Opportunity for Increasing the Soil Quality of Non-arable and Depleted Soils in South Africa: a Review

Angelique Daniell1 · Danél M. van Tonder1

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Abstract
Improving food security strategies on highly degraded soils has become a significant challenge for South Africa. The need to secure food sources for the growing population under harsher climatic conditions is crucial. South Africa is one of the many water-scarce countries and is labeled the 30th driest country in the world. Numerous methods exist to enhance and maintain soil quality, including applying fertilizers and geological materials to the soil. Basalt has been the focus of numerous long-term studies on soil fertility. The focus of this review paper is to determine the utility of augmentation with rock dust in terms of benefits to soil properties during the weathering of primary minerals. This review paper includes a background on the current situation in South Africa regarding soil and climatic conditions and how the usage of rock dust can improve the situation at hand. With the demand placed on food production by a growing population and water scarcity in South Africa, it becomes evident that it is necessary to search for new innovative methods to improve soil quality in South Africa. The potential for basalt remineralization and application on non-arable soil in South Africa holds enormous economic benefits.

Highlights
- Rock dust amendment shows improved and increased productivity of the soil
- The need for additional amendments gets reduced when rock dust is used
- Basalts are organic fertilizers as they supply high amounts of nutrients to the soil
- Rock dust was also found to reduce crop damage by acting as long-term pest control
- Basalt rock dust has been implicated in directly influencing soil quality and function

Keywords Basalt · Degraded soils · Non-arable soils · Rock dust · Soil fertility · Soil quality

1 Introduction
South Africa is only one of the countries globally challenged by improving food production and sustaining food security on highly degraded land (Sithole et al. 2016). South Africa needs to develop new innovative methods to ensure food security for the increasing population under changing climatic conditions, which are predicted to worsen in the future (Sithole et al. 2016). It is predicted that climate change will have adverse impacts on southern Africa due to more recurrent and protracted droughts with higher temperatures (Sithole et al. 2016; Stats S.A. 2010).
From the predictions mentioned above, more pressure is placed on South Africa’s already restricted arable land (Fig. 1) and available water required for food production and security on both a household and national level (Sithole et al. 2016). The usage of rock dust in areas already being cultivated for food production has shown considerable positive contributions to soil health as it increases essential nutrient remineralization and trace element addition where regular fertilizers are lacking. In recent decades, the increased greenhouse gasses in the atmosphere resulting in climate change have received much attention. As Robert (2001) stated, steps must be taken to reduce greenhouse emissions and increase the sequestration of these gases in soils and biomass. Billions of people globally suffer from malnutrition (Van Straaten 2002). We hear of the food...
crisis worldwide, which has spread in numerous regions due to climate change (Van Straaten 2002).

However, the lack of localized studies on the usage of rock dust in the improvement of non-arable and poor-quality soils on crops grown and climatic conditions in South Africa have created gaps in sustainable agricultural practices and food production currently implemented in South Africa. Contextualizing South Africa’s relative scarcity of available agricultural land against the increasing demand placed on food production, it is crucial to search for new innovative methods to improve the quality of soils deemed non-arable. The focus of this review paper is to determine the utility of augmentation with rock dust in terms of benefits to soil properties (soil quality and function). Within this review paper, a background will be discussed on the current situation in South Africa, followed by the properties of rock dust as an amendment and what properties of rock dust contribute to the improvement of soil properties with further literature cited relating to soil quality and sustainability, and includes an overview of rock dust usage in the agricultural sector as well as the benefits of this product. This article will also discuss the weathering of rock dust and secondary products, including their chemical makeup, which can enhance the chemical properties of the soil.

2 Review Questions

This review paper pursues to establish, through the available literature, the soil improvement abilities of rock dust amendment. The specific review questions to be addressed are as follows:

- “What influences the soil quality and properties when non-arable and depleted soils are amended by rock dust in South Africa?”
- “What weathering products of rock dust in South Africa contribute to soil quality?”

3 Review Methodology

3.1 Literature Search and Database

This review paper aims to identify the potential of the amendment of rock dust for soil property improvement in South Africa. To retrieve information on existing studies, data was retrieved from Google, Google Scholar, Science Direct, and EBSCO through the North-West University database by using the review questions. The search strategy was
developed using keywords such as rock dust usage in South Africa, crushed basalt, basalt as a nutrient, organic soil fertilizers, soil quality improvement, soil fertility of South African soils, South Africa soil improvement with rock dust, rock dust fertilizer, basalt as a fertilizer in South Africa, and weathering of basalt that contributes to soil health.

