

Kinetic Analysis of Leaching Reactions in Multi-component Mineral Systems

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Increasing local agricultural productivity is seen as a key step in achieving food security in Sub-Saharan Africa. One path towards raising productivity is raising rates of fertilizer application in the region, which trail world averages by large margins. Despite decades of policy initiatives and subsidy programs, fertilizer application rates remain low, as does overall productivity. Achieving a lasting increase in application rates necessitates the presence of economic incentives for increased fertilizer use; fertilizer application must provide more value in increased crop yield than it costs the farmer to acquire and apply. However, the price of fertilizers in Africa is high, largely due to inefficiencies in the supply chain, and the effectiveness of traditional fertilizers is hampered by the tropical soils present across much of the continent.

Traditional fertilizers, generally readily soluble salts of potassium, ammonium, and phosphorus, are ill-suited to the task of providing nutrients for intensive agriculture in tropical soils. These soils tend to have a poor cation exchange capacity, meaning that positively charged species like potassium and ammonium ions are very mobile. The rapid release of these nutrients from traditional fertilizers is easily carried away from the field as runoff, rather than remaining available for increasing crop growth.

These dual barriers of high costs and poor performance motivate the creation of alternative fertilizers better suited to tropical soils and the African context. Recent studies have shown that the processing of certain classes of abundant minerals, such as potassium feldspar, yields materials with desirable slow-release fertilizing properties. These materials are complex, heterogeneous, solid mixtures and isolating mixture components is often not possible, which makes quantifying the contribution of mixture components to the overall chemical behavior challenging with existing techniques. This difficulty hampers the ability to design and optimize processing strategies to adapt the academic research into alternative fertilizers for the economical production of suitable products.

To gain access to this information and enable the rational design of these materials, a general experimental and mathematical framework for investigating the kinetics of surface-controlled leaching reactions for heterogeneous solid mixtures was created. Continuum models for three-dimensional bulk powders, and two-dimensional surfaces in a microchannel were created and solved. Methods for the effective design of experiments and estimating the necessary experimental parameters were developed, and a full analysis of appropriate solution techniques and the propagation of uncertainty through the system was performed. These techniques enabled the simultaneous determination of component leaching rates from a solid mixture without requiring mixture separation. These findings extend the effective techniques available for studying the kinetic behavior of pure systems to the challenging task of complex mixtures.

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