Korean J. Ecol., 23(6): 445~452, 2000

# Effects of Fertilizer and Sewage Sludge Treatments on Germination and Growth of Woody Plants in Metal Mine Tailings

Lee, Sul-Ki and Do-Soon Cho

*School of Life Sciences, The Catholic University of Korea, Puchon 420-743, Korea*

**ABSTRACT: The effects of sludge and fertilizer application on germination and seedling growth of woody plants on heavy metal mine tailings were evaluated by greenhouse experiment. Two different mine tailings (Lead-zinc mine tailings from Kwangmyong, Kyonggi-do and tungsten mine tailings from Sangdong, Kangwon-do), four fertilizer treatments (N+P+K: 20, 40, 60, and 80 kg/m$^3$), and four sewage sludge treatments (5.5, 11, 22.5, and 45 Mg/m$^3$) were used in the experiment. Tested plants were *Pinus densiflora, Larix leptolepis, Amorpha fruticosa,* and *Alnus hirsuta.* There were three replicates for each treatment. In addition, vermiculite was used instead of mine tailings to determine the effect of physical amendments. Fifty seeds of a species were sown in a pot (upper diameter 13.5 cm, depth 10 cm) and seedling emergence were recorded daily for 30 days. The highest germination rate was 53% for all treatments. Germination rate of *Larix leptolepis* was lowest among the four species studied. One month later after seeding, seedlings were thinned and only 5 seedling were left in each pot, and fertilizer and sewage sludge were applied once again. Growth of seedlings were determined for 10 weeks since then. Most plants grew very poorly or died within 5 weeks on lead/zinc mine tailings from Kwangmyong. The analysis of heavy metal contents by the total dissolution method showed that heavy metals generally increased in the order of tungsten mine tailings from Sangdong < sewage sludge from Puchon < lead/zinc mine tailings from Kwangmyong. Growth of woody plants was improved significantly by the fertilizer treatments on tungsten mine tailings. In contrast, survival and growth of woody plants were not affected significantly by the sewage sludge treatment on both tailings. This study shows that fertilizer applied to established seeded stands may provide some benefits in terms of increased ground cover in the field. It is suggested that reclamation should be preceeded by the study of the physico-chemical and biological characteristics of mine tailings.**

***Key Words***: Fertilizer, Greenhouse experiment, *Pinus densiflora*, Restoration, *Robinia pseudoacacia*, Sewage sludge, Tailings, Tungsten mine, Zinc mine

## INTRODUCTION

The environmental problems induced by the mining activities are diverse including pollution of air, soil and water. Many abandoned metal mines have low pH and high heavy metal content which prevent the establishment of vegetation. Restoration to previous conditions will require a long time and high cost, and in the U.S.A. development of new mines are allowed only after a complete restoration plan is established.

In Korea, about 2,000 mines are scattered all over the country, but most of them have been closed during the 1980s and 1990s and abandoned. The spoils and tailings from these abandoned mines are polluting the environment. There are few cases where restoration is completed, and in most cases herbaceous plants were seeded or planted as a restoration effort. For successful restortaion, however, establishment of woody plants are indispensible (Barnhisel 1988).

Metal mines produce spoils and tailings (Harris *et al.* 1996). Spoils usually contain pyrites which induce very low pH. Tailings have high content of metals such as Mn, Ni, Cu, and Zn and low content of organic matter and inorganic nutrients such as N and P, and very pooly drained (Ye *et al.* 1999). Low N and P can be the major obstacle in the restoration of spoils and tailings (Li and Daniels 1994).

Reclamation and restoration of polluted areas by plants is called phytoremediation, and it is environmentally friendly and helps to restore nutrient cycling and accumulation although it is difficult to apply where pollution is very severe (Kim *et al.* 1999). Plants growing in soils polluted with heavy metals are divided into metallophyte, pseudometallophyte, and accidental metallophyte. Many metallophytes are from the families of Poaceae, Caryophyllaceae, Lamiaceae and Fabaceae (Cho and Kim 1995). Especially, legume plants of Fabaceae are very useful in the establishment of vegetation on the spoils and tailings due to the ability of nitrogen fixation.

Organic matters such as manures, sewage sludge, and saw dust are used for the reclamation of mine soils (Thorne *et al.* 1998). Sewage sludge can supply nutrients, and increase soil drainage, soil water retention, soil temperature, cation exchange capacity and microbial activities (Li and Daniels 1994). In the U.S.A. and Europe, more than 40% of the sewage sludge are applied to farmland and strip mine area and it will help in the establishment of harbaceous plants.

However, the amount of heavy metals or inorganic nutrients varies among the tailings according to particle size of tailings, rainfall, temperature, and surrounding vegetation, and thus effective methods for reclamation and restoration should be studied beforehand (Bergholm and Steen 1989).