The search sensitivity was increased; additional records were identified by hand searching and reviewing the referenced list of retrieved and screened papers. Data was eliminated based on product marketing and the purchase of products. Abstracts and keywords were used to identify relevant studies regarding the improvement capabilities of rock dust worldwide. The data and material were screened carefully based on duplication, relevance, importance, and references. The remaining material was reviewed and selected for further study. Geology, Soil Science, and Environmental books were examined for relevant information and cited accordingly.

### 3.2 Schematic Maps

The maps for this review article were created using Arc geographic information system (ArcGIS). The data for the shapefile was retrieved from the Council of Geoscience, Agricultural Research Council, Department of Environmental Affairs, Department of Agriculture Fisheries and Forestry, and Soil Science Society of South Africa.

### 4 Situation in South Africa

When considering the critical nature of the agricultural industry, the centrifugal role it plays within South Africa, and the current pressures it faces, developing more efficient, profound, and cost-reductive techniques for crop production becomes imperative. Food availability has become a growing concern for residents and policymakers alike within South Africa. Given the sustained population growth of 2% each year, it is expected that food production will need to double globally by 2050 (Hunter et al. 2017) and will need to double by 2035 for South Africa to sustain demand while leveraging potentially fewer resources available to producers today (Goldblatt 2010). Agriculture is one of the main driving forces of the South African economy. Therefore, agriculture and food production are integral to South Africa, its populace, and its overall sustainability from both social and economic perspectives. When expressed in export earnings, 2.59% of South Africa’s gross domestic product (GDP) is attributed to the contribution of agriculture, equal to around $4.89 billion toward the total economic value of South Africa in 2018 (Stats S.A. 2019).

However, of the 122.34 million ha of land which makes up South Africa’s surface area, around 12% is suitable for dryland and rainfed cropping, represented by classes I–III (11,040 ha) (Table 1, Figs. 1 and 2) (DAFF 2017; Goldblatt 2010; Pringle 2013; Twomlow et al. 2006). Of this, a quarter, 2–3% (approximately 4 million ha), may be of high agricultural potential, fertile land (Table 1, Figs. 1 and 2) (Beukes et al. 1998; Goldblatt 2010; Pringle 2013; Twomlow et al. 2006). The rest is either non-arable (grazing or wildlife, as illustrated in Figs. 1 and 2 and Table 1) or influenced by urbanization. As shown in Table 1, 98% of South Africa’s land use is dominated by classes III–VIII, which indicates severe limitations concerning climate (rainfall), terrain, or soils. Class IV covers around 11% of South Africa. Because of the persistent drought and uncertain political and economic conditions facing South Africa, the total number of producing farms has been reduced by a third since the early 1990s. In contrast, end-user demand has increased, leading to the amplified adoption of industrialized agricultural practices (Goldblatt 2010).

Barnard and du Preez (2004) and Scotney and Dijkhuis (1990) highlighted numerous changes in soil fertility in South Africa. Soil acidification is considered the most critical cause of declining soil fertility in South Africa (Du Preez et al. 2011). Soils with a low buffer capacity in high rainfall regions are naturally acidic (Barnard and du Preez 2004). The acidification problem is primarily anthropogenic, caused by extended cultivation in the same areas (Fig. 3) and excessive large quantities of reduced nitrogen (N) fertilizer (Mills and Fey 2004).

