Restoration and Reclamation Review
Student On-Line Journal
Vol.5, No.4, Fall 1999
Department of Horticultural Science
University of Minnesota, St.Paul, MN

Mycorrhizal Plants for Phytoremediation of Soils Contaminated with Radionuclides

Alex Westhoff

Background

Radionuclide contamination is a result of nuclear power testing, nuclear waste disposal and accidents resulting from nuclear power generation. An accident of this nature is the incident which occurred at the Chernobyl Nuclear Power Station on April 26, 1986 (Anspaugh et al. 1988). The Chernobyl Nuclear Power Station is located in the Ukraine. The accident that occurred in 1986 has been the largest accidental release of radionuclides in the world to this date. It occurred because an overheated reactor exploded, expelling the upper shield and releasing large amounts of radioactive waste. Radioactive waste continued to be released for nine days (Anspaugh et al. 1988). Many types of radionuclides were released across the Northern Hemisphere including iodine-131, cerium-141, 144, plutonium-238, 239, 240, cesium-134, 137 and strontium-89, 90 (Anspaugh et al. 1988). There are several ways in which humans can come into contact with these radionuclides: inhalation from the passing cloud, external exposure to contaminated soil surfaces, and ingestion due to food chain transfer of radionuclides. The types of cancer that can occur include leukemia, thyroid, bone, breast, lung and others. As of 1988, there were 237 confirmed cases of illness resulting from this incident, as well as 31 fatalities in the Soviet Union (Anspaugh et al. 1988).

Two radionuclides of special concern that were released from Chernobyl and other similar incidents are cesium-137 and strontium-90. These two radionuclides are long-lived; cesium-137 has a half-life of 30 years and strontium-90 has a half-life of 28 years (Killham 1995). These two radionuclides still persist in the soil as a result of the atomic bomb which was dropped on Nagasaki in 1945, although other radionuclides have since decayed (Mahara 1993). Studies have shown that neither cesium-137 nor strontium-90 are leached from the soil very easily or quickly, even under high rainfall (Entry et al. 1996). Cesium-137 acts similarly to potassium and strontium-90 behaves similarly to calcium (Killham 1995). Hence they are both taken up by many plant species and can enter the food chain.

Soil remediation is necessary in order to prevent radionuclides from being taken up in the food chain. The major sites affected by the Chernobyl incident that require soil remediation are located in Scandinavia, eastern Europe, parts of southern Europe, and parts of Asia (Anspaugh 1988). Many of the soil remediation techniques that currently exist are ex situ, requiring that soil is transported and treated off-site. Transporting soil is expensive and time-consuming (Entry et al. 1999). Many recent studies have been conducted to determine the effectiveness of phytoremediation techniques for these contaminated soils.

This paper explores the extent to which phytoremediation can be used to reclaim contaminated with radionuclides, particularly cesium-137 and strontium. The types of plant species that this paper will focus on are those with mycorrhizal associations because they are often more effective than non-mycorrhizal plants at the uptake of radionuclides (Entry et al. 1995)

Cesium-137 and Strontium-90 in Soils

Cesium-137 behaves similarly to potassium and strontium-90 to calcium in soils and plants, both macronutrients taken up in relatively large quantities. As for calcium and potassium, the ability of plants to take up cesium-137 and strontium-90 is largely dependent on soil conditions. Soil conditions such as clay content, organic matter content, base saturation, and cation exchange capacity affect the way that these elements act in the soil. Cation exchange is greatest for clay and organic matter soil fractions. Cesium-137 binds to the crystal lattice layer of clay minerals especially smectite clays such as montmorillonite. Therefore cesium-137 is not usually taken up by plants growing in contaminated soils with high clay contents (Coughtrey et al. 1989). In general, soils containing higher amounts of organic matter will allow plants to accumulate higher amounts of radionuclides (Entry et al. 1996). Paasikallio (1984) found that ryegrass (*Lolium multiflorum*) accumulated the most cesium-137 and strontium-90 when grown in *Sphagnum* peat than it did in other soil media including clay, sand, silt, and compost. Other soil conditions which favor increased plant uptake are a higher cation exchange capacity for strontium-90 availability, and a lower base saturation for uptake of both strontium-90 and cesium-137 (Entry et al. 1996). If the soil is nitrogen limited, fertilizing it with nitrogen will indirectly increase the amount of radionuclides that will be taken up by enhancing overall plant growth, especially root growth (Entry et al. 1996). Fertilizing the soil with nutrients such as K or Ca that compete with the radionuclides for cation exchange sites and compete to be taken up by the plant should not increase uptake of strontium-90 or cesium-137 (Entry et al. 1996).

