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A Comparative study between Brazil and Jordan on the feasibility of using rock dust as a homemade Fertilizer

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Abstract

Purpose: The partnership between Brazil's Ministry of Agriculture and Livestock (MAPA) and Germany's Ministry of Agriculture, Food and Regional Identity (BMLEH), through the Brazil-Germany Agricultural Policy Dialogue (APD), and also new provisions of the Trade and Sustainable Development Chapter (TSD) of the Mercosur-EU Trade Agreement of 2024 helped a lot the top leader in agribusiness commodity exports in the world: Brazil. However, some "natural" disasters occur.

The soil of Brumadinho, after the accident (large mud tsunami), shows many similarities to Jordanian soil, particularly due to the presence of sand, inherited from the clayey sandstone, and iron oxides, as well as quartz and calcite crystals. Researchers have already examined the possibility of improving the mechanical characteristics of the sandy soil using environmentally friendly materials, such as cement kiln dust (CKD).

Design: This research seeks to answer the following question: To what extent do bio-dynamic practices, such as the use of rock dust, help in the sandy soil of Brumadinho (X-Ray diffraction analyzes) and Ma'an (interviews) ?

Findings: In the book "Soil Remineralizers and Silicate Fertilizers" by the Brazilians researchers Eder Martins and Suzi Theodoro shows important disadvantages of rock dust such as slow release, logistical limitations, questions about carbon sequestration potential, and the need for studies to recommend management practices. In fact, the variability in weathering reactions between different rock types makes it difficult to anticipate nutrient release rates.

This study, in addition to showing the pros and cons of using rock dust, conducts an in-depth analysis of the soils of Brumadinho and Ma'an, concluding that they are very similar, but that there are difficulties related to cultural issues and raising awareness among farmers regarding bio-dynamic practices (homemade fertilizers), such as rock dust.

Originality: There is no farmer's data collection about the potential use of rock dust as a home-made fertilizer. In this study 20 farmers from Ma'an, Jordan, was interviewed.

Keywords: Bio-dynamic agriculture; National Culture; Network Governance; Rock dust; Sandy soil

Introduction

The results, from the farmer's point of view, demand further analyses of the application of rock dust due to the famous trade-offs - improved soil fertility, carbon capture, improved water holding & drainage, raising pH, improved nutrient retention (increased cation exchange capacity - and some rocks containing potentially toxic elements in harmful concentrations. Therefore, the agronomic results of the application of rock powder, especially in tropical soils, depend very much on the mineralogical composition and specific chemistry of rock, the deficiencies of the rock alone and the nutritional needs of the cultures.

This research presents a new methodology for soil remineralization, using rock dust, which is an economic miracle in Brazil, South America, and has yielded excellent results due to the formation of agricultural cooperatives (based on Network Governance) that allow for the exchange of knowledge and other resources, particularly financial ones, among farmers. The interviews were conducted in Jordan, where there are no cooperatives, to understand if farmers in that nation would accept using rock dust instead of chemical fertilizers. Given the difficulty of any change in farmers' habits, this work presents the culture-knowledge-intelligence model to understand how the beliefs, assumptions, traditions, and values of a given society impact the processes of knowledge creation, sharing, and application. Based on this understanding, it might be possible to lessen, albeit on a small scale, the strong impact of governmental intelligence on the formation of national culture.

Despite the slow release of nutrients from wastewater, which reduces leaching, most of the biological, physical and chemical parameters remain unchanged after one month and even one year of application. This work, in addition to presenting a management model of knowledge for bio-dynamic agriculture, aims to carry out a review of the literature on the advantages and disadvantages of using rock dust as a corrective/remineralizer alone.

In addition to the difficulties in identifying crops and carrying out laboratory analyzes of them on their own, farmers face difficulties in forming cooperatives that would allow them to share knowledge and resources and exchange knowledge on bio-dynamic agriculture (home-made).

In Minas Gerais, Brazil, the breakage of a barrage resulted in the death of 600 people and completely altered the mineralogy.

Based on 20 interviews with farmers in Ma'an, Jordan, this article presents the Culture-Knowledge-Intelligence model CKI to open space for biodynamic agriculture practices and proposes a Network Governance model to facilitate exchange of knowledge and experiences among farmers in Jordan.

The main limiting factors for nutrients in many tropical and subtropical environments are nitrogen (N) and phosphorus (P), and in some highly degraded soils, potassium (K) and other nutrients are also limited. While N can be obtained from the air through biological nitrogen fixation (BNF) and organic sources, P, K, and all other plant nutrients must be obtained from rocks and minerals (52).

