**Table 1.** Organic matter, bulk density, pH, soluble salts, nitrate-nitrogen ($NO_3$-N), phosphorus (P), sodium (Na), and potassium (K) in the 15-cm depth of four soil materials associated with copper mines near Tucson, Arizona in 1974.

| Soil materials | Organic matter | Bulk density | pH | Total soluble salts | $NO_3$-N | P | Na | K |
|---|---|---|---|---|---|---|---|---|
| | (%) | (g/cm³) | | (ppm) | (ppm) | (ppm) | (ppm) | (ppm) |
| Desert soil | 0.18 | 1.37 | 7.45 | 3,182 | 6 | 1 | 63 | 17 |
| Overburden | 0.14 | 1.29 | 7.85 | 2,452 | 7 | 2 | 135 | 15 |
| Overburden plus tailings | 0.11 | 1.34 | 7.78 | 2,869 | 7 | 26 | 189 | 25 |
| Tailings | 0.21 | 1.35 | 7.75 | 355 | 22 | 31 | 66 | 51 |

Barker et al. (1977). Jones et al. (1975) found that grasses seeded in a mulch grew well and resulted in excellent ground cover and soil erosion control. Day et al. (1976) compared the growth, fiber, protein, and amino acid contents of barley forage grown on four mine soil materials to determine if copper mine wastes can produce high yields of quality forage for livestock feed. In addition to providing economical, quick ground cover, forages aid in the restoration of the spoil material to a productive soil (Bennett, 1977). The objective of this research was to investigate the effects of four soil materials in copper wastes on the growth of three species of annual grasses grown in a semiarid environment.

## Materials and Methods

Experiments were conducted over a 2-year period (1973-1974) to study the stabilization of copper mine wastes at Cyprus Pima Mining Company, near Tucson, Arizona, with annual grasses. Four soil materials (desert soil, overburden, overburden plus tailings, and tailings) were broadcast planted with seeds of spring barley (*Hordeum vulgare* L.), sudangrass [*Sorghum sudanense* (Piper) Stapf.], and annual ryegrass (*Lolium temulentum* L. Darnel). Desert soil material (Anthony series) was the surface soil found in the semiarid environment in southern Arizona. The Anthony series is a member of the coarse-loamy, mixed (Calcareous), thermic family of the Typic Torrifluvents. Overburden was the non-ore material located above copper ore deposits. Overburden plus tailings was a mixture of overburden and tailings. Tailings was the waste material from the milling of copper ore. Table 1 shows the physical and chemical characteristics of the four soil materials as described by Ludeke et al. (1974).

The experimental design was a Split Plot with soil materials as main plots and annual grasses as sub-plots with four replications. To insure adequate sampling of each soil material, the replications were arranged horizontally along the berms containing each soil material. The plot size was 48m². A "sidewinder" and a "sheepfoot roller" were used to prepare a smooth, loose seedbed on a 1.5:1 berm slope in each soil material. Approximately 3 cm of irrigation water was sprinkled over the area prior to planting. Twenty-nine kg/ha of elemental nitrogen (N) was applied in the preplanting irrigation.

In May of each year, seeds of the three annual grasses were broadcast planted by hand on each soil material at the following rates: (1) spring barley—400 seeds/m², (2) sudangrass—350/m², (3) annual ryegrass—500 seeds/m². Immediately after planting, 11,200 kg/ha of barley straw were applied to the experimental area. Following the straw application, 19 kg/ha of N were applied in 1 cm of irrigation water. In 1973, three, and in 1974, five additional irrigation and fertilization applications were made throughout the growing seasons. During each of these subsequent irrigations, 1 cm of water and 50 kg/ha of N were applied.

The following data were recorded for each plot: (1) number of seeds germinated (emerged), (2) number of seedlings established, (3) number of stems produced, (4) plant height, (5) forage yield, and (6) percent ground cover. All data were analyzed using the standard analysis of variance and means were compared using Student-Newman-Keuls' test as described by Steel and Torrie (1960).

## Results and Discussion

In 1973 and 1974 (2-year average), desert soil resulted in the highest averages for all plant characteristics studied, for each of the three annual grasses. Overburden was the second most productive soil material, followed by overburden plus tailings, and tailings, in decreasing order (Table 2).

