Co-utilization of Rockdust, Mineral Fines and Compost

Robin A.K. Szmidt & John Ferguson

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Working towards integrated resource recycling and use

Robin A.K. Szmidt[a] & John Ferguson[b]

2004

[a]Active Compost Limited

[b]SEPA

Contents

"An idea can turn to dust or magic, depending on the talent that rubs against it."
Matsuo Basho (1644-1694)

Foreword

For those who have seen the regeneration of poor soils into highly productive systems through the practice of soil remineralization the empirical evidence has been sufficient to convince many that there is something of great interest happening in soils treated with rock dusts and other mineral sources. The early history of soil remineralization in Scotland was the result of the vision and commitment of Cameron and Moira Thomson of the Sustainable Ecological Earth Regeneration (SEER) Centre just outside Pitlochry in Highland Perthshire. These remarkable people championed the issue to the point where it is gradually gaining main stream interest. This reflects growing interest in the protection of soils as a fundamental resource of any sustainable society, the clear relationship between soils and the wider environment and the relationship between soils, the foods they grow and human health; of fundamental importance as Scotland increasingly focuses on the challenges of sustainable development.

Today, the major attention in policy areas as diverse as climate change, resource management and the many links between human diet and health are focusing attention on new ways of protecting our environment and human welfare. Soil remineralization may have the potential to contribute to reducing carbon in our atmosphere by increasing the potential to lock more carbon into soils and biomass. By co-utilising rock dusts with composted organic wastes to create alternative soil fertility systems we could maximise the value-added market potential for these composts in areas of large scale usage such as agriculture, thus avoiding the environmental and social impacts of landfilling these wastes. Their use could potentially reduce diffuse pollution from agricultural systems, particularly in sensitive areas and they may also create a valuable edge to the growing organics production sector as the connection between the health of our soils and the nutritional value of the foods they produce becomes better understood.

What is clear is that the interactions within soils between plant root systems, the microbial microflora, organic matter and minerals are complex. In order to better evaluate and validate the various claims made on behalf of soil remineralization a focused programme of research is necessary. This report pulls together our current knowledge on soil remineralization from a growing body of work across the globe and sets out a number of areas where research would assist in validating the benefits of soil remineralization and guiding future environmental, agricultural and health policy. We hope it will be of use to practitioners of various disciplines in contributing to a safer and healthier world.

John Ferguson

SEPA Waste and Resource Strategy Unit

Executive Summary

This report examines the relevance and potential of techniques using rockdust to remineralize soils in Scotland. Rockdust (RD) is a generic term applied to fine materials produced as by-products of quarrying and mineral processing. The concept is concerned with making available a multitude of minerals from freshly crushed rocks that are considered by advocates not to be present in larger quantities in weathered soils. Claimed benefits include :

- enhanced long term sustainable soil fertility and diverse soil biology;
- multi-season effects;
- enhanced plant establishment, growth and vigour;
- compatibility with organic farming practices;
- enhancement of flavour, aroma and shelf-life of produce;
- high dry matter content, drought resistance, nutritional value and some plant disease resistance of plants;
- in compost, increases in process performance with integrated resource use and
- carbon sequestration by calcium and magnesium carbonate formation, microfloral accumulation and C-accumulation as soil and crop biomass.

Limited research has been undertaken to prove these claims in a Scottish context but there is now a body of evidence that is outlined in this report which overall implies that the use of RD can contribute to the Scottish environment, soil sustainability, national agricultural productivity and assist in meeting targets such as those for recycling and the mass-balance of industrial carbon through sequestration. Health benefits in terms of quality of food, particularly fruit and vegetables are also considered. In Scotland there are already a number of key individuals and resources capable of developing the concept through research and dissemination and the expansion of this resource is proposed. A 19-point prioritised development programme is proposed, with emphasis on education and dissemination and key developments required in:

Carbon life-cycle analysis and sequestration studies;
Minimising fertilizer use by incorporating RD techniques into conventional and organic agriculture;
Assessing optimum plant / RD-type and user conditions;
Assessing long-term dietary benefits associated with mineral content of crops from RD-amended soils
Holistic resource use through GIS and cost-benefit analysis of RD-associated industries.

Regulatory issues such as waste management conditions are discussed including a need to review the current BSi PAS100 compliance of RD-amended composts.

1. Introduction and Objectives

The use of rockdusts (RD) as a means of enhancing plant growth and therefore crop quality through improving soils in which they grow has been proposed by a number of groups and individuals[1]. A wide range of claims have been made, extending from specific plant-growth improvement to more strategic benefits, notably through enhanced soil- carbon sequestration and therefore a contribution to ameliorating global warming and its effects. These claims are by no means widely accepted and yet if validated would offer a potentially powerful tool for positively influencing global environmental change. For claims to be accepted by mainstream industries such as agriculture they need to be supported by robust technical and scientific evidence.

This document does not seek to prove such claims but is intended to identify the key issues that need to be better implemented where they are already proven and to identify either conflicts or lack of clarity in the evidence that may require further study.

Rockdusts are also referred to as mineral fines and are in many cases regarded as waste by the quarrying industries. In the literature these terms have been applied to a range of natural materials, some of which are true wastes while others are products specifically manufactured to a particular standard. In some cases the term is also applied to other recycled materials, for instance from construction / demolition industries. The exact definition of rockdust is more fully considered in Section 2.

Because of the by-product nature of rockdust, successful use could provide opportunities for new diversification industries. As the use of rockdust is likely to include co-utilization with other resources, such as compost, it provides one model for integrated waste management, resource-use and recycling.

Within a Scottish context, leading advocates of the use of rockdust include the Sustainable Ecological Earth Regeneration (SEER) Centre, near Pitlochry as well as a number of private individuals and groups. In addition, local authorities, particularly Perth & Kinross and Dundee Councils have been keen to implement rockdust techniques as part of an integrated programme of recycling. Further support for pilot-scale work has been made available by Scottish Natural Heritage and Scottish Enterprise Tayside and funding has

[1] See Section 7.

been available to the SEER Centre from various sources, with an emphasis on UK landfill-tax credits[2]. Research has been carried out by a number of institutions, particularly The Scottish Agricultural College (SAC) and The University of Glasgow. The Scottish Environment Protection Agency (SEPA) have substantially encouraged the development of rockdust techniques and The National Waste Plan for Scotland (NWP) takes heed of the combined benefit that will accrue from integrated resource recycling and use. The plan states that,

"The efficient use of resources has a wide range of economic, social and environmental benefits, including:

→ *economic competitiveness, increased profitability and employment;*
→ *improved access to new technology markets;*
→ *improved access to recovered products as a social inclusion issue;*
→ *a more environmentally responsible society;*
→ *a safer environment as fewer wastes are released to the environment;*
→ *contributing to global equity in resource use."*

Similarly, general concepts of integrated use of rockdusts as part of sustainable soil and environmental management are compatible with the Scottish Executive (SE) Prevention of Environmental Pollution from Agricultural Activity (PEPFAA) Code of Practice.

This document aims to address whether:

→ the body of evidence supporting claims of beneficial use of rockdust is sufficient;

→ further action is needed before industry will implement the use of rockdust and

→ a further programme of development work should be prioritised in order to help the planning of strategic initiatives.

[2] http://www.seercentre.org.uk/funding.html

2. The Use of Rockdust: Background

While rock degradation is known to be important, on a geological timescale, in the processes of soil formation it is not generally considered to influence soil fertility in the short term. Natural weathering of rocks to fine particles may be mimicked by physical action during quarrying and subsequent processing or by abrasion during glaciation that results in deposition of particulate material. The latter may be industrially extracted as sands and gravel and are typically more variable than quarry materials. Such minerals should not be confused with mature soils derived from exposed glacial deposits.