Misuse of land causes degradation, which poses (Fig. 3) a threat to sustainable agriculture in South Africa (du Preez et al. 2011). Land-use practices in South Africa have adversely changed soil’s physical and chemical properties...
Significant soil is degraded because of over-utilization (Goldblatt 2010; van Straaten 2002). Unless these nutrients, removed from the landscape during crop production, are returned, soil fertility will dwindle over time (Fig. 3) (Swoboda et al. 2022; Mills and Fey 2004). There is significant acidification and nutrient depletion in South African soils, as well as a lack of soil structure due to degradation (Mills and Fey 2004). However, for water scarcity, the most challenging facet is the ability of the soil to absorb and retain rainwater. The dependence and overuse of synthetic fertilizers, pesticides, and herbicides on arable farmlands further reduce long-term soil fertility. Soil erosion, water pollution, and poisoning of the ecosystem aid in climate change not only in South Africa but worldwide (Goldblatt 2010). Following this, the history of agricultural practices proved that synthetic fertilizer had become a substantial element in producing optimal crop yield and sustainable economic return (Jim-ling et al. 2007; Paull 2009). South Africa’s largest synthetic fertilizer producers include Omnia and Sasol Chemical. Without excluding the other producers, the industry cohesively ensured that by 1982, 3-million-ton synthetic fertilizer was used to increase crop yield (Fertilizer Association of Southern Africa 2016). Unfortunately, the overuse of synthetic fertilizer directly causes soil degradation (Lal 2009; Savci 2012a, b; Massah and Azadegan 2016), implying that soils lose quality, known as the capability to perform the essential ecosystem functions. Essentially, soil degradation through the abundant use of synthetic fertilizer refers to the deterioration of a soil’s capacity to produce food. The mentioned soil degradation includes physical (e.g., decline in soil structure) and chemical (e.g., elemental depletion and imbalances) processes (Weil and Brady 2017). Although this might be true, the effects of excess fertilizer implementation may take time to be visible, as soils possess a high buffering power (Savci 2012a, b). While the effects may not be immediately visible, the most critical aspects concerning soil degradation, known as the decline in soil structure and pH, cause elemental deficiencies. Initially, soil structure is a good indication of soil quality. Savci (2012a) recognizes that the addition
of synthetic fertilizer enhances the concentration of sodium (Na), especially in the form of NaNO₃. They further the explanation by adding that exchangeable Na⁺ ions on the exchange sites on the clays negatively affect soil structure as it causes the soils to disperse, initiated primarily for two reasons. Its single charge, large, hydrated radius, and the number of Na⁺ ions needed to balance a soil surface result in soil productivity decline (Weil and Brady 2017).

Massah and Azadegan (2016) add that a decline in soil structure causes an increase in soil bulk density, impacting permeability, hydraulic conductivity, and groundwater recharge. In addition, soil structure degradation reduces root growth and yield production by 80% (Reintam et al. 2009). Following the decrease in soil structure, another pivotal aspect that may arise post-synthetic fertilizer application correlates with a decline in soil pH (Savci 2012a, b), defined by Weil and Brady (2017) as the soil’s acidity. With a change in pH, nutrient availability fluctuates and causes either elemental nutrient deficiency or plant function interference (Jones 2012). Furthermore, crop farmers are faced with persistently increasing input costs due to a volatile domestic currency, contributing to an overall reduction in profitability (Goldblatt 2010). Agricultural systems, which are productive and sustainable, are vital to a nation’s general well-being and the foundation of the development thereof (van Straaten 2002). Therefore, the soil is the basis of survival, food security, and employment in a country. To ensure sustainable agriculture, strategies, which ensure proper resource management of the land, must be adopted. Therefore, farmers must improve and maintain soil fertility (Swoboda et al. 2022; Goldblatt 2010).

5 Rock Dust Properties and Benefits

Soil health and quality can be improved and maintained in various ways, including applying fertilizers and geological materials to improve and increase soil productivity (Swoboda et al. 2022; van Straaten 2002, 2006). However, the fertilizer sector almost only focuses on the manufacture of synthetically concentrated products, which are soluble and contain macronutrients [N, phosphorus (P), and potassium...
(K)] with limited secondary and microelements. Except for N, 18 elements essential for plant health are derived from rocks (Swoboda et al. 2022; Weil and Brady 2017). The rate of release and solubility of nutrients derived from rocks and minerals are primarily low (Swoboda et al. 2022; van Straaten 2002; Van Straaten 2006). Chemical, physical, and biological modifying processes accelerate the rate at which nutrients are discharged (Swoboda et al. 2022). These methods, as described by the author, can benefit the practical usage of basalt rock powder in South Africa by decreasing the particle size and structure disordering of minerals within the rock fragments, alteration of the mineralogy by making use of the fusion of K-rich silicates within hydrothermal conditions as well as acid treatments (Swoboda et al. 2022).

