

## SILICATE AGROMINERALS AS NUTRIENT SOURCES AND AS SOIL CONDITIONERS FOR TROPICAL AGRICULTURE

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### Introduction

Two models of agriculture were developed from temperate and tropical climates conditions based on intensive use of natural resources. Both utilize resilient edaphoclimatic environments, though with marked differences in their natural fertility. In general, agricultural soils of temperate climate are young ( $10^3$  to  $10^4$  years) and very fertile, while the tropical soils are old ( $10^5$  to  $10^7$  years) and very poor in nutrients. The model of soil fertility management in tropical climate is an adaptation practices developed in the temperate climate from the same nutrient sources and soil conditioners. The strategies adopted to control of the soil acidity and the use of soluble sources of NPK were the key step that allowed the development of a highly productive tropical agriculture.

After the initial success of this approach, the challenges nowadays are dedicated on the efficient supply of nutrients for agriculture. The efficiency of the management of these soluble sources must improve to ensure the best use of the nutrients that are derived from finite mineral resources and high energy cost of production and transportation. The development of tropical agriculture needs a fertility management where nutrient flows for successive crops is synchronized with the demands at all stages of the plants. The established strategies for this efficiency challenge are based in the installment of nutrient application or the development of new fertilizers from soluble sources and its stabilization from slow release technology. One of the recognized slow release technology is related to the application of soluble fertilizers together silicate minerals such as zeolite to decrease the rate of nutrient release.

An assessment of the soil genesis processes is another way of addressing soil fertility. The most fertile agricultural soils of the temperate

zone were formed from sediment deposition of glacial, loess and fluvial origin. These processes are efficient ways to comminute rocks and facilitate the process of soil formation. High soil fertility is associated with the formation of 2:1 clay minerals on these sediments and the stabilization of organic matter. The weathering process releases nutrients to soil solution present in the silicate minerals while forming 2:1 clay mineral, like  $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$ ,  $\text{K}^+$ , sulphur and micronutrients. In consequence, these soils have high cation exchange capacity (CEC) and electron-negative physicochemical characteristics. These features facilitate the management of soluble cation nutrients in long terms due high stability of 2:1 clay mineral at agronomic scale.

On the other hand, tropical agricultural soils are the result of a very long process of chemical weathering action. The minerals of the kaolinite group and oxides and hydroxides of iron and aluminum are the most abundant in these soils. This mineralogical composition gives low CEC and electropositive physicochemical characteristics, which decreases the efficiency of nutrient flow at crop stages. Organic matter is the main source of tropical soil CEC, but usually have low concentrations and many agricultural practices lead to decline over time. On the other hand, the high anion exchange capacity (AEC) of tropical soils causes the retention of anions of agronomic importance, like  $\text{PO}_4^{3-}$ ,  $\text{SO}_4^{2-}$  and  $\text{NO}_3^-$ . These differences among tropical and temperate agricultural soils represent insights into the possibilities of fertility management of soils with silicate agrominerals.

However, the potential of silicate rocks as nutrient sources and as soil conditioners has been evaluated with positive and negative results. This paper reviews the research strategies of the silicate agrominerals and the significance of their findings in tropical conditions. The work proposes a research

approach that considers different interaction system levels among silicate agrominerals, agricultural soils and crops.

## Definitions and assumptions

The agrominerals are defined as raw materials of mineral origin for the production of soil conditioner or fertilizer for agricultural production. These raw materials are derived from geological resources that undergo industrial processing before turning into a product. Mineral processing involves physical and chemical processes. The physical processes are linked to comminution, separation, mixing, homogenization and heating (fusion). The chemical processes involve reactions and transformations in solid or solutions states (acid extraction, hydrothermal transformation) with or without biological process. If the mineral processing is only associated with comminution (crushing and grinding), then it is defined as *in natura*, where are maintained the main mineralogical characteristics. Even so, the crystallinity degree of the minerals can be affected by these physical processes and alters nutrient availability. Physical comminution processes in dry conditions and finer grain sizes favor a higher solubility.

Silicate agromineral utilized as K fertilizer can be prepared *in natura* or another mineral processing. There are many examples of silicate agromineral as *in natura* K sources, derived from different minerals, like micas (biotite, phlogopite), zeolites (clinoptilolite), and feldspathoids (kalsilite, nepheline). Alkaline rocks and schists rich in these minerals have proven potential as *in natura* K sources. K feldspars and clay minerals (illite, glauconite) rich rocks can be utilized as raw material for new fertilizers by another mineral processing beyond crushing.