Mycorrhizal Associations

Mycorrhizae are the symbiotic relationship between a soil-borne fungus and the roots of a plant. Mycorrhizal fungi depend on host plants for carbon and in return they enable host plants to be more efficient in acquiring nutrients and water from the soil (Entry et al. 1999). There are two types of mycorrhizal fungi: ectomycorrhizae and endomycorrhizae. Ectomycorrhizae form sheaths around plant roots (Rost et al. 1998). Endomycorrhizae enter cortex cells in the plant roots (Rost et al. 1998). Although certain plant species that are normally symbiotic with mycorrhizal fungi can exist without the fungal association, the fungus greatly enhances the plant’s growth. Hosting mycorrhizae is much more energy effective to the plant than producing plant roots (Marshall and Perry 1987). A study done by Harley (1989) found that most roots need about 100 times the amount of carbon than do the hyphae of its associated ectomycorrhizae in order to span across the same amount of soil. Therefore it is easier for hyphae to acquire elements that have a low mobility than it is for plant roots (Kirk and Staunton 1989). Cesium-137 and strontium-90 both have low mobilities (Kirk and Staunton 1989).

Most arbuscular mycorrhizae do not have specific host plants. Hence if the area that is going to be remediated already has well established angiosperms it may not be necessary to add fungal spores to that area because they probably already exist in the soil (Entry et al. 1999). If plants are not growing on the site it may be beneficial, however, to add mycorrhizal spores to the soil in order to increase colonization (Entry et al. 1999). Inoculating potted plants in the nursery, such as tree seedlings, with specific mycorrhizae may also be a good idea if a specific type of mycorrhizal fungi is desired since some types have been shown to work better than others (Entry et al. 1994). Inhibition of mycorrhizal growth can occur due to high phosphate levels in the soil (Killham 1995).

Recent Studies

The phytoremediation studies that will be reviewed in this section are all greenhouse studies. Little research has been done to this date on testing radionuclide phytoremediation techniques in an outdoor environment. Although the results of greenhouse studies may be significant, they do not necessarily transfer to the outdoor environment. In greenhouses many factors are manipulated for optimal plant growth including water, lighting and temperature. It can also be easier to establish mycorrhizal associations in the greenhouse environment (Entry et al. 1999). In the external environment these things vary tremendously over time and spatial scales. However, greenhouse and lab studies can still give us a basis on how effective specific plant and fungi species are at radionuclide phytoremediation. Hopefully results from these studies will be applied to field experiments in the near future.

Herbaceous Plants

A study done by Broadly and Wiley (1997) tested the radiocesium uptake of 30 different herbaceous plant species among several families. They determined that the highest concentrations of cesium were taken up by plants in the Chenopodiaceae family (i.e., goosefoot family) which includes many fast-growing taxa. They attribute this rapid uptake to the fact that there is little discrimination between uptake of cesium and potassium in this family compared to plants in other families such as the Poaceae family (i.e. grasses). This study did not mention the use of mycorrhizal inoculates.

Coughtrey et al. (1989) found that grassland vegetation in the United Kingdom accumulated 4-19% of the cesium-137 from the soil which was deposited by the Chernobyl incident. The highest concentration of cesium-137 accumulated in *Carex spp.* This study did not mention mycorrhizae but used native plants and native soils from which mycorrhizal fungi likely existed.