The aluminosilicate minerals present in rock powders (RPs) include orthosilicates (e.g., olivine), inosilicates (e.g., pyroxenes such as diopside and amphiboles such as hornblende), tectosilicates (e.g., orthoclase, plagioclase, nepheline, and leucite), and phyllosilicates (e.g., biotite and muscovite micas) (13; 54; 52).

Particularly in Brazil, rare earth elements (REEs) have gained relevance as a technological alternative to increase productivity and reduce dependence on highly soluble chemical fertilizers, which are controlled by only a few countries.

In Brazil, the growth in the production and commercialization of rare earth elements (REEs) has been exponential, doubling annually. In the last five years, more than 7 million metric tons have been sold, representing approximately 10% of the country's agricultural land. Brazil has established itself as a leader in research on the use of silicate rocks, with significant findings in studies by Theodoro (2000), 55), Martins et al. (2014), and Ramos et al. (43, 42), among others.

Dupla et al. (19) argue that the application of ground silicate rocks, such as basalt, to agricultural soils, in addition to carbon sequestration, has the potential to raise soil pH and release nutrients, thereby improving soil fertility. Residual granite dust was evaluated in Galicia (northwest Spain), where more than 90% of the national granite production is concentrated, on a highly acidic (pH 4.6) nutrient-deficient sandy loam soil, using ryegrass as a test crop (51). The rock residue contained additional amounts of Ca incorporated during pre-processing. Very high applications (25–100 t ha−1) increased yield, soil pH, cation exchange capacity (CEC), and available Ca, Na, Mg, and K, reduced exchangeable Al, and did not release critical amounts of potentially toxic elements.

Grecco et al. (22) also highlight that the low processing cost and the demand for alternative fertilizers incentivize the use of ground rock in agriculture. However, they caution that the variability in weathering reactions among different rock types makes it difficult to predict nutrient release rates, so further research in this area is needed.

In this sense, this work analyzes rocks collected in Jordan through a research action approach with 20 farmers localized in Ma'an.

Since the purpose of the rock is to remineralize the soil, samples of soils were collected in Brumadinho, Brazil, where there was a dam accident.

Even though the rocks and soils are collected in different countries, also due to the problem of finding labs in Jordan, it is possible to interpret the results (theoretical and practical) because the goal is to see the practical results of the application of rock dust in Jordan (tomato) and check if this experience can be also replicated in the damaged soil of Brumadinho.

However, this study identifies that culture (values, beliefs, assumptions and traditions) has a very important impact on the process of creation, sharing and in particular application of Knowledge (intelligence) and without an appropriate culture it will not be possible to carry on any Bio-dynamic study (home-made fertilizers).

In order to understand these processes of creation, sharing and application of knowledge between farmers, 20 interviews were conducted with Jordanian farmers.

Following this introduction, the article is divided into the following chapters:

1. Literature review on rock dust as a soil remineralizer. 2. Analyses of Brumadinho's soil after the dam accident in Brazil 3. Methodology 4. Interviews of Jordanian farmers. 5. Results and Discussion 6. The Culture-Knowledge-Intelligence model (CKI). 7. Bio-dynamic agriculture model based on Network Governance. 8. Conclusions and suggestions for future research.

Literature Review on Rock Dust as a Soil Remineralizer

Luchese et al. (2021) 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 limestone. However, the overall pH correction was less effective than in treatments with limestone alone.

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

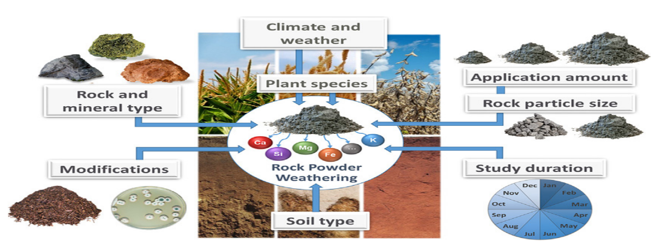

Figure 1: Factors influencing the use of silicate rock powders (SRP) (54).

In recent years rock dusts (SRPs) have sparked renewed interest in various fields. In the Anglo-Dutch literature, research has focused on the concept of "enhanced weathering," which aims to sequester CO2 through the weathering of silicate rock dust (47; 57). In tropical contexts, beneficial results are accumulating, especially in Brazil, which is currently the epicenter of research and where the "Rock Dusting" movement has led to the institutionalization of rock dust use in agriculture (Manning and Theodoro, 2020). Organic agriculture has long used rock dust, and its expansion is increasing the demand for suitable soil amendments that meet the criteria of organic producers (2).

