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Disadvantages and Advantages of Rock dust for agriculture: a case study in Brazil

Ventajas y desventajas del polvo de roca en la agricultura: un estudio de caso en Brasil

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Abstract: Terrestrial enhanced rock weathering (ERW) is a promising technology for carbon dioxide removal that consists of the application of ground silicate rocks, such as basalt, to agricultural soils. However, researchers criticize the lack of studies, mainly physical and biological studies of the rocks, in order to verify whether they really benefit soil nutrition, since the advantages of reduced leaching and increased calcium, iron (Fe), aluminum (Al) and magnesium (Mg) must be compared with the negative effects such as CO2 losses from the mineralization of organic matter, sodification and soil respiration. Some authors say that the advantages of rock dust are more pronounced in countries with tropical climates, while others say that there are no significant advantages. In this context, this work proposes two models: 1. A Culture-Knowledge-Intelligence model to understand how the cultural issue impacts the processes of knowledge creation and application, and 2. A biodynamic agriculture model (home-made fertilizers) based on cooperatives to improve home techniques in Brazilian agriculture.

Key-words: biodynamic agriculture, cooperatives, emotion, false economic miracle, rock dust.

Resumen: La meteorización mejorada de rocas terrestres (ERW) es una tecnología prometedora para la eliminación de dióxido de carbono que consiste en la aplicación de rocas silicatadas trituradas, como el basalto, a los suelos agrícolas. Sin embargo, los investigadores critican la falta de estudios, principalmente físicos y biológicos de las rocas, para verificar si realmente benefician la nutrición del suelo, ya que las ventajas de la reducción de la lixiviación y el aumento de calcio, hierro (Fe), aluminio (Al) y magnesio (Mg) deben compararse con los efectos negativos, como las pérdidas de CO_2 debidas a la mineralización de la materia orgánica, la sodificación y la respiración del suelo. Algunos autores afirman que las ventajas del polvo de roca son más pronunciadas en países con climas tropicales, mientras que otros sostienen que no existen ventajas significativas. En este contexto, este trabajo propone dos modelos: 1. Un modelo de «Cultura-Conocimiento-Inteligencia» para comprender cómo la cuestión cultural influye en los procesos de creación y aplicación del conocimiento, y 2. Un modelo de agricultura biodinámica (fertilizantes caseros) basado en cooperativas para mejorar las técnicas caseras en la agricultura brasileña.

Palabras clave: agricultura biodinámica, cooperativas, emoción, falso milagro económico, polvo de roca.

Introduction

This study is a literature review with an applied case study (Roraima, Brazil).

The literature review is heavily based on rock dust, since biodynamic agriculture helps in the fight against climate change.

Dupla et al. (2024) sustain that applying ground silicate rock such as basalt on agricultural soils. On top of carbon sequestration, Terrestrial enhanced rock weathering (ERW) has the potential to raise the soil pH and release nutrients, thereby improving soil fertility.

According to Arma et al. (2024) demonstrated an increase in total microminerals, fresh weight, total biomass, better water retention, root development, mineralization, MUFA (monosaturated fatty acid), protein content, and antioxidants in plant tissue produced using RD-based media amendments.

According to Li and Dong (2013) the nutritional content of Rock Dust - RD could be used as an amendment to improve soil fertility, particularly in nutrient-poor soils. RD contains calcium and trace elements such as iron (Fe), aluminum (Al), and magnesium (Mg) but lack a substantial amount of nitrogen (N), phosphorus (P) and potassium (K).

In fact, according to these researchers, most biological, physical, and chemical parameters remained unaffected after 1 month and even 1 year of application, with significant differences appearing primarily between fields rather than between rock powder treatments. This multi-site field trial highlighted, however, an increase in soil respiration and sodium concentration which, despite being encouraging signs of short-term weathering kinetics, should be further investigated before ERW can be deployed as both an efficient and safe carbon dioxide removal technology (Dupla et al., 2024).

It's well known that rock dust consists of pulverized rock particles and is gaining popularity as a chemical-free soil amendment for improving soil health. Mined from geologic rock deposits, rock dust can be used for carbon (CO2) capture, improving soil fertility, modifying soil pH,

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as well as improving soil drainage and water holding capacity (Arnott et al., 2019).

Bauwhede et al. (2024) suggest mixing lime (e.g. 3–5 Mg/ha) with RD (e.g. 15–25 Mg/ha) as a potential solution to sufficiently raise soil pH at an acceptable cost while still having sustainable slow-release buffering by the rock dust.

Bauwhede et al. (2024b) found that the mixed application of 3.1 Mg/ha basalt-diabase-lime rock powders and 1.6 Mg/ha of bentonite did not sustainably alter the pH but did raise the topsoil base saturation above 30 % in the top 10 cm of the mineral soil.

In the mining and quarrying industries, for example, Rock Dust is a mineral-rich by-product that can be used to improve soil fertility, promote plant growth, raise the activity of beneficial microflora, increase pest and disease resistance, as well as enhance the quality of fruits and vegetables. Future research should focus on optimizing these formulations for various crop types and conditions to maximize their benefits, thereby supporting sustainable agriculture and addressing waste management challenges in the mining sector (Khan et al. 2023).

