CHAPTER 1

Literature review on the *status quo* of degraded soils / substrates as a result of mining activities or intensive agronomic practices, and the alternative reclamation scenarios of such soils / substrates.

Wayne F. Truter and Norman F.G. Rethman

1. Introduction

Agricultural and industrial activities have greatly accelerated the pace of soil degradation. The mining industry plays a major role in the South African economy, and can often contribute to certain environmental challenges, with respect to soil degradation. Three of the most common factors that characterize degraded substrates are, soil acidification, nutrient depletion and loss of biological activity.

Many studies have been conducted to determine what measures can be taken to mitigate these problems, in agricultural lands. However, it has only recently been accepted world wide that there are other alkaline materials that are classified as industrial by-products, which can potentially serve the same purpose as the diminishing lime resources.

There exists an enormous amount of international literature regarding the use of class C fly ash, and to a lesser extent class F fly ash, as opposed to South African class F fly ash, which is predominantly produced in this country. This literature reflects the research outputs and findings of many scientists. It is, however, imperative to determine the local relevance and investigate the basic principles under South African conditions, with particular reference to the rehabilitation of degraded soils / substrates in the agricultural field and the mining environment.

With respect to the environmental problem of the concentration of organic wastes and the impact thereof on ground water pollution, this research has also provided an opportunity to investigate the nutrient and microbial contribution of organic materials such as sewage sludge, poultry and cattle manure, to soils degraded by intensive agronomic and mining activities.

The success of re- vegetation and sustainability of a once degraded soil / substrate is an indication, and a measure, of the amelioration success achieved. Seed germination, root development, plant yield, plant density and biological activity are parameters that can be used to support the conclusion that alternative substrate amendment practices can improve the plant growth medium.

2. Cause and effect of degraded soils / substrates

Many soils are impacted by activities such as intensive agronomic practices or surface mining activities. These soils, or newly created substrates / growth mediums, are often inhospitable to vegetation due to a combination of physical, chemical and microbiological factors. Areas disturbed by mining are highly susceptible to erosion due to a lack of vegetation, steep slopes and the presence of fine, dispersed particles (Limpitlaw *et al.* 1997).

South Africa is charaterized by a poor agricultural resource base, while the current population of 40 million continues to grow (Rethman *et al.*, 1999b). Sustainable increases in food production are difficult on this limited resource base. The effective use of acidic soils is also critical in many areas. Therefore, increased food production is urgently required to improve both national and household food security (Truter and Rethman, 2000).

Acid soils occupy about 30 % of the worlds ice-free land area. In South Africa 15 % of the soils, or 16 million hectares (Beukes, 2000; Truter 2002), available for dry land cropping, are classified as dystrophic, and much of the yield instability in the higher potential, eastern parts of the South Africa is attributable to shallow root development as a result of soil acidity and consequent susceptibility to short duration midsummer droughts (Farina and Channon, 1988; Truter 2002).

In agriculture, the increasing use of nitrogenous fertiliser and the oxidation of organic residues under cultivation, combined with incorrect management practices, are important contributors to acidification of soils. The burning of fossil fuels and industrial pollution (“acid rain”) have also contributed substantially to the acidification of many natural and agricultural ecosystems (Wang *et al.*, 2000; Truter 2002).

Soil acidity affects plant development by influencing the availability of certain elements required for growth (Tisdale and Nelson, 1975; Truter, 2002). Soil acidity is, therefore, of the greatest importance to plant producers and one that is easily corrected if dealt with immediately after detection. (Truter, 2002*)*.

Soil acidification and, indirectly, nutrient depletion are ongoing natural processes. In natural ecosystems the rate of acidification is largely determined by the loss of base minerals (Ca, Mg, K) from the soil by leaching. The central problem of acid soil management lies in the constraints, which arise from the soil condition. The most serious of these is that at low pH's; acids (H^+) can release soluble aluminium (Al) and manganese (Mn) from soil minerals. Both Al and Mn have direct toxic effects on many plants (Beukes, 2000; Truter 2002). Aluminium concentrations can be sufficiently high in acid soils, with pH values of 5.5 or below, to be toxic to plants (Ahlrichs *et al*, 1990; Truter 2002). Aluminium acts by restricting root extension growth, resulting in poor plant production and eventually a decline in food production.

Soil acidification is thus a serious socio-economic concern. Very few countries can afford a decline in food production, which often accompanies the changes, that are taking place in our soils.

Acidic conditions in the mining environment limit mined land re-vegetation through: **(i)** plant toxicity by elements that become more available to plants at a low pH, **(ii)** restriction of root growth into acidic spoil or cover material, **(iii)** reduction in the number of free living and symbiotic N fixing organisms, and **(iv)** increased populations of microorganisms that oxidize Fe and S (Alexander, 1964; Arminger *et al*., 1976; Barnhisel, 1977; Taylor and Schuman, 1988; Truter, 2002).

Nutrient management practices affect the viability of agricultural ecosystems. Nutrient management strategies based on the return of nutrients from plant and animal wastes back to the soil will require radical changes to both agriculture and society. External sources of plant nutrients will, therefore, continue to be an essential part of agriculture as we strive to replace the nutrients lost in successive crop harvests. Landowners must, nevertheless, be made aware of the need to increase the cycling of nutrients within agricultural ecosystems. Ways must be found to return plant residues to the soil. To help manage nutrient flows, it may be necessary to develop nutrient balances based on soil and plant analyses (Truter, 2002).

Crops need sixteen essential plant nutrients for growth and reproduction, thirteen of which are generally provided by the soil in sufficient quantities. These nutrients include three major (N,P,K), three secondary (Ca, Mg, S), and seven micronutrients (B, Cl, Cu, Fe, Mn, Mo, Zn). Quantities of N-P-K are usually applied in the greatest amounts to supplement the nutrients available from the soil to meet the needs of crops (Jacobs *et al.,* 1991).

The implications of chemical fertilization – inefficiency, deterioration in product quality, diminishing productivity of soils and negative effects on the environment- have created an urgent need for the study of fertility as a result of the activity of the bio-cycles of the ecosystems. With the aid of the advances of modern science, we can understand the defects and deficiencies of the chemical concept of fertility.

A few common management practices, such as application of acid forming N fertilizers, increased leaching and run-off of cations, N fixation by legumes and cation removal by harvesting crops, all contribute to soil acidification. Application of N fertilizers are essential for good crop yields, particularly on acid soils where the organic matter is low. Nitrogen fertilizers in the NH_4^+ form have long been recognized as increasing soil acidity (Tisdale and Nelson, 1975; Truter, 2002) due to the release of H^+ with plant absorption of NH_4^+ and with nitrification of NH_4^+ (He *et al*, 1999; Truter 2002). Acid (H^+) inputs into agricultural ecosystems revolve largely around the use of N fertilizers. The guidelines classifying the acidification potential of different N fertilizers are well established. The scope for managing acid conditions in agricultural ecosystems, therefore, largely revolves around the input of ammonium (NH_4^+) and the output of nitrate (NO_3^-) ions in biological cycles. The central principle in reducing acid input (N cycle) involves matching the N supply to plant demand and reducing leaching losses of NO_3^- from the system to near zero (Beukes, 2000; Truter 2002).