For vegetation restoration of abandoned mines in Korea, a few studies on vegetation composition (Na and Chun 1995, Kim *et al.* 1999) and metal tolerance (Cho and Kim 1995, Song *et al.* 1997, Lee and Cho 1999) have been conducted, but practical studies for restoration are needed now. The purpose of this study is to examine the effects of the application of sewage sludge and N, P, and K fertilizers on the germination and growth of woody plants tolerant to heavy metals growing on metal mine tailings.

## MATERIALS AND METHODS

### Conditions of mine tailings site

The tailings were collected from a lead/zinc mine in Kwangmyung City, Kyonggi-do, which was abandoned about 30 years ago, and from a tungsten mine in Sangdong, Kangwon-do, which are still being operated. A waste incinerating plant was built on the Kwangmyung mine site, but much of the tailings were still heaped up and few plants covered the site. Sangdong tungsten mine tailings were accumulated about 5 km away from the mine site.

On lead/zinc mine site in Kwangmyung, *Pueraria thunbergii* which were rooted outside covered much of the tailings area, and *Ambrosia artemisiifolia*, *Miscanthus sinensis* var. *purpurascens*, *Rubus crataegifolius*, and *Robinia pseudoacacia* were frequently found. On tungsten mine tailings site in Sangdong, less than 5% of the site was covered by plants, especially by *Phragmites japonica*. Other plants with high frequency on tungsten mine tailings site were *Oenothera odorata*, *Salix gracilistyla*, *Aster lautureanus*, *Artemisia capillaris*, and *Spiraea prunifolia* var. *simpliciflora*.

### Treatment of fertilizers and sewage sludge

Tailings were put into round pots (diameter 13.5 cm and heitht 11.0 cm) at the depth of 9.5 cm, and treated with compound fertilizers and sewage sludge. Compound fertilizers were composed of nitrogen, phosphate, and potassium with the ratio of 21:17:17. Sewage sludge was obtained from the Wastewater Treatment Plant of the Puchon City. Vermiculite produced for nursery treated at 1100℃ was used as a control medium for plant growth to examine the physical effects of sewage sludge. Fertilizers were applied on tailings after dissolved in water, but sewage sludge and vermiculite were mixed with tailings of about top 2 cm in each pot.

### Germination experiment

Fifty seeds of 4 woody species, *Pinus densiflora*, *Larix leptolepis*, *Alnus hirsuta*, and *Amorpha fruticosa*, were placed on each pot (diameter 13.5 cm, depth 11.0 cm) in April, 2000. Seeds were obtained from a nursery except for *Amorpha fruticosa*. Seeds of *Amorpha fruticosa* were collected from an abandoned coal mine in Jeungsanmyon, Jungsungun, Kangwondo Province in November, 1999. Germination rate was determined from the count of emerged seedlings for 30 days from the seed sowing. As a control, normal soil from the Catholic University Experimental Forest in Yangjugun, Kyonggido Province was used. All the treatments were replicated 3 times.

### Growth experiment

Thirty days after seeding, germinated woody plants were removed from each pot, leaving only 5 individual plants with similar shoot length. After thinning, each pot was treated with fertilizer or sludge once again. Shoot length was measured for 10 weeks after thinning, and plants were harvested in the first week of October, 2000. Harvested plants were divided into shoots and roots, and fresh biomass was measured. During the growth period, filtered water enough to avoid water stress was applied frequently to pots. The position of pots was randomly arranged, and was changed every two or three weeks. Survival rate was measured 10 weeks after thinning. All the experiments were triplicated.

### Chemical analysis

For the chemical analysis of mine tailings and sewage sludge, they were dried at 105℃ for 24 hours and then ground. Ground samples were extracted following the total dissolution method of Jackson (1958), and the contents of Na, Mg, Cd, Pb, Cu, Zn, and Mn were determined by atomic absorption spectrophotometer (Shimadzu). pH was determined by pH meter. Soil organic matter was calculated from the loss on ignition after ashing for 4 hours in electric furnace at 600 ℃. Phosphorus was determined by chlorostannous-reduced molybdophosphoric blue color method. Total nitrogen was determined by the micro-Kjeldahl method.

### Data analysis

Univariate analysis was used to analyze the germination rate, and analysis of variance with Duncan's classification ($p<0.05$) was used for the survival rate and biomass. Correlation coefficients were also calculated to determine the relationships between germination rate and survival rate, and between biomass and survival rate. SAS (release 6.12) (1999) was used for the data analysis.

## RESULTS

### Chemical analysis of samples

The analysis of heavy metal contents by the total dissolution method showed that heavy metal contents generally increased in the order of tungsten mine tailings from Sangdong < sewage sludge from Puchon < lead/zinc mine tailings from Kwangmyong. Inorganic nutrients were higher in sewage sludge from Puchon than tailings from both mines (Table 1).