However, Dekhordi et al. (2024) explain that waste products generated through mining activities can cause a significant loss of biodiversity, air quality, and water pollution affecting humans, plants, and animals through soil degradation. Despite the significant contributions to society, mining activities have become a severe threat to biodiversity and food security For instance, some mining activities adversely affect the ecosystem functioning, including the loss of arable land, soil degradation, polluted air, and reduced water quality, leading to declining agricultural productivity, food insecurity, and economic growth (Dekhordi et al., 2024), what is clear in the figure 1.

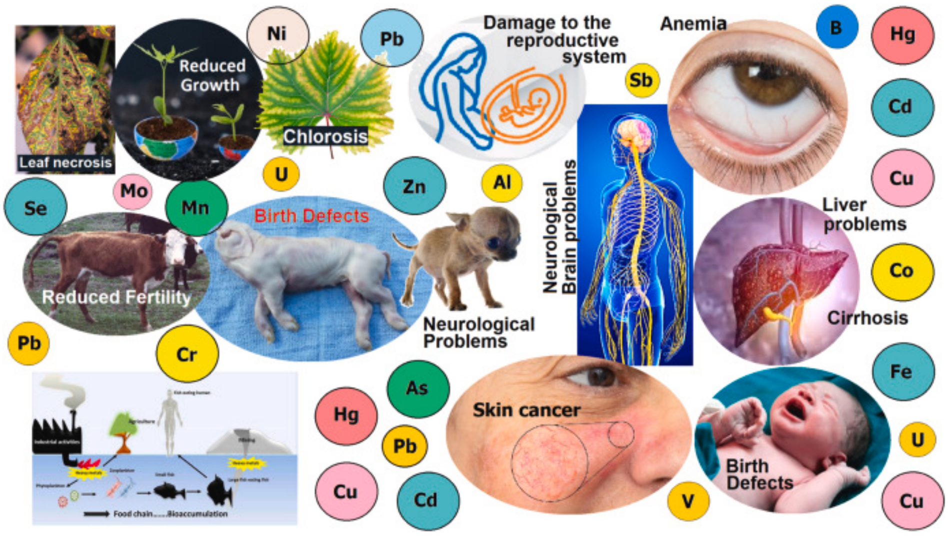

Fig. 1. Pollution generated by mining activities and its consequences (Dehkordi et al., 2024).

Some authors find no benefit in using rock dust as a fertilizer.

For example, the results of Ramezanian et al. (2024) show that the tested rockdust had no positive or negative effect on plant growth or nutrient composition. In addition, the microbial response to added substrates, a sensitive measure of changes in soil environment, were unaltered by the rockdust. As the rockdust had no nutrient or toxic effect it can probably be considered as an inert material which at least causes no harm but equally has no demonstrable ecological or agricultural benefit.

The scientific evidence about its effectiveness is however contradictory, which derives from inconsistent weathering rates and the complex interactions of several factors. Rock dust led to significant results when applied to highly weathered soils in tropical environments, as well as in combination with organic materials and microorganisms (Swoboda, 2016).

Application of rock fertilizers in tropical environments has advantages.

Firstly, the dissolution rate of rocks and minerals and the reaction between mineral surfaces and soil solution is enhanced under high temperatures and moisture regimes.

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Secondly, the potential of applying ground rocks and minerals to soils is elevated as the soils are characterized by low nutrient contents because of high amounts of weathering and leaching, and thus highly receptive to addition of nutrients (Straaten, 2006).

In addition several farmers do not consider rock dust as a Biodinamic Homemade fertilizer. The difficulty of cooperatives engaging in the acquisition of crushing machines depends on a closer relationship with agricultural entitles to analyze both rocks and soils (compatibility examination) besides the union among farmers for formation in this "novelty" and subsequent construction of crushing machines in their own farms.

For this reason, the research question is how culture relates to knowledge and intelligence in order to know what type of culture we have to build for effective Bio-dynamic agriculture.

Therefore, this work brings two research models that feed each other.

In addition to the Culture-Knowledge-Intelligence (CKI) model, this article presents a Bio-dynamic Agriculture model, a mature way of better using the resources available on the farm itself. The study concluded that this model is useful for small farmers to learn, through cooperatives, home-made farming practices, such as rock dust as a new fertilizer mixed or not with cattle manure.

Given this brief summary of the main topic and this proposal, the article is divided into the following chapters: 1. A literature review on rock powder 2. Agricultural cooperatives in the context of Biodynamic Agriculture 3. The Culture-Knowledge-Intelligence model 4. The biodynamic agriculture model

A literature review on rock dust

According to Straaten (2006) natural mineral and rock-based fertilizers can be subdivided into:

• Multi-Nutrient Silicate Rock Fertilizers, e.g. fine grained volcanic rocks,

• Single-Nutrient Rock Fertilizers, e.g. phosphate rock fertilizers,

• Rock Fertilizers from rock and mineral 'waste'

– unprocessed mine 'waste'

– processed rock and coal waste' (e.g. flyash).