It is well known that when ammonium is changed to nitrate as a result of the nitrification process, hydrogen ions are released and this contributes to acidification. It has also been noted that ammonium sulphate and ammonium phosphate are theoretically twice as acidifying as limestone ammonium nitrate (du Plessis, 1986; Truter 2002).

Chemical instability of clay minerals is a result of the saturation of H^+, which with time can lead to high lime requirements due to the wide range of Al forms that accumulate between clay layers (Jackson, 1960; Fouchè, 1979; Truter 2002). It is for this reason that, the higher the concentration of clay in the soil, the more acid cations (Al^{+3}, H^{+}.... etc.) can be adsorbed.

Plant sensitivities to Al can nevertheless be expressed secondarily through changes in water and nutrient supply, which occur in response to Al, and induced changes in root development. Acid soils are generally unable to supply critical plant nutrients (Ca, Mg, P, K, and Mo). The fundamental reaction underlying soil acidification involves the replacement of exchangeable base cations (Ca, Mg, and K) present in the soil solution by protons (H^{+}), as already mentioned.

The implication for yield reduction during periods of moisture stress, when subsoil reserves remain largely inaccessible to crops because of poor root penetration is obvious. Acid soils usually lack appropriate levels of N to support healthy plant growth and the application of N fertilizer is a common practice for sustainable crop production in acid soil regions (He *et al*, 1999; Truter 2002). In various plant species, Al can interfere with the uptake and efficient use of essential nutrients (Baligar *et al*., 1987, 1989, 1993a, b. 1996; Baligar and Bennet, 1986; Foy, 1992; Baligar and Fageria 1997; Truter 2002).

With respect to physical properties of soil, this is basically the result of soil texture, quantity and quality of salts in the soil, cultivation, and climatic and vegetative influences. Soils having good initial physical characteristics, either with large or small amounts of organic matter initially, has been known to sustain good crop production for several decades without benefit of added organic matter (Azevedo and Stout, 1974).

Due to the use of large agricultural machinery, for the cultivation of soils, excessive soil compaction has also often resulted. Not only is this problem visible in the agricultural industry but also it is very prominent in the surface coal mining industry. The use of heavy equipment in the transportation and reconstruction of severely disturbed soil profiles can contribute to severe and persistent soil compaction (Wells and Barnhisel, 1992).

The effects of soil compaction on physical properties include reduced water infiltration, increased bulk density, and reduced water holding capacity and increased runoff (Sopper, 1993). When the porosity of soil is such that aeration is restricted or when the soil is so dense, and its pores so small, that root penetration, drainage, infiltration and hydraulic conductivity is impeded, the soil is compacted (Limpitlaw *et al.* 1997).

Soil consists of mineral particles of various sizes and chemical components, together with plant roots, the living soil population, and an organic matter component in various stages of decomposition (Oades, 1993; Paul and Clark, 1996). Soil aggregation is of prime importance in controlling microbial activity and soil organic matter turnover. Aggregate formation is initiated when micro-flora and roots produce fibrils, filaments, and polysaccharides that combine with clays to form organomineral complexes. Soil structure is created when physical forces (drying, shrink-swell, freeze-thaw, root growth, animal movement, compaction) mould the soil into aggregates. Clays are basic to aggregate formation. Micro-organisms and most soil organic matter constituents are negatively charged at neutral pH values (Paul and Clark, 1996). Particles involved in aggregate formation include fine clays and organic molecules measurable in nanometres; micro-organisms, coarse clays, and silt measurable in micrometers; and sands, small metazoans, and small rootlets measurable in millimetres.

Aggregates vary greatly in size. Pore size distribution in certain micro-aggregates and macro-aggregates differ in different textured soils. Pore sizes determine the entry into and occupancy of pores by micro-organisms. Chemical analysis of the soil organic matter in micro-aggregates shows that the contained sugars are mostly of microbial origin. Aggregates show greater content of nutrients (C, N, S, P) than found in the soil generally. Soil particles, differing in size also differ in nutrient content. Soil aggregates and their constituent clays influence the interaction of enzymes with their substrates (Tiessen *et al.,* 1984; Hassink *et al*., 1993; Paul and Clark, 1996).

Many of the soils of the world are affected by excess acidity, a problem exacerbated by heavy fertilization with certain nutrients, acid rain, and soil dwelling S-oxidizing bacteria. Biological nitrogen fixation is sometimes said to increase soil acidity. It does not do so directly but only after the fixed N is transformed by ammonification and nitrification. Measurements of soil pH are important criteria for predicting the capability of soils to support microbial reactions. Most of the known bacterial species grow within a pH range of 4 to 9, or within smaller segments of that range (McLaren and Skujins, 1968; Paul and Clark, 1996).

The presence of organic matter has an additive effect as it reduces the concentration of toxic metals through sorption, lowers the C: N ratio and provides organic compounds, which promote microbial proliferation and diversity (Wong and Wong, 1986; Pitchel and Hayes, 1990).

3. Soil amelioration

Liming of acidic soils is an ancient agricultural practice to ameliorate soil. Limestone (calcite, dolomite or a combination) is basically the main liming material used to date, with the infrequent use of quicklime, hydrated lime and by-products such as slag and gypsum (for sub-soil amelioration). Current levels of pollution mean that more lime is now required to offset acidification, but extensification is likely to result in a cessation or reduction of liming for economic reasons, while afforestation may result in increased acid deposition and acidification (Goulding and Blake, 1998; Truter, 2002).

Although liming is usually an effective counter to soil acidification, liming acid soils does not always make economic sense. Many low–input agricultural systems (e.g. subsistence farming practices and extensive grazing lands) cannot use large amounts of lime and remain economically viable (Truter, 2002). Nevertheless, lime is an effective method of neutralizing acidity, but it still remains a natural non-renewable resource, which is becoming depleted.

Soil quality can be improved, or degraded, by management. Since the 1950's mainstream agriculture has attempted to optimize soil fertility through the application of commercial fertilizers. The access of farmers to in- expensive fertilizers permitted short-term amelioration of nutrient-deficient soils. However, increasing the soil nutrient supply capacity may better be accomplished by improving the soil's biological activity, not adding more nutrients (King, 1990, Brosius *et al.* 1998). The long-term use of commercial fertilizers may also reduce soil organic matter and biological activity (Fauci and Dick, 1994, Brosius *et al.* 1998).

The land application of by-products from agricultural, industrial or municipal sources is certainly not a new phenomenon. Wood ashes, manures, crop residues and coal combustion by-products, etc. are being applied to the land and, dependent upon site specifics, often show beneficial responses in subsequent cropping cycles. These positive responses led to agricultural practices, which were continued over time. However, recent interest in concepts such as sustainability, biodynamic farming, and natural resource conservation has stimulated the practice of applying by-products to land (Korcak, 1998).

With respect to the function of lime and inorganic fertilizer used in conventional agronomic practices and rehabilitation processes, alternatives to these materials need to be identified in order to address the problem of non-sustainability and improved soil physical, chemical and microbiological quality.