Swoboda et al. (2022) went on to explain that basalt rock powder can also be biologically modified by either combining these materials with dissolved microorganisms or with compost and manure in severely depleted soils.

Swoboda et al. (2022) stated that finely ground silicate rock powders could be referred to as rock dust, stone meal, agrominerals, or remineralized soil. Basalt rock powder application as a soil amendment has been the focus of numerous long-term studies on soil fertility (Gervais and Herbert 2014). Applying rock dust over long periods has reduced the need to constantly apply additional amendments, resulting in more sustainable farming operations (Swoboda et al. 2022). Gervais and Herbert (2014) showed that rock dust, as a sustainable soil amendment, can enhance the overall quality of the soil, stabilize the pH, increase cation exchange capacity (CEC) (Beerling et al. 2018; Hartmann et al. 2013), increase nutrient storage, and reduce leaching while offering better protection against contamination and degradation, improving soil texture and water retention and holding capacity. Previous studies by Gillman et al. (2002) showed that using crushed basalts could improve soil fertility by improving the soil’s pH, CEC, and electrical conductivity (EC). Van Straaten (2006) listed six subdivisions of natural mineral and rock-based fertilizers to increase soil fertility on smallholder farms:

- Multi-nutrient silicate rock fertilizers, e.g., fine-grained volcanic rocks,
- Single-nutrient rock fertilizers,
- Rock fertilizers from rock and mineral waste,
- Translocated rock fertilizers such as alluvial/sediment and volcanic ash,
- Specific nutrient rock fertilizers, and
- Biofertilizers, organic forms of nutrient extracting.

Von Fragstein et al. (1988) found that high silicate rocks, such as granite, release a lower number of cations than volcanic rocks, such as rock dust, due to fast weathering rates and release rates of macro- and micronutrients of basalt. As a result, basalt contains 72 macro- and micronutrients and trace elements resulting in the amendment of basalt being able to provide a more comprehensive variety of plant nutrients for more healthy plant growth and development with higher quality production and more nutritious food (Swoboda et al. 2022; Gervais and Herbert 2014).

Fyfe et al. (1983) stated that young volcanic areas with weathered lavas and ashes are often the most fertile. Healthy soil is the result of a sequence of complex interactions between geology and biology; as rock weathers, it reacts with soil microorganisms resulting in the release of essential minerals and plant nutrients such as calcium (Ca), magnesium (Mg), and iron (Fe) to increase crop yields and assist with plant growth and development (Earle 2015b). In the past, people instinctively settled near active volcanoes and volcanic islands due to the rich and highly fertile soil found near volcanoes (Brady 2018). Farmers have long before relied on powdered basalt to serve as a natural way to improve soil root system development, increase crop yields, and aid in plant health and conditions (Tanveer et al. 2017). By amending soil with crushed volcanic basalt, the biological process of healthy soils required for optimum and sustainable plant growth is mimicked (van Straaten 2002).

However, now that the global issue of soil degradation and food scarcity is at the forefront of research initiatives, the benefits of using rock dust to restore soil health and sustainable crop production are regaining attention (Tanveer et al. 2017). Basalts are generally used as rock dust in organic fertilizer since they have the highest supply of nutrients and micronutrients for soil remineralization (Earle 2015b; Ramos et al. 2014). According to Gillman et al. (2002), the earliest and most complete studies on the benefits of rock dust, primarily in the agricultural sector, was that by D’Hotman de Villiers in 1947 and 1961 on sugar cane in the volcanic island of Mauritius. The scientist at the Sustainable Ecological Earth Regeneration (SEER) Centre in Scotland noted that the benefits of rock dust amendment include increases in water retention, enhancement of the CEC, and improvement of the soil structure and drainage abilities of the soil (Campe 2014; Geater 2012). The Jatropha costaricensis trees in Costa Rica have illustrated an increase in yield and vigor with the application of rock dust (Campe 2014). In Tasmania, organic matter, available P, and pH values increased in soils formed on basalts (Sparrow et al. 2013). Scientists from Southern Philippines incubated soil that had severe fertility problems with, among others, ground pyroclastic basalt to study soil chemical property changes (Boniao et al. 2002). This study found that nutrient uptake increased with the applied amendments and that the comparative plant heights and weights of maize had a linear correlation with Mg concentration in the soil (Boniao et al. 2002).
in correcting the pH in nutrient supply and has a long residual effect with the presence of micronutrients such as zinc (Zn), boron (B), copper (Cu), Fe, and manganese (Mn) (Ramos et al. 2014). In the USA, soils amended with gravel dust produced double the volume of maize compared to chemically fertilized soils; the maize was higher in protein, Ca, P, Mg, and K than conventionally grown maize (Campe 2014). Rock dust was also found to reduce crop damage by acting as long-term pest control by destroying and disabling insects, thereby limiting their population (Campe 2014).

