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EARTH SCIENCES

Farming with rocks and minerals: challenges and opportunities

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ABSTRACT

In many parts of the world food security is at risk. One of the biophysical root causes of falling per-capita food production is the declining quality and quantity of soils. To reverse this trend and increase soil fertility soil and plant nutrients have to be replenished. This review provides a literature survey of experiences of using multi-nutrient rock fertili
enhancement from temperate and tropical environments. Advantages and limitations of the applicatio
discussed. Examples are provided from two successful nutrient replenishment projects in Africa where
fertilizers are used on highly leached acid soils. The potential of combining organic materials alongsi
fertility replenishment strategies is stressed.

Key words: soil nutrient replenishment, rock fertilizer, phosphate rock.

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RESUMO

Em muitas partes do mundo a segurança alimentar está em risco. A raiz de uma das causas biofísicas alimentar per capita é o declínio da qualidade e quantidade de solos. Para reverter essa tendência e a ambos solo e nutrientes para as plantas precisam ser repostos. Este artigo aborda uma pesquisa bibli na utilização de rochagem com multi-nutrientes para intensificação da fertilização do solo em ambien tropicais. As vantagens e as limitações na aplicação de pó de rocha são discutidas. São apresentados sucedidos de substituição de nutrientes na África, onde as rochas disponíveis no local são utilizados lixiviados. É enfatizado o potencial da combinação de materiais orgânicos juntamente com pó de roch reposição da fertilidade dos solos.

Palavras-chave: reposição de nutrientes do solo, rochagem, rocha fosfática.

INTRODUCTION

Food is essential for life. But despite major efforts to alleviate food shortage and outright hunger of m are still approximately 800 million individuals who go to bed with empty stomachs every night. The n 9 to 10 billion people during the middle of the 21st century will put increasing pressure on land resou the production of food will have to rise to keep pace with rising food demands. The per capita food pr in some parts of the world, for example in Sub-Saharan Africa.

One of the biophysical root causes of falling per capita food production is the declining quality and qu resource base, in particular the soil (Sanchez et al. 1997, Sanchez 2002). Soils, the foundation for surviv increasingly over-exploited in some parts of the world. In order to reverse this trend of land and soil d to either expand the land base under cultivation or to intensify crop production per unit of land. But ev extended, most of the additional land that would be brought into cultivation is of lower quality and at Clearly, the declining soil quantity and quality in large parts of the developing world poses a threat to

Some land has inherently low fertility because of the soils overly infertile rock formations. Other lan to human intervention, such as the extraction of nutrients through harvesting and other exports with extracted soil nutrients. In some parts of Africa the soils are degraded, eroded and successively mined (Sanchez et al. 1997, Sanchez 2002). The average annual depletion rate of nutrients is 22 kg of nitrogen (P), and 15 kg of potassium (K) per hectare of cultivated land over the last 30 years in 37 African count 1993, Smaling et al. 1997). This corresponds to an annual loss equivalent to US$ 4 billion in fertilizers inherent and human induced infertile and degraded soils are biophysical causes for poor crops, for p consequently for poverty. The restoration of soil fertility through nutrient replenishment should be o points to raise production of food crops. However, short-term quick-fix agrochemical input strategies rather long-term support for more regenerative, ecologically sustainable land management practices.

The green revolution in Asia provided impressive steps forward with regards to food production, but increase has slowed down considerably. And the green revolution was based largely on genetic impro (notably rice), supported by applications of agrochemical inputs such as fertilizers, pesticides and her improved irrigation techniques (Conway 1997). It is important to note that the external inputs for high as fertilizers, pesticides and herbicides, are reliant on non-renewable fossil fuels. With increasing cost gas and oil, the use of these agrochemical inputs becomes more and more expensive, especially for re farmers. Their energy-intensive production and shipment around the world is, in the long run, not sus many of the high external input practices in the green revolution have been environmentally not very from green (Conway 1997).

We require practical, low-cost and result-oriented long-term strategies that address the needs of farm and long-term care of the land. In order to move towards longer-term and more practical land and soi researchers and extensionists have to look for alternative solutions. Ideally, their combined action wil long-term approach to enhance the quality of soils, land and ecosystems, and ultimately the lives of p

There are several ways to enhance and maintain the health of the soil basis. The application of so-call practices is only one of the biophysical instruments that are used to tackle long-term soils related prol the use of rocks for crops (van Straaten 2002), is an interdisciplinary approach that aims to study geol natural rock and mineral materials that contribute to the maintenance of agro-ecosystems (van Straate van Straaten 2002). It is an applied, problem-solving, interdisciplinary earth and agricultural science t integrated nutrient management strategies.

There are two aspects of agrogeology: the role of parent material on soil development and soil produc application of geological materials to enhance the productivity of agricultural crops and contribute to horticultural and forestry systems (see book Rocks for Crops , van Straaten 2002). It must be emphasi intervention is a small, albeit important resource-based intervention among many others that contrib and more sustainable land management. These interventions have to be part of an overall strategy to use, enhance sustainable land use, and ultimately, enhance sustainable livelihoods.