Coal combustion by-products not only supply plant nutrients and increase soil pH but also decrease Al toxicity, enhance root penetration, improve soil structure, reduce bulk density of soil, improve water holding capacity, and act as a barrier to weeds (Chang *et al.*, 1989, Stratton and Riechcigl, 1998).

The coal combustion by-product, fly ash (a very fine, relatively inert, dry powder consisting mostly of Fe, Al, Ca, Si and O) provides a means of reducing the water content of wet mixtures, and can also provide B and other micro–nutrients. Fly ash is currently being used to improve the texture and water holding capacity of potting mixtures and artificial soils. Class C Fly ash (produced from burning coal from Western US) can have a calcium carbonate equivalency of up to 50% and may serve as a substitute for agricultural lime (Ritchey *et al.*, 1998), whereas, in South Africa only Class F fly ash is produced, with a much lower calcium carbonate equivalency. Very little work has been conducted on the use of fly ash to ameliorate degraded (acidic and nutrient poor) substrates in South Africa.

Class C fly ash usually has higher Ca concentrations than Class F fly ash. Fly ash consists of Al, Fe, Si, and O, with variable amounts of Ca and Mg, chemically bound into a glassy material. Small amounts of many plant nutrients and trace elements, such as B, Se, Cd, Mo, and As, are also present (Terman, 1978, Ritchey *et al.*, 1998). The material has been effective in improving the texture of many mixtures. Increased air-filled porosity, decreased bulk density, and improved moisture retention capacity were attributed to fly ash incorporation in West Virginia, United States (Bhumbla *et al.* 1993).

The results indicate that the combined use of fly ash and sewage sludge at a rational rate of application should not have any significant effect on drainage or water quality. Plant studies conducted using fly ash and sewage sludge mixtures indicated that these materials could also be beneficial for biomass production, without contributing to significant metal uptake or leaching. Applications of fly ash, as high as 560 tons ha^{-1} in a long-term field trial, had no detectable effect on in soil or groundwater quality and no substantial increases in plant uptake of metals and other trace elements were observed. Low to moderate rates of fly ash and sewage sludge could, therefore, be successfully used as soil amendments, particularly so when used as a mixture (Truter 2002; Sajwan *et al*. 2003).

Coal residues, especially fly ash, applied to agricultural land do not, however, supply crop requirements for essential plant nutrients such as N and P. Alkaline fly ash would also be effective in neutralizing soil acidity. Variable amounts of certain trace elements in fly ash may, however, limit its potential use for land application (Adriano *et al*., 1980).

Research to date has shown that there are many materials, such as coal combustion by-products, or various organic materials, that can be applied to soils to relieve soil physical problems such as compaction. Fly ash amended soils tend to have a lower bulk density, higher water holding capacity, lower hydraulic conductivity, increased organic carbon content and increased soil strength (Chang *et al*., 1977; Aitken and Bell, 1985; Eisenberg *et al*., 1986; Garg *et al*., 1996; Kalra *et al*., 1998).

Work done in India has proved that the addition of fly ash, at the time of maize planting, reduced bulk density and increased moisture retention and release characteristics in a sandy-loam soil in New Delhi, and that differences persisted even during the subsequent growth of a wheat crop (Garg *et al*., 1996). The favourable soil physical environment, induced by using fly ash, resulted in a greater root growth, which ensured enhanced water use by the crop and higher grain yields for maize as well as wheat. Therefore, fly ash incorporation in texturally variant soils modifies the soil physical and physico-chemical environment, which in turn may influence the crop yields (Kalra *et al*., 2000).

Jala and Goyal (2004) reported that the saturation moisture percentages of ash were higher than those of soil, but that the bulk density was lower than normal cultivated soils. The addition of fly ash, at 70 tons ha^{-1}, was reported to alter the texture of sandy and clay soils to loamy soils (Fail and Wochok, 1977; Capp, 1978; Jala and Goyal, 2004). The addition of fly ash generally decreased the bulk density of soils, which in turn improved soil porosity and workability and enhanced water retention capacity (Page *et al*., 1979). The water holding capacity of sandy/loamy soils was increased by 8% by fly ash amendment (Chang *et al.*, 1977) and was accompanied by an increase in hydraulic conductivity, which helped to reduce surface encrustation.

Little data is available on the impact of fly ash on the soil microbial populations. Soil micro organisms, however, drive biogeochemical cycles of elements and are responsible for humus formation and for important degrading reactions. Microbes, therefore, play an important role in maintaining soil fertility and biochemical functionality (Vallini *et al.*, 1999).

The addition of Class F, bituminous fly ash to soil, at a rate of 505 tons ha^{-1}, did not have any negative effects on the soil microbial communities. Analysis of community fatty acids indicated elevated populations of fungi, and gram-negative bacteria (Schutter and Fuhrmann, 2001; Jala and Goyal, 2004). Fly ash- sludge mixtures containing 10 % ash had a positive effect on soil micro- organisms in terms of enzyme activity, N and P cycling and reduction in the availability of heavy metals (Lai *et al.*, 1999; Jala and Goyal, 2004).

Fly ash composted with wheat straw and 2% rock phosphate (w/w) for 90 days was reported to have enhanced chemical and microbiological properties of the compost and fly ash up to 40-60%, and did not exert any detrimental effect on either C: N ratio or microbial population (Gaind and Gaur, 2003; Gaind and Gaur, 2004; Jala and Goyal, 2004). It has also been found that microbial activity was increased in ash-amended soils containing sewage sludge (Pitchel, 1990; Pitchel and Hayes, 1990, Jala and Goyal, 2004). When organic matter is present in the soil it has a positive effect in the sense that it reduces the concentration of toxic metals, lowers the C: N ratio and provides organic compounds, which promote microbial proliferation and diversity (Wong and Wong, 1986; Pitchel and Hayes, 1990; Jala and Goyal, 1990). Available data indicates that microbial incidence and diversity generally increases as ash weathers and nutrients accumulate (Rippon and Wood, 1975; Jala and Goyal, 2004).

For the purposes of this study the organic materials to be discussed were sewage sludge and animal manures. Many materials termed wastes are rich sources of nutrients and organic material for use in crop production, improvement in soil physical or chemical properties, or as feed for livestock production. Agricultural, municipal, or industrial by-products may be co-utilized, or combined, so that the materials are more easily land applied, provide more complete nutrition, or enhance the soil conditioning, economic, or environmental value of the individual by-products. (Stratton and Rechcigl, 1998).

The addition of organic matter, in general, improves soil chemical and physical characteristics. A large portion of the plant nutrients ingested by livestock is excreted and are returned to the soil for another season of crops. Poultry manure is considered the richest of the manures in supplying N. So much of this N is in the ammonium form, however, that care must be taken in its use on crops. Manures are rich in P and may even contribute to over-enrichment of soil P.