Overall, the results of Kelland et al. (20) are particularly relevant for several reasons: (a) they used basalt, one of the main rocks used in rock powder trials and abundant worldwide; (b) the particle size was relatively coarse (80% < 1.25 mm), similar to that of unprocessed, screened quarry residues (12; 51); (c) despite high application rates, critical quantities of heavy metals were not released; and (d) the experiments were conducted under temperate climatic conditions, so greater efficiency can be expected under tropical conditions.

Silicate rock powders can reduce agricultural emissions of nitrous oxide (N_2O) and ammonia (NH_3), which significantly compromise the sustainability of agricultural systems (16).

Like liming materials such as $CaCO_3$, silicate rock powders can reduce N_2O emissions from soils by correcting their acidity. While it was expected that increased soil pH would enhance microbial N mineralization and thus nitrification, liming has been repeatedly shown to decrease N_2O emissions (Borken and Brumme, 1997; Hénault et al., 2019; Samad et al., 2016). The N_2O reduction potential and preferential pH thresholds are not yet well understood, but they may be related to increased microbial production of enzymes that reduce N_2O to N_2 at neutral pH. Although basalts (approximately 20% CaO + MgO) have a lower pH buffering capacity than limestone (40% CaO by weight), preliminary data from basalt applications suggest reductions in N_2O emissions (11).

These tropical crops are typically grown in highly weathered and desilized soils, with Si concentrations generally 5 to 10 times lower than in temperate soils. The emerging role of Si in resistance to biotic and abiotic stress, and the Si deficiency in many tropical soils, should increase future demand for Si-containing nutrients (4). (2) Importantly, many tropical soils exhibit similar deficiencies in Si, a non-essential nutrient that is often overlooked and whose demand is projected to increase in the future, as 7 of the 10 most produced crops globally accumulate Si and there is ample evidence that Si can induce resistance to biotic and abiotic stress in plants. (3) Suggested rocks are those containing rapidly weathering minerals, such as feldspathoids or glauconites, and multi-nutrient mafic/ultramafic rocks, such as basalts. (4) Results in temperate soils remain inconclusive, and benefits will depend on careful selection of sufficiently soluble rocks with a nutrient content that meets crop requirements. (5) Applications should focus on obtaining fine-grained mining residues from quarries near the application site. For future research, we suggest considering the following points: (i) prior consideration of the presented SRP structure to avoid inappropriate factor selection, as, for example, multi-nutrient mafic rocks applied to tropical soils may be ineffective if the particle size is too coarse; (ii) methodologically consistent and statistically rigorous trials with a minimum set of information on the factors, including: physicochemical properties of the topsoil, such as texture, mineralogy, and pH; mineralogy of the rock dust; particle size; and application rates in t ha^{-1}; (iii) Conduct long-term trials to assess the cumulative effects and potential side benefits over several years, and potentially decades, focusing on combining multi-nutrient rocks, such as basalts, with Si-accumulating base crops that are capable of further enhancing weathering. (iv) Modifying SRPs to increase nutrient release shows considerable potential and should be promoted on several fronts, such as combining them with organic materials or hydrothermal acidification and alteration leading to K fertilizers with an efficiency at least equal to that of KCl.

However, according to some researchers, most biological, physical, and chemical parameters remained unchanged after a month and even a year of rock dust application. A multi-site field trial highlighted, however, an increase in soil respiration and sodium concentration, which, despite being encouraging indicators of short-term weathering kinetics, should be investigated further before ERWs can be implemented as an efficient and safe technology for carbon dioxide removal (19).

Methodology

Semi-structured interviews with 20 key farmers established in Ma'an, Jordan, were qualitatively analyzed to identify best practices and successful agricultural cooperatives strategies. A qualitative methodology was selected because it allows for exploration of developmental processes and provides insight into the complex and context-dependent nature of farmer's operations.

Systematic text condensation was used to analyze interview data and generate detailed descriptions of cooperatives (Network Governance) configurations and defining characteristics. This analytical approach supported understanding of the factors influencing the formation, sustainability, and effectiveness of the bio-dynamic agriculture. Data collection occurred in June 2026.

Before implementation, the interview guide was pilot-tested with a farmer called Ammar Ahmad located at Ma'an.

Interviewers used the guide as a flexible framework to ensure coverage of key topics while permitting respondents to expand on relevant experiences and share illustrative examples. Direct quotations were documented whenever feasible, and comprehensive interview notes were subsequently revised for clarity.

The analysis involved an iterative cycle of coding, interpretation, discussion, and revision to refine emerging themes and strengthen the validity of the findings. To enhance trustworthiness, summarized results were returned to interviewees for verification before submission for publication.