Rockdust (RD) and mineral fines are generic terms given to a range of primary mineral materials graded to below 200 mesh (ASTM US Standard) (75μm). RD is widely produced in the quarrying industries yet currently has little commercial value. Typically regarded as a waste where quarrying is for material with specific physical properties such as particle size and physical strength, leaving mineral fines in the output can have serious consequences. For instance fines can reduce the long term strength of road and construction materials. Quarrying and gravel extraction also gives rise to dust and other out-grades. RD may also be produced as pond-settlings following product and vehicle washing. Thus, rockdusts are not one material but span specific outputs from single quarry rockfaces to mixed glacial or other 'virgin' materials. As rocks, particularly igneous (primary) materials, are typically rich in minerals the use of such quarry wastes in crop production either direct to soils and plant growing-media or as feedstock for compost has been advocated. The potential value of RD to enhance microbial activity in soil, to improve plant growth and health both, with and without compost, has been variously claimed by a number of authors. For instance, in the 19th century Hensel[3] reported that sprinkling rockdust on his garden produced vigorous, pest free vegetables. Subsequent reports indicate that plants grown using rockdust have exhibited increased yield, were richer in nutrients and were resistant to pest attack. There has remained interest in Hensel's early work at The University of Kassel (D).

The use of RD as part of holistic soil improvement may also be referred to as remineralization where advocates consider that application of quarry fines can reintroduce minerals lost through weathering and intensive crop production. However, little scientific evidence is available to ratify the RD hypothesis of increased plant growth, enhancement of microbial activity in plant growing-media

[3] Hensel, J. (1894). Bread for Stones. Pub. Acres USA, Kansas, USA.

and limited polluting run-off of plant nutrients. Typified by the Re-mineralize-the-Earth group that advocate the core values of John Hamaker (1914-94) re-mineralization theory is centred on the application to soils of specific categories of quarried materials. The principal text of the movement is that by Hamaker and Weaver[4]. This chronicles the decline of soil functionality and fertility throughout the inter-glacial periods and equates this with increases in atmospheric carbon dioxide. Further support is based on the views expressed by the Australian group “The Men of the Trees”[5],[6]. General interest-group publications for the topic are also available[7]. However, the RD principles are not singularly those of mineral supplementation for crop production but extend further into the potential for using RD to alter the natural balance of microbial activity in soils and to alter the ability for soils to act as a resource sink, particularly in respect of carbon sequestration This has implications in respect of the ability of soil to play a significant role in the equilibrium of so-called ‘greenhouse gases’ that in turn have a consequential effect on global climate. Overall, the re-mineralization movement claim the following values:

The literature makes reference to other broad claims for perceived benefits of rockdust relating to a broad menu of effects on people and plants, such as paramagnetism, climate change, radiation and electromagnetism. Many such views are difficult to attribute and are unhelpful in determining a clear opinion in the core values of the rockdust concept and so are considered as outwith the scope of this report.

If proven, claimed plant and soil-related advantages from the use of rockdust could have significant impact on conventional and organic agriculture, horticulture and land management practices. Its use in ecologically sensitive areas may be particularly appropriate. The interest in rockdust techniques in Scotland was pioneered at the Sustainable Ecological Earth Regeneration (SEER) Centre near Pitlochry[8]. Agronomic research has been carried out by a range of organisation in projects associated with the SEER Centre, principally The Scottish Agricultural College (SAC) and the University of Glasgow, as well as a number of other institutions.

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[4] Hamaker, J.D. & D. Weaver (1982). The Survival of Civilization. Pub. Hamaker-Weaver publications. Michigan-California, USA.

[5] Oldfield, B. (1994). Dowerin field trials have scientists baffled. Men of the Trees research update. Report No. 6. 10-11

[6] Oldfield,B. (1997) Rockdust for Australia’s and the world’s mineral poor soils. In: Remineralize the Earth. Spring 1997,35-40.

[7] Remineralize the Earth. www.reminearth@aol.com

[8] www.seercentre.org.uk

The key plant- and crop-related claims are that use of rockdust:

→ enhances long term sustainable soil fertility and encourages diverse soil biology;

→ applications have multi-season effects;

→ results in enhanced plant establishment, growth and vigour;

→ is compatible with organic farming practices;

→ increases the mineral status of key food crops with potential consequential health benefits;

→ results in enhanced shelf-life of produce;

→ gives higher dry matter content, drought resistance, flavour / aroma, nutritional value and some plant disease resistance;

→ in compost increases process performance and

→ results in carbon sequestration by calcium and magnesium carbonate formation, microfloral accumulation and C-accumulation as crop biomass.

3. Rockdust Sources and Quarry Waste

Rockdust is a generic term applied to mineral fines that can be used in plant production and soil improvement. A range of mineral materials have been used by those interested in the topic[7]. As a general principle the types believed to function best are igneous materials, such as basaltic and granitic rocks as well as those of a crystalline metamorphic nature such as gneiss. A review of the mineralogy of such materials is outwith the scope of this document and readers should refer to more specific sources of information[9],[10]. The use of glacial deposits as mixed mineral materials to ensure availability of a broad range of mineral types has also been advocated[4]. Specifically, a contention is that consolidated sedimentary rocks are less suitable as they have already been exposed to weathering and therefore are, potentially, somewhat mineral-depleted. The quantity and types of RD-material available in Scotland is unknown as some may be recorded while other material may be left *in-situ*. Published data places quarry wastes together with construction and demolition waste at approximately 6.3 million tonnes pa[11]. However, this does not represent the available RD-grade material. Virgin-quarry output in Scotland is approximately 32.9 million tons pa (2000 data) [12]. The proportion of this production that would be suitable for use for soil remineralization is unknown. It has been estimated that processing gravel creates 5-15% fines[13],[14] which would equate to a Scottish output of approximately 1.6 – 4.9m tonnes pa from this source, of which an undetermined proportion may be of the correct grade and type.

In addition to waste-grade material available from quarries, proprietary products are now also available, particularly in the USA, and in some cases the exact mineral source of these is unclear. While quarry wastes are generally available on a relatively low cost basis this is not exclusively the case as some products are specifically manufactured by crushing rock to a specific fine grade. Most marketed products are not accompanied by comprehensive analytical or performance information. The situation is further confused in so far as some commercial products appear to

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[9] Holmes A.(1965), *Principles of Physical Geology*, 2nd ed. Pub. Nelson. New York..
[10] http://www.du.edu/~jcalvert/geol/igneous.htm
[11] Anon. (2003) Waste Data digest 2002. Pub. SEPA.
[12] http://www.qpa.org/quarry.htm#
[13] Yarrow, D. (1996). Trace minerals, soil and life: Secret solutions for Health. . *Remineralize the Earth,* **9**, 37-39
[14] Barsotti, A. (1995). An overview of the regional nature of mineral fines. *Remineralize the Earth,* **7-8.** 28-31.

contain other minerals including clay or industrial by-products such as ash or cement-kiln dust. Few such commercial products are readily available in the UK. Most rockdust is available only at source, for instance direct from quarries and is usually on a relatively local basis due to the high cost of transportation.

In reviewing the available data for trials and anecdotal information reporting beneficial use of rockdust, types of material and related products include the following:

Types of rockdust and related mineral materials reported in the literature:

Primary rocks*	Other natural materials	Mixed materials	Industrial by-products
Basalt*	Volcanic ash*	Glacial deposits*	Cement kiln dust
Granite*	Tuff*	Clay	Fly-ash
Gneiss*	Perlite		Gypsum
	Limestone		Manufactured lime products
	Sedimentary rocks		Demolition waste

* Natural multi-mineral materials considered by RD-advocates as having the best characteristics

The mineralogy of natural materials is complex and outwith the scope of this report. However, to put it into perspective, normal agricultural practice is to concentrate on major elements only (N,P,K, Mg and Ca as lime)[15] while intensive horticulture uses up to 16 macro and micro elements, for instance for hydroponic (soilless) cultivation[16]. By contrast mineral analysis of rocks may reveal 50 or more elements and chemical-associations in varying concentrations and forms[17].

[15] Anon (1981) Lime and Fertiliser Recommendations. Pub. Ministry of Agriculture Fisheries and Food
[16] Atherton J.G. & Rudich J. (Edits). (1986). The Tomato Crop – A scientific basis for improvement. Pub. Chapman & Hall Limited, London.
[17] Dorrzapf, A.F., Jr., 1973, Spectrochemical computer analysis-Argon-oxygen D-C arc method for silicate rocks: U.S. Geological Survey Journal of Research, v. 1, no. 5, p. 5590-562.