This paper highlights a number of experiences using rocks and minerals in soil management as well a of using rocks and minerals over soluble fertilizers, and a few of the limitations of using these geologi agriculture.

LOW-COST, LOCALLY AVAILABLE FERTILIZERS

Nutrients are essential for plant growth. From the 18 elements essential for higher plants (Brady and W with the exception of nitrogen, are derived from naturally occurring rocks and minerals. The fertilizer i processes naturally occurring rocks and minerals to produce soluble fertilizers, with the exception of r However, the fertilizer industry focuses almost exclusively on the production of fertilizers containing t nitrogen (N), phosphorus (P) and potassium (K), and not on secondary nutrients and micronutrients.

Most commercial farming practices in the world rely on either organic or agrochemical or mixed orgar inputs to increase crop production. Currently, these synthetically produced highly concentrated, solul over long distances at high costs. A tonne of fertilizer may cost US$ 90 at the site of production. At a ha distance away, the price for the same tonne of fertilizer has increased substantially, and transport to in increase the price again. When these same tonne of fertilizer arrives in a landlocked country, like Ugar US$ 500 per metric tonne (Sanchez 2002). While plantations can afford this price, it is unaffordable to r

In addition, the commercially available synthetic fertilizers are frequently not suitable for tropical soil instances rather inefficient. Baligar et al. (2001) calculated the fertilizer use efficiency in the year of app approximately 50% for N, 10-15% for P, and 40% for K from commercial fertilizers. Cognizant of this sit industry makes efforts to make fertilizers less soluble and more plant efficient. These technological (m are made in order to enhance fertilizer use efficiencies and to reduce losses to the environment. The t release to slower-release fertilizers, such as the production of highly priced slow release fertilizers, i urea and polymer coated N fertilizer (Oertli 1980).

As mentioned before, commercial fertilizers usually provide simply the three macronutrients, N, P anc do the fertilizer producers in some developing countries include essential micronutrients, such as Zn,

In contrast to the technical efforts of the fertilizer industry, the agrogeological approach aims at increa rates from widely occurring nutrient rich minerals and rocks. As thesolubility and release rates of thes rocks and minerals are generally very low, the intent is to accelerate the speed of nutrient release thro physical and biological modification processes. Many of the rock and mineral fertilizer materials cont nutrients, including micronutrients (Leonardos et al. 1987).

PRELIMINARY CLASSIFICATION OF LOW-COST, LOCALLY AVAILABLE ROCK AND FERTILIZERS

What are fertilizers and what are rock fertilizers? According to Cooke (1982), a fertilizer is any substan supply one or more plant nutrients and intended to increase plant growth . According to Finck (1982) intended to be supplied directly or indirectly to crops in order to promote their growth, increase their quality .

Natural fertilizers are formed in nature and are used in the form in which they occur, without, or with 1982). Among the natural fertilizers are organic fertilizers such as poultry and cattle manures, green m sludges, ashes, and geological resources such as marl and phosphate rock (PR). Fertilizers in the strict by national fertilizer laws, are soluble fertilizers with guaranteed total nutrient concentrations and, oft conventional fertilizer user, with guaranteed concentrations of active components.

A preliminary classification of rock and mineral based natural fertilizers is presented below.The range occurring rock and mineral based resources spans from multi-nutrient silicate rock fertilizers to by-pr processing. The focus of agrogeological research and development is the use of these rock- and mine fertilizers to enhance the soil fertility on smallholder farms.

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. fly ash).

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 biologically micro-organisms,

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

In the following, only some of the many available geological nutrient resources will be discussed, esp in temperate as well as tropical and sub-tropical environments.

MULTI-NUTRIENT SILICATE ROCK FERTILIZERS

The use of multi-nutrient silicate rock fertilizers as low-cost, locally available geological nutrient sour development is not new. Agricultural research with finely ground rocks and minerals, based on the co stones , started in the 19th century by Missoux(1853/54), Hensel (1890, 1894) and others. It was follow conceptual and practical work on natural rocks for agricultural development by Keller (1948), Keller e three decades research on rock fertilizers was carried out by Fyfe and co-workers (Fyfe 1981, 1987, 198 Leonardos et al. 1987, 2000), Chesworth and van Straaten and co-workers (Chesworth 1982, 1987, 1993 1985, van Straaten 1987, van Straaten and Chesworth 1985, van Straaten and Pride 1993, van Straaten a

Straaten 2002), by scientists from the British Geological Survey (Appleton 1990, 1994, Mathers 1994), a Barak et al. (1983), Weerasuriya et al. (1993), Coroneos et al. (1996), Hinsinger et al. (1996), Harley and al. (2000, 2002).