• Translocated Rock Fertilizers:

– alluvial Rock Fertilizer (e.g. nutrient rich river and reservoir sediments)

– airborne Rock Fertilizers (e.g. nutrient rich 'loess' and volcanic ash)

• Specific Nutrient Rock Fertilizers concomitantly applied with organic residues, or biolog-ically modified e.g. by micro-organisms,

• Biofertilizers, organic forms of nutrients extracted from rocks, e.g. organic matter, phyto-extracted from phosphate rock.

Bauwhede et al. (2024) aimed to: (1) compare how rock dusts (RDs) dissolve depending on their mineralogy and surface area, (2) examine RD dissolution in soils with different starting pH and buffer capacities, and (3) evaluate tests that simulate weathering to predict how well RDs improve soil pH. They tested five types of commercially available RDs—including two basalts, phonolite, foidite, and trachy-andesite—on four acidified forest soils with different textures and chemical properties.

The study underscores a key issue: soil acidification is worsening worldwide, and while silicate RDs are seen as a potential remedy, their effectiveness varies widely due to differences in dissolution rates and acid neutralising capacity - ANC. These properties are closely tied to the rock's mineral composition and the soil's buffering capacity. Bauwhede et al. (2024) emphasize the need for better evaluation methods to ensure the appropriate selection and use of RDs in soil restoration efforts.

Duppa et al. (2024) observed that the application of rock powder had a neutral to slightly positive influence on soil biological fertility indicators. Among the measured parameters, only earthworm abundance and soil respiration showed statistically significant changes, with the abundance of earthworms increasing by an average of 71% in treated soils after one month compared to controls. A general linear mixed model was used to evaluate the influence of various factors on earthworm abundance, including soil texture, soil organic carbon (SOC) content, pH, structural quality, bulk density, and the presence of toxic trace elements. Notably, aside from the effects of rock powder, elevated copper levels were the only factor with a significant negative impact on earthworm populations.

Additionally, rock dusts can enhance soil properties such as cation exchange capacity (Anda et al., 2015) and the water retention capacity

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of sandy soils (Kahnt et al., 1986). However, their effectiveness is inconsistent, and some contain potentially toxic elements at harmful concentrations. Therefore, the agronomic outcomes of rock dust applications, especially in tropical soils, are highly dependent on the specific mineralogical and chemical composition of the rock, the deficiencies of the soil, and the nutritional demands of target crops (van Straaten, 2017).

Swoboda, Döring, and Hamer (2022) analyzed 48 crop trials and concluded that rock dusts, particularly those derived from mafic and ultramafic rocks like basalt, nepheline, and glauconite-bearing materials, show potential as alternative potassium sources and multi-nutrient amendments in tropical soils. Basalt powders, in particular, are notable for their richness in magnesium and iron silicates and their basic pH, in addition to providing key nutrients such as phosphorus, potassium, calcium, and various micronutrients.

Viana, Caetano, and Pontes (2021) explored various techniques for improving soil fertility and found that combining moderate amounts of basalt powder with higher doses of cattle manure yielded the most effective results. Their findings suggest that the integration of rock dust with organic fertilizers enhances nutrient availability and soil health more efficiently than using rock dust alone.

Similarly, Da Silva et al. (2017) emphasized that the co-application of rock powders with organic materials that stimulate biological activity can influence the mineral weathering process. However, they also note a gap in knowledge regarding how such combinations affect the dissolution of minerals, particularly in basalt rock powders.

During composting, the nitrogen cycle is critical to compost quality, as noted by Hoang et al. (2022), who also discuss strategies to mitigate nitrogen loss. While some studies provide promising data, others lack rigorous scientific validation or real-world field applications.

For example, Ramos et al. (2022) report that combining organic fertilizers with rock powder can meet most macro- and micronutrient requirements, and reduce application costs by more than 60%, with long-lasting benefits for soil fertility. Conceição et al. (2022) observed that corn and beans grown in basalt-enriched soils produced yields up to five times higher than those in untreated soils.

Despite these benefits, it is widely acknowledged that rock dust releases nutrients more slowly than chemical fertilizers—a feature that, according to Theodoro and Leonardos (2006), provides the advantage of prolonged nutrient availability in the soil. Bauwhede et al. (2024)

support this view, stating that slow nutrient release from rock dust reduces leaching, although its effectiveness depends on rock mineralogy, soil pH, and testing methodologies.

Grecco et al. (2016) further highlight that the low processing cost and demand for alternative fertilizers encourage the use of ground rocks in agriculture. Nonetheless, they caution that the variability in weathering reactions across rock types makes it difficult to predict nutrient release rates, and that more research is needed in this field.

Dos Santos et al. (2016) explain that the nutrient release from rock dust occurs at a significantly slower rate compared to chemical fertilizers. While this gradual release can offer long-term benefits for soil fertility, it also presents challenges, such as requiring higher application rates and longer periods before noticeable agronomic responses are observed.