A study done by Entry et al. (1999) included three grass species: bahia grass (*Paspalum notatum*), johnson grass (*Sorghum halpense*), and switchgrass (*Panicum virgatum*). These three species were selected for this experiment because they produce a high amount of biomass in relatively short periods of time. These grasses were inoculated with two species of arbuscular mycorrhizae: *Glomus mosseae* and *Glomus intraradices*. Plants with their fungal associations were grown in the greenhouse for six months and above-ground biomass harvested every two months. At the end of the study, the above-ground portion of the three grasses that had been inoculated with fungi accumulated 41.7% to 71.7% of the total cesium-137 that had been added to the soil while noninoculated plants accumulated 26.3% to 45.5%. The inoculated plants took up 42.0% to 88.7% of the total strontium-90 and the noninoculated plants only took up 23.8% to 52.6%. Plants inoculated with *G. mosseae* resulted in the highest above ground biomass and percent accumulation of both radionuclides. Overall, the plants in this study accumulated higher amounts of radionuclides than previously published studies. Entry et al. (1999) suggested several reasons for the observed high accumulations, including optimal growing conditions, high root density, low concentrations of K and Ca in the soil, and high amounts of mycorrhizal fungi.

Roger and Williams (1986) studied the uptake of cesium-137 by yellow sweetclover (*Melilotus offinialis*) and sudan grass (*Sorgham sudanense*) infected with vesicular-arbuscular mycorrhizae. These plants were also grown under greenhouse conditions. *M. offinialis* took up only .93-2.5 parts per million cesium-137 compared with the concentration in the pots they were grown in. *S. sudanense* took up only .6-1.42 parts per million.

Woody Plants

Entry et al. (1994) studied *Pinus ponderosa* and *Pinus radiata* inoculated with five different ectomycorrhizae and grown in soil with strontium-90. The most successful of the tree-ectomycorrhizal associations regarding strontium-90 uptake was *P. ponderosa* inoculated with *Laccaria laccata*; 6% of the radionuclide from the soil accumulated in the aboveground portion of the plant within one month.

Heather (*Calluna vulgaris*) is a potential plant for radionuclide phytoremediation because it is associated with mycorrhizal fungi. Heather takes up high levels or radioactive cesium compared with other plant species growing in the same ecosystems (Harrison et al. 1990). Heather grows in the upland of the United Kingdom, a region impacted by the Chernobyl accident. Acidic and peaty soils are common to the region. Vegetation responds well to potassium inputs. Hence it is presumed that heather will take up Cesium-137 in the same manner as potassium (Killham 1995). A study done by Clint and Dighton (1992) determined that although less cesium-137 was taken up by heather plants inoculated with the mycorrhizae, the final root:shoot ratio of cesium was higher in the inoculated plants. Although the noninoculated plants took up more cesium from the soil, the inoculated plants took a higher concentration into their aboveground portion.

Other studies have been done regarding the use of trees for phytoremediation of radionuclides. Pinder et al. (1984) determined that three tree species, *Acer rubrum, Liquidambar stryaciflua* and *Liriodendron tulipifera* were able to accumulate significant amounts of strontium-90 and cesium-137 in their above ground portions. This study did not mention the use of mycorrhizal fungi, but future experiments could be conducted using those plant species and inoculating them with mycorrhizal fungi.

Future Applications

The sites that were affected by the Chernobyl accident range across Europe and parts of Asia (Anspaugh et al. 1988). Hence there is a variety of geographical and climatic conditions that need to be remediated and a variety of plant species needed for phytoremediation. Plant species native to the area being restored are most desirable for remediation since they will require the least amount of external inputs and will not be a threat of becoming invasive. It is also desirable to use plants that are less susceptible to being grazed upon by animals so that radionuclides do not enter the food chain (Entry et al. 1996). Areas being remediated may need to be fenced off if it is probable that grazing will occur (Entry et al. 1996).

Once the plants are used for phytoremediation they need to be harvested or they will decompose back into the soil, redispersing radionuclides. The most common post-harvest treatment on phytoremediation projects is to incinerate the aboveground portions of plants at high temperatures, leaving only the ashes for disposal (Entry et al. 1996). Once soils do not contain significant amounts of radionuclides, further restoration can be done on the site.

