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Soil degradation and the use of agricultural and organic industrial by products as soil amendments

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"A cloak of loose, soft material, held to the earth's hard surface by gravity, is all that lies between life and lifelessness."
Wallace H. Fuller
Soils of the Desert Southwest University of Arizona Press, 1975

Introduction

A soil's stability and resilience affects the stability and resilience of the remaining parts of the ecosystem – microbial, plant and animal. If a soil is degraded, the ecosystem is impaired. Replacing organic matter within a soil is a means of amending degraded soils. Organic matter helps stimulate microbial populations that are essential to the stability and resilience of the soil ecosystem as a whole. Organic matter also helps in soil revegetation and erosion control (Alexander 1999). Sources for organic matter can be found in agricultural by-products from corn (*Zea mays* L.) and soybeans (*Glycine max* [L.] Merr.) (Aulakh et al. 1991), sugar beets (Falih and Wainwright 1996), and cottage cheese whey (Kelling and Peterson 1981). Organic matter can also come from industrial by-products such as papermill and cardboard sludge (Xiao et al. 1999, Rosen et al. 1999).

These sources all provide fairly inexpensive, natural and benign organic materials for soil amendments. Recycling them back into the soil is an environmentally favorable alternative to landfilling. Collection and transportation costs, however, may not make recycling as financially favorable for industries and so by-products may be landfilled, even when recycling is feasible (Farrell 1995).

Nutrient requirements for soil microbes

A soil is an ecosystem containing thousands of microorganisms competing for organic matter and nutrients within and on the surface of the soil. The enormous range of organisms and their diversity and balance engender a stable and resilient ecosystem. In soils considered degraded, microorganism populations have lost their resilience to disturbances and are no longer able to perform their normal processes of cycling nutrients, assimilating organic wastes and maintaining soils structure (Brady and Weil 1999). Soil microbes cannot break down organic matter into smaller, mineral forms available for plant uptake, causing plants to become nutrient –deprived and lose their resilience. In extreme cases, all plant growth on the surface of the soil can die off, causing the soil to erode and the ecosystem to become severely degraded. In order to prevent soil degradation and further ecosystem degradation, the first step in restoring or reclaiming a soil is to re-establish soil microbial populations.

Soil microorganisms require specific physical and chemical soil conditions for optimal growth. Organic matter availability is the limiting factor for microbial populations. Microbes need a constant supply of organic matter, as it is their source of energy for metabolism. Microbes require carbon for building essential compounds and nitrogen to synthesize nitrogen-containing cellular components such as amino acids, enzymes and DNA. On average, microbes must incorporate eight parts carbon for every one part nitrogen into their cells. However, they only use one-third of the carbon, the other two-thirds being respired, and so microbes actually require 24 parts carbon to one nitrogen. Generally, microbes release nitrogen in a mineral form available for plant uptake at a carbon-to-nitrogen ratio of 20:1. Any ratio much higher than 20:1 results in nitrogen depletion in the soil, causing the microbes to scavenge for more nitrogen while retaining the nitrogen they have. Thus the incorporation of organic residues high in carbon forces intense competition between microbes for available nitrogen, depleting the soil of nitrogen, and causing higher plants to suffer from nitrogen deficiency (Brady and Weil 1999).

In addition to organic matter, microbes require a sufficient supply of oxygen, as most of their processes are aerobic. They also need moist but not wet soils, because water will limit oxygen supply within the soil pores; microbial growth is greatest when soil temperatures are stable, between 20 and 40 degrees Celsius, and soil pH is near neutral.

Nutrient requirements for plants

A stable and resilient soil microbial ecosystem is essential to higher plant growth. Plants rely on the microorganisms' abilities to break down organic matter into smaller mineral forms that plants can take up into their roots. Plants require both carbon and nitrogen, but often nitrogen is the most common limiting factor due to an insufficient supply of its mineral form in the soil. Plants also require ample amounts of phosphorus for photosynthesis, nitrogen fixation, flowering, and fruiting. It is also the second most common nutrient to limit plant growth and productivity. Plants require that phosphorus ions be dissolved in the soil and that they move to the root surface for uptake. However, phosphorus ions are strongly adsorbed to soil particles, especially clays, causing diffusion to the root to be slow enough that phosphorus availability is limited and plant growth stunted. Vesicular-arbuscular (VA) mycorrhizal fungi play an important role in phosphorus uptake by forming hyphae which extend out into the soil several centimeters from the root to prospect phosphorus for the plant in return for between 3 and 20% of the plant's carbon supply. Without the assistance of VA mycorrhizae in obtaining phosphorus, many plants could not survive in soils low in phosphorus (Brady and Weil 1999).