Lopes-Assad et al. (2006) reported that the fungus *Aspergillus niger* effectively solubilizes phosphate rocks by producing organic acids. Their study noted pH fluctuations during treatment: in acidic conditions, solubilization of potassium increased, whereas in treatments involving alkaline ultramafic rocks, a reduction in acidity was associated with a decrease in potassium release.

To address soil acidity effectively, liming with calcium and/or magnesium carbonates—such as calcite and dolomite—is considered the most efficient method. According to Goulding (2016), these minerals react with hydrogen ions in the soil solution and with aluminum compounds, thereby reducing aluminum toxicity and improving soil pH.

The suitability of rock dust as a fertilizer also varies depending on the crop type. For instance, crops like lettuce, which demand high concentrations of soluble nutrients over a short growth period, are unlikely to benefit from basalt application. Hanish et al. (2024) found that applying up to 100 grams of basalt powder per pot failed to improve lettuce yields, which remained nearly four times lower than those produced with conventional fertilizers. This result reinforces that basalt powder, due to its low nutrient concentration and slow release, is inadequate for short-cycle, high-demand crops.

Guimarães et al. (2020) observed that banana orchards fertilized exclusively with mineral fertilizers yielded more fruit than those treated with organic-mineral blends. However, the latter resulted in reduced

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soil acidification and greater availability of phosphorus and potassium. The study also noted that excessive potassium levels could lead to nutrient imbalances, negatively affecting plant productivity. Therefore, further research is necessary to develop optimized fertilization strategies for bananas that promote yield while maintaining soil health.

Finally, as emphasized by Viana, Caetano, and Pontes (2021), while rock dust holds considerable promise in Brazilian agriculture, particularly when combined with organic amendments like animal manure, its effectiveness is still under-researched. Caution should be exercised to avoid overestimating its benefits without sufficient empirical support.

Organicospro (2018) notes that limestone, a widely recognized ground rock, is composed primarily of calcium carbonate (in the form of calcite) or calcium magnesium carbonate (dolomite). In contrast, basalt powder is rich in silicate minerals, providing silicon—a vital nutrient for plant health and productivity. These contrasting compositions illustrate the distinct benefits each material offers. Basalt powder, in particular, plays a valuable role in restoring degraded or nutrient-depleted soils, enhancing microbial activity, and increasing overall agricultural output. Among the reported advantages of biomineralization using basalt are:

– Restoration of nutrient-deficient soils
– Progressive reduction of soil acidity
– Improvement in soil aeration and structure
– Lower dependence on chemical fertilizers
– Enhanced seed germination
– Better root and shoot development
– Strengthened plant stems and bark
– Formation of a protective leaf film against pests and environmental stress
– Improved post-harvest durability
– Increased nutrient density in crops

Batista (2016) investigated the effects of basalt powder applied in varying amounts, with and without limestone. Treatments with added limestone showed higher potassium content and elevated pH levels compared to those without. However, overall pH correction was less effective than in treatments using limestone alone.

Hammerschmitt et al. (2021) emphasized that soil re-acidification is a gradual process, and that superficial reapplication of limestone is generally adequate for correction. Their study showed that both surface application and incorporation of limestone produced similar soil chemical conditions. Soybean responded positively, though modestly, to reapplication (252 kg ha^{-1} $year^{-1}$ average yield increase), whereas corn exhibited minimal response.

Aluminosilicate minerals found in rock dusts (RDs) include orthosilicates (e.g., olivine), inosilicates (e.g., pyroxenes like diopside, and amphiboles like hornblende), tectosilicates (e.g., orthoclase, plagioclase, nepheline, and leucite), and phyllosilicates (e.g., biotite and muscovite micas) (Calabrese et al., 2022; Swoboda et al., 2022; van Straaten, 2006). While RDs can serve as an alternative to liming, they typically exhibit lower acid neutralizing capacity (ANC) and a slower release of alkalinity. Nonetheless, they provide essential nutrients such as calcium (Ca), magnesium (Mg), potassium (K), phosphorus (P), and sulfur (S) (de Vries et al., 2021; Ramos et al., 2022; Swoboda et al., 2022).

Supporting this, Swoboda, Döring, and Hamera (2020) observed that specific modifications to silicate rock powders (SRPs) can significantly improve their agronomic efficiency. Furthermore, enhanced weathering of SRPs may contribute to atmospheric CO_2 sequestration, while the silicon supplied through these amendments can bolster plant resilience to both biotic and abiotic stressors.

More research is needed to understand the use of silicate rock powders (SRPs) associated with limestone, or with a chemical fertilizer or with animal manure, and in particular the importance of the type of rock related to the type of soil and crop, in addition to the quantity, as is very clear in figure 1 below.

