2.910387 | 1.324959 | - | 0.04379972 | -2.197 | 0.030591 | * |
| **gpp:nutrient.classLOW** | 0.5007344 | 0.1411159 | 0.75653774 | 0.21320593 | 3.548 | 0.000615 | *** |
| **gpp:nutrient.classMEDIUM** | 0.5897503 | 0.1492076 | 0.7248549 | 0.18338927 | 3.953 | 0.000153 | *** |
| **gpp:age** | 0.00160319 | 0.0005973 | 0.24371494 | 0.09080813 | 2.684 | 0.008647 | ** |
| **R2=** | 0.8971 | **adj R2=** | 0.8858 | | | | |

**ANOVA table (type III)**

| | SumSq | DF | F value | Pr(>F) | | R2 |
|---|---|---|---|---|---|---|
| **(Intercept)** | 741158 | 1 | 17.565 | 6.42E-05 | *** | |
| **gpp** | 55170 | 1 | 1.3075 | 2.56E-01 | | 0.71958764 |
| **nutrient.class** | 393809 | 2 | 4.6665 | 0.0117675 | * | 0.01904361 |
| **age** | 366040 | 1 | 8.6749 | 4.10E-03 | ** | 0.00879914 |
| **management** | 397873 | 2 | 4.7147 | 1.13E-02 | * | 0.01802822 |
| **wd** | 203592 | 1 | 4.825 | 0.0305909 | * | 0.09880494 |
| **gpp:nutrient.class** | 659885 | 2 | 7.8194 | 0.0007349 | *** | 0.02221301 |
| **gpp:age** | 303933 | 1 | 7.203 | 8.65E-03 | ** | 0.01059682 |

## CUEe

| | Estimate | Std.Err | β | β Std.Err | t value | Pr(>\|t\|) | |
|---|---|---|---|---|---|---|---|
| (Intercept) | -0.05665285 | 0.0929213 | 0 | 0 | -0.61 | 0.5435 | |
| **gpp** | 0.00030991 | 5.251E-05 | 0.79007388 | 0.1338564 | 5.902 | 5.51E-08 | *** |
| **nutrient.classLOW** | -0.173781 | 0.064971 | -0.3085533 | 0.1153579 | -2.675 | 0.0088 | ** |
| **nutrient.classMEDIUM** | -0.02722514 | 0.0697433 | -0.04408481 | 0.1129332 | -0.39 | 0.6971 | |
| **age** | 0.00290722 | 0.0008546 | 0.68411616 | 0.2010993 | 3.402 | 0.001 | *** |
| **map** | -0.00016161 | 6.121E-05 | -0.29530044 | 0.1118445 | -2.64 | 0.0097 | ** |
| **gpp:age** | -1.9465E-06 | 6.354E-07 | -0.63595917 | 0.2076081 | -3.063 | 0.0028 | ** |

| | | | |
|---|---|---|---|
| **R2=** | 0.3763 | **adj R2=** | 0.3369 |

**ANOVA table (type III)**

| | SumSq | DF | F value | Pr(>F) | | R2 |
|---|---|---|---|---|---|---|
| **(Intercept)** | 0.0197 | 1 | 0.3717 | 0.5435249 | | |
| **gpp** | 1.8473 | 1 | 34.8383 | 5.51E-08 | *** | 0.1446 |
| **nutrient.class** | 0.5977 | 2 | 5.6359 | 0.0048644 | ** | 0.1056 |
| **age** | 0.6137 | 1 | 11.5728 | 9.81E-04 | *** | 0.0117 |
| **map** | 0.3696 | 1 | 6.9711 | 0.0096844 | ** | 0.0468 |
| **gpp:age** | 0.4976 | 1 | 9.3836 | 0.0028486 | ** | 0.0677 |
| **Residuals** | 5.0375 | 95 | | | | |

# GPP Models

## General

| | | **Estimate** | **Std.Err** | **t value** | **$Pr(>\lvert t\rvert)$** | | **$R^2$** |
|---|---|---|---|---|---|---|---|
| **(Intercept)** | | 1306.23 | 137.051 | 9.531 | 1.28E-13 | *** | |
| **mat** | | 74.397 | 6.163 | 12.072 | 2E-16 | *** | 0.65 |
| **wd** | | -8.874 | 2.581 | -3.438 | 0.00107 | ** | 0.1 |
| | **$R^2$=** | 0.7514 | **adj $R^2$=** | 0.7432 | | | |