6 Rock Dust Weathering

The particle size of the basalt rock powder plays an essential role in the weathering rate of the material as this increases the rate of physical weathering of the rocks, which is considered the first stage of weathering (Weil and Brady 2017). When the particle size is smaller, it creates more significant surface areas upon which chemical weathering can occur, primarily regulated by the mineral surface area (Weil and Brady 2017). Weathering silicate minerals, especially mafic minerals, is often considered one of the most critical mechanisms in removing carbon dioxide (CO₂) from the atmosphere and regulating global climatic changes (Swoboda et al. 2022; Dessert et al. 2003). When basalt or any other basic silicate rock weathers, it undergoes reactive dissolution reactions that emit base cations and silicic acid (H₄SiO₄) (Earle 2015a). The base cations react with water in the reactive dissolution process, initially yielding hydroxide ion, which reacts with dissolved CO₂ to form carbonate and bicarbonate ions in solution (Beerling et al. 2018; Earle 2015a; Hartmann et al. 2013; Kantola et al. 2017; Kelland et al. 2020). The thermodynamic equilibrium is re-established across the air/soil–water interface by dissolved atmospheric CO₂ (Walter 2002). This way, CO₂ is withdrawn from the atmosphere and transported in the water cycle in a chemically innocuous form until it ultimately resides in the sea (National Oceanic and Atmospheric Administration 2020). Basalt has also been implicated in the reduction of emissions of the greenhouse gas nitrous oxide (N₂O) (DeLucia et al. 2019). Thus, augmenting soil with basalt has the potential to address global warming problems from two gases, CO₂ and N₂O (Beerling et al. 2020; Dacey 2021; DeLucia et al. 2019).

Using rocks for soil remineralization is not a new concept, and volcanic rocks, such as basalts, have shown great potential for improving soil quality (Ramos et al. 2014; Van Straaten 2006). When primary minerals in these rocks weather, it results in the formation of secondary clay minerals and Fe-oxides, which release nutrients such as Ca, Mg, Fe, and, to a lesser extent, K, Na, and P (Boggs 2014; Gillman et al. 2002; Klein and Dutrow 2007). Micronutrients and trace elements that can also be released out of the rock include Cu, Zn, Mn, cobalt (Co), nickel (Ni), and vanadium (V) (Ramos et al. 2014). The weathering of basalt releases inorganic plant nutrients and micronutrients, which can support food production while generating alkaline conditions to reverse soil acidification caused by agricultural production (Beerling et al. 2018; Hartmann et al. 2013; Kantola et al. 2017).

In basaltic rocks, minerals are susceptible to chemical weathering, commonly following the reverse of the Bowen reaction series glass ≈ olivine > plagioclase ≈ pyroxene > Fe–titanium (Ti) oxide (Babechuk et al. 2014; Nesbitt and Wilson 1992). The generalized weathering sequence for primary minerals is illustrated in Fig. 4 (Weil and Brady 2017). Babechuk et al. (2014), Prudêncio et al. (2002), and Rasmussen et al. (2010) stated that the parent rock mineralogy, climate, biota, oxidation–reduction state, and drainage of the profile give rise to the pedogenetic mineralogy and order of mineral formation in the soil. However, the chemical weathering of basalt is incongruent as some primary minerals do not dissolve and secondary minerals are formed.