The content analysis was conducted according to the model by Bardin (8), synthesized by Bochaver et al. (6) and Valle and Ferreira (56) : a) Document selection: The diaries of four teachers, written during the three phases of the training program, were selected based on the described characteristics. b) Formulation of objectives: The objectives of the content analysis are as follows: - To analyze how farmers' self-perception improves throughout the explanation of Bio-dynamic practices. - Identify the topics of interest that constitute their "practical knowledge." - Discover the sources of concern or satisfaction among farmers. - Finally, compare the data obtained with observations of farmer's behavior to evaluate the effectiveness of the proposed training program about rock dust. c) Identification of indices and indicators: The indices (codes) represent the key ideas, topics of interest, and themes that shape the thinking of farmers, which are reflected in the content of their “Practical Knowledge”. The indicators used were the frequency of key ideas and the frequency of satisfactions or concerns. Positive (satisfactions) or negative (concerns) evaluations that the participant developed in each phase were recorded.

Data Collection

Jordan is divided into 12 governorates shown in Figure 2. The most important cities are: Amman (the capital), Irbid, Zarqa, Mafraq, Ajlon, Jarsh, Madaba, Salt, Karak, Tafila, Ma`an, Aqaba.

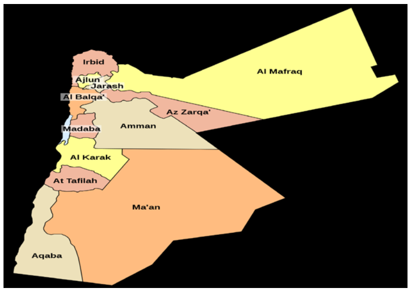

Figure 2: The 12 governorates of Jordan[1].

The interviews were conducted with 20 farmers from Ma'an.

Ma'an was the capital of the Arab state declared by Emir Abdullah for a short period of time in 1920 before moving the capital to Amman. Currently, the head of state and chief executive is King Abdullah II, who ascended the throne in 1999.

The blue part of the map (Al Mafraq, Az Zarqa, Amman and Ma'an), shown in the figure 3, is classified as desert soil.

[1]https://www.jaf.mil.jo/ContentstemplateC/_Geography_and_history.aspx

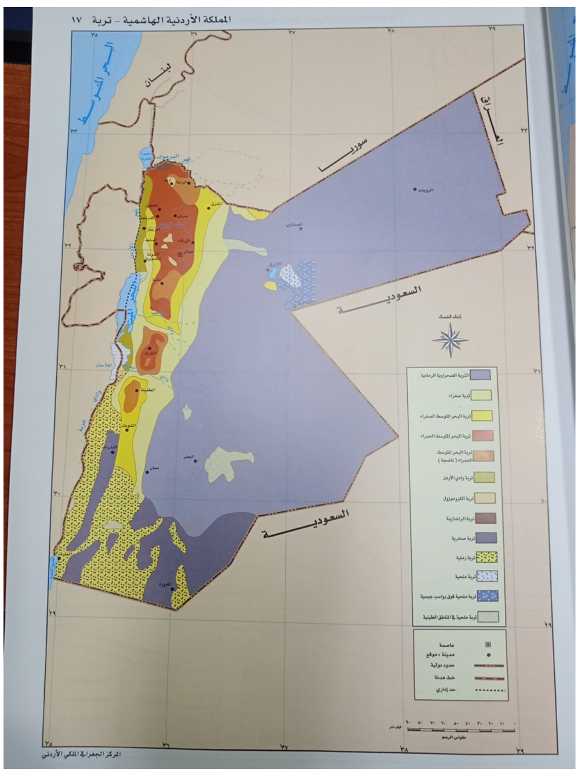

Figure 3: The soils of Jordan separated by regions (1).

Desert soil is defined as a type of soil formed in extreme environments characterized by low moisture and high heat, which limits biological activity and organic carbon accumulation. These soils often exhibit unique features and are vulnerable to erosion due to the lack of protective vegetative cover (18).

Analyses of Brumadinho's soil after DAM's accident: similarities with Jordan's soil

Due to the collapse of Dam I of the Córrego do Feijão complex in Brumadinho, Minas Gerais, Brazil, in 2019, a mudslide formed by mining waste composed of iron oxides, silt, and mainly sand was spread throughout the Paraopeba River basin. The affected area was approximately 280 hectares (41).

Simpler soil analyses of Brumadinho include: organic matter, nitrogen, phosphorus, potassium, calcium, magnesium, sodium, aluminum (in acidic soils), iron, copper, zinc, boron, manganese, sulfur, canonical ratios (Ca/Mg, Ca/K, Mg/K and (Ca+Mg)/Ky), and base saturation percentages. More complete analyses on soil samples integrate XRD and XRF. Some laboratories do not offer XRF, but perform laser particle size analysis, combined XRD whole rock and clay fraction, as well as elemental analysis with ED-XRF. However, bmore complete analyses are beyond the scope of this article, since the objective is to understand how to recover the soils of Brumadinho, Brazil, which lost part of their nutrients after a large mud tsunami caused by the rupture of a large dam.