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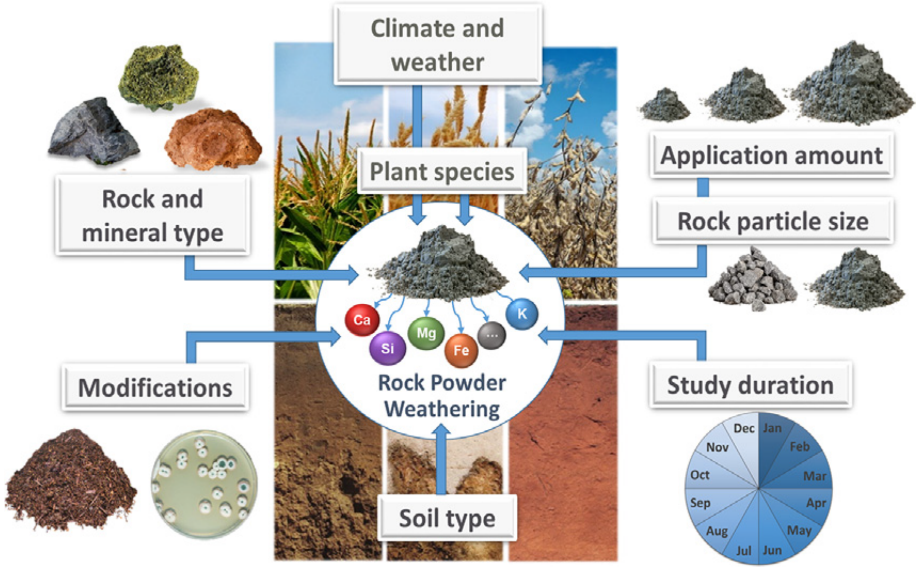

Figure 1- Factors influencing the use of silicate rock powders - SRPs (Swoboda Döringb & Hamera, 2022)

Bergmann and Holland (2014) emphasize that when evaluating a rock for use as a soil remineralizer, it is essential to analyze it using petrography—a technique that identifies minerals and assesses their texture, crystallization sequence, grain size, and degree of alteration. Additionally, any material applied to the soil must meet strict criteria, particularly regarding the presence of harmful or potentially harmful substances. These include toxic heavy metals, compounds that may lead to soil salinization, or inert minerals—such as sodium and quartz—that could negatively affect soil structure.

2. Best practices and lessons learned from bio-dynamic agriculture

An effective alternative to conventional industrial agriculture—which is increasingly criticized for its over-reliance on mechanization, synthetic chemicals, herbicides, and its disregard for ecological sustainability—is biodynamic agriculture. This approach builds upon organic principles and extends them through a holistic, ecological, and ethical framework that encompasses farming, gardening, nutrition, and broader human-nature relationships. It promotes a lifestyle rooted in a deep awareness of the landscape, personal development, and community engagement.

Biodynamic practices, as described by Paull (2011), emphasize striving for energy and input self-sufficiency (in fertilizers, seeds, and livestock), working in harmony with natural rhythms, cultivating biodiversity, and approaching farm work with diligence, precision, and mindful observation. Timeliness and attention to seasonal cycles are central to the system.

Soil fertility management is foundational in biodynamic farming. According to Campbell and Watson (2012) and Raupp (2001), improvements are achieved through effective humus management, including the use of well-fermented composts and manures, diverse crop rotations, protection against erosion (e.g., windbreaks), cover crops, green manures, and polycultures to promote interspecies support.

Boicean and Dent (2020) emphasize the importance of alternating soil-depleting crops like corn, potatoes, and cruciferous vegetables with soil-enriching legumes such as beans, peas, and clover. Crop rotations should also alternate deep- and shallow-rooted species and those requiring external nutrients with those that grow with minimal inputs.

In alignment with these principles, the FAO (2021) reported that sustainable agricultural practices, including those within the biodynamic paradigm, can mitigate environmental degradation, increase resilience to climate stressors, and progressively enhance soil and land quality.

Potential for Rock Dust Use in Roraima

An insightful study by Bergmann and Holland (2014), as part of Brazil's "Geodiversity of the State of Roraima" program, assessed the potential for soil remineralization using rock dust in the region. Their work delineated six geographic zones based on soil diversity, topography, climate, and land use limitations.

The most promising zone for rock dust application comprises areas dominated by mafic and ultramafic rocks (diabase, basalt, and gabbro), where soils like red argisols, red oxisols, vertisols, chernosols, and nitisols prevail.

In Roraima, most soils are naturally acidic and low in fertility, posing substantial barriers to conventional agriculture. Although more fertile eutrophic soils exist, they are less geographically widespread and often used with limited technological input, relying heavily on empirical practices in rural and settler communities.

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Additional constraints to agricultural productivity include poor infrastructure, an underdeveloped road network, lack of skilled labor, insufficient public investment, and a burdensome tax regime. Despite these challenges, the region benefits from an equatorial climate highly conducive to agriculture—often outperforming other regions in Brazil.

Promoting sustainable agricultural practices such as soil remineralization through rock dust represents a strategic opportunity to enhance productivity, foster environmental stewardship, support indigenous livelihoods, and drive inclusive economic development.