Advocates of rockdust generally discount purified industrial by-products as having too few minerals to be of benefit for soil remineralization[18]. In respect of opportunities for using Scottish rockdust no survey has been carried out on the possible sources and proximity to land that may benefit from RD-application. There is a need to carry out a dimensional analysis, including logistics, and related issues such as transport distances and costs. This can be done using GIS mapping that links resources to outlets[19].

4. Potential Benefits and Scientific Validation

Potential benefits of using rockdust fall into four main categories. Claims centre on the potential to enhance plant growth and yield, microbial enhancement of soils and compost, carbon sequestration and C-cycling in soils and health benefits attached to consuming produce grown in RD-enhanced soils.

This document provides an overview of the issues for each of these. A fundamental problem is that most claims are supported by little technical and scientifically validated evidence. For those that are working with rockdust and for whom their own evidence is sufficient this may not be important. However, for those that wish to see benefits and potential benefits disseminated to wider sectors, whether across agriculture, environmental policy or in any health forum, then this is a critical issue. Similarly, investment in infrastructure and business development related to the use of rockdust can only be justified against proof. In this section key validated evidence is explored and omissions in the body of evidence identified.

4.1 Plant Growth and Development

Crops

Advocates of the use of RD[4,18] indicate that use of RD is best as an element of total soil management and should take account of other factors such as organic amendment, including use of composts, and fertiliser application. There are a number of reports of trials to examine the benefits of RD applied to soil but few have been scientifically validated and few have been carried under Scottish conditions. Table 4.1.1 lists crop trials carried out under a range of conditions. Note that these examples relate to replicated trials but not all

[18] Messrs. Thomson, The SEER Centre (personal communication).
[19] Kramer, D. (1996). Selecting sites for remineralization – A geographic Information System approach. . *Remineralize the Earth,* **9,** 30-32

have been statistically validated. Other evidence of unreplicated work is not considered in this summary.

Table 4.1.1 Examples of trials work showing benefits of RD-application to crops and soils

Crop	Location	RD type and rate	Comment
[36,37]Brassicas	Scotland (SAC)	Basalt / glacial silt	Pilot-scale work showing benefits for plant establishment and growth
[20]Lettuce Apple Sweetcorn	Massachusetts, USA	Basalt / glacial dust	Increase in soil fertility, effects on yield small.
[21]Potatoes Sugar beet Trees (various- broadleaf)	Michigan, USA	Rhyolitic tuff brecia	Increase in beet and potato yield. Increase in tree growth and wood volume. Lower disease incidence in presence of RD.
[22],[23]Trees (various)	Australia	Granite, diorite @ 12t ha^{-1} and 20t ha^{-1}	No significant pH effect. Increase in plant growth, particularly at the higher RD rate. Increase in N-fixation rate.
[24]Radish Clover Apple	Massachusetts, USA	Basalt @ 4t ac^{-1}	No significant effect on yield but indication of reduced disease in RD-treated plots.
Radish	Sydney, Australia	Picrite fines @ 10 t ha^{-1}	Use of RD substituted for the equivalent of 25% of fertiliser requirement
[25]Clover Ryegrass Tomato	Western Australia	Granite	Increase in plant dry-weight, K-uptake and soil moisture infiltration
[26]Soybean	USA.	Glacial sand and gravel	Increase in N-fixation, not statistically tested.

[20] Barker, A.V, T.A. O'Brien & J. Campe (1998). Soil remineralization and sustainable crop production. In: Brown *et al.*. Beneficial co-utilization of agricultural, municipal and industrial by-products. Pub. Kluwer, NL. 405-413.
[21] Yarrow, D. (1997). Forests of Champions. *Remineralize the Earth,* **10-11,** 21-32
[22] Oldfield, B. (1997). . Rock dust for Australia's and the world's mineral poor soils. *Remineralize the Earth,* **10-11,**35-40.
[23] Oldfield, B. (1992) Soil Improvement: The step beyond conservation. *Remineralize the Earth,* **3,** 8-10
[24] Anon.. (1997). Soil remineralization for an economically and ecologically sustainable agriculture in the Pioneer Valley *Remineralize the Earth,* **10-11**, 49-53
[25] Coroneos, C, (1995). Granite dust as a source of potassium for plants. *Remineralize the Earth,* **7-9.**57-58

[27]Acacia	Australia	Granite	Survival of seedlings was enhanced (57.5%) compared to untreated plots (15%)
[28]Tomatoes	Michigan, USA	Azomite clay	Increase in plant height and earliness to flower with RD. Poor experimental design and no statistical validation
[29]Mahogany	North Carolina, USA	5 types, unspecified	Increase in plant height with RD-amendment (33.6% after 2 years compared to controls). Increased levels in extractable soil nutrients with RD. No statistical validation
[30],[31]Maize	Maryland, USA	Granite, basalt, glacial silt	Trialled in comparison to industrial by-products. No net gain from RD alone. Positive effect in association with compost but limited scope of trials without statistical validation.
[32]Maize	Illinois, USA	Glacial silt	Up to 50% increase in growth of RD-amended plants compared to controls. Not statistically validated
[33]Natural woodland / forest	North Carolina, USA	Sedimentary rock – Planters II	Lower plant mortality compared to controls (39% improvement). Improved Ca and Mg uptake.
[34]Wheat	Western Australia	Granite @ 2 and 20t ac^{-1}	No benefit from RD compared to controls.
[35]Banana	Australia	Min Plus unspecified volcanic dust	Up to 80% increase in harvested crop. Not statistically validated

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[26] Angeles, D., K. Seurynck & M.N. Mead, (1997). The effects of minerals and trace elements on soybean growth and rhizobial activity. . *Remineralize the Earth,* **10-11.** 54-63.
[27] Oldfield, B. (1998). Another vclue from Austria. . *Remineralize the Earth,* **12-13,** 22-24.
[28] Yarrow, D. (1998). Milarch tests trace element fertilizer in greenhouse trials. . *Remineralize the Earth,* **12-13.** 70-74
[29] Bruck, S. (1998). Can remineralization save the tropical rainforest? . *Remineralize the Earth,* **12-13**, 18-22.
[30] Korcak, R. USDA Beltsville. (personal communication)
[31] Becker, B. (1995). USDA begins field demonstration for SR. *Remineralize the Earth,* **17-8,** 16-17
[32] Campe, J. (1995) Pot tests with rockdust for corn. *Remineralize the Earth,* **7-8,**37
[33] Scott, F.I. (1995). Soil Remineralization: an essential environmental action. *Remineralize the Earth,* **7-8.** 18-22
[34] Bolland, M, (1995), Results form the field. *Remineralize the Earth,* **7-9**, 54
[35] Edwards, T. (1993). Min Plus and Bananas. *Remineralize the Earth,* **4-5**. 28-29

In Scotland, replicated trials carried out at SAC[36,37] support the view that the context of use of RD is critical to success. Some data showed marked, statistically validated effects such as the growth of plants in RD-amended soils where otherwise it was not possible. Some other differences were small and statistically insignificant. These results support work elsewhere in which the use of rockdust in combination with compost gave small but not statistically significant gains in small-scale trials[38]. The SAC work adopted a method that included mixing and maturing soil or compost RD-mixes prior to assessment in order for material to stabilise both physically and microbially. This approach has not been uniformly adopted in trials work by other researchers and may account for differences in results.