The stonemeal is a regional process of managing soil fertility from the direct application of comminuted rocks that improve the physical, chemical and biological characteristics of the soil and provide part of the necessary nutrients to crops (van Straaten, 2007). The anion classification of agrominerals for the stonemeal process indicates the behavior of each soil conditioners. Liming is one of the most known forms of stonemeal developed for control soil acidity. Other rock compositions can

also be employed in the process of stonemeal as rich in sulfates, phosphates and silicates. The rocks rich in Ca and Mg are most suitable as soil conditioners for silicate agrominerals.

The main idea of the use of silicate rocks as conditioners in agriculture is to develop the same formation process of temperate agricultural soils but at agronomic scale ( $10^0$  to  $10^1$  years). The hydrolysis process is the most important chemical weathering mechanism of aluminosilicates. This process always produce new minerals more stable than the primary aluminosilicates (Bonneville et al., 2011). Experiments are being conducted to investigate the role of the rhizosphere of crops in the weathering of silicate agrominerals and demonstrate the formation of new mineral phases in cycles of tens of days. The weathering process releases nutrients to soil solution and to plants present in the silicate minerals while forming 2:1 clay mineral, like  $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$ ,  $\text{K}^+$ , sulphur and micronutrients. These new phases are 2:1 clay minerals like vermiculite from biotite and smectite from Ca and Mg aluminosilicates. These new phases are stable in the soil for a long term in relation to the agronomic scale that facilitate the management of soluble cation nutrients. Moreover, similar systems without rhizosphere present any silicate agrominerals changes at the same time scale.

Initial calculations indicate that each 20 tons of silicate agrominerals by hectare is equivalent to 1% of the total 20 cm depth soil profile, and the increase in 2:1 clay minerals may be from 0.3% to 0.7% of soil. This amount of 2:1 clay minerals in soil is equivalent from 3 to 7  $\text{cmol}_c \text{ kg}^{-1}$ . In other words, each 1  $\text{cmol}_c \text{ kg}^{-1}$  in the soil can be obtained with the silicate agrominerals amounts from 3 to 7 tonnes by hectare. If is considered a 5 cm depth soil profile, due to the small vertical mobility, then these values fall into the range from 750 to 1,750 kg per hectare to reach 1  $\text{cmol}_c \text{ kg}^{-1}$ . The CEC production potential can be a fundamental metric for the silicate agrominerals classification.

## Proposed research approach

The proposed research approach involves different levels of experimental systems for understanding the transformation of silicate agrominerals in agricultural soils and their interaction with crops.

This work proposes the study of the following systems: agromineral-solution; agromineral-solution-soil; agromineral-solution-plant; and agromineral-solution-soil-plant. These systems can be studied in many ways, always with the aim of assessing the agrominerals weathering, the formation of new mineral phases, the availability of nutrients and the generation of CEC. The central hypothesis of silicate agrominerals bioweathering promoted by rhizosphere must be tested in all experimental systems.

The agromineral-solution systems indicate the efficiency of different extractants in the weathering process. The most important extractors are water, inorganic acids and organic acids. The organic acids of low molecular weight are important as plant exudates such as citric and oxalic acids, and may be more suitable extractors to evaluate nutrient availability in silicate agrominerals.

The agromineral-solution-soil systems show the behavior of equilibria solutions among agrominerals and soil, and the potential leaching of nutrients. Leaching columns experiments show the soil's role in the interaction with agrominerals and solutions. The soil can modify the acidity of the solution and buffer some agromineral reactions.

The agromineral-solution-plant systems show the direct results of the agrominerals weathering promoted by rhizosphere. The experimental systems are designed with a high proportion of agromineral in mixtures with inert materials acting as substrate for the plants rhizosphere. The agromineral transformed after the crop cycle is easily separated for subsequent mineralogical, chemical and physical-chemical analysis.

The agromineral-solution-soil-plant systems show the agronomic efficiency of silicate agrominerals. These systems should be designed after the indication of the behavior of agrominerals in other experimental systems. The dose response curves and the residual effects should be designed after understanding the other experimental systems

described above. These experimental system allow to evaluate the behavior of trace elements beneficial and potentially toxic, and ensure environmental and food safety.

This experimental systems approach allows understand the interaction processes and classify silicate agrominerals as fertilizers or as soil conditioners.

## Conclusions

The models of agriculture and the soil genesis in tropical and temperate climates are the references for the development of a new experimental approach to the research of silicate agrominerals.

The bioweathering promoted by crop rhizosphere becomes the central process of silicate agrominerals transformation at agricultural systems.

The proposed research approach is designed as multiscale experimental systems that allow to characterize the silicate agrominerals.

Keywords: Silicate agrominerals; system approach; bioweathering

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