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Effects of sludge application on prairie establishment

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EFFECTS OF SLUDGE APPLICATION ON

PRAIRIE ESTABLISHMENT

An Abstract of a Thesis

Submitted

In Partial Fulfillment

of the Requirements for the Degree

Master of Arts

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ABSTRACT

Native prairie in Iowa has all but disappeared since the development of agricultural land by European settlers over the past 165 years. Reconstructing prairie is one way to replace some of the acreage that was lost. A byproduct of settling an area is the generation of garbage and other wastes. Currently there is a surplus of sludge, the waste product of waste water treatment facilities. This material is usually disposed of in landfills, used on agricultural land or reclamation projects.

A small area of prairie was reconstructed on the top of a closed portion of the Black Hawk County Solid Waste Landfill, Black Hawk County, Iowa. A mix of four grasses and 49 forbs was seeded on the 0.5 acre (0.2 ha) study site. The site was divided into four non-replicated plots including a control. Each of three plots received liquid sludge once per year for two years. Plot 1 received 1/2 load of sludge, Plot 2 received 1 load and Plot 3 received 1 1/2 loads of sludge. One load contains about 2000 gallons (7576 liters) of sludge. The effect of sludge on prairie establishment and growth was studied. Coverage and frequency of the prairie species and other species present were measured from June through September, 1996 and 1997. Importance value was calculated from this data.

Graphical comparison of the September 1997 data showed that timothy (*Phleum pratense*) had a meaningful difference in plot means. The analysis of weeds showed no clear trend in plot means. There were no meaningful differences in plot means for native prairie. Some species showed an increase, some a decrease and others no clear trend in coverage. While other species were never found in sludge plots, and overall frequency of prairie species declined with increasing sludge application. Timothy (*Phleum pratense*) benefits from sludge application; sludge did not promote weed growth except at high application rates; and establishment of some prairie species did not appear to be affected by the application of sludge.

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CHAPTER 1

PROBLEM

Municipal sewage sludge, the product of waste water treatment, is currently in surplus in the U.S. Most of the sludge, also called biosolids, is disposed of by placement in landfills or oceans, while a lesser amount is applied to land. Sludge is made up mostly of water; solids generally comprise less than 10 percent of the total by weight. It contains nitrogen, phosphorus, potassium and heavy metals such as cadmium, copper, chromium, iron, lead, and nickel.

Agricultural and reclamation lands receive the majority of land-applied sludge. The fertilization sludge provides is important to these land uses. Lands supporting native vegetation such as prairie and forest, receive little disposed sludge. State and federal regulations establish the application rate of sludge to land by specifying the nutrient levels and heavy metals quantities which can be applied. These regulations are designed to prevent high levels of heavy metals and other compounds from accumulating in the soil and making their way up the food chain.

As native prairie has been virtually destroyed in Iowa (Drobney 1994), reconstructing new prairie areas preserves some of our natural heritage. Prairie, from a utilitarian perspective, is a low maintenance cover compared to turf grasses or other vegetation that require frequent mowing and watering. Also, the extensive roots of some prairie species may hold the soil better and be more drought resistant (Weaver, 1954) than other common permanent vegetation covers such as crownvetch (*Cornillia varia*) and brome grass (*Bromus inermis*).

By applying sludge to reconstructed prairie, we may concurrently provide a remedy for two problems. It would be especially beneficial if sludge application were to promote establishment of reconstructed prairie. The result could be an increase in reconstructed prairies and less sludge put into landfills. This study was designed to determine the effect of sludge application on establishment of prairie vegetation.

CHAPTER 2

LITERATURE REVIEW

Native Prairie in Iowa

Native tallgrass prairie in North America has all but disappeared. Iowa was once covered by about 85 percent prairie totaling 30 million acres (ac) (12.1 million hectares (ha)). Currently, Iowa has only about one-tenth of one percent remaining, which is less than 30,000 ac (12,141 ha) (Roosa 1976). Conversion of land to agricultural use was the primary cause of the prairie's demise. The depletion of one of our primary native ecosystems compels us to attempt to restore and reconstruct tallgrass prairie.