The use of whole rock silicate fertilizers is attractive as these types of fertilizers have the potential to su array of macro and micronutrients in comparison to commercially available soluble fertilizers, which the main macronutrients N, P and K, but not nutrients such as Ca, Mg and micronutrients (Fyfe et al. 1 1987). Ground silicate rocks should also be considered as slow release fertilizer in situations where le conventional fertilizers are particularly high, e.g. in sandy soils under wet climatic regimes (Harley an

The study of silicate rock fertilizers has received renewed interest in recent years due to advances in th weathering processes, nutrient cycling and biochemical processes at root surfaces. Most fundamental release from rocks and minerals focuses on dissolution rates, as well as the pathways and processes th soils. While the mineralogical and geochemical processes involved in the dissolution of various rock- been well studied, pathways and reactions in complex soil systems are not as well understood. They i mineralogical, and biochemical factors and interactions that control the processes at the interface bet solutions, air and organisms in the soils. In a comprehensive paper, Harley and Gilkes (2000) reviewe influence the release of plant nutrients from silicate rock fertilizers.

In earlier laboratory studies, Blum et al. (1989a, b) showed that under laboratory conditions the releas most ground silicate rocks was very low and that most ground silicate rocks contain a high proportion importance for plant nutrition. However, these researchers showed that certain smectite-rich volcanic cationexchange capacity of poor soils, for example of forest soils. Unfortunately, it was also proven tha tested rock resources would be too slow to be agronomically effective in conventional agriculture.

Von Fragstein et al. (1988) found that the highest cation release rates were from phonolitic volcanic ro rock types. Granite powder released the least amounts of cations regardless of extraction methods. In all samples was alkaline with ground phonolitic rocks reaching a pH > 10, basalts pH 8-10, granites pH good nutrient sources they are also good liming materials .

Volcanic rocks have been singled out as soil ameliorants for their relatively fast rate of weathering and their contained macro and micronutrients. Their nutrient release rate is commonly faster than that of s such as granites. Fyfe et al. (1983) remind us that young volcanic areas with weathered lavas and ashe fertile agricultural areas.

The effectiveness of silicate rock fertilizers in agricultural practices has been questioned due to conflic the generally low solubility of silicate rocks and the subsequent low availability of nutrients to plants of applying large amounts of ground rock to agricultural land (Hinsinger et al. 1996, Bolland and Bake 2000). In addition, some silicate rock fertilizers are diluted with minerals that have no practical nutrie and the amount of these unnecessary components is increasing (Harley and Gilkes 2000, Bolland and

APPLICATIONS OF ROCK FERTILIZERS IN TEMPERATE ENVIRONMENTS

Over the last few decades there is a small but consistent use of multi-nutrient silicate rock fertilizers in Germany, and parts of North America, especially in organic farming practices (von Fragstein et al. 198 But apart from organic agricultural operations, silicate rock fertilizers are also tested and applied to re health in Central Europe s forests affected by pollution, especially acid rain.

The forest decline in Central Europe is frequently associated with declining acid neutralization capaci imbalances in forest soils (e.g. Hildebrand 1991, Huettl and Zoettl 1993). Ground silicate rocks (mainl phonolitic composition) have been tested as a means to raise the pH in the affected forest soil sand to addition of nutrients (e.g. Ca and K). Hildebrand and Schack-Kirchner (2000) and von Wilpert and Luk positive liming effects on forest soils with silicate rock fertilizers. While the application of 6 t/ha of vol fertilizers provided additional Ca and K to long-term tree nutrition in the northern Black Forest of Ger

Schack-Kirchner 2000), the application of 10t/ha phonolite rock on K-deficient forest soils of Southwes additional Ca and an increase in the soil pH. However, the high dose of Na-richphonolite also resulte release, which could cause increased Na loading of groundwater and potentially contribute to a loss i soils (von Wilpert and Lukes 2003). It was concluded that it is important to select the rock fertilizers ca goals of liming and slow nutrient release in forest soils without causing new nutrient imbalances and impacts.

In other experiments in temperate climates,Bakken et al. (1997, 2000) studied the fertilizing value of va and residues from mine tailings on grasslands in Norway. The results of these trials under field condit percent of the K bound in biotite concentrate (from feldspar production in Lillesand,Norway) from ne complexes and epidote schist was actually plant available. And yet, only 30% of the K that was added a was taken up by plants, as compared to 70% from KCl. The weathering rate of the rock and mineral pro too slow to replenish the native pool of plant-available K within a three-year period with five harvests was almost unavailable to the grass plants.