### Seed germination

Germination rates were generally low, except for those of *Pinus densiflora* and *Amorpha fruticosa* which showed about 50% germination rate (Tables 2 and 3). *Larix leptolepis* and *Alnus hirsuta* showed less than 20% germination rate, and especially that of *Larix leptolepis* from the lead/zinc mine tailings was less than 10% (Table 3). However, the germination rates from normal soil were mostly higher than 70% with the exception of *Larix leptolepis.*

### Plant growth

There were differences in plant growth among species and between tailings (Tables 4 and 5). Plants grown on lead/zinc mine tailings mostly died within 5 weeks and showed less than 50% survival rate (Table 5). In contrast, plants grown on tungsten mine tailings could survive up to 7

Table 1. Chemical characteristics of pretreatment tailings and sludge

| Chemical characteristics | Tungsten mine tailings | Lead/zinc mine tailings | Sewage sludge |
|---|---|---|---|
| pH | 6.85 ±0.004 | 5.97 ±0.11 | 7.66 ±0.01 |
| Organic matter (g/kg) | 0.07 ±0.0002 | 2.40 ±0.0001 | 0.15 ±0.0003 |
| K (g/kg) | 5.498±0.600 | 2.013±0.006 | 14.563±0.751 |
| Mg (g/kg) | 2.193±0.276 | 1.274±0.086 | 1.410±0.003 |
| Zn (g/kg) | 5.874±0.054 | 10.128±0.202 | 16.482±0.093 |
| Pb (g/kg) | 0.452±0.148 | 10.720±0.202 | 3.151±0.168 |
| Cu (g/kg) | 0.214±0.004 | 13.478±0.678 | 10.125±1.530 |
| Cr (g/kg) | 0 | 0 | 4.525±0.094 |
| Cd (g/kg) | 0.016±0.001 | 0.445±0.003 | 0.050±0.0004 |
| P (g/kg) | 1.551±0.001 | 1.396±0.0001 | 26.147±0.0008 |

Table 2. Germination rate (%) of several woody plants on tungsten mine tailings

| Treatment* | *Pinus densiflora* | *Amorpha fruticosa* | *Larix leptolepis* | *Alnus hirsuta* |
|---|---|---|---|---|
| Control | 40.67 | 42.00 | 10.67 | 12.00 |
| 20F | 49.33 | 48.00 | 11.33 | 11.33 |
| 40F | 49.33 | 35.33 | 11.00 | 12.33 |
| 60F | 56.67 | 44.67 | 12.00 | 15.00 |
| 80F | 55.33 | 40.67 | 12.33 | 11.67 |
| 5.5S | 29.33 | 36.67 | 11.00 | 11.33 |
| 11S | 40.00 | 38.67 | 11.00 | 11.33 |
| 22.5S | 36.67 | 40.00 | 10.33 | 12.00 |
| 45S | 37.33 | 42.00 | 12.67 | 13.33 |
| 22.5V | 51.33 | 37.33 | 12.00 | 16.67 |

*F = Treatment of fertilizers on tailings ($kg/m^3$), S = Treatment of sludge on tailings ($Mg/m^3$), V = Treatment of vermiculite on tailings ($Mg/m^3$).

Table 3. Germination rate (%) of several woody plants on lead/zinc mine tailings

| Treatment* | *Pinus densiflora* | *Amorpha fruticosa* | *Larix leptolepis* | *Alnus hirsuta* |
|---|---|---|---|---|
| Control | 26.67 | 33.33 | 7.33 | 10.00 |
| 20F | 25.33 | 25.33 | 9.67 | 9.67 |
| 40F | 22.67 | 26.67 | 8.00 | 9.67 |
| 60F | 34.00 | 33.33 | 9.00 | 13.00 |
| 80F | 32.00 | 25.33 | 9.00 | 11.00 |
| 5.5S | 20.67 | 20.00 | 9.67 | 12.00 |
| 11S | 23.33 | 20.67 | 9.00 | 11.33 |
| 22.5S | 24.00 | 18.00 | 9.67 | 12.33 |
| 45S | 25.33 | 25.33 | 11.00 | 12.33 |
| 22.5V | 27.33 | 24.67 | 9.67 | 10.00 |

*F = Treatment of fertilizers on tailings (kg/m$^3$), S = Treatment of sludge on tailings (Mg/m$^3$), V = Treatment of vermiculite on tailings (Mg/m$^3$).

