

The Sahara as a Global Fertiliser: Mineral Dust Transport and Its Ecological Consequences for Amazonia and European Forests

Abdelkader BOUSABAA

A quantitative assessment of trans-continental
aeolian biogeochemical fluxes

August 18, 2025

Abstract

The Sahara Desert, commonly perceived as an ecological wasteland, constitutes one of the most consequential biogeochemical engines on the planet. Each year, approximately 182 Mt of mineral dust are mobilised from its surface by aeolian erosion, of which roughly 27.7 Mt are carried westward across the Atlantic Ocean by the trade winds, ultimately reaching the Amazonian rainforest basin. This trans-Atlantic flux delivers an estimated 22 000 t of phosphorus annually to Amazonia — a quantity that almost exactly compensates the 22 200 t of phosphorus leached each year from its notoriously nutrient-depleted soils. A second branch of dust transport, the Sirocco, conveys Saharan aerosols northward across the Mediterranean, depositing calcium, iron and magnesium onto European forests. This paper provides a comprehensive, quantitative analysis of these two dust transport pathways. We describe the physical mechanisms of dust emission and atmospheric transport, review the observational and modelling tools used to characterise these fluxes — including satellite retrievals from CALIPSO and MODIS, trajectory models such as HYSPLIT and the MERRA-2 reanalysis — and quantify the biogeochemical impact on recipient ecosystems. We further examine the long-term trend of declining Saharan dust transport since 1980, driven by the North Atlantic Oscillation and Sahel rainfall recovery, and discuss the potential consequences of this decline for terrestrial carbon sequestration and global climate regulation.

Keywords: Saharan mineral dust, trans-Atlantic transport, Amazon phosphorus budget, Sirocco, MERRA-2 reanalysis, biogeochemical cycle, aerosol deposition, climate change

7. Conclusion

The central argument of this paper is easily stated, yet its implications are vast and still imperfectly understood: the Sahara Desert, far from being an ecological dead zone, is one of the most important nutrient suppliers in the global biosphere. Through the medium of aeolian mineral dust — mobilised in prodigious quantities from its surface, transported across ocean basins by the great wind systems of the tropics, and deposited upon forest soils tens of thousands of kilometres from their source — the Sahara underwrites the productivity of the Amazon rainforest and contributes measurably to the mineral nutrition of European forest ecosystems. This finding inverts the conventional geographical intuition that links biological richness to proximity of nutrient sources, and demands a more globally interconnected view of ecosystem function.

The quantitative picture that emerges from this synthesis is striking in its precision. Of the 182 Mt yr^{-1} of mineral dust emitted from the Saharan surface, approximately 27.7 Mt yr^{-1} traverse the tropical Atlantic carried by the trade winds, delivering roughly 22 000 t of phosphorus to the Amazon basin each year. This quantity compensates 99% of the phosphorus lost annually from Amazonian soils through leaching — a biogeochemical balance of extraordinary accuracy maintained across a distance of 10 000 km. A second flux, conveyed northward by the Sirocco, deposits calcium, iron and magnesium onto European forest soils at rates of $5\text{--}15 \text{ g m}^{-2} \text{ yr}^{-1}$, contributing to soil acid-buffering capacity and foliar mineral nutrition in communities already under stress from acid deposition and progressive climate warming.

The methodological infrastructure that has made this quantitative synthesis possible is itself a remarkable scientific achievement, representing the integrated effort of space agencies, meteorological centres and field research programmes over several decades. The combination of CALIPSO/CALIOP lidar profiles, MODIS aerosol optical depth retrievals, HYSPLIT trajectory analysis, BSC-DREAM/MONARCH dust transport modelling, and the MERRA-2 long-term reanalysis provides a multi-layered observational and diagnostic framework whose individual components are independently validated and mutually consistent. Continued investment in this observational infrastructure — particularly the maintenance of the AERONET ground network and the timely launch of successor satellite missions — is essential to sustaining the monitoring capability on which our understanding of these long-range teleconnections depends.

Perhaps the most urgent message of this work, however, concerns not the present state of the dust transport system, but its trajectory. The MERRA-2 record, corroborated by independent *in situ* observations at Atlantic receptor sites, indicates a decline of approximately 10% in trans-Atlantic dust transport over the period 1980–2020, driven by a combination of Sahel regreening associated with the partial recovery of West African Monsoon rainfall and interannual variability in the North Atlantic Oscillation. While this trend is modest over the observed period, model projections for the 21st century under high-emission scenarios suggest that continued Sahel greening, combined with potential changes in the large-scale atmospheric circulation, could produce reductions in Saharan dust export of 20–30% relative to the late 20th century. The ecological consequences of such a decline for Amazonian phosphorus nutrition, forest biomass and ultimately for the atmospheric carbon balance, have not been adequately incorporated into current Earth System Model projections and represent a significant source of uncertainty in assessments of the global carbon budget.

The philosophical dimension of this result is as significant as its scientific content. It is a reminder that the Earth system does not organise itself according to the administrative or

conceptual borders that human perception tends to impose upon it. A grain of sand lifted from a dried lake bed in northern Tchad by the January winds does not know that it will travel for ten days across the Atlantic before settling onto the leaf of a cecropia tree in the Brazilian state of Amazonas, replenishing a phosphorus atom that was washed out of that soil by the previous season's rains. The system simply operates, with a precision that continues to astonish those who study it, as though the desert and the forest had long ago reached an arrangement for their mutual sustenance.

This paper has attempted to illuminate the mechanisms, quantify the fluxes, and assess the vulnerabilities of that arrangement. Much remains to be done. The full coupling of dust-ecosystem feedbacks in Earth System Models, the extension of the deposition monitoring record to the full extent of European and Amazonian forest ecosystems, and the attribution of long-term dust trends to specific climatic forcings all represent frontiers where scientific progress is urgently needed. The Sahara has been fertilising the world's forests for millions of years. Understanding the conditions under which it may cease to do so is one of the more consequential problems in contemporary Earth system science.