Biodynamic agriculture offers a compelling alternative to industrial farming, which is increasingly unsustainable due to its overuse of machinery, chemicals, herbicides, and neglect of environmental impacts. Going beyond organic farming, biodynamic agriculture takes a holistic and ethical approach to food production. It emphasizes the interconnectedness between people, land, and nature, focusing on ecological balance, personal awareness, and community involvement.

As outlined by Paull (2011), common biodynamic practices include achieving self-sufficiency in energy, fertilizers, and livestock; aligning work with natural rhythms; using diverse plant and animal systems; and maintaining precision, observation, and timeliness in farming tasks.

According to Campbell and Watson (2012) and Raupp (2001), healthy soil in biodynamic systems is maintained through composted organic materials, crop rotation, soil protection (e.g., windbreaks), and the use of mixed cropping instead of monocultures. Boicean and Dent (2020) also recommend alternating nutrient-depleting crops (e.g., corn, potatoes, cabbage) with enriching ones (e.g., legumes) and balancing shallow- and deep-rooted crops to sustain soil fertility.

The FAO (2021) confirms that sustainable farming practices like biodynamics can protect ecosystems, improve food resilience in the face of climate change, and improve soil health over time.

In Roraima, the potential for applying rock dust as a soil amendment was analyzed in a key study by Bergmann and Holland (2014), under the broader "Geodiversity of the State of Roraima" initiative. The study identified six distinct land zones, with the most suitable for rock dust use being areas with basic rocks like basalt, gabbro, and diabase. These regions feature red oxisols, argisols, and other weathered tropical soils.

Roraima's soils are mostly acidic and nutrient-poor, limiting agricultural productivity. Eutrophic soils with better fertility exist but are less widespread and often managed with low-tech methods in isolated rural zones. Compounding this are challenges like poor infrastructure, limited labor skills, and lack of government investment.

Nonetheless, Roraima's favorable equatorial climate gives it a competitive edge for crop performance compared to other parts of Brazil. Applying sustainable methods such as remineralization with rock dust could address many challenges—boosting yields, improving soil health, supporting indigenous agriculture, and promoting regional sustainability.

In Roraima, agriculture is mostly practiced in the *La Sabana* region. According to Júnior and Schaefer (2010), the dominant soils here include several types of *canosols* (yellow, red-yellow, and red), *argisols* (red and yellow-red), and *neosols* (hydromorphic, organic, fluvic, and litholic). These soils typically have low fertility, with high acidity, low base saturation, and weak nutrient retention. Exchangeable phosphorus is especially low, so regular pH correction is needed for successful farming.

The most fertile agricultural soils in the state are found in areas with basic rock formations:

- The Pedra Preta sill in the Uiramutã region,
- Apoteri volcanic rocks near Serra de Nova Olinda, and
- The Taiano area, known for its fertile basalt-derived soils.
- Top sites include:
- Vila do Taiano (northwest Roraima),
- Serra de Nova Olinda (central Roraima), and
- Near Flechal, an indigenous village in Uiramutã.

In these areas, soils formed from weathered basalt and other basic rocks—such as oxisols, chernosols, and organic soils—are rich in nutrients. In the Pedra Preta sill, rocks like diabase, diorite, and gabbro contribute to fertile soils such as nitisols, found in hilly forested areas.

A diabase rock sample from the Taiano region (Alto Alegre municipality), shown in Figure 1, gave a strong positive reaction in the phosphomolybdate test, confirming its potential as a phosphorus-rich soil amendment.

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Figure 3. Samples of diabase from Taiano (municipality of Alto Alegre) with strong positive phosphomolybdate test.

In addition to the municipality of Alto Alegre, in the municipality of Iracema, the presence of rare earth minerals, niobio, barium and phosphate are cited.

In Brazilian family farming, farmers often combine rock powders with organic waste, like animal manure and green fertilizers, to improve soil health. These inputs are usually made on the farm through composting, using microorganisms to help release nutrients. Nitrogen is typically supplied by planting green manure species, especially *Tithonia diversifolia* (Mexican sunflower), which can add up to 4.3% potassium through its leaves and stems (Palm et al., 1997 apud van Straaten, 2007). To get the best results, it's important to understand that rock powder interacts with the entire soil system, including soil microbes and the specific ways that plant roots absorb nutrients (Mundstock, 2013).

Studies show that rock dust can be used on most crops and applied in grain sizes between 0.105 mm and 4.0 mm—similar to how lime is applied—either by hand or with machinery. Recommended doses range from 0.5 to 8 tons per hectare depending on the soil and crop. In Brazil, basalts and diabases from the Serra Geral region are promising for use in agriculture. These rocks are rich in calcium, magnesium, and iron and are often already available in powder form from quarrying. Because their minerals break down more easily, they can release nutrients relatively quickly when ground to the right size.

Alkaline volcanic rocks, which have high potassium content and fine crystal structures, are also excellent for soil remineralization. So far, only one rock—phonolite from Poços de Caldas—has been officially approved in Brazil as a local replacement for imported potassium chloride (KCl) fertilizer (Cortes et al., 2009). Still, it's essential to test these rocks for micronutrient levels and any potentially harmful elements (Bergmann & Holland, 2014).