During the initial early stages of basalt weathering, 2:1-layer phyllosilicates typically form while important hydration occurs (Babechuk et al. 2014). End products such as 1:1-layer clay minerals (kaolinite or halloysite) are stable during weathering progress of intermediate to advanced phases (Babechuk et al. 2014). The secondary products produced from weathering primary minerals in basalt are presented in Table 2. Gislason et al. (1996) showed that the mobility of elements during the weathering of basalt decrease as follows: sulfur (S) > fluoride (F) > Na > K > Ca > silicon (Si) > Mg > P > strontium (Sr) > Mn > aluminum (Al) > Ti > Fe. These workers also showed that close to 90% of Mg and Ca in the original rock is left behind at the weathering site of the original rock. An overall net loss of mobile elements, including Mg, Ca, Na, and K, accompanies the mineralogical transformations in the early weathering stages of basalt, while Al, Fe, and Si are mainly retained (Babechuk et al. 2014; Chesworth et al. 1981; Kronberg and Nesbitt 1981; Nesbitt et al. 1980; Nesbitt and Wilson 1992).

Several factors can contribute to the rapid and enhanced weathering of basalts, such as deuteric alteration of primary minerals, swelling and shrinking of smectite clays (an alteration product of either volcanic glass or primary silicates such as olivine, pyroxene, and plagioclase) and zeolites as well as extensive micro-fracturing (Bell 2007). Mechanical disruption of small rocks close to an exposed surface results from recurring hydration and dehydration (Bell 2007). This process of swelling and shrinking leads to flaking and surface cracking, which allows water access, causing the degree and rate of weathering of these rocks to increase (Bell 2007). Once exposed to the atmosphere, some basalt is susceptible to rapid weathering, referred to as slaking (Bell 2007).
The weathering of minerals takes place in three stages. During the first weathering stage, rocks and minerals are disintegrated, and primary minerals are present in the soil (Van Straaten 2007). Primary minerals form Fe oxides, and secondary minerals, such as 2:1 clay minerals like smectite, as illustrated in Fig. 4. This causes nutrients to be released from the crystal lattice during the second stage of secondary weathering (Boggs 2014; Orr 1979), where the weathering of secondary 2:1 clay minerals form 1:1 clay minerals such as kaolinite in the third stage of weathering (Fig. 4) (Van Straaten 2007). The development of these mineral phases and the release of elements contribute to soil fertility (Van Straaten 2007).

The weathering processes are critical in soil formation, especially the formation of secondary minerals, which mainly control nutrient availability through adsorption–desorption, dissolution–precipitation, and oxidation–reduction reactions owing to their small size and large external and internal surface area (Weil and Brady 2017; Singh and Schulze 2015). The adsorption reactions in the soil are often more significant in regulating plant nutrient availability than releasing nutrients by mineral weathering (Singh and Schulze 2015). Some phyllosilicates

![Diagram illustrating weathering of primary minerals and the influence of climatic conditions. Magnesium (Mg), iron (Fe), sodium (Na), calcium (Ca), potassium (K)](image)

**Fig. 4** Diagram illustrating weathering of primary minerals and the influence of climatic conditions. Magnesium (Mg), iron (Fe), sodium (Na), calcium (Ca), potassium (K)

**Table 2** Mineral composition and weathering products of basalt (Weil and Brady 2017)

| Mineral name | Composition | Weathering products |
|--------------|-------------|---------------------|
| Labradorite  | (Na, Ca)₂Si₂O₆ | Allophone and smectite (Winegardner 1995) |
| Calcic plagioclase | Ranges from NaAlSi₃O₈ (anorthite) to CaAl₂Si₂O₈ | Allophone and smectite (Winegardner 1995) |
| Augite       | (Ca, Na)(Mg, Fe, Al)(Si, Al)₂O₆ | Chlorite (Bell 2007), smectites (Winegardner 1995) |
| Pigeonite    | (Ca, Mg, Fe)(Mg, Fe)Si₂O₆ | Chlorite (Bell 2007), smectites (Winegardner 1995) |
| Olivine      | (Mg, Fe)₂SiO₄ | Serpentine, talc, carbonate, smectite and oxidized iron (Fe) (Bell 2007; Winegardner 1995) |
| Hornblende   | (Ca, Na)(Mg, Fe, Al)₂Si₃O₂₂(Al, Si)₂(OH)₂ | Chlorite (Bell 2007), smectites (Winegardner 1995) |
| Biotite      | K(Mg, Fe)(AlSi₃O₁₀)(OH)₂ | Vermiculite, montmorillonite, and goethite (Winegardner 1995) |
| Volcanic glass | – | Chlorite and epidote (Tuğrul 1997) |
with a permanent charge (e.g., vermiculite and smectite) have
exchange sites that can hold high quantities of essential nutri-
teins in their cationic form, i.e., their CEC (Singh and Schulze
2015). Generally, the plant nutrients are held closely to the clay
surface by outer-sphere complexes, which cause the nutrients to
become effortlessly available for plant root uptake, increasing
soil fertility (Singh and Schulze 2015). In addition to holding
and releasing adsorbed nutrients, clay minerals attract and hold
numeral amounts of water molecules, increasing the water-
holding capacity of soil water for plant uptake (Weil and Brady
2017). Adding to the advantages of having clay minerals in the
soil is increased buffer capacity (Weil and Brady 2017). This is
important mainly because the buffering ensures some stability
in soil pH, preventing extreme variations that could damage
plants and microorganisms in the soil (Weil and Brady 2017).