Therefore, intermediate analyses were performed between those mentioned above: Simple X-ray Diffractometer (XRD) to identify the minerals present in the sample through the Diffractogram, accompanied by TFSA to identify the mineral peaks in the samples and their spacing, before and after treatment (dithionite-citrate-bicarbonate - DCB, a reducing solution that destroys iron oxides).

The three soil samples were collected on October 25, 2019, in the regions of Parque da Cachoeira and Fundão. Due to the mud tsunami (dam rupture in Brumadinho), the sandy soil became more ferrous, with the presence of iron oxides, particularly Hematite (Hm) and Ilmenite (Im), and to a lesser extent Goethite (Gt). The samples were prepared in powder form (random mounting) and all the XRDs were corrected for the position of the quartz peak. All diffractograms were interpreted using the COD-Inorg VER 211633 database. Quartz is identified in the sample with the highest intensity peak, quite crystalline, as inferred from the Width at Half Height – WHT.

Gibbsite (Gb) was identified in . Amorphous phases are probably present with an approximate spacing of 0.48 nm, making the identification of Gb in the untreated XRD difficult. Diffractogram of the initial sample and the "mud" sample.

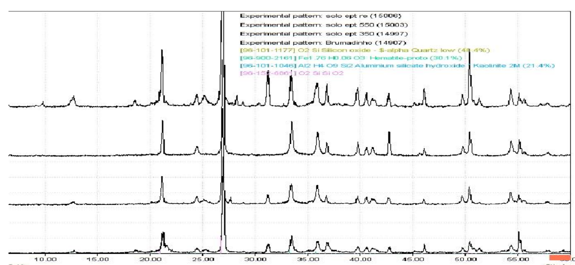

Figure 4: XRD Analysis (research group, Recuperation of Brumadinho's soil, 5).

The soil in Brumadinho, after the accident, has many similarities to Jordanian soil, particularly due to the presence of sand. In fact, Torriorthents are the dominant soils in Jordan followed by calciorthids, while small areas of torrifluvents are found in recent channels and torripsamments on dunes and sand mantles (3).

Mohammed, Athraa and Athraa (38) examined the possibility of enhancing the mechanical characteristics of sandy soil by using environmentally friendly materials, such as cement kiln dust (CKD) and natural palm fibers. Different percentages of palm fibers of 0%, 0.5%, 1% and 1.5% (dry wt.) with a 12-mm length and an aspect ratio of 31.57 were utilized to reinforce plain soil and soil treated with 5% (dry wt.) of CKD.

There are other factors that can prove the similarities between Brazil and Jordan's soils (Brumadinho and Ma'an).

The geology of Jordan (9) includes Basaltic rocks, sandstone, limestone, chalks, marls and cherts and various Pleistocene and Holocene deposits, both of alluvial and eolian origin. In Jordan, they are mostly stony or sandy and are associated with the Aridisols. They have low or very low water-holding capacity and high infiltration rates and posses single-grain texture, mainly formed by quartz with or without coating. This coating is mainly iron oxides that give the red colour to the material inherited from the argillaceous sandstone near these soils. Especially, in sandy soils in southern parts of Jordan, tillage increases the danger of wind and water erosion, both of which cause structure deterioration by stratification (3).

Al-Hawari and Yaseen (26) explains that there are abundant sand to silt sized quartz and calcite crystals in all samples studied. It is wellknown that basalt does not have quartz as a rock forming mineral. Consequently, quartz and calcite must have been brought to this area, most probably by wind or water annual flooding (28).

The Table 1 shows a comparative study of the mineralogy of soils in Brazil and Jordan

Comparative of the mineralogy of the soils	Brazil (Brumadinho)	Jordan (Ma'an)
Sandy Soils	After the “natural disaster”, a mudslide formed by mining waste composed of iron oxides, silt, and mainly sand was spread throughout the Paraopeba River basin, (41) Presence of iron oxides, particularly Hematite (Hm) and Ilmenite (Im), and to a lesser extent Goethite (Gt) (5)	Mostly stony or sandy and are associated with the Aridisols. Torriorthents are the dominant soils followed by calciorthids, while small areas of torrifluvents are found in recent channels and torripsamments on dunes and sand mantles (3).
Mineralogy of the soil	Quartz is identified in the sample with the highest intensity peak, quite crystalline, as inferred from the Width at Half Height – WHT. Great amount of Kaolinite (Kt), which is at level 7 (and the primary peak of phyllosilicates) (5)	Basaltic rocks, sandstone, limestone, chalks, marls and cherts and various Pleistocene and Holocene deposits, both of alluvial and eolian origin, mainly formed by quartz with or without coating (3) Abundant sand to silt sized quartz and calcite crystals in all samples studied (Al-Hawari and Yaseen, 2012)

Table 1: Mineralogy of soils in Brazil and Jordan (own elaboration)

Despite the possibility of using rock dust as a potential substitute for chemical fertilizers used in Brazil and Jordan, it is a real challenge to convince farmers to accept this experiment.