Waste recycling developments

Waste recycling through composting and land application is a relatively new field. It was begun in the 1960's as an alternative to landfilling and as a way to amend or fertilize degraded or nutrient-depleted soils. Waste recycling techniques focused mostly on municipal solid wastes, sewage sludge and industrial solid wastes. These techniques continued to develop and gain interest throughout the following forty years largely due to stricter environmental regulations in assigning landfill permits (Rosen et al. 1993) and an abundance of studies focused largely on land application (Chaney 1990). Recycling food processing wastes and papermill and cardboard sludges are more recent developments in the field of waste recycling and are just beginning to be explored.

In 1979, the P.H. Glatfelter Co., a large paper company, began to consider landfill alternatives for the disposal of their primary and secondary paper sludges. In light of what they felt was changing technology, growing public awareness and tightened government regulations, the company began preliminary tests and a pilot scale composting facility. By 1980, they were composting 90 out of the approximately 300 tons of primary and secondary sludge produced per day. In addition, the money the company saved by composting was able to offset the cost of the pilot facility (Smyser 1982). Their success marked the beginning of numerous other studies exploring the feasibility of papermill composting, and the effects of sludge and compost land application (Henry 1991, Pichtel et al. 1994, Kost et al. 1997).

Landfill alternatives for food residues received only intermittent attention and were slower to gain interest. In 1962, the Food Processors Association published the results of their study done on composting food wastes from fruit and vegetable processing industries (Riggle 1989). Twenty seven years later, in 1989, their study results were "rediscovered" and published under the new title "Revival time for composting food industry wastes." Shortly afterwards other studies were published on composting and land application of numerous other food processing residuals (Cato 1989). By 1995, the number of composting projects being implemented was on the rise. Canada experienced a 17% increase in their number of projects from 1993 to 1995. This increase was partly due to cooperation between composters and local industries. Composters found they could easily obtain reliable feedstock supplies from local industries, specifically granaries, while helping the industries dispose of large volumes of a particular type of organic residual (Gies 1995).

Today, the composting market continues to grow as more opportunities for environmental applications are being discovered (Alexander 1999). Erosion control is a fairly new and promising application for composts. Compost applications can often stabilize slopes more effectively than the conventional methods of hydroseeding and hay or straw mulching by absorbing the energy from rainfall and reducing flow velocity and improving percolation rates. Composts should be applied 3-4" deep and can be used on slopes up to 2:1. Composts can also be used for soil reclamation and revegetation of sites with marginal or degraded soils, such as landfills, factories, roadsides, and mines. Composts supply the soil with microbes and essential plant nutrients such as carbon, nitrogen, and phosphorus, which increase soil quality and enhance plant establishment. Composts can also immobilize toxic metals and filter out pesticides (Alexander 1999).

Industrial food processing residuals

Recycling corn residues into degraded soils has been shown to improve soil quality in a number of ways. Corn leaves have a relatively low carbon content. Their C:N ratio is approximately 40:1, which makes them a versatile organic amendment for soils lacking an organic layer (Aulakh et al. 1991). The leaves can be applied as dried mulch or as compost, and are easily broken down in the soil.

Corn straw has high, although variable, levels of carbon. C:N ratios are normally around 60:1, but can go as high as 300:1 (Harinikumar et al. 1990). Corn straw is an effective amendment for soils low in carbon, such as soils that have a stripped or eroded organic layer. Incorporating the straw into a degraded soil stimulates microbial populations, particularly fungi (Wagner and Broder 1993). In fact, corn straw has been shown to stimulate microbial populations enough to degrade methabenzthiazuron or MBT, the active ingredient of TRIBUNIL®, which is a herbicide used on cereal crops (Printz et al. 1995). Applications should be managed carefully, however, because adding too much corn straw to a soil with only a small carbon shortage can cause a significant decrease in the mobility of mineral nitrogen (Aulakh et al. 1991).

Corn stalks decompose slowly the first three to four months after incorporation into the soil (Mott et al. 1988). Corn stalks can be incorporated into eroded organic layers to help prevent further erosion and increase soil infiltration rates while adding carbon in a slow-release form (Brown et al. 1998). Corn stalks that are dried and chopped to 2-cm bits can be broken down more quickly and effectively in the soil and can provide supplies of carbon and nitrogen faster for plant uptake (Harinikumar et al. 1990).