Tallgrass prairie is found in the higher rainfall areas of the grasslands region of North America. It is a diverse ecosystem supporting hundreds of species of plants, invertebrates, birds and mammals. Often, ecosystems are considered for the uses that humans can attain from them. Prairie has many beneficial uses such as soil development, erosion control, wildlife habitat, recreation and education uses. These benefits and the aesthetic qualities of prairie drives the need to regain some of the biodiversity that has been diminished in our North American heritage.

In the past 30 years or so, prairie restorations and reconstructions have been actively attempted and successfully completed. Eight years after the First Midwest Prairie Conference (held in 1968), Schramm (1976) noted it was obvious there was much we did not know about prairie restoration. Only a few present at the conference could offer concrete suggestions on how to propagate various species and achieve some semblance of a prairie community. As a result of the many ideas shared at the Midwest Prairie Conference and now the North American Prairie Conferences, a great deal more is known than in 1968.

An overview of the considerable amount of literature on prairie restoration and reconstruction follows.

Re-Establishment Definitions

Prairie restoration and reconstruction should imply two different things. The terminology is in flux and the two terms are often misused. Reconstruction is when an area has no prairie vegetation or no vegetation at all, and the prairie has to be established by planting seeds or transplanting seedlings. On the other hand, if relic prairie species exist and prairie can be re-established by burning, clearing, or planting seeds or a combination of these, then this is a restoration (personal communication Daryl Smith 1995).

Restoration is taking an existing prairie parcel that is degraded and restoring it to a higher quality prairie.

This could include adding other species, clearing it of invading weeds and/or woody vegetation, burning it or a combination of these things. The term restoration is used more often and in a more general way than reconstruction.

Local Ecotypes

Particularly important is the use of local ecotypes in establishing prairie (Schramm 1990; Knapp and Rice 1994). Plants are adapted to the regional climate where they are located. Ecotypes are defined as genetically differentiated strains of a population that have become adapted to specific site characteristics, i.e., soil moisture, length of growing season, etc. (Smith and Houseal 1997). Before there was an understanding of local adaptation, plantings of non-local seeds sometimes resulted in poor stand vigor, reduced productivity, or failure of the stand (Knapp and Rice 1994). Local ecotypes should improve establishment of prairie plantings.

Establishment and Management Techniques

A prairie planting takes several years to become established depending on the climate and soil conditions, competition from other plants, and seed germination rate. Several management techniques have been developed to aid the establishment of reconstructed prairie in the early phase.

Some of these techniques are used after a prairie is growing well on its own.

Weed Control and Early Establishment

Reduction of competition by weeds is important in the early stages of prairie reconstruction. Well known weed control techniques include burning, chemical and hand removal, and mowing (Betz 1984; Diboll 1987; Kurtz 1992; Schramm 1976; Schramm 1990).

Burning is probably the best method for continued maintenance of native prairie. Prairie is adapted to fire and responds positively to it, whereas most weeds are not so adapted and will die out following fire. This technique can also be used to aid in initially establishing a prairie to remove weeds and provide a bare area to sow the seeds (Schramm 1976; Schramm 1990).

Hand weed removal is an effective method to assist prairie in becoming established but is very labor intensive. Also, those removing the weeds must be able to tell the difference between prairie and weed species, so that "good" plants are not removed. Chemical weed removal can be harmful to prairie plants and still not completely control the weeds. This method can be expensive as well. Chemicals are most often used to rid an area of weeds before the prairie seeds are planted (Schramm 1976; Schramm 1990). It is not common practice to use chemical herbicides on native prairie.

Given enough time, prairie plants will generally out compete the weeds. In a reconstruction experiment by Kirt (1990), no burning or weed removal was done. After four years, weed coverage decreased and prairie plant coverage increased. This example illustrates the hardiness of native prairie over non-native or early successional species.

Another very effective method to aid prairie establishment is mowing (Kurtz 1992; Diboll 1987). Mowing removes the tops of the weeds, thus preventing seed development. Mowing allows more sunlight to reach the slower growing prairie underneath the weeds.

Nitrogen Manipulation

A little known technique that would aid in the establishment of a reconstructed prairie is soil impoverishment. This involves applying materials such as sawdust and sugar or other organic material such as compost to tie up the available nitrogen in the soil. Prairie plants can tolerate low levels of available nitrogen while weeds cannot. This technique, suggested and presented by Morgan (1994), allows the prairie species to get a head start in establishment without weed competition.