Brazil's Dependence on Imported Fertilizers

Rock powders provide a wider variety of nutrients than most chemical fertilizers. In addition to the main nutrients (P, K, Ca, S, Mg), they can supply important micronutrients like Zn, Cu, Fe, Mn, Mo, B, Co, and Ni—depending on the rock type. On the other hand, standard fertilizers usually offer just N, P, and K, and only some newer products include Ca, Mg, or micronutrients like B and Zn. However, these highly soluble fertilizers often lose nutrients quickly in Brazil's hot, rainy climate.

That's why rock dust and soil remineralization are gaining attention as sustainable ways to restore soil fertility. This is especially urgent in Brazil, which imports about 65% of the materials used to make fertilizers. By 2025, that number could climb to 83%—a serious concern for food security and farm sustainability (Bergmann & Holland, 2014; see Figure 2).

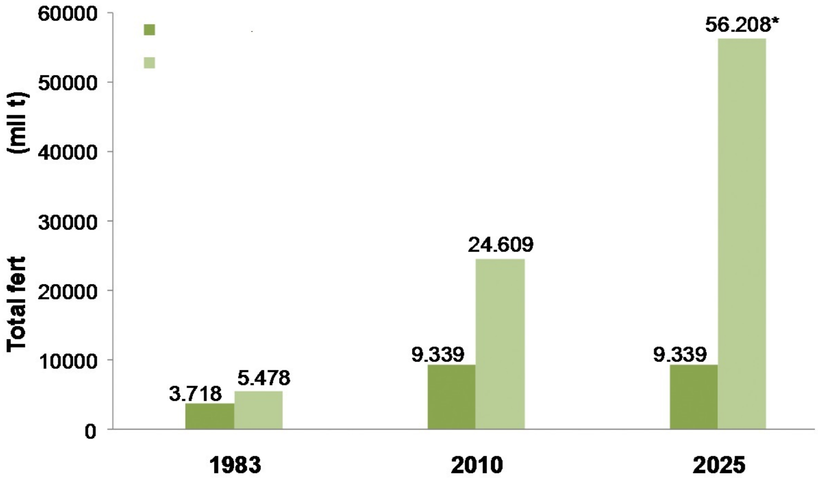

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Figure 4 - Production andmand graph of fertilizers in Brazil. Adapted from Martins (2013). Source: ANDA (2011). Mbagro Project.

Goulart et al. (2023) report that the Novos Campos region in Roraima contains magmatogenic phosphate deposits linked to the anorthosite-manager-chanockite-shanite (AMCG) rock association. There are also magmatic-hydrothermal phosphate minerals and rare earth elements tied to alkaline volcanic complexes. The gabroanorthosite units of the AMCG Mucajaí group have the highest phosphate potential in the area.

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Brazil's heavy reliance on imported fertilizers makes it vulnerable to international market changes like currency fluctuations, trade policies, and shipping delays. These factors can disrupt the steady supply of fertilizers essential for farming, which risks agricultural production and food security. Fertilizer imports require long-distance transport and solid infrastructure for storage and distribution, which drives up costs and ultimately increases prices for farmers. Taxes on fertilizer imports, such as ICMS, add to these costs and lead to higher food prices for consumers.

To address this, the Brazilian government launched the National Fertilizer Plan (PNF) in November 2022. This plan aims to reduce dependence on fertilizer imports and guide the fertilizer sector through 2050. Despite this, many farmers remain hesitant to adopt biodynamic or homemade fertilization methods. Small farmers often lack education on these practices, while medium and large farms continue relying on imported chemical fertilizers.

There is also a gap in laws and government support for easier farmer access to alternative fertilizers, like rock dust, and for developing infrastructure such as rock crushers. More support is needed for soil studies and sharing scientific research from agencies like Embrapa and the Geological Service of Brazil.

Brazil's Law No. 12,890 (2013) regulates the production and marketing of fertilizers, soil amendments, inoculants, biofertilizers, and remineralizers. Regulatory Instruction No. 39 (2018) sets detailed rules for mineral fertilizer registration, labeling, and advertising.

Recently, the Ministry of Agriculture (MAPA) standardized rules for producing and selling remineralizers (rock dust), which improve soil quality differently from regular fertilizers mainly due to lower solubility. With these new rules, farmers can now verify product quality through official registration. The regulations published in June 2023 (Instructions 5 and 6) require manufacturers to meet strict standards, ensuring consistent and safe products.

This regulation opens up new options for farmers, especially organic growers who avoid mineral fertilizers but accept rock dust. It addresses a long-standing demand and is recognized in the Official Gazette as a valuable alternative for soil fertility restoration.

3. The Culture – Knowledge- Intelligence model

According to Kroeber (1949), humans differ from animals primarily because of culture. Culture allows humans to surpass their biological limits by accumulating experiences over time, creating a shared legacy.

Culture, more than genetics, guides behavior and influences human actions.