Table 4. Survival rate of several woody plants on tungsten mine tailings

| Treatment** | *Pinus densiflora* | *Amorpha fruticosa* | *Larix leptolepis* | *Alnus hirsuta* |
|---|---|---|---|---|
| Control | $0.1333^{de}$ | $0.6667^{a}$ | $0.0000^{d}$ | $0.2000^{b}$ |
| 20F | $0.2667^{dc}$ | $0.7333^{a}$ | $0.1333^{bcd}$ | $0.6000^{ab}$ |
| 40F | $0.6667^{b}$ | $0.8000^{a}$ | $0.2000^{abc}$ | $0.5333^{ab}$ |
| 60F | $0.9333^{a}$ | $0.9333^{a}$ | $0.2667^{ab}$ | $0.7333^{a}$ |
| 80F | $1.0000^{a}$ | $0.8667^{a}$ | $0.2667^{ab}$ | $0.6667^{a}$ |
| 5.5S | $0.6667^{b}$ | $0.6667^{a}$ | $0.0667^{cd}$ | $0.2000^{b}$ |
| 11S | $0.4000^{c}$ | $0.6000^{a}$ | $0.2667^{ab}$ | $0.4000^{ab}$ |
| 22.5S | $0.0000^{e}$ | $0.6000^{a}$ | $0.2000^{abc}$ | $0.4000^{e}$ |
| 45S | $0.2000^{dce}$ | $0.6000^{a}$ | $0.2000^{abc}$ | $0.4000^{ab}$ |
| 45V | $0.8667^{ab}$ | $0.7333^{a}$ | $0.3333^{a}$ | $0.8000^{a}$ |

*Means followed by the same superscript letter are not significantly different between treatments at $p<0.05$ (ANOVA).
**F = Treatment of fertilizer on tailings (kg/m$^3$), S = Treatment of sludge on tailings (Mg/m$^3$), V = Treatment of vermiculite on tailings (Mg/m$^3$).

Table 5. Survival rate of several woody plants on lead/zinc mine tailings

| Treatment** | *Pinus densiflora* | *Amorpha fruticosa* | *Larix leptolepis* | *Alnus hirsuta* |
|---|---|---|---|---|
| Control | $0.2000^{ab}$ | $0.0667^{a}$ | $0.0000^{b}$ | $0.0000^{b}$ |
| 20F | $0.1333^{ab}$ | $0.1333^{a}$ | $0.0000^{b}$ | $0.0000^{b}$ |
| 40F | $0.2667^{ab}$ | $0.1333^{a}$ | $0.0000^{b}$ | $0.2667^{ab}$ |
| 60F | $0.2000^{ab}$ | $0.2000^{a}$ | $0.1333^{ab}$ | $0.5333^{a}$ |
| 80F | $0.2000^{ab}$ | $0.2000^{a}$ | $0.2000^{a}$ | $0.3333^{ab}$ |
| 5.5S | $0.4667^{a}$ | $0.0000^{a}$ | $0.4667^{a}$ | $0.1333^{b}$ |
| 11S | $0.2667^{ab}$ | $0.0000^{a}$ | $0.0667^{ab}$ | $0.2667^{ab}$ |
| 22.5S | $0.2667^{ab}$ | $0.0667^{a}$ | $0.0667^{ab}$ | $0.2667^{ab}$ |
| 45S | $0.3333^{ab}$ | $0.1333^{a}$ | $0.0000^{b}$ | $0.3333^{ab}$ |
| 45V | $0.4667^{a}$ | $0.2000^{a}$ | $0.0000^{b}$ | $0.3333^{ab}$ |

*Means followed by the same superscript letter are not significantly different between treatments at $p<0.05$ (ANOVA).
**F = Treatment of fertilizer on tailings (kg/m$^3$), S = Treatment of sludge on tailings (Mg/m$^3$), V = Treatment of vermiculite on tailings (Mg/m$^3$).

weeks and showed more than 50% survival rate except for *Larix leptolepis* (Table 4). *Larix leptolepis* died within 5 weeks regardless of tailings and had less than 20% survival rate. *Amorpha fruticosa* showed a big difference in survival rate between tailings (Tables 4 and 5, Fig. 1). Survival rate increased by the application of higher amount of fertilizers (120 and 160 kg/ha), especially in *Pinus densiflora.* Vermiculite could also increase the survival rate. In contrast, sewage sludge did not show any significant effect on surval rate of plants (Tables 4 and 5).

Biomass of shoots and roots were measured 10 weeks after thinning. Generally, plants with high survival rate had bigger biomass (Table 6).