Corn straw can also be used to amend phosphorus deficient soils such as oxisols. Oxisols are tropical soils that have and approximate 0.0013% phosphorus content and accumulations of low-activity clays that highly adsorb the phosphorus to the clay particles (Brady and Weil 1999). The average shoot phosphorus concentration in corn straw is 0.13%. Adding phosphorus to the soil stimulates activity of vesicular-arbuscular (VA) mycorrhizal fungi and increases phosphorus uptake by plants (Harinikumar et al. 1990).

Residue from the stems of soybeans is extremely similar to that of corn straw in its nitrogen content and C:N ratio, and can be used to amend soils in a similar fashion (Aulakh et al. 1991). The by-products of soybeans after extraction of the oil, however, are much different from the stems in that they contain rich nitrogen compounds and are a source of vegetable proteins commonly used in cooking oils (Kubo et al. 1994). These residuals have been most commonly reused as feed for animals, but can also be used to amend nitrogen deficient soils such as soils high in clay content or soils that have been rigorously cultivated. Applying the residues directly to the soil provides a slow-release form of nitrogen fertilization that minimizes loss of nitrate ions due to leaching. In 1994, microorganisms that specifically degrade soybean by-products were isolated and characterized (Kubo et al. 1994). These microbes hasten the availability of nitrogen to soil microbes and plants, but need to be managed carefully for nitrate leaching and contamination of groundwater, domestic wells and surface waters such as streams and lakes (Brady and Weil 1999).

Sugar beets and sugar beet tops are a third source for soil amendments. The by-products from processing sugar beets, and the beets themselves, are very high in glucose. Glucose is a source of carbon that is easily broken down by soil microorganisms. Incorporating the sugar beet by-products directly or as a compost into a carbon-deficient soil quickly stimulates populations of soil bacteria. In the presence of nitrogen and phosphorus, these bacteria can trigger nitrification, phosphorus solubilization and urea hydrolysis (and the subsequent nitrification of NH^{4+}) (Falih and Wainwright 1996). In contrast, sugar beet tops, which are the green tops left in the fields after harvesting, contain high levels of nitrogen and can be used as fertilizers in soils that are nitrogen deficient (Kapur and Kanwar 1994).

Cheese whey is a by-product of the conversion of milk to cheese. All whey is fairly acidic (pH between 4.0 and 6.1) with cottage cheese whey being the most strongly acidic (Kelling and Peterson 1981). Whey can be used to amend soils low in nutrients. It is a source of phosphorus and potassium and most of the nutrients are inorganic constituents or simple organic compounds, both of which are conducive to plant uptake. The C:N ratio of whey is commonly around 20:1, which allows it to be used as a slow release form of nitrogen fertilizer. Whey can also improve soil aggregate stability and infiltration rates in acidic soils (Kelling and Peterson 1981), soils high in calcium carbonates (Lehrsch et al. 1994), and soils with salt concentrations at levels that interfere with plant growth (Jones et al. 1993). Acid whey from cottage cheese manufactured using phosphoric acid can be used to amend unproductive sodic soils by lowering the soil pH, exchangeable sodium percentage (ESP), and sodium adsorption ratio (SAR), without increasing the soluble salt levels (Jones et al. 1993). Keeping soluble salt levels steady is necessary to avoid adverse effects on plant growth.

Paper and cardboard industry residuals

Papermill by-products can be used as soil amendments, although they are not quite as benign as agricultural by-products. Papermill sludge is generally high in organics, including microorganisms, cellulose, lignin and wood extracts, and is relatively low in trace metals and calcium carbonate. Leaching of trace metals from sludge is minimal (Xiao et al. 1999). Papermill sludge consists of both primary and secondary forms, but both forms are very different from each other. When they are applied to soils separately, they have very different effects on plant growth.

Primary sludge is produced in the primary clarifier and consists of rejected wood fibers, lime, clay and sand, and small amounts of fly ash. It has an extremely high C:N ration, between 100-500:1. Secondary sludge is produced in aeration basins and consists of dead bacteria and other microorganisms. Its C:N ratio is much lower, around 5:1. In a study done on the effects of the C:N ratios of primary and secondary sludges on Douglas-fir (*Pseudotsuga menziesii*) and western white pine (*Pinus monticola* Douglas ex D. Don), height and diameter growth were monitored (Harrison et al. 1996). The C:N ratio of the primary sludge showed a significant negative correlation with the height and diameter growth of these trees. The high carbon content in the primary sludge reduced soil nitrogen availability for uptake by the trees and deterred tree growth at a critical stage in development (Harrison et al. 1996). The C:N ratio of the secondary sludge showed a positive correlation with height and diameter growth of the Douglas-firs and white pines. Growth increased with more available nitrogen in the soil. This study, however, was short-term, lasting only two years, and the results cannot be extrapolated to the long-term growth of a forest stand.