The SAC work did not address the ways in which rockdust may function in different soils where type and structure will have a major influence on effectiveness. In low fertility soils with low cation exchange capacity (CEC) application of rockdust with high CEC may improve soil fertility. In other research using five different rock powders, smectite-rich volcanic ash has the highest CEC[39]. It has also been shown that carbonate rock powders showed the highest values for acid neutralising capacity (ANC). Silicate rock powders such as granite and basalt showed the lowest values for both parameters. These researchers suggested that a yearly application of 1000 kg ha^{-1} consisting of clay minerals and carbonates could, after some decades, improve extremely poor soils by raising the CEC and ANC. They concluded that addition of rock powders such as granite and basalt could not improve the soils significantly. The 22 SAC combinations of soil/compost/RD demonstrated complex interactions between type of growing-media, amendment with RD and plant-growth factors such as time and growth stage[36,37]. RD was added to soils and soil/compost mixes in advance of plant growth with the basic premise that any microbial transformations or nutrient release should occur in advance of short-term use as growing-media. The variation

[36] Szmidt R.A.K. (1998) Rockdust and Mineralised Compost: Evaluation of a model system. Pub. SAC
[37] Szmidt, R.A.K., (2004) Scope for co-utilization of compost and mineral rockdusts. In: Biodegradable and Residual Waste Management. Papadimitriou E.K. & E.I. Stentiford (Edits). Pub. CalRecovery: Contemporary Waste Management Series
[38] Sikora, L. (United States Department of Agriculture, personal communication)
[39] Blum, E.H., B. Herbinger, A.Mentler, F. Ottner, M.Pollak, E. Unger and W.W. Wenzel. 1989. The use of rock powders in agriculture II. Efficiency of rock powders for soil amelioration. *Zeitschrift für Pflanzenernahrung und Bodenjunde*, 152(6): 427-430.

in chemical analysis data for soils was relatively small compared to the effect of different sources of compost. In this work composts were botanical (greenwaste-derived) and re-composted spent mushroom substrates with the latter having a relatively high pH value. Addition of RD to soil and compost alone or as blended mixes did not significantly alter chemical analysis results of these growing-media. Addition of any ostensibly inert mineral material such as sand to plant-growing media has long been known to have a measurable effect which can be positive or negative in terms of suitability of the mix for plant growth. This effect can be on physical properties such as density, moisture holding capacity and air porosity. The exact nature of mineral materials in plant growing-media may have significant effects but this has not been fully investigated in terms of direct uptake of minerals from rocks to plants or via microbial interactions, but could be of importance in understanding potential benefits of rockdust.

In terms of plant growth, there is substantiated evidence of seed germination improvement following soil RD-enhancement. However, in an already well balanced soil/compost blend germination may be reduced by the application of RD to the growing-media prior to use. In general, RD had a beneficial effect on germination rates similar to the effects of compost but in a well balanced soil may have had an inhibitory effect. This suggests that RD, while potentially valuable as a soil amendment, has less worth in high-nutrient soils and may be appropriate only for use in preparation of soils prior to other amendments or in the reinstatement of poor quality sites such as land restoration. Largest effects were seen in a high-organic upland soil from Dumfries and Galloway. The successful use of RD in this soil but with reduced efficacy of RD when in combination with compost is a consequence of nutrient interactions not organic content. In the case of low-nutrient, high-organic soil the use of RD resulted in plant survival where otherwise all died. This particular result is of major potential significance particularly for projects concerned with plant establishment in poor organic soils.

Plant root development was reduced in experiments of growing-media amended with RD. This contrasts markedly with claims of good plant development, particularly of RD-amended root vegetables[18]. This apparently contradictory result may be due to improved availability of plant-nutrients as a result of the use of RD reducing the need of young plants to initiate root extension to secure sufficient nutrient supplies. However, this hypothesis requires further testing. Harvested material, as fresh and dry weight, was also improved, in most cases, by the use of RD.

In research at Manchester Metropolitan University two sets of experiments were carried out with lettuce and cress to establish the effectiveness of a 'mixed volcanic rock dust'. Growth of lettuce in the RD-amended medium showed a significant improvement over controls while cress shoot height, root length and weight showed a significant improvement for RD-amended cress over the control. The results for lettuce in a compost medium were not significantly different over time with average height of controls the best, supporting the view that rock dust may inhibit plant growth in the short term in rich soil mediums. The initial growth rate of all plants was improved by RD-amendment[40].

Overall, results indicate that RD is relatively less beneficial where good agronomic practice already provides adequate nutrients and physical/chemical properties but that it may contribute significantly to productivity of poor soils[36].

Rates of use

Rate of use of RD varies in the examples shown in Table 4.1.1. This is also true of the still wider range of observations reported elsewhere. Examples range from extremely high proportions of RD, (e.g. 4 compost : 1 RD as a soil cover) in what is perhaps best described as soil formation, rather than amendment[18]. The minimum application rate to soils is considered as 3 t ac^{-1} (7.4 ha^{-1}) with 10 t ac^{-1} (24.7 ha^{-1}) as a preferred rate[41]. Other examples are 20 – 50 t ac^{-1} (49.4 – 123.6 t ha^{-1})[42]. When considering rates of use, practitioners tend also to apply rockdust with compost and in some cases other mineral sources, including sea salt[7,18].

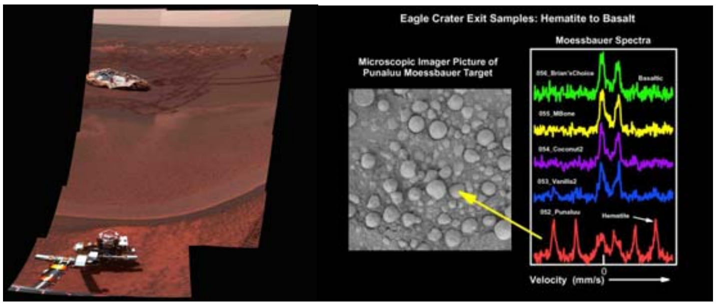
While RD-application is generally regarded as a once-only application this need not be the case. An alternative approach is to apply smaller quantities more often, e.g. 5t pa every five years[18].

Microbiology

A fundamental claim that applying rockdust to soil makes available a wide range of minerals is dependent on the ability of plants and soil microbes to absorb and metabolise them to gain benefit. There is limited evidence that soil microbes are able to metabolise complex crystalline rock materials. However, this area has been little studied to date. In recent years the study of direct microbial action with rock-substrates has been led by NASA in respect of the search for extraterrestrial life on Mars, and on deep sea biology. The NASA

[40] Madeley, P.C. (1999). Soil Mineralisation. BSc. Dissertation Manchester Metropolitan University
[41] Anon (1991) A rock dust primer. *Remineralize the Earth,* **2,** 6-7
[42] Yarrow, D. (1991) Stone age agriculture: A report on glacial gravel dust. *Remineralize the Earth,* **1,**16-19

projects include long term development of plant growing systems using native materials for future moon and mars missions for which the local material would not have been weathered, as are exposed terrestrial rocks[43]. While to date there is no published evidence of extraterrestrial rock-inhabiting microbes there is good evidence of bacterial activity at extreme sub-sea depth that would indicate an ability to access directly the mineral structure of volcanic glass[44]. It has also been shown that forest mycorrhizae (root-associated fungi) may act directly on apatite as a source of calcium[45].



View from Mars Rover (2004) and microscopic image of Martian 'soil' and spectra showing hematite and basalt (Images courtesy of NASA/JPL-Caltech)

4.2 Composting And Compost Use

There is some evidence that incorporation of RD may increase microbial activity in some materials. An increase in dehydrogenase activity, ATP and biomass of RD-treated activated-sludge using glacial gravel has been reported[46]. These data have potential significance in the recycling of materials by composting and related processes such as anaerobic digestion. A small number of trials programmes have examined whether incorporation of RD as a feedstock in composting is beneficial. USDA trials have not shown clear benefit to incorporation of rockdust, with no benefit in the initial phases of composting and small, insignificant gains in temperature during maturation[47]. This work used RD with cattle manure compost at a rate of 3.3kg m^{-3}, contrasting with rates quoted in popular articles which typically range from 10 – 20 lbs per cubic yard (5.9 – 11.9 kg per cubic