## Weighted

| | | **Estimate** | **Std.Err** | **t value** | **$Pr(>\lvert t\rvert)$** | | **$R^2$** |
|---|---|---|---|---|---|---|---|
| **(Intercept)** | | 1379.807 | 140.646 | 9.811 | 4.39E-14 | *** | |
| **mat** | | 63.475 | 6.473 | 9.805 | 4.47E-14 | *** | 0.56 |
| **wd** | | -10.171 | 2.751 | -3.697 | 0.000474 | *** | 0.15 |
| | **$R^2$=** | 0.7056 | **adj $R^2$=** | 0.6958 | | | |

## GPP < 2500

| | | **Estimate** | **Std.Err** | **t value** | **$Pr(>\lvert t\rvert)$** | | **$R^2$** |
|---|---|---|---|---|---|---|---|
| **(Intercept)** | | 1406.357 | 135.555 | 10.375 | 1.83E-14 | *** | |
| **NA.LOW** | | -263.7 | 97.152 | -2.714 | 0.0089 | ** | 0.11 |
| **mat** | | 56.63 | 7.272 | 7.787 | 2.18E-10 | *** | 0.47 |
| **wd** | | -5.408 | 2.517 | -2.149 | 0.0362 | * | 0.04 |
| | **$R^2$=** | 0.6223 | **adj $R^2$=** | 0.6013 | | | |

## GPP < 2500 Weighted

| | Estimate | Std.Err | t value | Pr(>\|t\|) | | $R^2$ |
|---|---|---|---|---|---|---|
| **(Intercept)** | 1386.784 | 133.901 | 10.357 | 1.57E-14 | *** | |
| **mat** | 51.652 | 7.161 | 7.213 | 1.69E-09 | *** | 0.44 |
| **wd** | -9.159 | 2.644 | -3.464 | 0.00104 | ** | 0.14 |
| **$R^2$=** | 0.5799 | **adj $R^2$=** | 0.5646 | | | |

## Only Managed forests

| | Estimate | Std.Err | t value | Pr(>\|t\|) | | $R^2$ |
|---|---|---|---|---|---|---|
| **(Intercept)** | 1048.172 | 119.347 | 8.783 | 1.77E-10 | *** | |
| **NA.LOW** | -309.188 | 117.171 | -2.639 | 0.0122 | * | 0.07 |
| **mat** | 74.979 | 9.498 | 7.894 | 2.29E-09 | *** | 0.59 |
| **$R^2$=** | 0.6598 | **adj $R^2$=** | 0.6409 | | | |

## Only Eddy covariance data

| | Estimate | Std.Err | t value | Pr(>\|t\|) | | $R^2$ |
|---|---|---|---|---|---|---|
| **Intercept)** | 1223.0939 | 167.9484 | 7.283 | 1.43E-09 | *** | |
| **mat** | 51.4191 | 8.761 | 5.869 | 2.76E-07 | *** | 0.38 |
| **map** | 0.363 | 0.1423 | 2.551 | 0.0136 | * | 0.27 |
| **wd** | -12.0537 | 2.6356 | -4.573 | 0.0000284 | *** | 0.16 |
| **$R^2$=** | 0.811 | **adj $R^2$=** | 0.8005 | | | |

## Alternative Classification

| | Estimate | Std.Err | t value | Pr(>\|t\|) | | $R^2$ |
|---|---|---|---|---|---|---|
| **(Intercept)** | 1569.856 | 123.786 | 12.682 | 2E-16 | *** | |
| **alternutrLOW** | -216.12 | 90.99 | -2.375 | 0.0209 | * | 0.04 |
| **mat** | 67.954 | 5.944 | 11.433 | 2E-16 | *** | 0.58 |
| **wd** | -11.626 | 2.252 | -5.163 | 0.00000321 | *** | 0.13 |
| **$R^2$=** | 0.7514 | **adj $R^2$=** | 0.7384 | | | |

**CUE Models**

## General

| | Estimate | Std.Err | t value | Pr(>\|t\|) | |
|---|---|---|---|---|---|
| **(Intercept)** | -0.2251 | 0.113 | -1.993 | 0.050969 | . |
| **gpp** | 0.0003517 | 0.0000645 | 5.452 | 0.00000107 | *** |
| **age** | 0.004071 | 0.0009644 | 4.221 | 0.0000866 | *** |
| **NA.LOW** | -0.1956 | 0.05992 | -3.264 | 0.001843 | ** |
| **gpp:age** | -2.944E-06 | 7.065E-07 | -4.168 | 0.000104 | *** |
| **$R^2$=** | 0.4349 | **adj $R^2$=** | 0.3959 | | |