Humans develop and age according to cultural norms, as many instincts have weakened through long evolutionary changes.

Culture is a cumulative process formed by the historical experiences of past generations, which can either limit or encourage an individual's creativity.

Based on these ideas, the Culture-Knowledge-Intelligence (CCI) model was created (see Figure 3). Its main points include:

(i) Culture consists of a society's beliefs, values, assumptions, and traditions (Schein, 2010).
(ii) For education to be effective, curricula should be restructured around four learning pillars: knowing, doing, living together, and being (Smith, 2018).
(iii) Intelligence depends on three pillars: prediction, strategy, and action (Rothberg & Erickson, 2004).

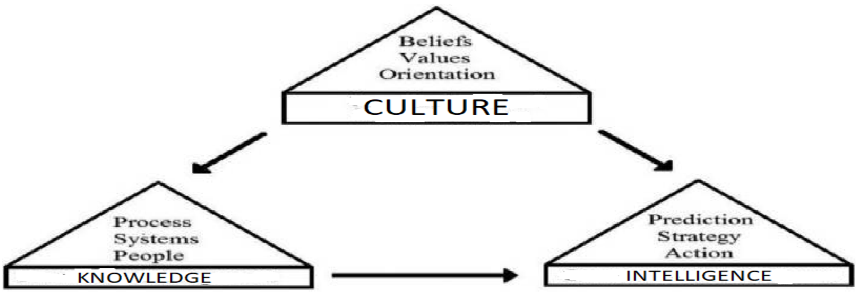

Figure 5. THE CULTURE-KNOWLEDGE-INTELLIGENCE MODEL (adapted from Choo, 1998)

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The CCI model is based on three hypotheses (Table I):

Table I. *Assumptions of the CCI model*

Hypotheses	Sources	Results
Cultural has a positive impact on Knowledge	Leidner et al. (2006), Deal and Kennedy (1982) and Tweed and Lehman (2002) suggest that the way in which individuals perceive, organize and process information and the way in which they communicate with others and the way in which understand, organize and generate knowledge and solve problems, is related to culture.	SUPPORTED
Cultural has a positive impact on intelligence	Culture, more than genetics, determines behavior and determines its actions (KROEBER, 1949). Umuteme et al.(2023) posit that factors such as values, norms, beliefs and practices embedded in organizational culture significantly shape the overall project environment and affect team dynamics.	SUPPORTED
Knowledge has a positive impact on intelligence	Rothberg and Erickson (2004) maintain that knowledge is static and, ultimately, only has value if people use it (intelligence)	SUPPORTED

4. Bio-dynamic AGRICULTURE MODEL

Thanks to their ability to create and share collective knowledge, cooperatives have made significant contributions to local and national development. Silva et al. (2006) found that 60 agricultural cooperatives increased their profits by 130%.

Cooperatives exist in many sectors, such as agriculture, health, credit, transport, and education. Of these, agriculture is the most developed and widely recognized sector both nationally and internationally.

Rural cooperatives play a key role in building social capital by uniting cooperative members and the surrounding community in common efforts.

Figure 4 presents the Bio-dynamic family farming model.

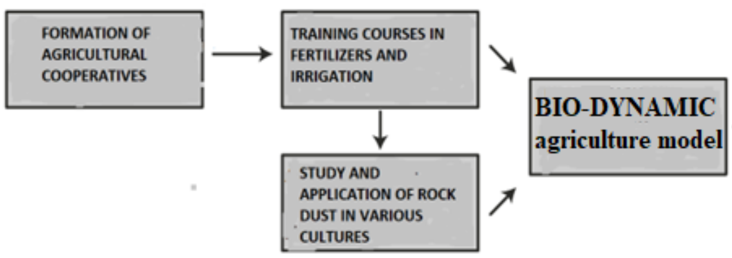

Figure 4: Bio-dynamic family farming model. Fuente: Author, 2024

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The Bio-dynamic agriculture model shows that agricultural cooperatives are central to this farming system. For farmers to unite and solve their problems, there must be a culture that welcomes training, especially on fertilizers, as discussed earlier. Training focused on rock dust application is a key foundation for developing and sustaining Bio-dynamic agriculture.

Additionally, this model demonstrates that cultural changes among small family farmers positively affect knowledge management within cooperatives and help develop and implement the Farmers' Technical and Financial Assistance Plan, representing the intelligence component.

Conclusions

Bio-dynamic agriculture depends on a mature culture that encourages farmers to create farm-based solutions using natural resources. This article reviewed literature on rock dust and biological nitrogen fixation and proposed two connected models: the Culture-Knowledge-Intelligence model and the Bio-dynamic Agriculture model based on cooperative knowledge sharing.

The study found that more research is needed to address challenges related to dissolving silicate rock powders in crops, including the material's quality and quantity, and the possibility of mixing it with limestone, manure, or chemical fertilizers.

This work happens in a cooperative, collaborative setting between farmers and researchers, highlighting how important it is to understand culture's role in managing knowledge and intelligence to build a strong culture that applies useful knowledge.

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