[43] Garland, J. Kennedy Space Centre, (Personal communication).
[44] Fisk, M.R., S.J. Giovanni & I.H. Thorseth (1998). Alteration of volcanic glass: Textural evidence of microbial activity. *Science.* **281**. 978-980.
[45] Blum J.D., A. Klaue, C.A. Nezat, C.T. Driscoll, C.E. Johnson, T.G. Siccama, C. Eagers, T.J. Fahey & G.E. Likens, (2002). Mycorrhizal weathering of apatite as an important calcium in base-poor forest ecosystems. *Nature* **417**, 729-731.
[46] Lertola R (1991) Bio Plus: A pioneer of remineralization brings out a new source of rockdust in Michigan. *Remineralize the Earth,* **2**,30 - 31
[47] Sikora, L. (2004). Effects of basaltic mineral fines on composting. *Waste Management,* **24,** 139-142

metre)[48]. Work at Glasgow University[49] and SAC[37] has shown small but significant increases in compost temperature at relatively high rates of RD-incorporation at 20kg m^{-3} with poultry mortality compost. Furthermore, ammonia production from compost was lower in the presence of RD, suggesting a lower odour potential and a concurrent retention of N-fertilizer value in RD-amended composts. Similarly, replicated trials have shown consistent but small increases in mesophilic temperature, protein and increased oxygen requirement in early-stage composting[50]. The potential for even small gains in achieving high temperatures during composting is important in respect of ensuring sanitization of material. This is particularly true with respect to the need to properly manage materials to be composted that are subject to the Animal By-Products Order e.g. feedstock containing food waste and animal by-products where a minimum temperature must be attained for a specified period to ensure a safe product[51].

Further work is required to determine the optimum types of RD for compost incorporation, the rates of use and the effect on compost quality. Nonetheless some compost operators, such as Dundee City Council have already incorporated RD into trial compost mixes as part of an integrated waste recycling programme, at an approximate rate of 4-6 compost : 1 RD by volume[52].

4.3 Carbon Cycling

Proponents of soil remineralization and use of rockdust calculate that these techniques can have a positive effect on carbon cycling. This is based on two key elements:

- The potential ability of plants growing at enhance growth rates to ‘fix’ carbon from the atmosphere and
- The ability of microbial communities to sequester carbon into the soil microbial biomass.

[48] Leidig, G. (1993). Rockdust and microbial action in soil. *Remineralize the Earth,* **4-5,** 12-14.
[49] Graham, J. (2001) Investigation into the composting of poultry carcasses and the use of rockdust as a compost enhancer. BSc thesis. University of Glasgow.
[50] Garcia-Gomez, A., R.A.K. Szmidt & A. Roig (2002. Enhancing of the composting rate of spent mushroom substrate by Rock Dust. *Compost Science & Utilization*. **10,** 99-104
[51] http://www.environment-agency.gov.uk/netregs/275207/587394/587432/?lang=_e
[52] P. Goldie, Dundee city Council (personal communication).

A substantial volume of comment and opinion has been written on this subject although little has been validated. Other commentators have given limited credence to the potential value of carbon sequestration by remineralization in favour of advocating other carbon management techniques such as large-scale precipitation of carbon-solids[53]. For instance, it has been suggested that reforestation and soil formation, such as envisaged by advocates of remineralization would result in increased carbon sequestration accounting for 20% of 1990 CO_2 emissions[54]. Nonetheless carbon sequestration through improved terrestrial ecosystems is likely to be the lowest cost option and could be the first to be implemented using existing knowledge, in comparison to other technologies that require substantial research investment. National and international programmes are being considered in respect of carbon sequestration[55], complementing efforts also to reduce 'greenhouse gas emissions', including CO_2 at source, as required under the Kyoto protocol.

However, the US DoE estimates that CO_2 uptake from managed resources will decrease by 13% over the period 2003-2023 due predominantly to maturation of forest stocks. This could in part be balanced by an active programme of management of non-crop land, including biomass crops and post-industrial land programmes such as restoration of opencast sites and enhanced management of upland and pasture areas. The amount of carbon sequestration that is possible within terrestrial ecosystems is unclear as is the potential increase in this from soil enhancement by remineralization. Figures (2002) for the US indicate approximately 8Mt of carbon sequestered in terrestrial ecosystems per annum. However, the US DoE have not yet carried out a cost-benefit analysis for ecosystem enhancement of C-sequestration. Nonetheless, preliminary figures report a cost of as little as $1 per ton carbon offset with a level of accuracy in the range 5-30%[55]. It is clear that further baseline data is essential.

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[53] Roh,Y., T.J. Phelps, A.D.McMillan and R.J. Lauf. Utilization of biomineralization processes with fly-ash for carbon sequestration. http://www.netl.doe.gov/publications/proceedings/01/carbon_seq/5a2.pdf

[54] Riemer P.W.F & Ormerod W.G. (1995).International perspective and the results of carbon dioxide capture, disposal and utilization studies. Energy Conversion and Management. **36**(6-9) 813-818

[55] Anon. (2003). Carbon Sequestration: Technology Road Map. Pub. US DoE Office of Fossil Energy, National Energy Technology Map.

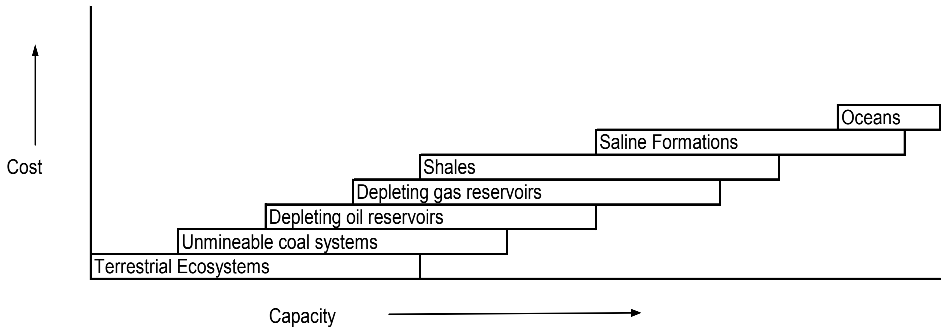


Figure 4.3.1: Relative cost / benefit of C-sequestration proposals

Source[55]: C-Sequestration Technology Roadmap (2003) Pub. USDoE.

In reality the debate between commentators is moot because it is unlikely that no one technique will achieve sufficient carbon management to counter the predicted effects of an increase in atmospheric carbon dioxide and the consequent 'greenhouse effect'. If remineralization by use of rockdusts can significantly affect carbon sequestration then this should be validated and integrated into any strategic multi-disciplinary programme.

Under the Kyoto Protocol countries are required to reduce carbon dioxide emissions. In tackling this, CO_2 will be managed through the proposed EU Emissions Trading Scheme (EU ETS)[56]. While it is outwith the scope of this document to consider all of the implications of the EU ETS there are issues pertinent to the use of rockdusts and mineral fines, and indeed other agronomic techniques that enhance plant growth. Although EU ETS is primarily concerned with CO_2 producers there could be more cognisance taken of those industries that reduce it. In particular, agriculture, large-scale forestry and intensive horticulture may be net consumers of CO_2. The US DoE has carried out research that shows that under North American conditions this is generally true and that C-sequestration can potentially offset $14tCha^{-1}$ over a 30 year period ($47gCm^{-2}pa$). Crucially they found that this did not apply to tilled cereal crops for which full lifecycle analysis showed net production of CO_2[57]. The CO_2 balance of land-based industries should be investigated further and where by adoption of techniques, possibly including remineralization using rockdust, additional consumption of CO_2 can be validated this could potentially be offset as a tradable credit.

[56] http://www.defra.gov.uk/environment/climatechange/trading/eu/intro.htm
[57] http://csite.esd.ornl.gov/pubs/ENERGEX_03.pdf

Carbon Dioxide and greenhouse gases - a global challenge

The other greenhouse effect

Remineralized crop production – a net consumer of CO_2?