The term sewage sludge has been applied to the solid human waste collected from wastewater, treated at central processing plants, and which remains as a residue after the liquid effluent is removed. The term biosolids is also used. With careful application, biosolids can be a good source of nutrients for agronomic use. Since the “503 Regulations” some biosolids are detoxified by removal of heavy metals either at the source, or by special processing known as auto-thermal aerobic digestion or liquid composting (Jewell, 1994, Stratton and Rechcigl,1998)

The National Research Council report provides considerable reassurance that properly treated and managed municipal wastewater effluents and biosolids can be safely and effectively used in food crop production, while presenting negligible risk to crop quality or consumers. Public acceptance and implementation issues, rather than scientific information or the health and safety risks from food consumption, may, however, be the critical factors in determining whether reclaimed wastewater effluents and biosolids are used in food crop production. (Bastian, 1998).

Plant and animal-based wastes may substitute for commercial fertilizers and enhance chemical and biological attributes of soil quality in agricultural production systems. Organic matter increases the soil’s abilities to hold and make available essential plant nutrients and to resist the natural tendency of soil to become acid (Cole *et al.,* 1987; Brosius *et al.,* 1998). Build up of organic matter through the additions of crop and animal residues have been shown to increase the population and species diversity of micro-organisms and their associated enzymatic activity and respiration rates (Kirchner *et al.,* 1993; Weil *et al., 1993;* Brosius *et al.* 1998). Materechera and Mkhabela (2002) found that although leaf litter and chicken manure can be effective in ameliorating acidity, they were not as efficient as lime. Both amendments had a significant effect on the pH of an acid soil and markedly reduced acid saturation as compared to the control.

Sewage sludge has been utilized for agriculture and horticulture for many years and in addition to being a good source of nutrients for plant growth a soil conditioner to improve soil physical properties (Jacob, 1981; Matthews, 1984; Logan & Harrison, 1995). However, sludge can also contain a range of toxic metals and high amounts of soluble salts, which may become a problem (Chaney, 1983; Elseewi and Page, 1984). Coal fly-ash, however, is rich in CaO and MgO, which results in a high pH and makes coal fly ash a potential liming material to stabilize sewage sludge by reducing heavy-metal availability and killing pathogens in the sludge (Logan & Harrison, 1995; Wong, 1995, Rethman *et al.*, 1999a,b, 2000a,b; Reynolds *et al.,* 1999, 2002; Reynolds and Kruger, 2000, Truter 2002). The coal fly ash and sewage sludge mixture can, therefore, be used as a soil conditioner to improve soil physical and nutrient properties. However, applying the ash / sludge mixture to soil may initiate the decomposition of the organic matter in the sewage sludge causing the release of NH_4^+, NO_3^-, PO_{3-}^{-}, B and possibly some trace elements. Another concern is the leaching of NO_3 from the ash-sludge mixture, leading to the contamination of groundwater. Also, the released trace elements may be toxic to plants and represent a potential hazard to animals consuming plants grown in the ash-sludge mixture (Chaney, 1983; Wong and Su, 1997). It has been shown that alkaline fly ash did not cause phytotoxic effects to plants or depress activity of microbial populations in either sandy or clayey soil. In particular, vegetable biomass production was increased in soil that was amended with fly ash composted with lignocellulose waste (Vallini *et al.*, 1999).

Efforts are in progress throughout the world to find economic uses of fly ash to solve the above-mentioned environmental problems. Many research workers (Mulford and Martens, 1971; Page *et al.,* 1979; Hill & Lamp, 1980; Elseewi *et al.,* 1980; Truter 2002) have demonstrated the use of fly-ash for increasing crop yields of alfalfa, barley, white clover, Swiss chard, maize, wheat, cereal grain crops and certain sub-tropical grasses and improving the physical, chemical and microbiological characteristics of the soils.

4. Ameliorated soils: Effect on aspects of plant production

With intensive cropping, the continuous use of high levels of chemical fertilizers often leads to nutritional imbalances in the soil and a consequent decline in crop productivity (Nambiar, 1994; Rautaray *et al.*, 2003). The alternative soil amendments available today, show tremendous potential as sources of macro- and micronutrients with added benefits to soil physical and microbiological properties. Research has demonstrated that fly-ash amendments improved initial seedling emergence and root development relative to untreated controls (Truter 2002). Seed germination and root length had significant negative correlations with soil EC, NH_4^+, Cu and Zn ($P<0.05$) at day 7 and day 14 of an incubation period of an experimental trial conducted by Wong and Su (1997), indicating that these were the major factors reducing seed germination and root growth, especially in the initial period following the application of an ash-sludge mixture. The rapid decomposition of sewage sludge during the initial phase also contributed to the low seed germination and poor root growth in sludge-amended soil. The results show a potential use of the "artificial soil mix", derived from coal fly ash and sewage sludge, to improve soil conditions for plant growth. (Wong and Su, 1997; Truter 2002)

Germination and crop stand establishment are prime plant-growth processes, which play a major role in deciding subsequent growth and yield, and so need to be evaluated under varying levels of ash incorporation within the soil. Kalra *et al* (1997) evaluated the effect of ash incorporation on germination of several crops, to determine the optimum level of ash application and relate germination effects with changes in soil characteristics caused by mixing ash with the soil. The incorporation of fly ash in soil may delay the germination of crops, most likely because of increased impedance offered by the soil/ash matrix to germinating seeds. This causes reduced growth of crops in the earlier stages, which subsequently may lead to reduced yields under unfavorable environments. Differential responses of crops to ash mixing in soil were noted: rice and maize were less sensitive than temperate crops; mustard was most affected by ash addition for germination and stand establishment. The delay index showed variations for crops as well as for ash levels within a crop. The effects of fly ash on germination need to be linked with subsequent plant-growth activities to understand the differences in final growth and yield. (Kalra *et al*., 1997).

There is a need to evaluate the impact of coal ash on both the environment and agriculture. In the past, various research studies evaluated the impact of fly ash on soil and crop productivity, but most of them were confined to laboratories or research stations (Singh and Singh, 1986; Mishra and Shukla, 1986; Garg *et al.,* 1996; Sikka and Kansal, 1995; Singh *et al*., 1996; Kalra *et al.,* 1997).

Applications of fly ash had a profound effect on the dry matter yield of rice in all the soils tested although the magnitude of the response to fly ash varied with the soil type. The variation in response to fly ash addition to the different soils could have been caused by the inherent differences in their physical and chemical characteristics, which are shown in the yield variations in the control treatments (Sikka and Kansal, 1995). Beneficial effects of fly ash on plant growth at a rate of 10% were achieved by Singh *et al* (1997). However, the recommendation for large-scale application of fly ash to the agricultural soils in a region cannot be made, until extensive trials have been conducted to determine the proper combination of fly ash with each type of soil and for each crop to be grown in the region (Singh *et al*., 1997; Truter 2002).

With respect to biosolid amelioration, it has been noted that rangeland restoration using surface applications of biosolids (municipal sewage sludge) is becoming an increasingly common practice. In a study conducted by White *et al*, (1997), nitrogen mineralization potentials were significantly higher ($P< 0.05$), in the 45 and 90 tons ha^{-1} applications, after nine years, indicating that site fertility remained higher even though most soil chemical properties were returning to untreated levels (White *et al*, 1997).