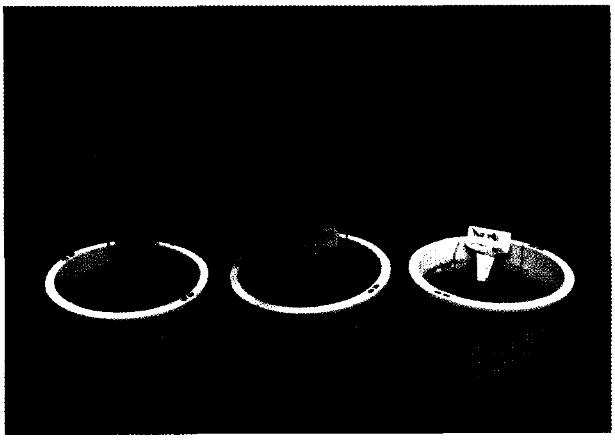

Fig. 1. Stem growth of *Amorpha fruticosa* on soil (left), tungsten mine tailings (middle), and lead/zinc mine tailings (right).

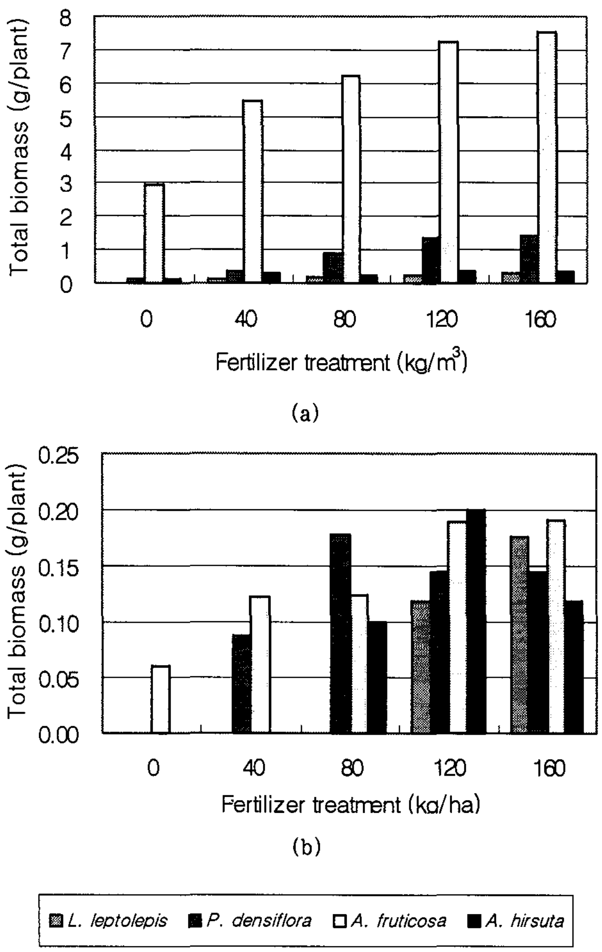


Fig. 2. Effects of fertilizer treatment on the biomass of selected plant species on (a) tungsten mine tailings, and (b) lead/zinc mine tailings.

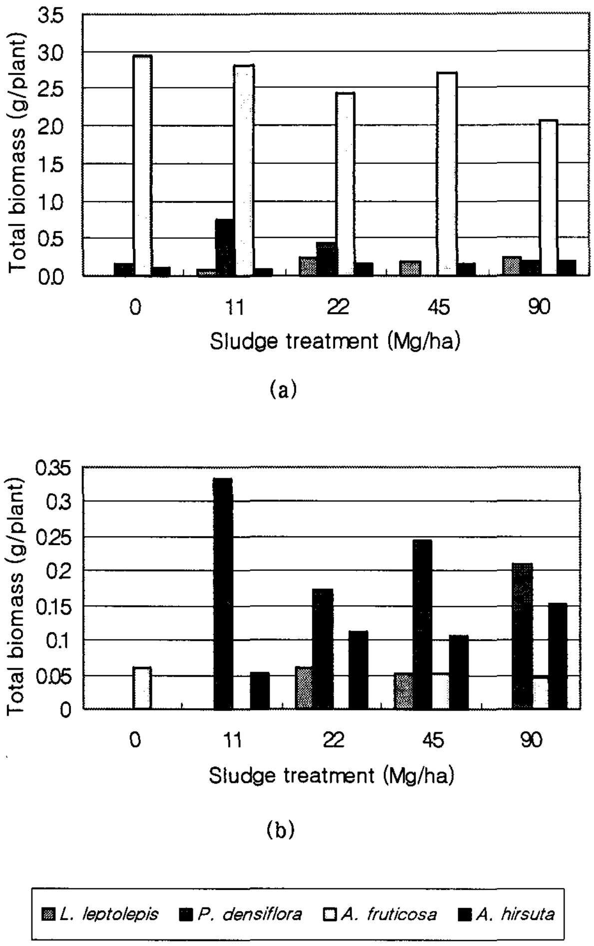


Fig. 3. Effects of sludge treatment on the biomass of selected plant species on (a) tungsten mine tailings, and (b) lead/zinc mine tailings.