Therefore the focus of this study is to identify the culture (values, belives, assumptions and traditions) of the farms through a questionnaire to understand if they are familiar with Bio-dynamic techniques and if they want use it, in particular rock dust. Besides that, we identify the current agriculture model in Jordan and the perspectives for the future, considering the scarcity of water and therefore artificial irrigation.

Results and Discussion

Dimension 1 – Awareness

Question 1 – Almost all the farmers in Jordan (18 out 20) do not know bio-dynamic approach for agriculture since they prefer to use Chemical fertilizers. They do not receive training from the government and they are not familiar with agriculture-knowledge innovation.

Question 2- All of the farmers are not familiar with rock dust and they want to know the advantages and disadvanges.

Question 3 - They (all of them) are interested in testing the rock dust to check the potential to remineralize their soils

Dimension 2 - Capacity for applying rock dust.

Question 1- Yes, but they highlighted that they do not have money to invest in this new way of fertilization and they asked about the results. To be convinced they need to learn and practice this new technique and save the money that they usually paid for the chemical fertilizers.

Question 2 – They have the hammer but they consider the necessity to have a great amount for rocks to use in at least 22 m of the tomato plantation (one of the farmers said).

Question 3- Very few farmers (2 out 20) integrate livestock with agriculture therefore they can not mix rock with bovine manure. Only one farmer said that he is using Chicken manure as a fertilizer (little and around the crop not in the crop itself). The other ones prefer to buy a nitrogen, phosphorus, or potassium package (NPK).

Dimension 3 - Techniques Used and Sales

1. In terms of fertilizer 70% of the participants use the German package (NPK) as you see above.

However, 30% of the farmers interviewed (small community in Ma'an) are closer to the bio-dynamic agriculture since they use natural fertilizers (organic agriculture). They use ammonia with iron and 20/20 from the agriculture shop (NPK).

2. The community of farmers in Ma'an (20 farmers) has 15 employees for each farm, in average.

3.How many bags of tomatoes do you harvest and what is the selling price?

The small farmers in Ma'an can collect 15 bags of tomatoes per week and sell 1kg for 0,15 JOD and the people in the market buy it for 0,75 JOD.

In the case of the big farmers they can take 120 bags of tomatoes per week the price is the same.

These results make it clear that farmers need to form agricultural cooperatives (based on Network Governance) to organize training courses and share human and material resources. Furthermore, it is crucial to understand the extensive process of soil erosion in Jordan and the importance of remineralizing this soil by utilizing the farm's own resources, especially considering the poverty experienced by the vast majority of farmers, the lack of rainfall, and the degradation of the soil's natural composition (acidification or alkalization, for example).

Through a social survey, a sample of 146 Rajeb area farmers, in Ajloun Governorate in Jordan (Kafranga), Al-Taha’at and Al-Slaibi (2025) found a moderate level of sustainable agriculture practices was exhibited by around 39.7% of farmers, and the main impact's factor is education, what proves the necessity of practical training and real financial incentives.

The Culture-Knowledge-Intelligence model (CKI)

Most people have an intuitive sense that knowledge is broader, deeper, and richer than data or information.

Knowledge is a fluid mix of framed experience, values, contextual information, and expert insight that provides a framework for evaluating and incorporating new experiences and information. It originates and is applied in the minds of knowers. What this definition makes immediately clear is that knowledge is not clear or simple. It is a mixture of several elements; it is fluid and formally structured; it is intuitive and, therefore, difficult to capture in words or fully understand in logical terms (17).

The transformation of knowledge into intelligence is an operation performed by the human capacity to interpret, analyze, integrate, predict, and act.

Information is analyzed in the context of the patterns, criteria, and personal expectations of the decision-maker to acquire knowledge. Finally, the decision-maker applies knowledge of a specific situation to create intelligence.

Rothberg and Erickson (46) state that knowledge is socially constructed through collaborative activities, but access to this knowledge is not successful in decision-making, as knowledge without application is harmless. In short, knowledge is the foundation of intelligence, and intelligence is knowledge in action to solve problems.

Rothberg and Erickson (46) argue that knowledge is static and ultimately only has value if people use it.