For plants to grow and complete their life cycle, they
require at least 17 nutrient elements, of which 13 are derived
from rocks and minerals (Van Straaten 2007). The primary
macronutrients required for plant growth and productivity
are N, P, and K, where N is mainly sourced from biological
processes (Van Straaten 2007). In addition, Ca and Mg are,
among other functions, essential for helping plants overcome
environmental stresses (Weil and Brady 2017). Micronutri-
teins comprise 8 of the 13 essential nutrients, including Fe,
Mn, Zn, Cu, B, molybdenum (Mo), Ni, and chlorine (Cl),
which are all essential for plant growth and reproduction (Van
Straaten 2007; Weil and Brady 2017). These micronutrients
are required in small quantities, and if too high or too low
concentrations are present within the soil, these elements may
lead to stunted growth, low yields, dieback, and plant death
(Weil and Brady 2017). The availability and toxicity of nutri-
teins are highly dependent on the soil pH, with most of the
micronutrient cations being highly soluble and available under
acidic conditions (Weil and Brady 2017). This is an important
concept that would assist areas where albic soils dominate
the area, such as in the Kosi Bay in the province of KwaZulu-
Natal, South Africa, where soils are acidic, sandy, low CEC,
and have low nutrient content where no cultivation is taking
place. Therefore, the weathering and composition of the rock
dust used determines the degree of remineralization of soils,
as it depends on the composition and elements released from
the crystal lattice during weathering.

7 Locality of Basalt in South Africa

Intrusive varieties of basalts, known as gabbro and dol-
erite, are formed from magma having the same chemical
composition range; however, gabbro crystallized slowly at
deeper depths while basalt solidified rapidly when erupted.
onto the earth’s surface (Dunlevey and Stephens 1996). Dolerites crystallize from molten Mg-rich and Fe-rich magma; they are relatively silica-poor magma trapped at shallow depths in the earth’s crust (Dunlevey and Stephens 1996). Six basalt and dolerite quarries in South Africa are in the KwaZulu-Natal province. In Fig. 5, the basalt, dolerite, and gabbro formations and locations are shown. These locations make it easy for soils in Kosi Bay to be remineralized and potentially become arable.

8 Conclusion

Contextualizing South Africa’s relative scarcity of available agricultural land (Fig. 1, Table 1) and harsh climatic conditions against the increasing demand placed on food production by a growing population combined with water scarcity, it is necessary to search for new innovative methods to improve soil quality, which is deemed non-arable and depleted. Furthermore, because of the increased population, the demand for food and land space increased dramatically, placing considerable strain on arable soil resources for food production. Therefore, the food produced on the same soil needs to increase exponentially unless non-arable, poor-soil-quality areas can be improved to contribute to food production.

As an ameliorant, basalt rock dust has been implicated indirectly in influencing soil quality and function by increasing fertility and the proportion of soil organic carbon, and enhancing moisture retention. Augmenting poor-quality soils, caused by repeated cycles of growing crops on the land and removal of the crops, with basalt rock dust has proven successful elsewhere in the world. The amendment of croplands with rock dust can modify sandy soils and produce soils with higher clay content. Basalt rock dust also can increase the pH and the CEC of soils for water production. Therefore, the food produced on the same soil needs to increase exponentially unless non-arable, poor-soil-quality areas can be improved to contribute to food production.

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Declarations

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