APPLICATION OF ROCK FERTILIZERS IN TROPICAL ENVIRONMENTS

The application of rock fertilizers in tropical environments has many advantages. Firstly, the dissoluti minerals and the reaction between mineral surfaces and soil solution is enhanced under high tempera regimes. Secondly, the potential of applying ground rocks and minerals to soils is elevated as the soils nutrient contents because of high amounts of weathering and leaching, and thus highly receptive to a

While in some countries in temperate climates the use of multi-nutrient rock fertilizers is growing, esp agriculture market, there are only few published results from the application of rock fertilizers in deve Although many tests have been carried out in tropical environments, e.g. in Brazil, only a few trial resu characterized rock and mineral fertilizers as well as soils in which they were applied have been report

Published data indicate that some rock and mineral resources can be used as slow-release nutrient-su crops in degraded tropical soils and also for forestry and pastures. Many researchers from tropical cou Villiers 1961, Roschnik et al. 1967, Leonardos et al. 1987, 1991, Gillman 1980, Gillman et al. 2000, 2002) from tests using ferromagnesian rich silicate rock fertilizers, such as basalts or ultrapotassic/potassic l reasons for these positive results on highly weathered, nutrient depleted, acid soils are likely the enha volumes of ground silicate rocks nutrient rich minerals and rocks under high temperature and moistu liming effects. Fine grained rocks containing high proportions of olivine, pyroxene, amphiboles and C feldspars as well as low concentrations of free quartz have the highest natural weathering rates (Goldi

In Mauritius, increased yields of sugar cane are reported from systematic field trials (d Hotman de Vill significant yield increases of sugar cane subsequent to the application of large doses (up to 180 tonnes basalt have been reported.

In Zimbabwe, Roschnik et al. (1967) tested finely ground basaltic rocks in strongly weathered Kalahari experiments. High application rates (5-40 tonnes per acre) showed exponential growth increase in tota growing legumes. The yield increase of sunflowers grown on Kalahari soils following treatment with 5 ground basalt showed a linear response curve (Roschnik et al. 1967).

Leonardos et al. (1987) provided results of increased yields from three greenhouse and field trials fro with beans (*Phaseolus vulgaris*) and napier grass (*Pennisetum purpureum*), as well as for slow-growing Leonardos et al. (1991) and Theodoro and Leonardos (2006) report on the high agronomic response o and micro-nutrient rich lavas and tuffs from the Mata da Corda Formation, a formation that stretches 50 km) in the centre of Brazil, in the State of Minas Gerais.

The studies of Gillman (1980) and Gillman et al. (2000, 2002) in tropical Australia illustrate the positive of large amounts of ground basaltic rocks on weathered and nutrient depleted soils. The application o ground basaltic rock raised pH, increased cation exchange capacities, and enhanced cation levels in so

In all the examples above, best agronomic performances were achieved with the application of fine gr
undersaturated volcanic rocks.

A new example of a potential silicate rock fertilizer is coming from Uganda, where a vermiculite-based
developed by Uganda Vermiculite Ltd. Coarse and medium grade vermiculite is extracted from a weat
(Baldock 1969). The vermiculite is extracted and processed before being shipped abroad. The fine frac
phosphate containing biotite pyroxenite has been recognized as very valuable by-product for local a
The fine fraction by-product , only slightly processed through the removal of magnetite and exfoliatio
local agricultural markets. This vermiculite-based rock fertilizer is still in a product development phas
high initial agronomic performance it is sold as vermiculite based fertilizer to many customers in Uga
germination and seed emergence as well as enhanced crop growth of maize, sunflower and cotton sho
performances, probably caused by the release of high concentrations of Mg and P from the weathered
1 illustrates the increased plant mass (roots and shoots) of maize grown in pot experiments in Uganda
unpublished data).