Biomass of roots were proportional to that of shoots. Biomass of plants on tungsten mine tailings were significantly increased by the application of fertilizers, but not by the application of sewage sludge. On lead/zinc mine tailings, however, only *Larix leptolepis* and *Amorpha fruticosa* were increased in biomass by the application of fertilizers (Table 6).

Correlation ananlysis showed that in most cases germination rate and survival rate were not significantly correlated except for *Amorpha fruticosa* grown on lead/zinc mine tailings and *Pinus densiflora* on tungsten mine tailings (Table 6). In contrast, total biomass and survival rate were significantly positively correlated (Table 6).

## DISCUSSION

This study was conducted in the hope that directing seeding on abnadoned mine tailings

Table 6. Biomass of species on tungsten mine tailings (g/ plant)

| Species | Part | Control* | 40F | 80F | 120F | 160F | 11S | 22S | 45S | 90S | 45V |
|---|---|---|---|---|---|---|---|---|---|---|---|
| *L. leptolepis* | Shoot | 0.00 | 0.05 | 0.10 | 0.14 | 0.14 | 0.04 | 0.13 | 0.09 | 0.13 | 0.18 |
| | Root | 0.00 | 0.05 | 0.09 | 0.11 | 0.13 | 0.03 | 0.11 | 0.09 | 0.12 | 0.17 |
| *P. densiflora* | Shoot | 0.08 | 0.18 | 0.49 | 0.71 | 0.74 | 0.41 | 0.22 | 0.00 | 0.11 | 0.58 |
| | Root | 0.07 | 0.17 | 0.41 | 0.66 | 0.66 | 0.35 | 0.21 | 0.00 | 0.09 | 0.56 |
| *A. fruticosa* | Shoot | 1.51 | 2.76 | 3.20 | 3.70 | 3.84 | 1.50 | 1.28 | 1.47 | 1.11 | 2.75 |
| | Root | 1.44 | 2.68 | 3.05 | 3.52 | 3.70 | 1.31 | 1.15 | 1.22 | 0.94 | 2.66 |
| *A. hirsuta* | Shoot | 0.06 | 0.16 | 0.14 | 0.21 | 0.20 | 0.05 | 0.09 | 0.09 | 0.09 | 0.25 |
| | Root | 0.05 | 0.14 | 0.13 | 0.18 | 0.18 | 0.04 | 0.08 | 0.07 | 0.09 | 0.23 |

*F = Treatment of fertilizer on tailings (kg/m$^3$), S = Treatment of sludge on tailings (Mg/m$^3$), V = Treatment of vermiculite on tailings (Mg/m$^3$).

can restore the area with ease and relatively low cost. The 4 woody plant species, *Pinus densiflora, Larix leptolepis, Alnus hirsuta,* and *Amorpha fruticosa,* were not increased in germination rate by fertilizer treatment. Among them, *Larix leptolepis* showed very low germination rate on tailings, indicating that it may not be a suitable species for restoration of mine tailings. Khan (1985) explained that germination is the result of respiration and is influenced by soil texture, soil temperature, and soil acidity. Generally low germination rate on tailings than on normal soil in this study can be due to fine texture and very low air space in the soil. Other methods such as transplanting turves or planting young trees and shrubs are recommended on tailings instead of direct seeding.

Heavy metals in soil can affect plant growth directly or indirectly (Yang 1990). In addition, many literatures suggest that fertilizer does not increase plant growth (Smith *et al.* 1985, Mcginnies and Crofts 1986, Yang *et al.* 1997, Ye *et al.* 1999). In this study, seedlings grew better on tungsten mine tailings than lead/zinc mine tailings. Better seedling growth on the tungsten mine tailings seems to be due to lower heavy metal content and higher inorganic nutrient content except for N and P in the soil (Table 1). Fertilizer application also affected seedling growth of *Pinus densiflora* and *Amorpha fruticosa* on tungsten mine tailings, not on lead/zinc mine tailings. Fertilizer also affected survival rate of seedlings probably through better growth in this study. The effective amount of fertilizers seems to be 120 kg/ha (Yang *et al.* 1997). Biomass of shoots and roots was also increased by fertilizers. These results indicate that fertilizer can be effective for some plant species on tailings with relatively low heavy metal content and that selection of plant species will be important in the abandoned mine restoration.