**ANOVA table (type III)**

| | SumSq | DF | F value | Pr(>F) | | $R^2$ |
|---|---|---|---|---|---|---|
| **(Intercept)** | 0.1901 | 1 | 3.9722 | 0.050969 | . | |
| **gpp** | 1.42266 | 1 | 29.7273 | 1.068E-06 | *** | 0.14 |
| **age** | 0.85283 | 1 | 17.8204 | 0.00008656 | *** | 0.004 |
| **NA.** | 0.50995 | 1 | 10.6556 | 0.0018432 | ** | 0.12 |
| **gpp:age** | 0.83122 | 1 | 17.3688 | 0.0001038 | *** | 0.17 |
| **Residuals** | 2.7757 | 58 | | | | |

## Weighted

| | Estimate | Std.Err | t value | Pr(>\|t\|) | |
|---|---|---|---|---|---|
| **(Intercept)** | -0.03192 | 0.1037 | -0.308 | 0.75943 | |
| **gpp** | 0.0001887 | 0.0000578 | 3.265 | 0.00185 | ** |
| **age** | 0.003124 | 0.001041 | 3.001 | 0.00398 | ** |
| **NA.LOW** | -0.03051 | 0.05347 | -0.571 | 0.57044 | |
| **gpp:age** | -1.967E-06 | 6.16E-07 | -3.193 | 0.0023 | ** |
| **age:NA.LOW** | -0.001373 | 0.0005272 | -2.604 | 0.01173 | * |
| **$R^2$=** | 0.3448 | **adj $R^2$=** | 0.2873 | | |

**ANOVA table (type III)**

| | SumSq | DF | F value | Pr(>F) | | $R^2$ |
|---|---|---|---|---|---|---|
| **(Intercept)** | 0.043 | 1 | 0.0947 | 0.759431 | | |
| **gpp** | 4.8367 | 1 | 10.6612 | 0.001854 | ** | 0.01 |
| **age** | 4.087 | 1 | 9.0088 | 0.003982 | ** | 0.03 |
| **NA.** | 0.1478 | 1 | 0.3257 | 0.570442 | | 0.16 |
| **gpp:age** | 4.6239 | 1 | 10.1922 | 0.002296 | ** | 0.09 |
| **age:NA.** | 3.0765 | 1 | 6.7813 | 0.011726 | * | 0.05 |
| **Residuals** | 25.8594 | 57 | | | | |

## GPP<2500

| | Estimate | Std.Err | t value | Pr(>\|t\|) | |
|---|---|---|---|---|---|
| **(Intercept)** | -0.504 | 0.1096 | -4.598 | 0.0000261 | *** |
| **gpp** | 0.0004657 | 7.229E-05 | 6.442 | 3.31E-08 | *** |
| **age** | 0.003238 | 0.001097 | 2.952 | 0.00466 | ** |
| **gpp:age** | -2.172E-06 | 8.525E-07 | -2.548 | 0.01371 | * |
| **$R^2$=** | 0.4552 | **adj $R^2$=** | 0.4249 | | |

**ANOVA table (type III)**

| | SumSq | DF | F value | Pr(>F) | | $R^2$ |
|---|---|---|---|---|---|---|
| **(Intercept)** | 1.03712 | 1 | 21.1416 | 0.00002612 | *** | |
| **gpp** | 2.03587 | 1 | 41.5013 | 3.308E-08 | *** | 0.38 |
| **age** | 0.42758 | 1 | 8.7162 | 0.00466 | ** | 0.01 |
| **gpp:age** | 0.31848 | 1 | 6.4922 | 0.01371 | * | 0.07 |
| **Residuals** | 2.64901 | 54 | | | | |

## GPP<2500 weighted

| | Estimate | Std.Err | t value | Pr(>\|t\|) | | $R^2$ |
|---|---|---|---|---|---|---|
| **(Intercept)** | 0.187674 | 0.036618 | 5.125 | 0.00000396 | *** | |
| **NA.LOW** | -0.126927 | 0.035287 | -3.597 | 0.00069 | *** | 0.15 |
| **mat** | 0.012343 | 0.003086 | 4 | 0.000191 | *** | 0.19 |
| **$R^2$=** | 0.3397 | **adj $R^2$=** | 0.3157 | | | |

