GLOBAL NUTRIENT LIMITATION IN TERRESTRIAL VEGETATION FROM REMOTE SENSING

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$\text{CO}_2 + 2\text{H}_2\text{O} \xrightarrow{\text{energy (light)}} (\text{CH}_2\text{O})_n + \text{H}_2\text{O} + \text{O}_2$
THE NATURE OF NUTRIENT LIMITATION IN PLANT COMMUNITIES

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The concept of nutrient limitation was developed in agriculture to refer to the
limited productivity in an individual plant or a monospecific stand because of
the inadequate supply of an essential nutrient in the soil (e.g., Ulrich and Hill's
1973). If the particular nutrient were available in greater abundance, productivity
would increase by definition. We suggest that this concept cannot be extrapolated
simply to natural plant communities. For several reasons, plant communities
occupying the most fertile sites are not always the most responsive to nutrient
addition.

NUTRIENT LIMITATION TO INDIVIDUALS

When a crop plant is grown with a limiting supply of an essential nutrient, it
produces less biomass than if the limiting nutrient were more available. The more
nutrient-limited an individual is, the more its productivity increases in response to
a large addition of the limiting nutrient (fig. 1). This relationship between nutrient
availability and productivity provides an objective criterion for evaluating the
extent of nutrient limitation to the growth of individual plants or monospecific
stands. Similar growth responses to nutrient addition have been observed in wild
plants (Chapin 1980). Wild plants that are restricted to infertile soils, however,
generally exhibit lower maximum potential growth rates and respond less to
nutrient addition than do related plants from more-fertile soils (fig. 1; see also
Mitchell and Chandler 1938; Clarkson 1967; Safford and Felip 1974; Giirke 1977;
Achieson and Smith 1979; Ellis 1979; Chapin 1980; Farber 1980; Veerkamp et
al. 1980; Chapin et al. 1982, 1983).

COMMUNITY NUTRIENT LIMITATION

In individual plants, nutrient limitation is recognized by an increase in growth in
response to an addition of the limiting nutrient. The analogous response at the
community level is an increase in total community production in response to
fertilization. Three major difficulties attend the application of this concept of
nutrient limitation to a comparison of communities.

Abstract. The widespread occurrence of nitrogen limitation to net primary production in
terrestrial and marine ecosystems is somewhat of a puzzle. It would seem that nitrogen
fixation should have a substantial competitive advantage wherever nitrogen is limiting, and
that their activity in turn should reverse limitation. Nevertheless, there is substantial
evidence that nitrogen limits net primary production much of the time in most terrestrial
biomes and many marine ecosystems.

We examine both how the biogeochemistry of the nitrogen cycle could cause limitation
to develop, and how nitrogen limitation could persist as a consequence of processes that
prevent or reduce nitrogen fixation. Biogeochemical mechanisms that favor nitrogen limita-
tion include:

--- the substantial mobility of nitrogen across ecosystem boundaries, which favors nitrogen
limitation in the "surplus" ecosystem — especially where denitrification is important in
sediments and soils of terrestrial ecosystems where fires are frequent;

--- differences in the thermodynamic stability of nitrogen as opposed to phosphorus (with derived N
mostly carbon-based and derived P mostly enterobacteriodes), which favor the develop-
ment of nitrogen limitation where decomposition is slow, and allow the development of a
positive feedback from nitrogen limitation to production, to reduced decomposition of
their detritus, and finally to reduced nitrogen availability.

--- after more specialization, but perhaps no less important, processes.

A number of mechanisms could keep nitrogen fixation from reversing nitrogen limitation.
These include:

--- energetic constraints on the colonization or activity of nitrogen fixers;

--- limitation of nitrogen fixers or fixation by another nutrient (phosphorus, molybdenum, or
...), which would then represent the ultimate factor limiting net primary production;

--- other physical and ecological mechanisms.

The possible importance of these and other processes is discussed for a wide range of
terrestrial, freshwater, and marine ecosystems.

Introduction

Nitrogen limitation to primary production is believed to be widespread. A
NUTRIENT LIMITATION
NUTRIENTS BY BIOME

Forest

Savanna and Grassland

Cropland

Shrubland

Mean: -0.1055
σ: 0.2032

Mean: -0.02701
σ: 0.1924

Mean: -0.04582
σ: 0.2903

MORE LIMITED

L I M I T E D
Land-use history from Hurtt et al. 2006: *Global Change Biology*