Annual ryegrass had the highest seed germination (emergence), per number of seed planted, in all soil materials. Sudangrass and spring barley had similar seed germination. In all soil materials except tailings, annual ryegrass established the highest number of seedlings, per number of seed planted, per unit area. In desert soil and in overburden, spring barley was intermediate and sudangrass had the lowest seedling establishment. There was no difference in seedling establishment between spring barley and sudangrass in overburden plus tailings (Table 2).

Stem production was the greatest for annual ryegrass followed by spring barley and sudangrass, in decreasing order, in all soil materials. There was no difference in the height of the three annual grasses in overburden. In all other soil materials, spring barley grew taller than sudangrass and ryegrass. In all soil materials, spring barley had the highest forage yield followed by sudangrass and annual ryegrass, in decreasing order. Spring barley and annual ryegrass produced the most complete ground cover in all soil materials (Table 2).

The number of seeds germinated per unit area is usually an indication of the amount of seedling establishment. High seedling establishment produces a more pleasing appearance for a disturbed area than does a low seedling establishment. High seedling establishment is accompanied by the development of many separate roots resulting in a more compact root community below the soil surface. A compact root community stabilizes a disturbed area more effectively and makes it more resistant to the harmful effects of erosion and trampling by wildlife than does a sparse root system. The number of stems produced is an indication of vegetative cover and forage production. A high number of stems per unit area creates a favorable habitat and food supply for wildlife. Plant height is important because, in general, taller grasses produce more vegetation per unit area than shorter grasses and they are more effective in improving the appearance of the disturbed area. Complete ground cover protects the soil surface against wind and water erosion and enhances the general eye-appeal of an area.

Wind and water erosion can be controlled by planting copper mining wastes with adapted grasses to stabilize the slopes. To obtain successful overall revegetation and to most effectively blend disturbed areas into the surrounding environment, a variety of adapted grass species should be used in a revegetation program in the southwestern United States and in similar environments throughout the world.

**Table 2.** Average germination, seedling establishment, number of stems produced, plant height, forage yield, and ground cover for three annual grasses grown on four soil materials associated with copper mines near Tucson, Arizona in 1973 and 1974 (2-year average).

| Soil materials | Plant species | Seeds germinated in 1 m² | Seedlings established in 1 m² | Stems produced in 1 m² | Plant height | Forage yield (12% moisture) | Ground cover |
|---|---|---|---|---|---|---|---|
| | | (no.) | (no.) | (no.) | (cm) | (kg/ha) | (%) |
| Desert Soil | Spring barley | 336 b + | 301 b | 667 b | 38 a | 2335 a | 70 a |
| | Sudangrass | 310 b | 189 c | 405 c | 24 b | 1115 b | 56 b |
| | Annual ryegrass | 492 a | 468 a | 1023 a | 20 b | 243 c | 68 a |
| Overburden | Spring barley | 331 b | 222 b | 581 b | 25 a | 2265 a | 65 a |
| | Sudangrass | 301 b | 171 c | 334 c | 22 a | 1074 b | 45 b |
| | Annual ryegrass | 453 a | 409 a | 985 a | 18 a | 228 c | 65 a |
| Overburden & tailings | Spring barley | 269 b | 201 b | 549 b | 20 a | 2133 a | 60 a |
| | Sudangrass | 202 b | 159 b | 324 c | 13 b | 1023 b | 40 b |
| | Annual ryegrass | 419 a | 378 a | 958 a | 16 b | 210 c | 61 a |
| Tailings | Spring barley | 124 b | 107 a | 409 b | 15 a | 1918 a | 30 a |
| | Sudangrass | 95 b | 75 b | 258 c | 10 b | 970 b | 20 b |
| | Annual ryegrass | 301 a | 103 a | 490 a | 11 b | 135 c | 30 a |
| Significance of differences: | | | | | | | |
| Between soil materials | | * | * | * | ** | * | ** |
| Between plant species | | * | * | ** | * | ** | * |

** = Significant at 1% level; * = significant at 5% level.

+ Means followed by the same letter, within soil materials and between plant species, are not different at the 5% level of significance using the Student-Newman-Keuls' test.

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