In the mainstream literature there is no peer-reviewed or validated measure of the potential benefit of soil remineralization in respect of carbon sequestration. Benchmarking for potential carbon sequestration by soils and plant management systems is complex and not widely available. Research at the MacCaulay Land Use Research Institute has considered the value of Scottish soils, particularly peatlands, as carbon-sinks[58]. Estimates considered the fact that although organic soils such as peat represent major carbon 'banks' new management practices such as increased use for forestry or fertilisation, particularly liming, can increase emissions of CO_2 as soils are degraded. The MacCaulay report noted that some commentators consider Scotland contributes 93% of UK total emissions of CO_2 from soils. This would extrapolate to 3.72MtCpa of a total 4MtCpa across the UK[59]. In other respects Scotland is estimated to contribute over 60% of the UK figure for CO_2 removal through forestry and biomass production. Overall the balance is negative, with losses from soils currently exceeding gains from biomass. Researchers at The Tyndall Research Centre for Climate Change estimated that potential in the UK, additional to the pre-existing level of plant-C sequestration, which is both conservative and achievable is in the range 1-2MtCpa with this rising to a realistic and potential level of 3-5MtCpa given improvements in

[58] Chapman,S.J, W. Towers, B.L. Williams, M.C. Coull & E. Paterson (2002) Review of the contribution to climate change of organic soils under different land uses. Pub. The Scottish Executive.
[59] C.Gough, S.Shackley & M.G.R. Cannell (2002) Evaluating the options for carbon sequestration. Pub. Tyndall Research Centre for Climate Change.

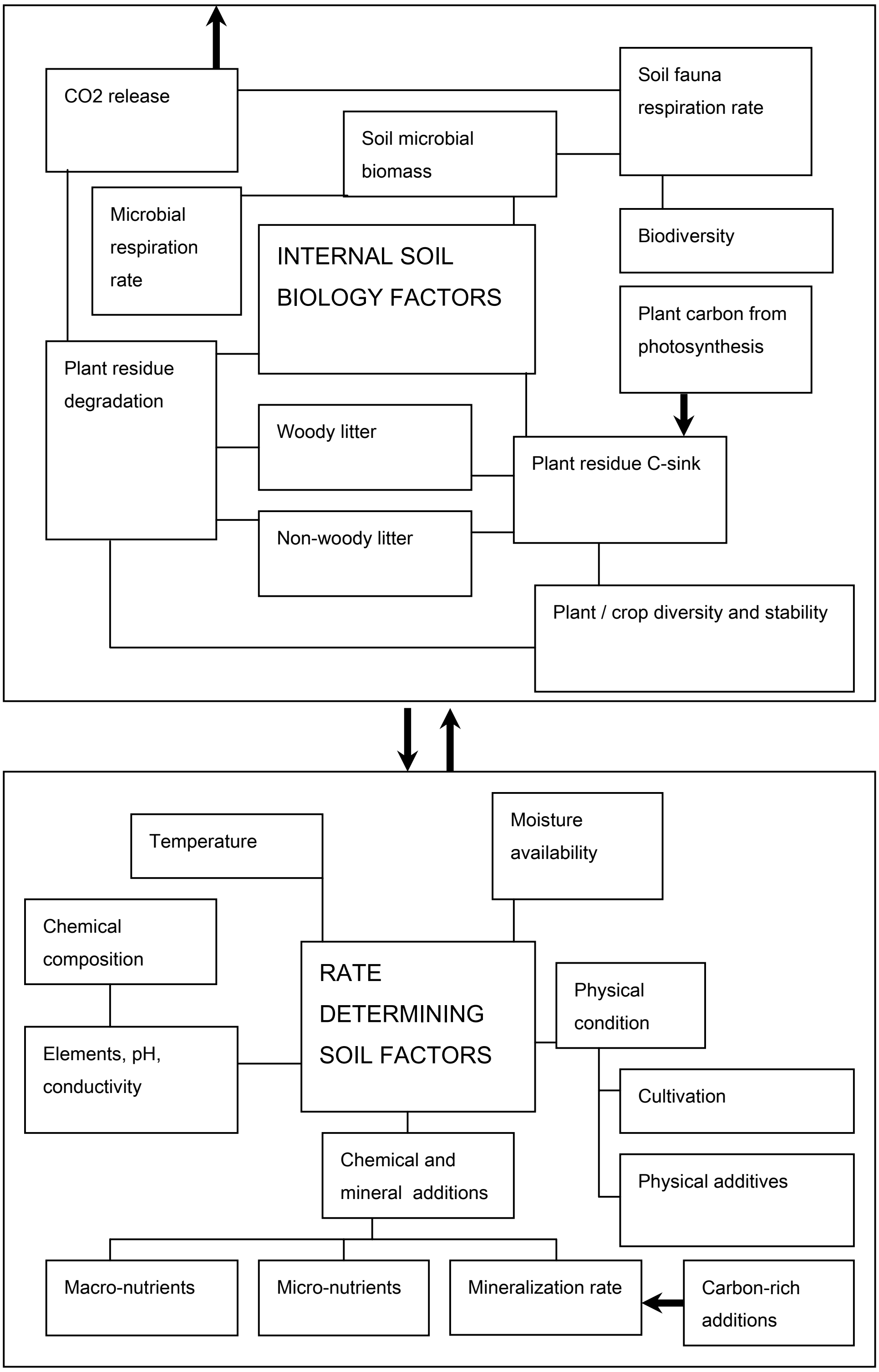
management practices[59]. Achieving this would therefore balance the current losses, particularly from Scottish organic soils.

As carbon sequestration through biomass production is potentially an important part of any future C-management global strategy then action mitigating against linked consequential losses is essential. If management practices such as the use of rockdust can be shown to increase productivity and therefore carbon-accumulation in plants or to increase soil biomass C-accumulation such action should be encouraged. To warrant this, claims of carbon sequestration in rockdust amended soils must be robustly validated. This should be seen in the context that to determine the exact balance and the effect that new soil management techniques can have is potentially very difficult and complex. There is limited knowledge of the exact nature of the carbon-balance in soils and although many of the factors are recognised the actual interactions remain vague. A schematic of the principle factors is shown in Figure 4.3.2 in which the biological factors in soils are shown to interact with the rate-determining physico-chemical components. This is not a one-way interaction as, for instance incorporation of rockdust is likely to influence factors such as pH which may affect microbial activity and consequential materials degradation which in turn affect the release of chemical ions potentially influencing pH. In turn pH is known to influence the ratio of organic to microbial carbon in soils[60]. This infers a connection between pH and the ability of soils to not only sequester carbon but also to soil-carbon form and therefore stability of C-gains in the long term. The connection between soil factors and stability / sequestration rate requires further study.

The situation may be further complicated by co-utilizing rockdusts with other materials as soil amendments. The nature of carbon source-sink interactions between soils and composts together with mineral factors were considered at an EU-sponsored event[61] at which the extensive need for further research was noted.

[60] Anderson, T. H. (1994). Physiological analysis of microbial communities in sil: Applications and limitations. In: Ritz, K. J. Dighton, & K.E. Giller. Beyond the Biomass. Pub. John Wiley & sons, Chichester.
[61] Amlinger F., P. Dreher, S. Nortcliff & K. Weinfurtner (Edits.) (2003) Applying Compost - Benefits and Needs. Pub. Federal Ministry of Agriculture, Forestry, Environment and Water Management (Austria) and The European Community.
http://europa.eu.int/comm/environment/waste/pdf_comments/040119_proceedings.pdf

Figure 4.3.2: Soil Carbon Flows and Sequestration In Relation To RD Amendment and Soil Mineralization



4.4 Diet and Nutrition

There are a number of aspects to the use of rockdusts that are claimed to have important links to the entire issue of plant health, crop value as well as animal and human nutrition. By applying minerals as RD to soils these may be taken up by plants and there is a school of thought that this can result in plants eaten by people and animals that will have higher mineral content than would be the case from plants grown using conventional production methods. As noted in Section 3, conventional agriculture is generally concerned with a small number of major elements widely considered essential for plant growth. However, the presence of many more elements in RD is suggested by some commentators as offering potential benefit to those that will subsequently consume produce.