## Only Managed

| | Estimate | Std.Err | t value | Pr(>\|t\|) | | $R^2$ |
|---|---|---|---|---|---|---|
| **(Intercept)** | -0.3887 | 0.1444 | -2.693 | 0.0109 | * | |
| **gpp** | 0.0004172 | 7.783E-05 | 5.36 | 0.00000585 | *** | 0.37 |
| **age** | 0.00461 | 0.001737 | 2.655 | 0.012 | * | 0.03 |
| **NA.LOW** | -0.171 | 0.08213 | -2.082 | 0.0449 | * | 0.09 |
| **gpp:age** | -2.712E-06 | 1.304E-06 | -2.079 | 0.0452 | * | 0.05 |
| **$R^2$=** | 0.5477 | **adj $R^2$=** | 0.4945 | | | |

## Eddy covariance

| | Estimate | Std.Err | t value | Pr(>\|t\|) | | $R^2$ |
|---|---|---|---|---|---|---|
| **(Intercept)** | -0.2325 | 0.1195 | -1.945 | 0.057055 | . | |
| **gpp** | 0.0003537 | 7.426E-05 | 4.763 | 0.0000152 | *** | 0.12 |
| **age** | 0.004067 | 0.001055 | 3.857 | 0.000313 | *** | 0.02 |
| **NA.LOW** | -0.1892 | 0.06651 | -2.845 | 0.006295 | ** | 0.09 |
| **gpp:age** | -2.933E-06 | 8.006E-07 | -3.663 | 0.000576 | *** | 0.15 |
| **$R^2$=** | 0.3728 | **adj $R^2$=** | 0.3255 | | | |

## Alternative Classification

| | Estimate | Std.Err | t value | Pr(>\|t\|) | | $R^2$ |
|---|---|---|---|---|---|---|
| **Intercept)** | -0.2209 | 0.115 | -1.921 | 0.05998 | . | |
| **gpp** | 0.0002462 | 7.852E-05 | 3.136 | 0.00275 | ** | 0.12 |
| **age** | 0.004683 | 0.001057 | 4.43 | 0.0000453 | *** | 0.01 |
| **alternutrLOW** | -0.1627 | 0.06088 | -2.672 | 0.0099 | ** | 0.07 |
| **mat** | 0.01454 | 0.006533 | 2.225 | 0.03017 | * | 0.06 |
| **gpp:age** | -3.202E-06 | 7.429E-07 | -4.31 | 0.000068 | *** | 0.18 |
| **$R^2$=** | 0.4426 | **adj $R^2$=** | 0.392 | | | |

## Using Factor 1 and 2 from the nutrient classification analysis

| | Estimate | Std.Err | t value | Pr(>\|t\|) | |
|---|---|---|---|---|---|
| **(Intercept)** | -0.09955499 | 0.0714464 | -1.393 | 0.17 | |
| **f1** | 0.01556442 | 0.0053638 | 2.902 | 0.01 | ** |
| **f2** | 0.04844199 | 0.0200583 | 2.415 | 0.02 | * |
| **gpp** | 0.00020052 | 4.541E-05 | 4.416 | <0.0001 | *** |
| **managementUM** | 0.1584173 | 0.0931077 | 1.701 | **0.09** | . |
| **f2:gpp** | -2.6022E-05 | 1.143E-05 | -2.277 | 0.03 | * |
| **gpp:managementUM** | -0.0001458 | 5.589E-05 | -2.609 | 0.01 | * |
| **R2=** | 0.4812 | **adj R2=** | 0.4246 | | |

**ANOVA table (type III)**

| | SumSq | DF | F value | Pr(>F) | | $R^2$ |
|---|---|---|---|---|---|---|
| **(Intercept)** | 0.03965 | 1 | 1.9416 | 0.169098 | | |
| **f1** | 0.17194 | 1 | 8.4201 | 0.005328 | ** | 0.18 |
| **f2** | 0.1191 | 1 | 5.8325 | 1.91E-02 | * | 0.02 |
| **gpp** | 0.39819 | 1 | 19.4996 | 4.76E-05 | *** | 0.09 |
| **management** | 0.05912 | 1 | 2.8949 | 0.094507 | . | 0.04 |
| **f2:gpp** | 0.1059 | 1 | 5.186 | 0.02668 | * | 0.07 |
| **gpp:management** | 0.13899 | 1 | 6.8064 | 0.011675 | * | 0.09 |
| **Residuals** | 1.12313 | 55 | | | | |