In organic, non-alkaline soils, papermill sludges containing both primary and secondary forms can be used as suitable tools for amending degraded soils. The potential benefits of applying the organic materials found in these sludges to abandoned mineland soils has been studied extensively. Mineland soils are highly acidic, low in plant nutrients and high in metals. Sludges have been used to add nitrogen, phosphorus, calcium, and potassium to improve these soils and their groundcover and tree growth (Sutton and Dick 1987, Pichtel et al. 1994, Kost et al. 1997).

Cardboard sludge is a by-product of cardboard recycling facilities. It contains some nutrients beneficial to the soil, low levels of soluble salts and trace elements, and most importantly a near-neutral pH and a C:N ratio of 7:1, indicating high nitrogen availability (Rosen et al. 1999). The higher nitrogen content makes the sludge susceptible to leaching on sandy soils due to residual soil nitrate. Despite this, cardboard sludge can be used as an effective amendment for many different types of soils.

Current challenges

Collecting and transporting residuals and compost poses many serious challenges. For industries unable to compost their residuals on site due to limited space or resources, they need to be able to transport their material to an independent composting facility off site. Feasibility for this depends on the haulers. Companies that haul residuals and compost need to have the right equipment, a dense route of industries located within a short distance of each other, and a nearby composting facility. In 1995, Minnesota Waste Management set up an off-site compost pilot. They agreed to collect food residuals from any generator who wanted to participate, and so customers were spread out over a wide area. Drivers spent more than 8 hours a day, traveling more than 30 miles to collect from only 30 or 40 stops, in addition to the two hours spent hauling the materials back to the Wright County composting facility (Farrell 1995). Composting facilities need to be located near the hauling company and the company's customers.

Composting fees need to be lower than alternative disposal options, although in many cases they are not. Through the duration of the compost pilot in Minnesota, Hennepin County gradually decreased their incinerator fees to match composting fees because their incinerators were losing materials, and therefore, profits (Farrell 1995). But as landfills close and air-emission standards are increased for incinerators, composting is becoming much more economically feasible than it was in the past (Mamo et al. 1993). However, there are still limited markets and available land space for using composted materials in land application. Facilities are often forced to landfill a large percentage of the by-products they composted because they have nowhere else to place them (Rosen et al. 1998).

Competition for materials can extend beyond disposal facilities. Farmers may plow straw left after a grain harvest into the field or leave it for cattle forage. Corn silage is normally used or sold as cattle feed; sugar beet tops are left in the fields after harvest as nitrogen fertilizers. Any company seeking to use these organics as soil amendments would have to compete for them with farmers in the market (Kuchenrither et al. 1983).

Conclusion

Degraded soil ecosystems need organic matter supplements to stimulate microbial populations, which in turn will be able to support higher plant growth and reduce erosion from bare soils. Sources of organic matter from many different types of soil restorations or reclamations can be found in residues containing nutrients originally taken from the soil, such as agricultural by-products and papermill and cardboard sludges. Recycling them back into the soil directly or as compost is an effective and fairly safe way to restore soil ecosystem balance. However, collection and transportation costs and inconvenience, as well as competition for materials, keep recycling and land application of food and papermill residuals from being the most affordable and convenient method of waste disposal.

Literature Cited

Alexander, R. 1999. Compost markets grow with environmental applications. Biocycle 40(4):43-48

Aulakh, M.S., J.W. Doran, D.T. Walters, A.R. Mosier, and D.D. Francis. 1991. Crop

residue type and placement effects on denitrification and mineralization. Soil Science Society of America Journal. 55:1020-1025.

Brady, N.C. and R.R. Weil. 1999. The Nature and Property of Soils, Twelfth Edition. Prentice Hall, Upper Saddle Hall, NJ.

Brown, M.J., C.W. Robbins, and L.L. Freeborn. 1998. Combining cottage cheese whey and straw reduces erosion while increasing infiltration in furrow irrigation. Journal of Soil and Water Conservation 53:152-156.

Cato, J.C. 1989. Putting crab wastes to use. Biocycle. 30(11):38.

Chaney, R.L. 1990. Twenty years of land application research. Part 1. Biocycle 31(9):54-59.

Falih, A.M.K. and M. Wainwright. 1996. Microbial and enzyme activity in soils amended with a natural source of easily available carbon. Biology of Fertile Soils 21:177-183.