Choo (2002) defines Intelligence as a continuous cycle of activities that includes sensing the environment, developing knowledge, and creating meaning through interpretation, using the memory of past experiences to act on the interpretations developed.

Based on the previous theoretical foundations, the Culture-Knowledge-Intelligence (CKI) model is constructed, which is shown in Figure 4.

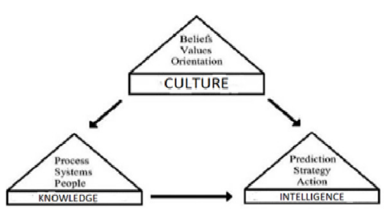

Figure 4: The Culture-Knowledge-Intelligence Model (adapted from Choo, 1998).

The premises of the CKI model are:

(i) Culture is formed by the beliefs, values, assumptions, and traditions of a society (50)

(ii) The central argument is that, for education to succeed in its tasks, the curriculum as

its core must be restructured or reformulated around the four pillars of learning:

learning to know, learning to do, learning to live together, and learning to be (Nan-Zhao, 2000)

(iii) The three pillars of intelligence are: forecasting, strategy, and action (46)

Figure 1: The culture-knowledge-intelligence model (adapted from Choo, 1998).

The CCI model is based on three assumptions (Table 2):

Hypotheses	Sources	Results
Culture has a positive impact on knowledge	The 9ug6nyxfdsuccessful implementation of a knowledge management system hinges on a thorough analysis of the existing organizational culture (de Ré et al., 2017).	supported
Culture has a positive impact on intelligence	Culture shapes organizational and social behaviors, influencing how individuals think, make decisions, and respond in various situations (50).	supported
Knowledge has a positive impact on intelligence	Effective knowledge management is crucial for enhancing organizational performance, improving problem-solving capabilities, and supporting informed decision-making (31).	supported

Table 2: Premises of the CKI model.

The CKI model showed the relationship between culture, knowledge, and intelligence. In the case of Cooperatives (Network Governance), it became very clear that the cultural aspect becomes the most important to guarantee the processes of creation and application of knowledge. Many people end up not sharing what they know due to this cultural barrier. Therefore, a process of raising awareness about the importance of Organizational Knowledge Management is of utmost importance for the development of trust, engagement, responsibility, and especially honesty.

Consistent with the previous literature, the results of this study suggest that the development of an organizational culture (macro-level national culture) supports the application of knowledge management – KM practices (Davenport and Prusak, 2000; Nonaka and Takeuchi, 1995; 21; Janz and Prasarnphanic, 2003; Lee and Choi, 2003; Donate and Guadamillas, 2010).

Some authors point out that organizational culture is not only a critical success factor for Network Governance, but also the most difficult and important factor to address, especially if an adequate culture does not yet exist (Davenport and Prusak, 1998).

However, changing a culture in an organization or community is a formidable challenge.

The process of cultural change encompasses the following requirements:

1. People must be willing to cooperate (there must be appropriate incentives and rewards);
2. Basic understanding of how KM can improve communication between farmers, academia, the private sector, and government.

Bio-dynamic agriculture model based on Network Governance

Network Governance is defined as "entities that merge the collaborative provision of public goods and services with the development of collective policies" (Isett et al. 2011). Research on network governance, many scholars argue, originated in academic interests in corporatism, state theory, policy networks, co-implementation, and co-provision of services, where a variety of interest groups or stakeholders in the political and public policy system (network) mitigate conflicts among themselves and instead create broad policy consensus, contributing to the co-provision of public services (Molina and Rhodes 2002; Ottaway 2001).

Cooperatives (Network Governance) have become a clear alternative for socioeconomic development, but critics argue that there is no methodological coherence to support this claim. However, the enormous potential of cooperatives to facilitate the creation, development, and accumulation of social capital is undeniable, through strategic actions that intensify mutual trust among members and, consequently, the exchange of goods, knowledge, and experiences in this collaborative environment.

Interaction, trust, the definition of common objectives, and the structuring of the social network are fundamental aspects for understanding the cooperative process.

According to Silva and Salanek (2006), social capital affects service provision, development, improves the management of shared resources, contributes to improved education, and reduces social conflicts.

However, according to Lucungu et al. (2022), traditionally marginalized groups, such as youth, women, and Indigenous peoples, still lack equitable representation in the decision-making bodies of cooperatives and local communities. In fact, the main income-generating activities, such as logging, are controlled by men and people from rural areas. Regulatory reforms are needed to ensure the equitable distribution of benefits and the participation of all stakeholders in decision-making, while reducing conflicts and strengthening the sense of belonging.

Silva, Salanek, and Filho (2006) identified that 60 agricultural cooperatives showed a significant increase of 130% (already discussed in the other text).