Long-term benefits to rangelands are the desired result of biosolid application, in addition to the direct benefit realized from its disposal. The benefit is expected to occur through increased primary production resulting in more above- and below – ground litter, which in combination with soil microbial production contributes to soil organic matter (OM) through the process of decomposition. The increase in N mineralization with increasing rates of biosolid application (significant for the 45 and 90 tons ha^{-1} applications), nine years after application, is a very good indicator that long-term benefits, in terms of site productivity, may be realized from surface-applied biosolids. Although biosolids are recognized for increasing N availability after addition to soils (Garau *et al*., 1986; Wiseman and Zibilske, 1998), these results indicate that the frequently measured short-term increase in N availability and productivity may indeed extend for much longer periods, which is the desired result. There may be no long-term benefit from applications in excess of about 45 tons ha^{-1}. This rate would be recommended because it reduces the contribution of metals compared to higher application rates yet maximizes the long-term nutrient benefit (White *et al*., 1997).

The nearly universal short-term response to N applications to rangelands is an increase in site productivity, regardless of whether the N is in the form of inorganic fertilizers or biosolids (Fresquez *et al*., 1990a,b, 1991; Aguilar *et al*., 1994; Loftin and Aguilar, 1994; Wester *et al*., 1996). However, a short-term response may not necessarily lead to long-term benefits. Soils often respond to N additions with further increases in mineralization of indigenous soil-N, a response known as the "priming effect" (Woods *et al*., 1987; White *et al*., 1997), which is seen as a short term increase in productivity. The addition of N stimulates decomposition of indigenous soil OM (Organic matter), as shown by an increase in CO_2 liberation from fertilized soils. This results in a short-term decrease in soil OM and a short-lived pulse of productivity. If repeated frequently, fertilizer-N applications deplete soil OM, resulting in long-term declines in potential site productivity (DeLuca and Keeney, 1993; White *et al*., 1997).

Plant growth may also be stimulated following the application of biosolids to semiarid calcareous soils due to the increased availability of essential micronutrients (O'Connor *et al*, 1980; White *et al*, 1997). If, however, biosolids were readily incorporated into the soil through the movement of fine biosolid particulates, and/or stimulation of plant growth, it could provide the nutrient resources necessary for long-term recovery of degraded grasslands (White *et al*., 1997).

The rationale behind co-utilized or combined agricultural, industrial or municipal by-products is that the mixture itself is a superior soil amendment than either component alone. The use of an organic material addresses the deficiency of macronutrients in coal combustion by-products, such as class F fly ash, while fly ash can act as a bulking agent for the organic materials, and these products can substantially improve chemical, physical and microbiological properties of degraded soils or substrates (Truter 2002).

5. Conclusion

Agricultural, municipal and industrial by-products are materials, which are rich sources of nutrients or organic material, and can be beneficially, utilized for crop production, to improve the physical, chemical or microbiological properties of soils or inert substrates. These materials can be co-utilized, or combined, so that the materials are more easily applied to land, or to provide a more complete/balanced nutrition, or enhance soil conditioning, economic, or environmental value of these individual by-products.

Returning nutrients and organic matter to soil, or substrates, via industrial-, municipal-, domestic by-products, animal manures or other organic materials complete the natural cycle on which all life depends. The value of these materials in supplying nutrients for crops has been noted since the beginnings of agriculture when, for example, manured crops grew visibly better than those without. In recent years, numerous studies conducted in various parts of the world have examined the nutrient supplying power of alternative soil amendments. Apart from the traditional values placed on animal manures for example as fertilizers supplying N-P-K, supplementary traits that encourage plant growth have often been attributed to manures. These accessory benefits have been ascribed to plant nutrients such as Ca, Mg, or micronutrients, or to physical changes in soil structure. Difficulties in separating individual physical and chemical effects, contributed to soils by alternative soil amendments, usually results in less than satisfactory identification of growth promoting factors, either quantitatively or qualitatively. Chemical fertilizers have mostly replaced the fertility demand formerly supplied by animal manures and organic materials, but the extensive use of chemicals and mechanization has led to the degradation of soils, and recently, the value of industrial, municipal, domestic by-products, animal manures and organic materials as soil conditioners are increasing, thereby contributing to more holistic and sustainable ameliorating solutions.

6. References

Adriano, D.C., Page, A.L., Elseewi, A.A., Chang, A.C. and Straughan, I. 1980. Utilization and disposal of fly ash and other coal residues in terrestrial ecosystems: A review. *J Environ. Qual*. **9**: 333-344

Aguilar,R., Loftin, S.R. and Fresquez, P.R. 1994. Rangeland restoration with treated municipal sewage sludge. p. 211-220. *In* C.E. Clapp *et al*. (ed.) Sewage sludge: Land utilization and the environment, SSSA Misc. Publ., SSSA, Madison, WI.

Ahlrichs, J.L., Karr, M.C., Baligar, V.C. and Wright, R.J. 1990. Rapid bioassay of aluminium toxicity in soil. *Plant and Soil* **122**:279-285.

Aitken, R.L. and Bell, L.C. 1985. Plant uptake and phytotoxicity of boron in Australian fly ashes. *Plant Soil*, **84**:245-257.

Alexander, M. 1964. Introduction to soil microbiology. John Wiley & Sons, Inc., New York.

Arminger, W.H., Jones, J.N. and Bennet, O.L. 1976. Revegetation of land disturbed by strip mining of coal in Appalachia. *USDA Rep. ARS-NE-71. U.S. Govt. Print. Office, Washington, DC*

Azvedo, J. and Stout, P.R. 1974. Farm Animal Manures. An overview of their role in the agricultural environment. University of California. Manual **44**.p 75-82.

Baligar, V.C. and Bennet, O.L. 1986. NPK-fertilisers efficiency. A situation analysis for the tropics. *Fert. Res*. **10**, 147-164.

Baligar, V.C. and Fageria, N.K. 1997. Nutrient use efficiency in acid soils: Nutrient management and plant use efficiency. *Plant Soil Interactions at Low pH, A.C. Moniz et al. (ed.)* 75-95.

Baligar, V.C., Wright, R.J. Kinraide, T.B., Foy, C.D. and Elgin, J.H. 1987. Aluminium effects on growth, mineral uptake and efficiency ratios in red clover cultivars. *Agron. J*. **79**: 1038-1044.

Baligar, V.C., Dos Santos, H.L., Pitta, G.V.E., Filho, E.C., Vasconcellos, C.A. and Bahia Filho, A.F. de C. 1989. Aluminium effects on growth, grain yield, and nutrient use efficiency ratios in sorghum genotypes. *Plant and Soil* **116**; 257-264.

Baligar, V.C. Schaffert, R.E., Dos Santos, H.L., Pitta, G.V.E. and Bahia Filho, A.F. de C. 1993a. Soil aluminium effects on uptake, influx and transport of nutrients in sorghum genotypes. *Plant and Soil* **150**: 271-277.

Baligar, V.C. Schaffert, R.E., Doa Santos, H.L., Pitta, G.V.E. and Bahia Filho, A.F. de C. 1993b. Growth and nutrient uptake parameters in sorghum as influenced by aluminium. *Agron. J*. **85**, 1068-1074.