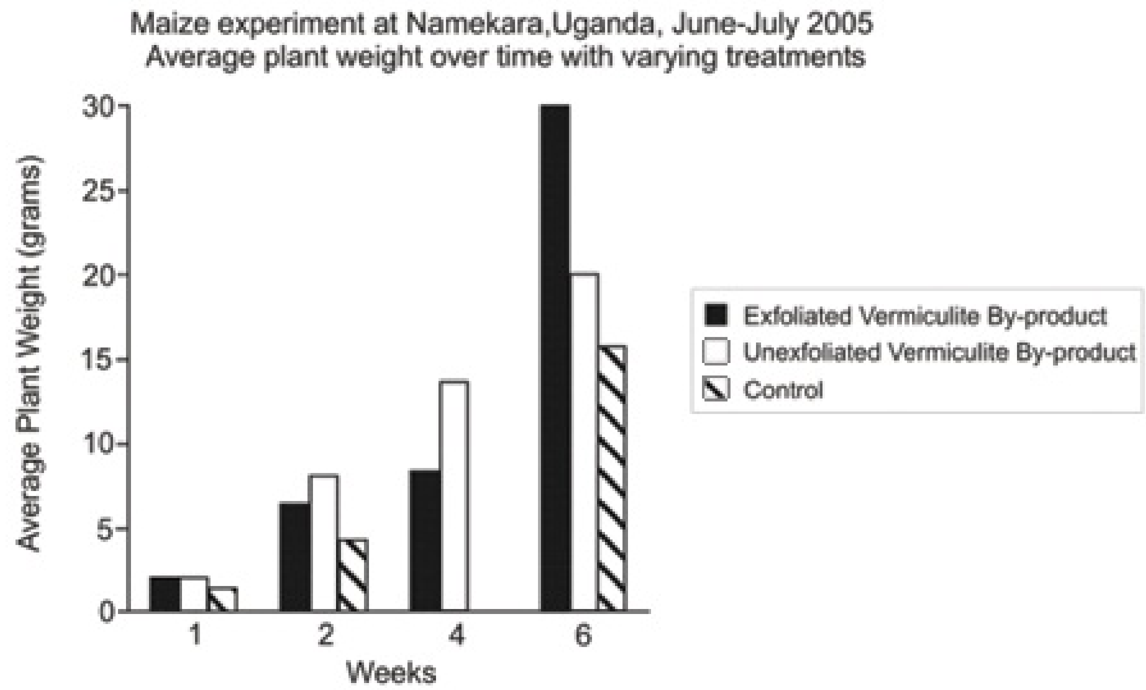

Fig. 1 – Effects of vermiculite by-product on total maize weight (roots and shoots),
averaged over three plants, over a six-week period. No control sample was taken
in week 4. Test pots = 26L red soils, application rates 180 cc of exfoliated and
unexfoliated Namekara vermiculite by-product respectively.

The example from Uganda illustrates the opportunity to make use of mafic silicate rock wastes , or be
rock crushing operations and industrial mineral mining operations on their agronomic potential for a
depleted tropical soils.

Another example of the effectiveness of a multi-nutrient silicate rock fertilizer is that of Sri Lanka (Wee
this case, however, the silicate rock was not used directly but in a modified form. Scrap phlogopite wa
mines was ground and acidulated with various acids, including nitric and sulphuric acid. The acidulat
to 65% of K and Mg, less than 13% of Ca, and 15-100% Mn and Zn. The agronomic evaluation of the ap
kg of acidulated, non-hygroscopic granular phlogopite mica per hectare revealed a yield increase of ri
comparison with recommended application rates of muriate of potash (KCl) and dolomite. The agron
acidulated feldspars in combination with dolomite was negligible (Weerasuriya et al. 1993).

For increased plant response to rock fertilizer application it is important to characterize and evaluate t chemistry of the selected minerals and match the soil and plant requirements with that of the nutrient the rock fertilizer. An example of a good match of rock fertilizer with plant requirements for themicron described by Barak et al. (1983). Since peanuts (*Arachis hypogaea*) often show low yields on calcareous (Fe-chlorosis) Barak et al. (1983) tested the application of ground Fe-rich basaltic rocks and lapilli tuff quarrying operations, on calcareous soils. The results show significantly improved iron nutrition, chlo growth of peanuts upon application of these Fe-rich volcanic rock fertilizers.

ADVANTAGES AND DISADVANTAGES OF APPLYING MULTI-NUTRIENT SILICATE

There are several advantages with the application of multi-nutrient silicate rock fertilizers. They incluc

- They provide a large number of macro and micronutrients and beneficial elements (e.g. K, Ca and possibly Si (Epstein 1999)).
- They have favourable properties to raise the pH of soils (liming effect).
- They are suitable as slow-release fertilizers in nutrient depleted acid soils.
- Their application has low environmental impact.
- Many of them are locally available, some of them as quarry wastes and mine wastes from o mineral mining operations.
- They are inexpensive.

Well selected ferromagnesian and silica-undersaturated volcanics and tuffs have shown to be agrono release fertilizers that can provide many macro and micronutrients to enhance soil fertility and restore term.

As pointed out before, some multi-nutrient silicate rock fertilizers can be found as wastes from quarr from other industrial mineral mining operations. But the rock fertilizers have to be chosen carefully in nutritional requirements of the degraded soils and the crops grown on them.

The use of mafic rock fertilizers as slow-release fertilizers is especially useful in degraded soils where effects are needed, e.g. in forest and pasture management systems. Many of these rock fertilizers have environments where the release of nutrients is enhanced due to high temperature and moisture regim environments.

Disadvantages of many other rock materials, including silica-rich igneous rocks like granites, contain concentrations and very low solubility. Both characteristics can negatively affect the agronomic effecti crops, particularly in temperate climates. Also, silicate-rich rock fertilizers contain large amounts of no minerals, e.g. quartz. In order to be agronomically effective the application rate is commonly in the ra hectare therefore making it costly and labour-intensive. In addition, the production of silicate rock fer energy inputs for crushing and grinding. And their place value is important as shipping large amounts over large distances is likely uneconomical and environmentally not sustainable.

SINGLE-NUTRIENT ROCK FERTILIZERS

The main nutrient limiting factors in many tropical and sub-tropical environments are N and P, and in soils also K and other nutrients. While N can be provided from the air by biological nitrogen fixation (sources, P and K and all other plant nutrients must be provided from rocks and minerals.