Farrell, M. 1995. Collecting and transporting food residuals. Biocycle 36(8):38-39.

Gies, G. 1995. Composting food processing residuals. Biocycle 36(8):36-37.

Harinikumar, K.M., D.J. Bagyaraj, and B.C. Mallesha. 1990. Effect of intercropping and organic soil amendments on native VA mycorrhizal fungi in an oxisol. Arid Soil Research and Rehabilitation 4:193-197.

Harrison, R.B., S.P. Gessel, D. Zabowski, C.L. Henry, D. Xue, D.C. Cole, and J.E. Compton. 1996. Mechanisms of negative impacts of three forest treatments on nutrient availability. Soil Science Society of America Journal. 60:1622-1628.

Henry, C.L. 1991. Nitrogen dynamics of pulp and paper sludge amendment to forest soils. Water Science and Technology. 24:417-425.

Jones, S.B., C.W. Robbins, and C.L. Hansen. 1993. Sodic soil reclamation using cottage cheese (acid) whey. Arid Soil Research and Rehabilitation. 7:51-61.

Kapur, M.L. and R.S. Kanwar. 1993. Sugar beet tops as a source of nitrogen for maize and rice grown in rotation with sugar beet in subtropical north-west India. Tropical Agriculture. 71:12-16.

Kelling, K.A. and A.E. Peterson. 1981. Using whey on agricultural land – a disposal alternative. College of Agriculture and Life Sciences, University of Wisconsin – Madison.

Kost, D.A., D.A. Boutelle, M.M. Larson, W.D. Smith, and J.P. Vimmerstedt. 1997. Papermill sludge amendments, tree protection, and tree establishment on an abandoned minesoil. Journal of Environmental Quality 26:1409-1416.

Kubo, M., J. Okajima, and F. Hasumi. 1994. Isolation and characterization of soybean waste-degrading microorganisms and analysis of fertilizer effects of the degraded products. Applied and Environmental Microbiology. 60:243-247.

Kuchenrither, R.D., D.G. Smith, and W.J. Martin. 1983. Identifying and selecting organic compound amendments. Biocycle 24(6):50-53.

Lehrsch, G.A., C.W. Robbins, and C.L. Hansen. 1994. Cottage cheese (acid) whey effects on sodic soil aggregate stability. Arid Soil Research and Rehabilitation 8:19-31.

Mamo, M., T.R. Halbach, and C.J. Rosen. 1998. Utilization of municipal solid waste compost for crop production. University of Minnesota Extension Service, St. Paul, MN.

Mott, S.C., J.R. Davenport, and R.L. Thomas. 1988. Mineralization and redistribution of carbon from surficial and buried corn stalks. Canadian Journal of Soil Science 68:687-691.

Pichtel, J.R., W.A. Dick, and P. Sutton. 1994. Comparison of amendments and management practices for long-term reclamation of abandoned mine lands. Journal of Environmental Quality 23:766-772.

Printz, H., P. Burauel, and F. Fuhr. 1995. Effect of organic amendment on degradation and formation of bound residues of methabenzthiazuron in soil under constant climatic conditions. Journal of Environmental Science and Health 30:435-456.

Riggle, D. 1989. Revival time for composting food industry wastes. Biocycle 30(5):35-37.

Robbins, C.W., C.L. Hansen, M.F. Roginske, and D.L. Sorensen. 1996. Extractable potassium and soluble calcium, magnesium, sodium, and potassium in two whey- treated calcareous soils. Journal of Environmental Quality 25:791-795.

Rosen, C.J., T.R. Halbach, and B.T. Swanson. 1993. Horticultural uses of municipal solid waste composts. HortTechnology 3(2):167-173.

Rosen, C., T. Halbach, G. Titrud, and M. McNearney. 1999. Evaluation of cardboard sludge as a soil amendment for crop production. Final report submitted to the City of Becker. Department of Soil, Water, and Climate, University of Minnesota, St. Paul, MN.

Smyser, S. 1982. Compost paying its way for paper production. Biocycle 23(3):25-26.

Sutton, P. and W.A. Dick. 1987. Reclamation of acidic mined lands in humid areas. Advanced Agronomy. 41:377-405.

Wagner, G.H. and M.W. Broder. 1993. Microbial progression in the decomposition of corn stalk residue in soil. Soil Science 155:48-52.

Xiao, C., L.Q. Ma, and T. Sarigumba. 1999. Effects of soil on trace metal leachibility from papermill ashes and sludge. Journal of Environmental Quality 28:321-333.