Others have had mixed results with this technique (Davis and Wilson 1997; Seastedt et al. 1996; Wilson and Gerry 1995). In the Davis and Wilson (1997) experiment, the plants were killed following the second sugar treatment. Seastedt et al. (1996) reported that one weed species density was reduced but the other two species, one native and one weed, were not significantly effected. Wilson and Gerry (1995) found that the area of bare ground increased while nitrogen availability decreased, but native seedling density did not increase. Perry et al. (1986) noted that low amounts of available phosphorus allow established warm season grasses to persist. Also lack of persistence has not been attributed to too little nitrogen or potassium. Wedin and Tilman (1996) found that nitrogen loading caused a loss of diversity, increased abundance of non-native species and disrupted ecosystem functioning. However, warm season grasses showed an increase in biomass at very low nitrogen loading rates. Warm season grass biomass decreased as nitrogen was added to the areas.

The research presented here deals with soil enrichment not soil impoverishment. Although no experiment exactly like this has been done before, other experiments with nitrogen loading have been done. Sludge contains nitrogen, potassium and phosphorus in varying amounts and thus fertilizes the soil. This experiment may show that at very small amounts of sludge application, there is no harmful effect on a reconstructed prairie. Further, it may show that some amount of sludge can be safely placed on native prairie as a way of using some of the large quantities that are produced each year.

Sludge--the Problem

As of 1982 in the United States, an estimated 8.6 million dry metric tons of sludge were produced annually (Feliciano 1982). Sludge contains fecal material, paper fibers, food wastes, oil, paints, detergents, cleaning agents and industrial wastes. These wastes contain nearly every inorganic and organic compound known to man, and a variety of viruses, bacteria, and parasites (Feliciano 1982).

Since sewage sludge is so abundant, disposal and use is becoming an increasingly difficult task. There are five basic ways to currently use or dispose of sludge: land application, landfilling, incineration, ocean dumping, and lagooning. According to the U.S. Environmental Protection Agency as reported by Elliott (1986), land application accounted for 42 percent by volume of sludge generated in 1981. This was an increase from 26 percent in 1976.

The Solution to Sludge

Land-applied sludge is most frequently placed on agricultural land. Other land applications include park land development, reforestation projects and strip mine reclamation. Little or no land-applied sludge has been placed on reconstructed prairie.

Sludge has been reported to assist vegetation establishment on impoverished soil (Elliott 1986) and mine tailings (Joost et al. 1987; Pietz et al. 1989). When sludge is applied in reclamation projects, it is generally added to improve soil conditions such as soil structure, organic carbon, and water-holding capacity (Joost et al. 1987). Since sludge contains so much water (approximately 90%), it provides much needed moisture to newly planted seeds and seedlings.

The public has an unfavorable view of sludge for many reasons including odor, pathogens, contamination of ground and surface waters, toxicity to plants and increased potential of toxic metals in the food supply (Council for Agricultural Science and Technology 1976).

Government regulations govern the application of and the rates at which sludge can be applied to land. Currently, the heavy metals in many municipalities' sludge are of major concern because once they enter the soil they are considered permanent soil constituents. Heavy metals can accumulate in the food chain and pose a human health hazard when food (grain crops, beef, pork) is produced on land that received one or more sludge applications (Feliciano 1982; Elliott 1986). Because heavy metals are taken up by food crops such as vegetables, their intended use as food for human consumption poses a health hazard (Valdares et al. 1983; King 1986). Some commercial distributors will not accept produce grown by farmers who use sludge. Also, the public has a negative perception of sludge use in food production (Feliciano 1982). However, King (1986) reports that when sludge is applied at a rate to supply only the nitrogen a crop requires, the heavy metal loading rates are generally low and don't pose a significant risk to crops, animals or humans. Metal loading rates depend on the plant species and the metal. Some plant species accumulate metals more than others and cadmium tends to accumulate in plants more than other metals (King 1986). Information on long term effects of metal loading on native prairie species was not found.

Another problem associated with sewage sludge use on land is pathogens. The most common way to reduce pathogen numbers is to stabilize the sludge by adding lime. This method substantially reduces, but does not eliminate pathogens. Other treatments to reduce pathogens include composting and heat treatment which generally inactivate these microorganisms (Feliciano 1982). The risk of human and animal exposure to pathogens can be reduced. Using specified waiting periods after application depending on the intended land use (Elliott 1986) accomplishes this. Also, as reported by Elliott (1986), there is little danger of disease transmission from properly managed land application. Properly managed application includes not applying sludge on steep slopes, not applying it near waterways, and not allowing grazing or other activity on the land for several days following the application.