Thanks to their capacity to create and apply collective knowledge, cooperatives have achieved remarkable results in the local and national development process.

Cooperative institutions are found in various sectors of the economy, such as agriculture, health, credit, transportation, education, etc. Of these sectors, agriculture has the best structure and is considered of great national and international importance.

Interaction, trust, the definition of common goals, and the structuring of the social network are essential aspects for understanding the cooperative process and the relative importance of social capital for the development of the area where it takes place. The idea of creating cooperatives in rural areas has enormous potential for generating social capital, as it promotes actions aimed at integrating not only the group of cooperative members but also the local community.

Cooperatives provide services to their members, such as technology transfer, specific technical assistance, lending of inputs and machinery among members, acquisition of inputs, production of seeds and fertilizers, processing of other products (storage and drying), transportation, and marketing.

The creation of cooperatives depends on farmers' training in this area, and given that the culture is based on families with a high level of distrust, a cultural shift is necessary.

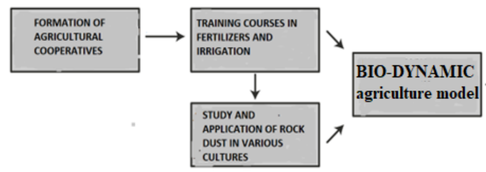

Figure 5 shows the Bio-dynamic family farming model.

Figure 5: Bio-dynamic Family Farming Model. Source: Author, 2026.

Halal (24) argues that intelligence is an organization's capacity to generate knowledge, and the CCI model shows that the cultural shift of small family farmers has a positive impact on knowledge management practices applied within cooperatives, as well as on the development and implementation of the Technical and Financial Assistance Plan for Farmers (intelligence). Some authors point out that organizational culture is not only a critical factor for the success of knowledge management, but also the most difficult and important factor to address, especially if a suitable culture does not yet exist (Davenport and Prusak, 1998). However, changing the culture in an organization or community is an enormous challenge. The cultural change process encompasses the following requirements: 1. People must be willing to cooperate (adequate incentives and rewards must exist); 2. A basic understanding of how cooperatives can improve communication among farmers, academia, the private sector, and government. 3. Networking to Promote Cultural Change; Culture also plays an important role in creating learning conditions with the internal and external environment.

Conclusions and suggestions for future Research

This article clearly presented Bio-dynamic agriculture as an excellent alternative to industrial agriculture, which is in decline due to excessive mechanization, chemical manipulation and the use of herbicides, as well as a lack of respect for environmental conservation.

Through a literature review, this manuscript demonstrated that a cultural shift among small-scale farmers would lead to the adoption of best practices such as rock dust.

This cultural shift would support the development and implementation of a technical and financial assistance plan. All of this is clearly illustrated in the Culture-Knowledge-Intelligence (CKI) model.

Small farms have little communication with medium-sized farms because there is no space for the exchange of knowledge and experiences, nor for the exchange of machinery such as tractors, plows, harrows, spreaders, and harvesters. One solution could be the creation of cooperatives.

Cooperatives would also be responsible for transferring relevant knowledge and opening lines of credit to farmers. Cooperatives are the foundation of Bio-dynamic agriculture, which has much stronger ties to agroecology than any other type of farming.

As a suggestion for future research, it would be interesting to select specific rocks and soils to find a better physicochemical combination that improves crop nutrition compared to crops treated with chemical fertilizers, organic compost alone, or even pure asphalt powder or asphalt mixed with bovine manure.

Questionnaire on the Formation of Bio-dynamic Cooperatives (focus: application of rock dust as a bio-dynamic fertilizer). Available at https://forms.gle/EEZW7XrTSwKGv3XQA

Answers (Likert Scale): I completely agree, I only agree, I neither agree nor disagree, I disagree, I completely disagree.

Dimension 1: Awareness about Bio-dynamic

3. Are you familiar with bio-dynamic practices (solar energy, fertilizers made on the farm, irrigation through artesian wells, etc.)?
4. Are you familiar with the potential of rock dust for soil remineralization and its advantages and disadvantages?
5. Are you interested in making better use of the resources on your own farm, in particular rock dust?

Dimension 2: Capacity for applying rock dust.

6. Would you be interested in conducting a serious rock dust experiment on your farm (6 months)?
7. Do you have a special hammer to crush rocks or a connection with a laboratory to analyze the rocks and soil to check results?
8. Would you also like to mix rock dust with bovine manure to see if it is even more effective?

Dimension 3: Techniques Used and Sales

9. Do you like the results of the Chemical fertilizer that you are using?
2. Do you like the irrigation technique that you are using in the sandy soil ?
3. Would you like to try another irrigation technique such as artesian wells?

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Conflict of Interest

No conflict of interested is detected.

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