Sewage sludge has been applied to the restoration of abandoned mines. It supplies organic matter, and increases water drainage and water retention capacity of tailings (Smith and Giller 1992, Kost *et al.* 1997, Throne *et al.* 1998, Lee and Cho 1999). However, contrary to our expectation, sewage sludge did not affect seed germination or seedling growth in this study. Sewage sludge used in this study had high viscosity and was

Table 7. Biomass of species on lead/zinc mine tailings (g/ plant)

| Species | Part | Control* | 40F | 80F | 120F | 160F | 11S | 22S | 45S | 90S | 45V |
|---|---|---|---|---|---|---|---|---|---|---|---|
| *L. leptolepis* | Shoot | 0.00 | 0.00 | 0.00 | 0.06 | 0.08 | 0.00 | 0.03 | 0.02 | 0.00 | 0.00 |
| | Root | 0.00 | 0.00 | 0.00 | 0.06 | 0.08 | 0.00 | 0.03 | 0.02 | 0.00 | 0.00 |
| *P. densiflora* | Shoot | 0.00 | 0.05 | 0.10 | 0.08 | 0.08 | 0.19 | 0.09 | 0.13 | 0.12 | 0.18 |
| | Root | 0.00 | 0.04 | 0.08 | 0.07 | 0.07 | 0.14 | 0.08 | 0.12 | 0.09 | 0.12 |
| *A. fruticosa* | Shoot | 0.03 | 0.07 | 0.07 | 0.11 | 0.10 | 0.00 | 0.00 | 0.03 | 0.03 | 0.10 |
| | Root | 0.03 | 0.06 | 0.06 | 0.08 | 0.09 | 0.00 | 0.00 | 0.02 | 0.02 | 0.08 |
| *A. hirsuta* | Shoot | 0.00 | 0.00 | 0.06 | 0.11 | 0.07 | 0.03 | 0.06 | 0.06 | 0.08 | 0.08 |
| | Root | 0.00 | 0.00 | 0.04 | 0.09 | 0.05 | 0.02 | 0.05 | 0.05 | 0.07 | 0.07 |

* F = Treatment of fertilizer on tailings (kg/m$^3$), S = Treatment of sludge on tailings (Mg/m$^3$), V = Treatment of vermiculite on tailings (Mg/m$^3$).

Table 8. Correlation coefficients between survival rate and germination rate and between survival rate and total biomass of species

| Substrate | Species | Survival rate *vs* germination rate | Survival rate *vs* total biomass |
|---|---|---|---|
| Tungsten mine tailings | *P. densiflora* | 0.621** | 0.981** |
| | *L. leptolepis* | 0.147$^{NS}$ | 0.986** |
| | *A. fruticosa* | -0.133$^{NS}$ | 0.818** |
| | *A. hirsuta* | 0.398* | 0.963** |
| Lead/zinc mine tailings | *P. densiflora* | -0.273$^{NS}$ | 0.964** |
| | *L. leptolepis* | -0.020$^{NS}$ | 0.998** |
| | *A. fruticosa* | 0.349* | 0.910** |
| | *A. hirsuta* | 0.280$^{NS}$ | 0.987** |

* $p<0.05$, ** $p<0.005$, $^{NS}$ not significant

coagulated by itself to become small balls, and thus could not ameliorate the physical characteristics of soil.

In general, sewage sludge increases plant growth on mine tailings (Smith *et al.* 1985, Smith and Giller 1992, Berti and Jacobs 1998, Thorne *et al.* 1998). Kost *et al.* (1997) suggested that sewage sludge can be very effective on tailings with fine soil texture. In this study, however, sewage sludge did not affect plant growth. Many researchers have also shown that sewage sludge may inhibit plant growth by increasing the heavy metal content of soil (Page 1974, Lagerwerff *et al.* 1976). Freedman (1995) indicated that sewage sludge in developed countries has high level of toxic substances and heavy metals. The sewage sludge used in this study came from Puchon City which has many factories, and the chemical analyses showed that it had more heavy metals than the tungsten mine tailings. U.S. Environmental Protection Agency set up the maximum heavy metal content of sewage sludge in the applincation for restoration (U.S. EPA 1977), and Cr and Pb content of sewage sludge from Puchon exceeded that limit set by U.S. EPA. Even though plants can grow better by sludge application, they may accumulate higher heavy metals in their body and affect the food chain.

In this study, application of 120~160 kg/ha N, P and K fertilizers increased the growth of *Pinus densiflora* and *Amorpha fruticosa* on tailings of Sangdong tungsten mine, and we can use these species and apply fertilizers to the actual restoration of abandoned mines. However, in the application of sewage sludge, we have to analyse its chemical and physical characteristics first since sewage sludge from waste waters polluted by industries may induce secondary pollution, and then consider the transport cost. For successful establishment of vegetation on mine tailings, more studies on the tolerance for water stress and heavy metals of different species and on the reclamation methods are needed.

## ACKNOWLEDGEMENTS

This work was supported by the Research Fund, The Catholic University of Korea, 2000. Thanks are due to Dr. Kyu Song Lee of Kangnung National University and Dr. Young Han Yoo of Seoul Women's University for helpful comments on earlier draft of the manuscript, and to Ki-Hwan Cho, Mi-Young Park and Ji-Hyun Kim of the Catholic University of Korea for field work.