Baligar, V.C., Pitta, G.V.E., Gama, E.G., Schaffert, R.E., Bahia. A.F. de C. and Clark, R.B. 1996. Soil acidity effects on nutrient use efficiency in exotic maize genotypes. Int. Symposium, *Plant-Soil Interactions at Low pH, Bel Horizonte, Brazil.*

Barnhisel, R.I. 1977. Reclamation of surface mined coal spoils. *USDA/EPA Interagency Energy-Environment res. and Develop. Program Rep. CSRS-1. EPA 600/7-77-093. USEPA, Cincinnati, OH.*

Bastian, R.K. 1998. NRC Committee review of using biosolids and effluents in food crop production. S.Brown, J.S. Angle and L. Jacobs (eds.) Beneficial Co-utilization of Agricultural, Municipal and Industrial By-products, pp 45-54.

Beukes, D.J. 2000. The management of acid soils. *Institute for Soil, Climate and Water.* Agricultural Research Council. South Africa.

Bhumbla, D.K., Keefer, R.F. and Singh, R.N 1993. Ameliorative effect of fly ashes on acid mine soil properties. In: Proceedings 10th International Ash Use Symposium (**Vol. 3**. pp 86.1-to 86.31) American Coal Ash Association. Washington, DC.

Brosius, M.R., Evanylo, G.K., Bulluck, L.R. and Ristaino, J.B. 1998. Comparison of commercial fertilizer and organic by-products on soil chemical and biological properties and vegetable yields. S.Brown, J.S. Angle and L. Jacobs (eds.) Beneficial Co-utilization of Agricultural, Municipal and Industrial By-products, pp 195-202.

Capp, J.P., 1978. Power plant fly ash utilization for land reclamation in the eastern United States. In: Schaller, F.W., Sutton, P. (Eds.), Reclamation of Drastically Disturbed Lands. ASA, Madison, WI, pp.339-353.

Chaney, R.L. 1983. Potential effects of waste constituents on the food chain. In Land Treatment of Hazardous Wastes, ed. J.F. Parr. Noyes Data Corp., pp. 50-76.

Chang, A.C., Lund, L.J., Page, A.L. and Warneke, J.E. 1977. Physical properties of fly ash amended soils. *J. Environ. Qual.* **6** (3), 267-270.

Chang, A.C. , Page, A.L., Lund, L.J., Warneke, J.E. and Nelson, C.O. 1989. Municipal sludges and utility ashes in California and their effects on soils. In: Bar-YosefB, Barrow, N.J. and Goldshmid (Eds). Inorganic contaminants in the vadose zone (pp125-139). Ecological Studies Vol. 74, Springer-Verlag, Berlin.

Cole, C.V., Williams, J., Shaffer, M. and Hanson, J. 1987. Nutrient and organic matter dynamics as components of agricultural production system models. In: Follett, R.F. (Ed) Soil Fertility and Organic Matter as

Critical Components of Production Systems (pp 147-166). SSSA Spec. Publ. 19. ASA, CSSA, and SSSA, Madison, WI.

De Luca, T.H. and Keeney, D.R. 1993. Soluble organics and extractable nitrogen in paired prairie and cultivated soils of Central Iowa. *Soil Sci.* **155**:219-228

Du Plessis, M.C.F. 1986. Grondagteruitgang. *S.A. Tydskrif vir Natuurwetenskap en Technologie* **5**, no. 3: 126-138

Eisenberg, S.H., Tittlebaun, M.E., Eaton, H.C. and Soroczak, M.M., 1986. Chemical characteristics of selected fly ash leachates. *J. Environ. Sci. Health* **21**, 383-402.

Elseewi, A.A., Straughan, I.R. and Page, A.L. 1980. Sequential cropping of fly ash-amended soils: Effects on soil chemical properties and yield and elemental composition of plants. *Sci. Total.Environ.,* **15**:247-259.

Elseewi, A.A., and Page, A.L.. 1984. Molybdenum enrichment of plants grown on fly ash-treated soils. *J. Environ. Qual.* **13**:394-398.

Fail, Jr., J.L. and Wochok, Z.S., 1977. Soya bean growth on fly ash amended strip mine spoils. *Plant and Soil* **48**., 473-484.

Farina, M.P.W. and Channon, P. 1988. Acid-subsoil amelioration: II Gypsum effects on growth and subsoil chemical properties. *Soil Sci. Am. J.* **52**: 175-180.

Fauci, M.F. and Dick, R.P. 1994. Soil microbial dynamics: Short – and long term effects of inorganic and organic nitrogen. *Soil Science Society of America Journal* **58**: 801-806.

Fouchè, P.S. 1979. Kalkbehoefte. *Fert. Soc. of South Afr. J.* **1** 25-28.

Foy, C.D. 1992. Soil chemical factors limiting plant growth. In limitations to plant root growth. Eds. J.L. Hatfield and B.A. Stewart. *Adv. Soil Sci.* **19**, 97-149.

Fresquez, P.R., Francis, R.E. and Dennis, G.L. 1990a. Influence of sewage sludge on soil and plant quality in a degraded semiarid grassland. *J. Environ. Qual.* **19**:139-143

Fresquez, P.R., Francis, R.E. and Dennis, G.L. 1990b. Soil and vegetation responses to sewage sludge on a degraded semiarid broom snakeweed/blue grama plant community. *J. Range. Manage.* **43**:325-331.

Gaind, S. and Gaur, A.C. 2003. Quality assessment of compost prepared from fly ash and crop residues. *Bioresource Technology.* **87**, 125-127.

Gaind, S. and Gaur, A.C. 2004. Evaluation of fly ash as a carrier for diazotrophs and phosphobacteria. *Bioresource Technology* **95**, *187-190.*

Garg, R.N., Singh, G., Kalra, N., Das, D.K. and Singh, S., 1996. Effect of soil amendments on soil physical properties, root growth and grain yields of maize and wheat. *Asian Pacific J. Environ. Development.* **3.** (1), 54-55.

Garau, M.A., Felipo, M.T. and Ruiz de Villa, M.C.. 1986. Nitrogen mineralization of sewage sludge in soils. *J. Environ. Qual.* **15**:225-229.

Goulding, K.W.T. and Blake, L. 1998. Land use, liming and the mobilization of potentially toxic metals. *Agriculture, Ecosystems and Environment*. Iss. 2-3, **67,** pp. 135-144.

Hassink, J., Bouwman, L.A., Zwart, K.B., and Brussard, L. 1993. Relationships between habitable pore space, soil biota and mineralization rates in grassland soils. *Soil. Biol. Biochem*. **25,** 47-55.

He, Z.L., Baligar, V.C., Martens, D.C., Ritchey, K.D. and Elrashidi, A.M. 1999. Effect of byproduct, nitrogen fertilizer, and zeolite on phosphate rock dissolution and extractable phosphorus in acid soil. *Plant and Soil* **208**: 199-207.

Hill, M.J. and Lamp, C.A. 1980. Use of pulverised fuel ash from Victorian brown coal as a source of nutrients for pasture species. *Aust. J. Exptl. Agric. Animal Husb.* **20**, 377-384.

Jackson, M.L. 1960. Structural role of hydronium in layer silicates during soil genesis. *Trans. of 7th Int. Congr. Soil Sci*. **2** , 445-455.