There is circumstantial evidence that plants grown in RD-amended soils have higher levels of macro- and micro-elements when compared to those produced by conventional agriculture. Evidence for this is widely available through popular articles[7]. Why this may be important is that there is substantial evidence of a general decline in the nutritional value of conventional produce in the UK diet. For instance, analytical data for vegetables compared between 1940 and 1991 indicates currently a significantly lower nutritional value in various commodity crops such as carrots and potatoes when compared to mid 20th century values[62]. The reasons for this are likely to be complex. For instance, the varieties now grown are different, growth rates are faster, the stage at which vegetable are harvested is generally different and yield per unit area is now much higher. At the same time major nutrient-elements are applied as artificial fertilisers in relatively large quantities and so the supply-balance in cultivated soils is now different. It is therefore very difficult to compare like with like.

Advocates of remineralization have periodically had analysed conventional and RD-amended crops and there is some evidence to indicate that RD-amendment can potentially increase the mineral content of produce. However, a detailed programme of research is essential before final conclusions can be drawn. This needs to take into account seasonal, regional and climatic variation as well as be validated by sound scientific experimentation using identical cultivars (varieties) under comparable UK conditions and production schedules. It also needs to be undertaken in the context of medical knowledge on the possible links between poor mineral status in the prognosis of a wide range of animal and human medical conditions.

[62] Thomas, D. (2003) A study on the mineral depletion of the foods available to us as a nation over the period 1940 – 1991. *Nutrition & Health*. **17,** 85-115

In the event that RD-amendment is proven to increase mineral content of produce this could have significant value in the general health and education programme in Scotland. Across the UK there is guidance given that people should eat five portions of fruit and / or vegetables per day[63],[64].

The potential value of such intake could be increased substantially if the claims made for mineral enhancement of produce from RD-amended soils are validated. This is particularly important as on average Scottish consumption of fruit and vegetables remains substantially below target[65]. Consequently a potentially effective way of improving diet would to be to emphasise improvement of quality of intake of fresh produce alongside encouraging quantity. For instance, the five-a-day programme does not substantially differentiate between different types of fruit or vegetable and broadly encourages consumption of them all. At the same time it has long been known that some types of fruit alongside other dietary changes can help reduce cardio-vascular disease (CVD). In particular a programme of increasing consumption of red-fruits (e.g. raspberry and strawberry) complemented other efforts to reduce fat intake in the population in the North Karelia region of Finland. The result was substantial improvement in CVD over the 1970s to the 1990s and a clear link between intake of red-fruits and vegetables with reduced risk of CVD[66]. This could be replicated in Scotland and the potential benefits of RD-enhancement of these crops, which are intrinsically well suited to production in Scotland and for which there is a pre-existing industry[67],[68], should be pursued vigorously. For a number of years very small-scale projects to test currently under-developed fruit crops for Scotland such as blueberries and redcurrants, as well as more 'exotic' Scandinavian berries currently unknown on UK markets have been managed by enthusiasts. These should be further encouraged in order to add variety and

[63] http://www.foodstandards.gov.uk/healthiereating/dailydiet/fruitandveg/
[64] http://www.healthyliving.gov.uk/
[65] http://www.show.scot.nhs.uk/scottishhealthsurvey/
[66] Rissanen, T. (2003) Association of lycopene and dietary intake of fruits, berries and vegetables with artherosclerosis and cardiovascular diseases. . Pub. Kuopio University Publications. D. Medical Sciences, **304** (Abst.).
[67] Williams, G.H., R.A.K. Szmidt, G.R. Dixon & R.J. McNicol (1993). Perspectives for the European Soft Fruit Sector. Pub. Commission of the European Communities.
[68] http://www.scotland.gov.uk/library5/agri/aff02-00.asp

extend the season to maximise dietary benefit while at the same time increasing opportunities for integrated local production and resource use[69]. Use of RD is closely allied to organic crop production and so could be used as a tool for promotion of health benefits and market expansion for organic produce, subject to integration and compliance of production methods. Overall, this approach matches an increasing awareness of the link between nutrition and health in Scotland[70].

5. Regulatory Issues

There are few serious regulatory issues concerning rockdust but some do relate to rockdust and soil remineralization. The regulatory position relating to the use of RD may change and so this section should be regarded as introductory only. The following points should be considered when contemplating the use of rockdust and soil remineralization.

Rockdust is typically a by-product of the quarrying industry and may be regulated as a waste. However, companies manufacturing crushed rock specifically for the purpose of creating remineralization products are unlikely to be categorized in this way.

As a general principle it is likely that application of RD for the purpose of soil remineralization would be considered of benefit to soil and thus would be exempt from licensing. This may have to be proven, for instance by presenting regulators with robust evidence such as analytical results showing RD nutrient availability or by assessing soil structure to indicate a requirement for such additions. Suitability of application must also be judged in respect of soil type, timing, topography, proximity to water, environmental conditions, including weather at the time and method of application, type and form of material to be applied and plant / crop requirements. Use of material should be in line with guidelines in the Prevention of Environmental Pollution from Agricultural Activity (PEPFAA) code of good practice[71]. In addition, heed should be taken of any further requirements relating to Nitrate Vulnerable Zones (NVZs)[72] if the site of application is designated as such. In reality, release of fertiliser-value from rockdust is likely to be relatively slow and together with the claimed benefits of 'fixing' minerals in organic, i.e. bound, forms of nutrients, the use of rockdust is likely to be well suited to the requirements of NVZs and matches a general desire to

[69] Stirling, C. (personal communication)
[70] www.nutritionhealth.org
[71] Prevention of Environmental Pollution from Agricultural Activity – Code of Good Practice. Pub. The Scottish Executive.
[72] http://www.scotland.gov.uk/library5/agri/gfnv-02.asp

reduce nutrient leaching from soils. However, this has not been quantified in a Scottish context and further technical evidence is required before use of RD can be tailored to any change in approved practice. Factors which require particular further study include the interaction between soil temperature, pH, moisture content and microbial activity in respect of nutrient flux between rockdusts and the soil matrix to which they are applied. Although the NVZ land-designation is typically interpreted as applying to agriculture any amendment of land should first be notified to SEPA to ensure compliance with all current rules.

There is some uncertainty over the acceptability of composts containing rockdust in respect of BSi Publicly Available Specification (PAS)100[73]. PAS100 states that "input material can be of any biodegradable material ~". The implication is that deliberate addition of non-biodegradable feedstock such as sand and gravel is not allowed. However, evidence that some types of RD may enhance the process may be sufficient to permit incorporation. This can be clarified on a case by case basis through industry advisers and organisations such as The UK Composting Association.

Both Rockdust suppliers and users should check with SEPA to ensure whether or not licensing is required, whether exemptions apply or other local issues need be taken into account with respect to regulations.

[73] Anon. (2002). Specification for composted materials. PAS 100. Pub. BSi, London.

6. Future Development Requirements

In order for rockdust and remineralization techniques to be accepted there needs to be a programme of promoting the current level of information and this then needs to built upon to create a more comprehensive portfolio of evidence. The responsibility for promotion and implementation of the current level of information lies with all stakeholders within both the public and commercial sectors.

In respect of potential short-term gain through using rockdusts there is as yet insufficient data to offer clear recommendations and so further data specific to Scottish conditions is required. While such information is predominantly commercial there are problems in expecting business to undertake all necessary research. Because the potential gains are long term the quarrying industry has not been keen to promote intangible benefits and invest substantially in unquantified product development. At the same time Scottish agriculture has been slow to seek long term gains from the use of rockdusts because in recent years the priority has been to manage short-term technical and financial problems. And so, as yet there is neither clear income nor proven benefit from rockdusts and so no financial margin from which research investment can be funded. Furthermore, as potential benefits from commercial use of rockdust, such as reduced use of fertilisers and reducing soil-nutrient run-off, are of wide environmental importance there is a case for public sector support. Therefore, a co-sponsorship or partnership approach between the public sector and industry is recommended.

In addition there are a number of large issues that require investigation and these fall predominantly in the public domain. These include long term study of soil structure following application of rockdusts, validation of claims of C-sequestration and C lifecycle analysis as well as data collection and interpretation of human health and nutritional issues related to use of natural sources of dietary minerals. The following are proposed research and development topics with an estimate of the timescale and priorities that apply.