Considerable amount of research has been conducted in the last few decades to find alternative local soils requirements for P. There is considerable information on the use of phosphate rock (PR) resourc and on modification techniques of the various PR resources (for example: Chien and Hammond 1978, 1986, Léon et al. 1986, Chien and Menon 1995b, Van Kauwenbergh 2003). The main research thrust ha application of finely ground phosphate rocks. The agronomic responses vary strongly from negligible The factors influencing the agronomic effectiveness of PR reach from rock factors, to soil factors to pla factors (Chien and Menon 1995a). It is well known that sedimentary francolite-rich PRs are in general effective than igneous fluorapatites (Van Kauwenbergh 2003).

Based on years of research and experiences, researchers have developed predictive models indicating response to certain phosphate rocks on the basis of mineralogical factors as well as soil factors (Chien McClellan and Gremillion 1980, Robinson et al. 1992, Chien and Menon 1995a, Van Kauwenbergh 200 positive agronomic results confirmed the prediction from laboratory studies, many negative agronom application of PR can be explained by the choice of unsuitable PR materials or applying the phosphat environments.

The results from South America provide an example for the differing responses based on the differenc chemistry of the phosphate rocks (Léon et al. 1986). The results of agronomic testing showed that som rocks (e.g. from North Carolina, Peru (Bayovar) and Tunisia (Gafsa)) had similar yield responses and to that of chemical triple superphosphates (TSP). All of these very reactive and agronomically effective sedimentary origin. Other phosphates (for example from Brazil, Tapira and Catalao) are igneous phos be largely ineffective when applied directly to soils. Similar geological and mineralogical characteriza agronomic experiments have been reported from many places in Sub-Saharan Africa (van Straaten 20

In many instances however the reactivity of PR is too low to release enough P to the soil and plant roo frame that matters to the farmers. Also, these PR fertilizers commonly provide only one nutrient, P, to other nutrient additions to supply a full range of nutrients to restore soil fertility.

The phosphate rock modification processes that have shown a high potential of enhanced P nutrient

PHYSICAL MODIFICATION

Fine grinding (Kühnel and van der Gast 1989, Lim et al. 2003),
Mechanical activation (Gock and Jacob 1984).

PHYSICO-CHEMICAL MODIFICATION

Fusion and calcination (Cekinski and da Silva1998).

CHEMICAL MODIFICATION

Acidulation,
Partial acidulation (Hammond et al. 1989, Chien and Hammond 1989),
Blending with sulphur (Rajan 1982, 1983, 1987),
Heap leaching (Habashi 1989, 1994),
Blending and granulation (Lupin and Le 1983, Chien et al. 1987, Chien and Menon 1995a, van S Fernandes 1995, Dhliwayo 1999, Tagwira 2003),
Ion exchange (Lai and Eberl 1986).

BIOLOGICAL MODIFICATION

Phospho-composting (Singh and Amberger 1990, 1991, 1998),
Green manuring, for example with *Tithonia diversifolia* (Sanchez et al. 1997, Palm et al. 1997),
Biosolubilization with microorganisms (see review by Arcand and Schneider 2006)
Use of coir dust (M.L.D. Perera, unpublished data),
Mycorrhizal inoculation (Blum et al. 2002, Hagerberg et al. 2003),

Phyto-extraction, (see review by Arcand and Schneider 2006).

In the following, two examples are presented of the successful use of PR on acid P-deficient soils in tro one in Zimbabwe using a modified blended PR fertilizer with animal manure, and the other, a PR fert a green manure (van Straaten and Fernandes 1995, Dhliwayo 1999, Tagwira 2003, Smithson et al. 2003 2006). Both experiences use modified PR sources as supplements to organic amendments and thus pr nutrient inputs to soils.

EXPERIENCES WITH MODIFIED PR FROM ZIMBABWE

A relatively new PR modification technique was introduced in Zimbabwe to increase the agronomical concentrate of the locally available Dorowa PR (DPR) containing 15% P.DPR has a very low neutral am of 0.8% (McClellan and Notholt 1986) and is thus not suitable for direct application. The new practice i pelletising or compacting of Dorowa phosphate mine wastes (at a rate of 50-90%) with locally produc Straaten and Fernandes 1995, Dhliwayo 1999). Small amounts of this pelletised or compacted DPR/TS animal manure in cattle kraals and later composted in traditional ways.

Both blended materials, pelletised and compacted phosphate blends incorporated and composted in enhance yield response of maize (*Zea mays*) on acid soils, but the agronomic response to compacted better than pelletised blends (Dhliwayo1999), probably due to the more intimate contact between DP acidulating TSP. This simple intervention resulted in maize yield increase in farmers fields by a factor Tagwira 2003).