Jacob, L.W. 1981. Agricultural application of sewage sludge. In Sludge and its Ultimate disposal, ed. J.A. Borchardt, W.J. Redman, G.E. Jones and R.T. Sprague. Ann Arbor Science Publishers, Ann Arbor, Michigan, pp. 109-126.

Jacobs, L.W., Erikson, A.E., Berti W.F. and MacKellar, B.M. 1991. Improving crop yield potentials of coarse textured soils with fly ash amendments. *In* Proc. 9th Int. Ash Use Symp. Vol 3. EPRI GS – 7162. Am. Coal Ash Assoc., Alexandria, VA.

Jala, S. and Goyal, D. 2004. Fly ash as a soil ameliorant for improving crop production – a review. *Bioresource Technology* **95**.

Jewell, W.J. 1994. Engineering and cost considerations: Sludge management and land application. In: Clapp C.E., Larson, W.E. and Dowdy, R.H. (Eds) Sewage sludge: Land utilization and the environment (pp 41-54). SSSA Misc. , Publication ASA, CSSA, SSSA, Madison, WI.

Kalra, N., Joshi, H. C., Chaudhary, A., Choudhary, R., and Sharma, S. K., 1997. Impact of flyash incorporation in soil on germination of crops *Bioresource Technology* **61** 39-41 0

Kalra, N., Jain, M. C., Joshi, H. C., Choudhary, R., Harit, R. C., Vatsa, B. K., Sharma, S. K. and Kumar, V. 1998. Fly ash as a soil conditioner and fertilizer *Bioresource Technology* **64** 163-167.

Kalra, N., Harit, R.C., and Sharma, S.K., 2000. Effect of fly ash incorporation on soil properties of texturally variant soils. *Bioresource Technology* **75**, 91-93.

Korcak, R.F. 1998. Why Co-utilization? Beneficial co-utlization of agricultural, municipal and industrial by-products. S. Brown, J.S. Angle and L. Jacobs (eds.) Kluwer Academic Publishers. p 1-7.

King, L.D. 1990. Sustainable soil fertility practices. In: Francis, C.A., Butler, C.B. and King, L.D. (Eds) Sustainable Agriculture in Temperate Zones (pp 144-177). John Wiley and Sons, Inc., New York.

Kirchner, M.J., Wollum II, A.G. and King, L.D. 1993. Soil microbial populations and activities in reduced chemical input agro ecosystems. *Soil Science Society of America Journal* **57**: 1289-1295.

Lai, K.M., Ye, D.Y. and Wong, J.W.C. 1999. Enzyme activities in a sandy soil amended with sewage sludge and coal fly ash. *Water, Air Soil Pollution.* **128**. 234-254.

Limpitlaw, D., Aken, M., Kilani, J., Mentis, M., Nell, J.P., and Tanner, P.D. 1997. Rehabilitation and Soil Characterization. Proc. Of the 11th International Conference on Coal Research. Calgary. pp 297-309.

Logan, T.J. and Harrison, B.J., 1995. Physical characteristics of alkaline stabilized sewage sludge (N-Viro Soil) and their effects on soil physical properties. *J. Environ. Qual.* **24**:153**-**164.*Bioresource Technol.* 37:93-102.

Loftin, S.R. and Aguilar, R. 1994. Semi-arid rangeland response to municipal sewage sludge: Plant growth and litter decomposition. p. 221-229. *In* C.E. Clapp. *et al*. (ed) Sewage Sludge: Land utilization and the environment. SSSA Misc. Publ., SSSA, Madison, WI.

Materechera, S.A. and Mkhabela, T.S. 2002. The effectiveness of lime, chicken manure and leaf litter ash in ameliorating acidity in soil previously under black wattle (*Acacia mearnsii*) plantation. *Bioresource Technology* **85**; 9-16

Matthews, P.J. 1984. Control of metal application rates from sewage sludge utilization in agriculture. CRC *Crit. Rev. Environ. Control*, **4**, 199-250.

McLaren, A.D. and Skjins, J. 1968. The physical environment of microorganisms in soil. *In* "The Ecology of Soil Bacteria" (T.R.G. Gray and D. Parkinson, eds.), pp. 3-24. Univ. of Toronto Press, Toronto.

Mishra, L.C. and Shukla, K.N., 1986. Effects of fly ash deposition on growth, metabolism and dry matter production of maize and soybean. *Environ. Pollution*. 42, 1-13.

Mulford, F.R. and Martens, D.C., 1971. Response of alfalfa to boron in fly ash. *Soil Sci. Soc. Am. Proc*. **35**, 296-300.

Nambiar, K.K.M., 1994. Soil fertility and crop productivity under long-term fertilizer use in India. ICAR Publication, New Dehli.

Oades, J.M. 1993. The role of biology in the formation, stabilization and degrading of soil structure. *Geoderma* **56**, 377-400.

O'Connor, G.A., McCaslin, B.D. and Sivinski, J.S. 1980. Fertility value of gamma-irradiated sewage sludge. *Trans. Am. Nucl. Soc.* **34**:336-338.

Page, A.L., Elseewi, A.A., and Straughan , I.R., 1979. Physical and chemical properties of fly ash from coal-fired power plants with special reference to environmental impacts. Residue Rev. 71, 83-120.

Paul, E.A. and Clark, F.E. 1996. Soil Microbiology and Biochemistry. ISBN0125468067. Academic Press. United States of America.

Pitchel, J.R. 1990. Microbial respiration in fly ash / sewage sludge amended soils. *Environmental Pollution*. **63**, 225-237.

Pitchel, J.R., and Hayes, J.M., 1990. Influence of fly ash on soil microbial activity and populations. *J. Environ. Qual*. **19**, 593-597.

Rautaray, S.K., Ghosh, B.C., and Mittra, B.N. 2003. Effect of fly ash, organic wastes and chemical fertilizers on yield, nutrient uptake, heavy metal content and residual fertility in a rice-mustard cropping sequence under acid lateritic soils. *Bioresource Technology* **90**, 275-283.

Rethman, N.F.G., Reynolds, K.A. and Kruger, R.A. 1999a. Crop responses to SLASH (Mixture of sewage sludge, lime and fly ash) as influenced by soil texture, acidity and fertility. *Proc. 1999 Internat.l Ash Utiliz. Sympos.* Lexington, Kentucky, U.S.A. pp. 387-397.

Rethman, N.F.G. , Reynolds, K.A., Kruger, R.A.., Ramagadza, E.J. and du Toit, E.S. 1999b. SLASH for flower and vegetable production in the informal sector in South Africa. *Proc. Internat. Ash Utiliz. Sympos. Lexington*, Kentucky, USA. pp.83-86

Rethman, N.F.G., du Toit, E., Ramagadza, E. and Truter, W.F. 2000a. The use of fly ash and biosolids to ameliorate soils, revegetate disturbed areas and improve plant productivity. *Proc. 25th Conf. Canadian Land Recl. Assoc.* Edmonton, Canada.

Rethman, N.F.G., du Toit, E., Ramagadza, E., Truter, W.F., Reynolds, K.A.,and Kruger, R.A. 2000b. Soil amelioration using waste products. *Proc. Remade Lands Recl. Conf.* Perth, Western Australia. pp. 127-128.