Despite the problems of land-applied sludge, there are other acceptable uses. Another use for sludge other than traditional agricultural land and reclamation projects, is on grass that is not intended for consumption, such as golf courses, sod farms, and other turf grasses (Elliott 1986). The problems discussed above are not major issues for non-consumptive types of vegetation. Reconstructed prairie would also fall under this category and thus be minimally affected by the problems discussed above.

Vegetation Establishment Using Sludge

Sludge has been used to assist in vegetation establishment. Most of the related literature focuses on two areas: 1) reclamation projects using native and non-native vegetation, particularly on coal refuse strip-mine spoils, and 2) agricultural land, generally forage crops.

Pietz et al. (1989), reported on the revegetation of coal refuse material using sludge in the Metropolitan Sanitary District of Greater Chicago, Fulton County, Illinois. Several different treatments were used with various combinations of sewage sludge, lime, and gypsum. The vegetation included three species: smooth brome (*Bromus inermis*), tall fescue (*Festuca arundinacea*), and alfalfa (*Medicago sativa*). They reported plant yields increased each year between 1978 and 1980. The highest yield obtained occurred in 1980 under a treatment of sludge and lime (Pietz et al. 1989).

A similar study was conducted by Joost et al. (1987) in Williamson County, Illinois at Peabody Coal Company's Will Scarlet Mine where reed canarygrass (*Phalaris arundinacea*), tall fescue, and redtop (*Agrostis alba*) were seeded. The various treatments (sludge plus lime in different amounts) sustained stands of grass for the four years of this study. Sabey and Hart (1975) reported that wheat (*Triticum aestivum*) plots treated with municipal sewage sludge had yields greater than or equal to no-sludge plots.

Another study by Schramm and Kalvin (1976) used native prairie species on a strip mine reclamation. Unlike the previous studies discussed they did not use sludge. No fertilizer of any kind was used. They reported that 10 days after planting, germination of grasses and forbs occurred. For strip mines, they concluded that some species will grow in this harsh environment, but that rainfall more than nutrients may be a limiting factor. On a landfill, conditions can be quite dry as well. A capped cell at a landfill is designed to drain quickly and not allow water to pool. Liquid sludge provides much needed moisture, as it is over 90 percent water and nutrients.

In agriculture, sludge as an additive is considered a low grade fertilizer (Elliott 1986), since there is little control over the amount of nutrients in it. The amount of nitrogen (N) in sludge is inconsistent and unreliable. To get the needed amount of N in an application, the level of phosphorus (P) can be extraordinarily high. These high levels of P, then can cause eutrophication of nearby ponds and lakes (Knezek and Miller 1978). However, the sludge does improve yields and forage quality (King 1986; Knezek and Miller 1978) or has no effect on it (King 1986). Because of the high P in many sludges, Iowa Department of Natural Resources (DNR) has placed restrictions on where and when sludge is applied to any land. Iowa DNR stipulates the steepness of slope, distance from a waterway and length of waiting period for continued or future use. These items are different depending on the type of sludge being applied (IAC 1994).

Prairie on low relief and a sufficient distance from surface water should be an acceptable site for sludge disposal and use. If the sludge positively effects prairie vegetation establishment and after further testing demonstrates no adverse effect on the wildlife and human managers, it should be an excellent avenue for sludge use. In ideal prairie situations, the current maximum allowable rates of application set by state regulations could be relaxed. Then we could begin to more broadly distribute the large surplus of sewage sludge in the U.S. in places never thought of before.

Objectives

The purpose of this study was to determine the effect of sludge application to recently reconstructed prairie.