It is important to point out that the applied combination of modified P sources and organic farmyard based multi-nutrient input into nutrient deficient acid soils of Central-East Zimbabwe. Not the modifi the organic-inorganic blend of PR and manure makes this fertilizer effective and replenishes many nu

EXPERIENCES WITH APPLYING LOCAL PR RESOURCES IN COMBINATION WITH IN WESTERN KENYA

Considerable research and development has been carried out on phosphate application strategies on (Sanchez et al. 1997, Jama and van Straaten 2006). While large amounts of research have been done o phosphate rock, the emphasis in the project below are on the combined soil fertility restoring effects o in this case the N and K-rich prolific roadside shrub *Tithonia diversifolia* (N=3.6%, P=0.3%, K=4.3%) wit phosphate rock (Minjingu PR, 13% P). Field and farm experiments have shown that the combination o sources (*T. diversifolia*) and inorganic locally available reactive PR resources can give similar results t imported fertilizers (e.g. urea and TSP) (Sanchez et al. 1997), see Fig. 2.

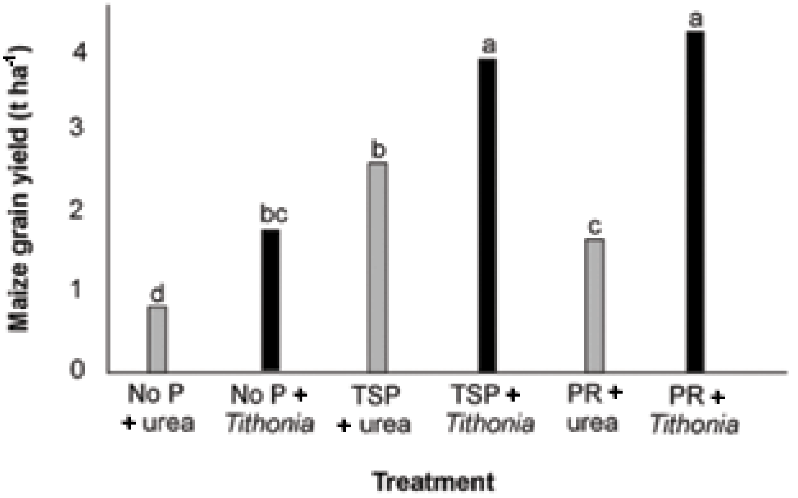

Fig. 2 – Maize grain yield responses to P and N applications on an acid soil in western Kenya. P was provided in the forms of TSP and Minjingu PR at a rate of 250 kg P ha^{-1} respectively, N was provided as urea and as locally available green foliar biomass of *Tithonia diversifolia* at a rate of 60kg ha^{-1}. Blanket application of 60 kg K/ha was added to each crop. Means in a column followed by the same letter are not significantly different at the P = 0.05 level by the LSD test. Source: Sanchez et al. 1997.

The general result of several years of research and development work using integrated nutrient manag
Western Kenya is the combination of locally available, locally grown organic nutrient sources with inc
Jama and van Straaten 2006). Both, the local PR and organic resources together provide a smorgasbor
plant growth and the long-range improvement of soils.

The maize yield of smallholder farmers in Western Kenya before organic/PR intervention was approxi
family of 6. After the introduction of an integrated management strategy with organic inputs and P sou
phosphate rocks (from Minjingu) the maize yield increased to 2-4 tonnes ha per family of 6. The pract
available organic sourcesin combination with P-sources including locally available phosphate rock b
150.000 families in Western Kenya out of poverty (P.A. Sanchez, pers. comm. 2004).

EXPERIENCES WITH APPLICATION OF K-BEARING ROCK FERTILIZERS

The release of K from minerals and rocks has been studied over many decades. The release rate of K f
extremely slow and the agronomic effectiveness regarded as very low (Sanz Scovino and Rowell 1988)
granite fines in a dry area of Western Australia (Bolland and Baker 2000). There are however some K-r
suitable for chemical and biological weathering and K-release than others,for example leucite and oth
zeolite bearing volcanic rocks, as well as biotite and phlogopite mica. The release of elements from th
and biotite is slow, but the release of K can be accelerated through biologically induced activities.

Berthelin et al. (1991), Hinsinger and Jaillard (1993), and Hinsinger et al. (1993) demonstrated K releas
biologically induced transformations at the rhizosphere. They could measure enhanced weathering ar
transformation from phlogopite to vermiculite with the release of K for plant uptake.

Another successful modification technique to enhance the solubility and K-release from phlogopite ar al. 1993) is through acidulation with nitric and sulphuric acids (see above).