Reynolds, K.A. , Kruger, R.A. and Rethman, N.F.G. 1999. The manufacture and evaluation of an artificial soil prepared from fly ash and sewage sludge. *Proc. 1999 Internatl. Ash Utiliz. Sympos*. Lexington Kentucky, U.S.A. pp. 378- 385.

Reynolds, K.A. 1996. Ash utilization – Evaluation of ash soil. Eskom Research Report. TRR/S96/158. Eskom Technology Services.

Reynolds, K.A., and Kruger, R.A. 2000. SLASH Field Trials, Eskom Research Report. RES/RR/00/13251. Eskom Technology Services International.

Reynolds, K.A., Kruger, R.A., Rethman, N.F.G. and Truter, W.F. 2002. The production of an artificial soil from sewage sludge and fly ash and the subsequent evaluation of growth enhancement, heavy metal translocation and leaching potential. Proc. WISA, Durban, South Africa. *Water SA Special Edition* ISBN 1-86845-946-2.

Rippon , J.E. and Wood, M.J. 1975. Microbiological aspects of pulverized fuel ash. In: Chadwick, M.J., Goodman, G.T. (eds.), The ecology of resource degradation and renewal. John Wiley, New York, pp. 331-349.

Ritchey, K.D., Elrashidi, M.A., Clark, R.B., and Baligar, V.C. 1998. Potential for utilizing coal combustion residues in co-utilization products. S.Brown, J.S. Angle and L. Jacobs (eds.) Beneficial Co-utilization of Agricultural, Municipal and Industrial By-products, pp139-147.

Sajwan, K.S., Paramasivam, S., Alva, S.K., Adriano, D.C. and Hooda, P.S. 2003. Assessing the feasibility of land application of fly ash, sewage sludge and their mixture. *Advances in Environmental Research* **8;** 77–91

Schutter, M.E. and Fuhrmann, J.J., 2001. Soil microbial community responses to fly ash amendment as revealed by analyses of whole soils and bacterial isolates. *Soil Biol. Biochem*. **33**, 1947-1958.

Sikka, R. and Kansal, B.D. 1995. Effect of fly-ash application on yield and nutrient composition of rice, wheat and on pH and available nutrient status of soils *Bioresource Technology* **51**, 199-203

Singh, N.B. and Singh, M., 1986. Effect of fly ash application on saline soil and on yield components, yield and uptake of NPK of rice and wheat at varying fertility levels. *Ann. Agric. Res*. **7** (**2**), 245-257.

Singh, S.P., Tack, F.M.G. and Verloo, M.G., 1996. Extractability and bioavailability of heavy metals in surface soils derived from dredged sediments. *Chemical Speciation and Bioavailability* 8 (3/4), 105-114.

Singh, S.N., Kulshreshtha, K and Ahmad, K.J. 1997. Impact of fly ash soil amendment on seed germination, seedling growth and metal composition of *Vicia faba L. Ecological Engineering* **9**, 203-208.

Stratton, M.L. and Rechcigl, J.E. 1998. Agronomic benefits of agricultural, municipal, and industrial by-products and their co-utilization: An overview. S.Brown, J.S. Angle and L. Jacobs (eds.) Beneficial Co-utilization of Agricultural, Municipal and Industrial By-products, pp9-34.

Sopper, W.E. 1993. Municipal Sludge Use in Land Reclamation. Review of Land Reclamation Projects using Municipal Sludge. ISBN 0873719417. Lewis Publishers. p 13-141.

Taylor, E. and Schuman, G.E. 1988. Fly ash and lime amendment of acidic coal spoil to aid re-vegetation. *J. Environ. Qual.* **17, 1**: 121-124

Terman, G.L. 1978. Solid wastes from coal fired power plants: Use or disposal on agricultural lands. Bull. Y- 129. Tennessee Valley Authority, Muscle Shoals, Al.

Tiessen, H., Stewart, J.W.B., and Hunt, H.W. 1984. Concepts of soil organic matter transformations in relation to organomineral particle size fractions. In. "Biological Processes and Soil Fertility" (J. Tinsley and J.W. Darbyshire, eds.) Nijhoff, The Hague.

Tisdale, S.L. and Nelson, W.L. 1975. Soil Fertility and Fertilizers. *Macmillan, New York.*

Truter, W.F. and Rethman, N.F.G. 2000. Crop productivity in fly ash/sewage sludge amended soils. *Proc. Joint. Conf.* Pretoria, South Africa.

Truter, W.F. 2002. Use of waste products to enhance plant productivity on acidic and infertile substrates. MSc (Agric) Thesis, University of Pretoria, South Africa.

Vallini, G., Vaccari, F., Pera, A., Agnolucci, M., Scatena, S. and Varallo, G. 1999. Evaluation of co-composted Coal Fly ash on Dynamics of Microbial Populations and Heavy Metal Uptake. *Compost Science and Utilization.* **7**, no. 1 81-90.

Wang, H.F. , Takematsu, N. and Ambe, S. 2000. Effects of soil acidity on the uptake of trace elements in soybean and tomato plants. *Applied Radiation and Isotopes*. Iss. 4. **52** , pp 803-811.

Weil, R.R., Lowell, K.A. and Shade, H.M. 1993. Effects of intensity of agronomic practices on a soil ecosystem. *Am. J. of Alt. Agric.* **8**: 5-14.

Wells, L.G. and Barnhisel, R.I. 1992. Bulk density response to placement methods and remedial measures in reconstructed prime farmland soils.. Prime Farmland Reclamation. (Edited by R.E. Dunker, R.I. Barnhisel and R.G. Darmody). p. 213-220.

Wester, D.B., Sosebee, R.E., Zartman, R.E. and Fish, E.B. 1996. Use of municipal biosolids on semiarid rangelands. p. 2.31-2.35. *In* 10th Annual Residuals and Biosolids Management Conference: 10 Years of Progress and a Look Toward the Future, Denver, CO. 18-21 Aug. 1996. Water Environ. Fed., Alexandria, VA.

White, C.S., Loftin, S.R. and Aguilar, R. 1997. Application of biosolids to degraded semiarid rangeland: Nine year responses. *J. Environ. Qual.* **26**:1663-1671

Wiseman, J.T. and Zibilske, L.M. 1988. Effects of sludge application sequence on carbon and nitrogen mineralization in soil. *J. Environ. Qual.* **17**:334-339.

Woods, L.E., Cole, C.V., Porter, L.K. and Coleman, D.C. 1987. Transformation of added and indigenous nitrogen in gnotobiotic soil. A comment on the priming effect. *Soil Biol. Biochem.* **19**:673-678.

Wong, J.W.C. 1995. The production of artificial soil mix from fly ash and sewage sludge. *Environ. Technol.* **16**:741-751.

Wong, J.W.C. and Su, D.C. 1997. Re-utilization of coal fly-ash and sewage sludge as an artificial soil-mix: Effects of pre-incubation on soil physico-chemical properties. *Bioresource Technology* **59**, 97-102

Wong, M.H. and Wong, J.W.C. (1986) Effects of fly ash on soil microbial activity. *Environ. Pollut. Ser.* **40**, 127-144.