## LITERATURE CITED

Barnhisel, R.I. 1988. Fertilization and management of reclaimed lands. *In* L.R. Hossner (ed.). Reclamation of Surface-Mined Lands. Vol. 2: CRC Press, Boca Raton, FL. pp. 1-12.

Bergholm, J. and E. Steen. 1989. Vegetaion establishment on a deposit of zinc mine wastes. Environ. Pollut. 127-141.

Berti, W.R. and L.W. Jacobs. 1998. Distribution of trace elements in soil from repeated sewage sludge applications. J. Environ. Qual. 27: 1280-1286.

Cho, D.S. and J.H. Kim. 1995. A study on the heavy metal tolerance of a few herbaceous plant species. Korean J. Ecol. 18: 147-156.

Freedman, B. 1995. Environmanetal Ecology. Vol. 2: Academic Press. 571 p.

Harris, J.A., P. Birch and J.P. Palmer. 1996. Land Restoration and Reclamation: Principles and Practice. Addison Wesley Longman Ltd. 227 p.

Jackson, M.L. 1958. Soil Chemical Analysis. Prentice-Hall.

Khan, A.A. 1985. The Physiology and Biochemistry of Seed Dormancy and Germination. 602 p.

Kim, J.K., S.K. Yim, S.H. Lee, C.H. Lee and C.Y. Chung. 1999. Plant resource search for phytoremediation of polluted soils of abandoned mine area. J. Kor. Environ. Agr. 18: 28-34.

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 coal mine soil. J. Environ. Qual. 26: 1409-1416.

Lagerwerff, J.V., G.T. Biersdorf and D.L. Brower. 1976. Retention of metals in sewage sludge. I. Constituent heavy metals. J. Environ. Qual. 5: 19-22.

Lee, S.M. and C.M. Cho. 1999. Transport charateristics of Cd, Cu and Zn in a sewage sludge treated calcareous soils, J. Kor. Soil Soc. 32: 412-420.

Li, R.S. and W.L. Daniels. 1994. Nitrogen accumulation and form over time in young mine soils. J. Environ. Qual. 23: 166-172.

Mcginnies, W.J. and K.A. Crofts. 1986. Effects of N and P fertilizer placement on establishment of seeded species on redistributed mine topsoil. J. Range Manage. 39: 118-121.

Na, C.H. and S.R. Chun. 1995. The effects of mine spoils from abandoned Moak gold and silver mine on surrounding watershed and ecosystems. Econ. Environ. Geol. 28: 231-239.

Page, A.L. 1974. Fate and effects of trace elements in sewage sludge applied to agricultural land, EPA-670/2-74-005. Office of Research and Development, U.S. Environmental Protection Agency, Cincinnati, OH.

S.A.S. 1999. User's guide: statistics. Version 6.12 edition. SAS Institute Inc., Cary, N.C., U.S.A.

Smith, J.A., G.E. Schuman, E.J. Depuit and T.A. Sedbrook. 1985. Wood residue and fertilizer amendment of bentonite mine spoils: I. spoil and general vegetation responses. J. Environ. Qual. 14: 575-580.

Smith, S.R. and K.E. Giller. 1992. Effective *Rhizobium leguminosarum* biovar. *trifolii* present in five soils contaminated with heavy metals from long-term applications of sewage sludge or metal mine spoil. Soil Biol. Biochem. 24: 781-788.

Song, S.D., H.S. Chung, K.S. Rho, J.S. Song and T.K. Park. 1997. The effects of cadmium on the growth and nitrogen fixing activities of *Lespedeza bicolor*. Korean J. Ecol. 20: 35-41.

Thorne, M.E., B.A. Zamora and A.C. Kennedy. 1998. Sewage sludge and mycorrhizal effects on secar bluebunch wheatgrass in mine spoil. J. Environ. Qual. 27: 1228-1233.

Yang, W.J. 1990. Environmental Botany - Soil Pollution and Plants. Dong-Hwa Tech. Pub. Co. pp. 34-41.

Yang, Z.Y., J.G. Yuan, F.R. Xin, H.T. Chang and M.H. Wong. 1997. Germination, growth and nodulation of *Sesbania rostrata* grown in Pb/Zn mine tailings. Environmental Management 12: 617-622.

Ye, Z.H., J.W.C. Wong, M.H. Wong, C.Y. Lan, and A.J.M. Baker. 1999. Lime and pig manure as ameliorants for revegetation lead/zinc mine tailings: a greenhouse study. Bioresource Technology 69: 35-43.

(*Received November 23, 2000*)