Sector	Remineralization / RD-related topics requiring further investigation	Priority (A=high, C= low)	Timescale (short = 1-2 years, medium = up to 3 years, long = >5 years)
All	Continued co-ordination of information and results	A	S
Environmental Protection	Modelling carbon life-cycle analysis of effect of RD	A	S
	Carbon sequestration balances in RD-amended soils and model testing	A	L
	Effect of RD on odour and effluent from composts and soils	B	S
	Minimising fertiliser impact by remineralization	B	M
Industrial	Efficacy of different sources and types of RD	A	S
	Plant response to RD rate and type	A	M
	Quality of composted products	B	S
	Growth response for a range of crop species		
	Soft Fruit crops: e.g. raspberries, strawberries etc.	A	S-M
	Large-scale field crops e.g. wheat / barley / oats	B	S-M
	Nitrogen fixing crops – e.g. peas / beans	B	S-M
	Forestry	B	M-L
	Turf	B	S
	GIS analysis of RD sources and potential areas of use	A	S
	Maturation of RD-amended soils and composts	C	M-L
	Evaluation of the potential competitive advantages in the marketing of mineral enriched organic foods.	A	S-M
Research	Minimising fertilizer inputs and NVZ compliance using RD	A	S-M
	Dietary and medical benefits of consumption of RD-amended food	A	M-L
	Microbial hierarchy and population dynamics in RD-amended soils	B	M
	Plant-nutrient preservation in RD-amended soils	B	M
	Nutrient release from RD-amended composts	B	S

7. Sources of Further Information

A number of individuals and organisations may provide technical, regulatory and general agronomic information about the use of Rockdust and remineralization. A charge may be levied by some providers for this service. Information is also freely available on the web although care should be taken when considering such information as it may not have been fully validated. Companies selling commercial products may also offer advice about their own products. Independent advice is available from a number of advisers and private companies. Land owners and those applying materials such as rockdusts are recommended to use an independent adviser compliant with The British Agrochemical Standards and Inspection Scheme (BASIS) and having registered with the Fertiliser Advisers Certification and Training Scheme (FACTS).

The following are key sources of independent rockdust-related information and advice:

The Scottish Environment Protection Agency (SEPA) Waste and Resource Strategy Unit Erskine Court Castle Business Park Stirling, FK9 4TR www.sepa.org.uk	**The Sustainable Ecological Earth Regeneration (SEER) Centre** Ceanghline Straloch Farm, Enochdhu, Nr. Blairgowrie, PH10 7PJ www.seercentre.org.uk
The Scottish Executive Environment Group Victoria Quay Edinburgh, EH6 6QQ www.scotland.gov.uk	**The Scottish Executive Rural Affairs Department** Pentland House 47 Robb's Loan Edinburgh, EH14 1TY www.scotland.gov.uk
Remineralize the Earth 152 South Street, Northampton, MA 01060-4021, USA. www.remineralize.org	**The University of Glasgow** Environmental, Agricultural and Analytical Chemistry Department of Chemistry Glasgow, G12 8QQ www.chem.gla.ac.uk

The Composting Association Avon House Tithe Barn Road Wellingborough Northamptonshire, NN8 1DH www.compost.org.uk	**Active Compost Limited** Scaur O'Doon 25 Scaur O'Doon Road Doonfoot Ayr, KA7 4EP www.activecompost.com
REMADE Caledonian Shanks Centre for Waste Management 3rd Floor, Drummond House 1 Hill St. Glasgow G3 6RN www.remade.org.uk	**The Scottish Agricultural College (SAC)** SAC Environmental Auchincruive, Nr. Ayr KA6 5HW www.sac.ac.uk
Men-of-the-Trees PO Box 103 Guilford Western Australia 6935 www.menofthetrees.com.au	**The McCarrison Society** c/o Institute of Brain Chemistry and Human Nutrition, London Metropolitan University, 166-222 Holloway Rd, London, N7 8DB www.nutritionhealth.org/cont.htm
BASIS (Registration) Ltd. 34 St John Street Ashbourne Derbyshire, DE6 1GH www.basis-reg.co.uk	**The Starduster Society** 28 Sefton Circle Piscataway NJ 08854 USA www.energywave.com/environmental_issues/rock_dust/rock_dust_and_the_environment.htm

8. Acknowledgements

The author would like to acknowledge the following:

- Moira and Cameron Thomson for extensive discussions on the subject of rockdust and soil remineralization and for allowing access to the resources of the SEER Centre.

- Joanna Campe (Remineralize the Earth) for helping locate information.

- The many unnamed and named individuals that through observation and publication have brought to our attention the complex effects of materials-use, waste and recycling that science must address.

- Dr. Peter Olsen for reviewing the manuscript.

"An idea can turn to dust or magic, depending on the talent that rubs against it."[74]

9. Limitations and Disclaimer

This publication is intended for information only in so far as it contributes to understanding the potential benefits, costs and opportunities of using rockdusts and the techniques of remineralization. This information is not intended as recommendations for products or techniques as individual conditions of use vary and are outwith the control of the author. Specific advice should be sought from a qualified adviser. Where reference to commercial products is made or implied this is for illustrative purposes only and no endorsement or otherwise is implied. Omission of reference to products does not imply disparagement.

[74] Matsuo Basho (1644-1694)

10. Glossary

ac	acre
ADAS	Agricultural Development and Advisory Service
ASTM	American Society for Testing and Materials
BASIS	British Agrochemical Standards and Inspection Scheme
BSi	British Standards Institute
C	Carbon
Ca	Calcium
CVD	Cardio-Vascular Disease
EU	European Union
EU ETS	EU Emissions Trading Scheme
FACTS	Fertiliser Advisers Certification and Training Scheme
GIS	Geographic Information System
ha	hectare
K	Potassium
M	Million
m	Metre
Mg	Magnesium
N	Nitrogen
P	Phosphorus
pa	Per annum
PAS	Publicly Available Specification
PEPFAA Code	Prevention of Environmental Pollution from Agricultural Activity (Code of Good Practice)
pH	Units of acidity / alkalinity
RD	Rockdust
SAC	The Scottish Agricultural College
SE	The Scottish Executive
SEER	Sustainable Ecological Earth Regeneration
SEPA	Scottish Environment Protection Agency
t	Metric tonne
USDA	United States Department of Agriculture
USDoE	United States Department of the Environment

11. About the Authors

Dr. Robin Szmidt

Robin has more than 20 years' experience in developing bespoke composts and related materials. A Horticultural Science graduate (Wye College, University of London) he completed his PhD at Stirling University where he researched microbial interactions in mushroom composts. Initially he worked for The Ministry of Agriculture (ADAS) as an experimental officer at Lea Valley Experimental Horticulture Station before moving to the Scottish Colleges as head of protected crops research. Subsequently he was appointed head of The Scottish Horticultural Advisory Service within SAC. He was responsible for developing SAC compost technology services before moving into commercial consultancy in 2003. For a number of years he has been involved in rockdust-related research as part of a programme to develop integrated resource-use for agriculture and horticulture and has published some of the first validated research into the topic. He has served as chairman of a number of national and international development committees for plant and environmental science and has a substantial portfolio of UK and worldwide consultancy.

www. activecompost.com Active Compost

John Ferguson

John Ferguson is the manager of SEPA's Waste and Resource Strategy Unit. He was educated at St Andrew's University gaining his degree in Plant Biochemistry and at the Cranfield Institute with an MSc in Soil and Water Engineering. After working off-shore as a drilling fluids engineer he joined a local authority as one of Scotland's first recycling officers in 1990. He was a founding member of the Recycling Advisory Group Scotland (RAGS) and currently sits on the Scottish Centre Council for the Chartered Institute of Wastes Management. He has chaired various groups including ReMaDe Scotland the Scottish market development organisation which he helped establish. In 1996 John joined the Scottish Environment Protection Agency to develop the National Waste Strategy for Scotland. He is a passionate believer in the need to find creative ways of addressing the complex range of environmental challenges faced by 21st century society across the globe and believes that this is only achievable by a combination of good science, political commitment and cross-sectoral partnership working.

www.sepa.org.uk SEPA