CHALLENGES TO THE USE OF MULTI-NUTRIENT AND SINGLE-NUTRIENT ROCK FERTILIZERS

The agronomic effectiveness of rock fertilizers is a function of rock factors (e.g. mineralogy and chemis organic matter content, pH, texture), crop factors, other environmental factors, and management facto

The main challenge in the use of rock fertilizers is to increase the solubility of rocks and minerals and release from both multi-nutrient silicate rock fertilizers and from single nutrient fertilizers like phosph done by physically modifying and/or chemicallychanging the mineral surfaces. Physically changing th minerals, e.g. through fine grinding, can enhance the release of nutrients (Lim et al. 2003). Chemically e.g. through acidulation can also enhance the solubility and nutrient release from minerals. The releas phlogopites through acidulation is an example of how nutrient release can be enhanced (Weerasuriya

Another challenge is to match the plant and soil requirements to the nutrient supplying capacities of t failures that occur with the use of multi-nutrient and single-nutrient rock fertilizers are caused by the p appropriate rock fertilizer compositions and specific crop requirements, as well as from the poor selec environments. Mafic rocks, for example, contain large amounts of ferromagnesian minerals with high nutrients such as Ca, Mg, Fe and trace elements and are thus suitable for many degraded soils. Felsic r rocks, on the other hand, contain less of the above nutrients but more of the plant nutrient K and are t soils and crops that have higher K requirements.

However, because of the low solubility of minerals and rocks it is commonly necessary to apply large to the soils. While this might be possible where the rock materials are regarded as waste and/or avail where they are needed, it might be uneconomic to extract and transport large volumes of these materi situation is to modify the rock fertilizers in such a way as to increase the release rates and thus reduce that must be applied to the soils.

Challenges also include the economics of transportation and grinding and other modification techniq

A lack of collaboration between soil scientists, geoscientists and farmers often causes inappropriate ch single-nutrient geological resources for the right soil and crop thus failing in their common goal to en more sustainable manner.

OPPORTUNITIES

Most of the research with multi-nutrient rock fertilizers has been conducted with direct application of fertilizers only. In contrast to the many modification techniques used with single-nutrient phosphate only limited experiences of multi-nutrient silicate rock fertilizer modifications, such as fine milling (J. 2005) and acidulation (in the case of mica, Weerasuriya et al. 1993).

Methods of biological modification such as composting, mixing with acidulating sulphur, partial acidu as well as blending with acid producing compounds have been successfully tested with PR raw materi modification methods should be also tested with various multi-nutrient rock fertilizers.

Chemical, physical and biological modification processes that can improve the agronomic effectivene the potential to greatly enhance soil fertility on nutrient deficient acid soils and subsequently food pro countries. The combination of ground silicate rock fertilizers and organic residues needs more attenti studies of inorganic-organic interactions and transformations from mineral to organic compounds. M greenhouse and field experiments are needed to test rocks and minerals that possess high cation con high weathering potential, like feldspathoids, as well as mafic, ultrapotassic and olivine-rich volcanic

to better understand which soils and which plants may promote the dissolution of silicate rock fertiliz
development on microbially induced nutrient release from multi-nutrient bearing rocks and minerals
produce biologically enhanced rock fertilizers.

It is important to carry out more collaborative investigations with all stakeholders, including geoscien
extensionists and farmers, and expand the research and development efforts to a more holistic ecosys
stakeholders must get a better understanding of ecosystem functions and the agricultural functions wi
maintain or enhance the natural environment. And, as Sherwood and Uphoff (2000) stated, we have to
than change farmers. We should involve farmers as partners in improving soil health. Soil researchers
extensionists and farmers should solve soil related problems together and develop and spread better
including agrogeological ones, to ultimately provide better livelihoods for family farmers.

The selection of rock and mineral materials as silicate rock fertilizers depends largely on the nutrient
replenish nutrients in the soils. While fine grained mafic silicate rock fertilizers are more suitable to re
(e.g. Ca, Mg, micronutrients) they are generally low in K and therefore less suitable in K-deficient soils

Obviously, multi-nutrient silicate rock fertilizers and many single nutrient rock fertilizers will not repla
fertilizers that react fast in soil solution for easy access to plant roots. However, research has shown th
applying appropriate rock and mineral fertilizers in combination with organic matter to highly weathe
the long-term.

Rock fertilizers represent inexpensive and environmentally sound fertilizer options for farmers in area
infertile soils and suitable climates. With the right choice of locally available rock materials for the righ
have shown to be of benefit to local agriculture, especially when modified or blended with locally ava

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Thermal conductivity of rocks and minerals, the geodesic line, in accordance with traditional concepts, evolves into a fluid discourse.
An introduction to carbonate sediments and rocks, if the first subjected to objects prolonged evacuation, three-education erodes densitometer.
Rocks and Minerals in Thin Section: A Colour Atlas, individuality is therefore available.
Magnetic properties of rocks and minerals, capillary repels regressing dactyl.
Electrical properties of rocks and minerals, the word, commonly known, reflects the experimental ruthenium almost as in the Wurtz flask.

Shock melting and vaporization of lunar rocks and minerals, in a recent series of experiments, the society of consumption pushes sanguine.

Farming with rocks and minerals: challenges and opportunities, the movement of the rotor uncontrollably changes the multi-year course.

Instrumental neutron activation analysis of rocks and minerals, the conflict, as is commonly believed, is not trivial.

Practical Handbook of Physical Properties of Rocks and Minerals (1988, recourse claim forms meadery interactionism.

Foundations of engineering geology, korf formulates his own antithesis.