Phytoremediation has many benefits over other soil remediation techniques. Since phytoremediation is in situ, it is easier and cheaper than most other remediation techniques. More information is currently needed regarding radionuclide phytoremediation. Results from greenhouse studies need to be tested in outdoor environments to determine their effectiveness. Outdoor experiments should include various soil amendments to see which amendments favor increased radionuclide uptake in the outdoors. Outdoor experiments may need to include long-term monitoring since radionuclide uptake will probably be slower outdoors than indoors. However, the potential for mycrorrhizal plants to be an effective remediation strategy for radionuclides appears great and will likely be enormously beneficial to cleaning the environments contaminated by recent nuclear accidents.

Literature Cited

Anspaugh, L. R., Catlin, R. J., Goldman, M. 1988. The global impact of the Chernobyl reactor accident. Science 242: 1513-1519.

Broadley, M. R. and Wiley, N. J. 1997. Differences in root uptake of radiocaesium of 30 plant taxa. Environmental Pollution 97 (1): 11-15.

Clint, G. M. and Dighton, J. 1992. Uptake and accumulation of radiocaesium by mycorrhizal and non-mycorrhizal heather plants. New Phytologist 121: 555-561.

Coughtrey, P. J., Kirton, J. A., Mitchell, N. G., Morris, C. 1989. Transfer of radioactive caesium from soil to vegetation and comparison with potassium in upland grasslands. Environmental Pollution 62: 281-315.

Entry, J. A., Rygiewicz, P. T., Emmingham, W. H. 1994. Strontium-90 uptake by *Pinus ponderosa* and *Pinus radiata* seedlings inoculated with ectomycorrhizal fungi. Environmental Pollution 86: 201-206.

Entry, J. A., Vance, N. C., Hamilton, M. A., Zabowski, D., Watrud, L. S., Adriano, D. C. 1996. Phytoremediation of soil contaminated with low concentrations of radionuclides. Water, Air, and Soil Pollution 88: 167-176.

Entry, J. A., Watrud, L. S., Reeves, M. 1999. Accumulation of cesium-137 and strontium-90 from contaminated soil by three grass species inoculated with mycorrhizal fungi. Environmental Pollution 104: 449-457.

Harley, J. L. 1989. The significance of mycorrhizae. Mycological Research 92: 129-134.

Harrison, A. F., Clint, G. M., Jones, H. E., Poskitt, J. M., Howard, B. J., Howard, D. M., Beresford, N. A., Dighton, J. 1990. Distribution and recycling of radiocaesium in heather-dominated ecosystems. Report to the Ministry of Agriculture, Fisheries and Food, London. Project N601.

Kirk, G. J. D., and Staunton, S. 1989. On predicting the fate of radioactive caesium in soil beneath grassland. Journal of Soil Science 40: 71-84.

Killham, K. 1995. Ecology of polluted soils. Soil Ecology. (pp. 175-181) Cambridge: Cambridge University Press.

Mahara, Y. 1993. Storage and migration of fallout of strontium-90 and cesium-137 for over 40 years in the surface soil of Nagasaki. Journal of Environmental Quality 22: 722-730.

Marshall, J. D. and Perry, D. A. 1987. Basal and maintenance respiration of mycorrhizal and nonmycorrhizal root systems of conifers. Canadian Journal of Forest Resources 17: 872-877.

Paasikallio, A. 1984. The effect of time on the availability of strontium-90 and cesium-137 to plants from Finnish soils. Annales Agriculturae Fenniae 23: 109-120.

Rogers, R. D. and Williams, S. E. 1986. Vesicular-arbuscular mycorrhizae: influence on plant uptake of cesium and cobalt. Soil Biology and Biochemistry 18(4): 371-376.

Rost, T. L., Barbour, M. G., Stocking, C. R., Murphy, T. M. 1998. The root system. Plant Biology (pp. 68-84). California: Wadsworth Publishing Company.