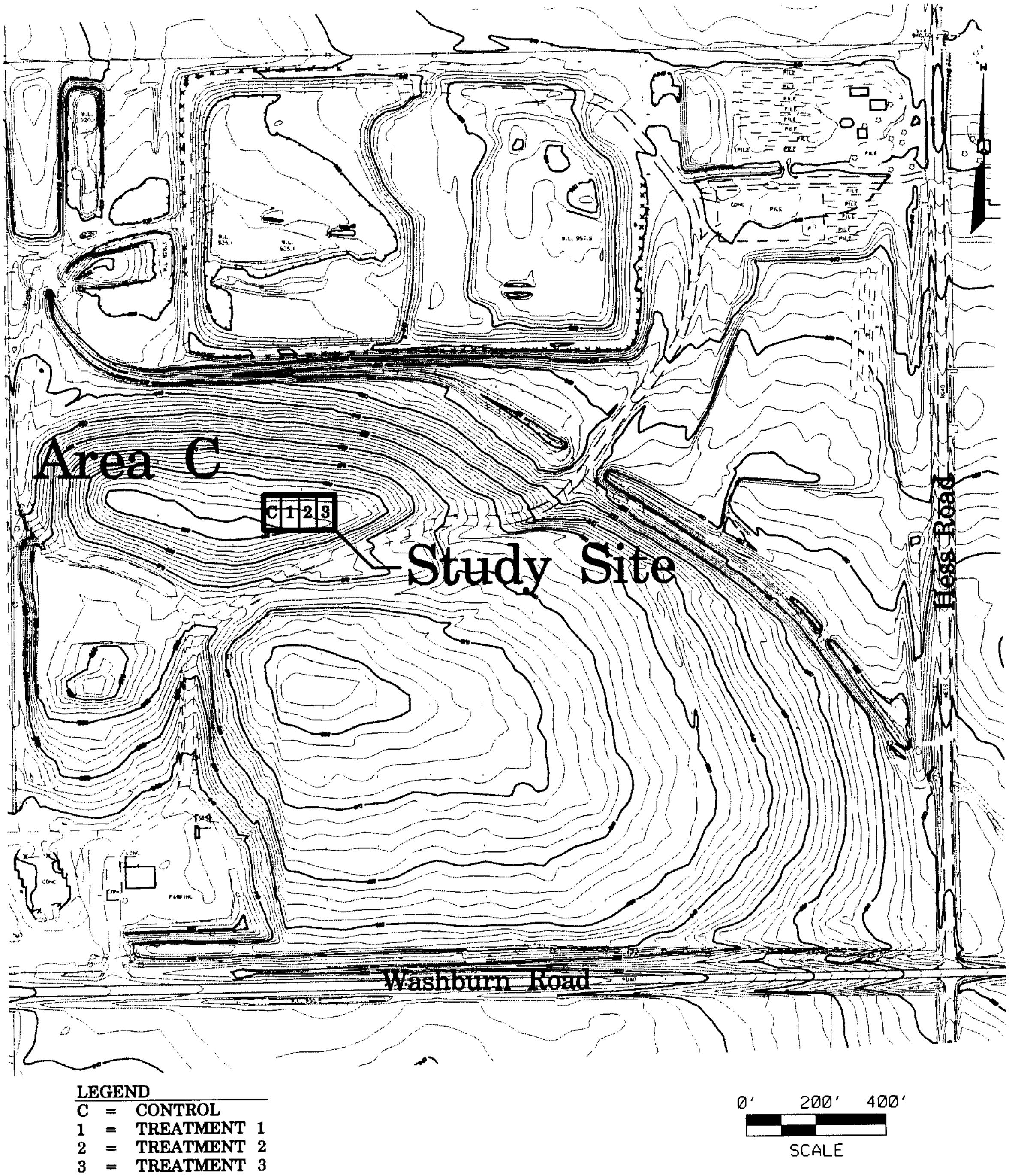
The objectives of this study were to measure and compare the effect of three rates of sludge application on 1) recently seeded prairie plants, and 2) non-native species including weeds and timothy (*Phleum pratense*). Another objective was to use the data obtained to evaluate the practicality of sludge disposal on reconstructed prairie in the future. The null hypotheses are that coverage and frequency of 1) prairie grasses and forbs will not be effected by the sludge application, 2) timothy (*Phleum pratense*) will be effected by sludge application and 3) weed species will be effected by sludge application. The data will be used to determine how sludge effected native prairie species interrelationships within the treatment community.

CHAPTER 3

METHODS

This project was conducted at the Black Hawk County, Iowa sanitary landfill located south of Waterloo on Washburn Road in Section 23 T88N R13W (Orange Township) (Figure 1). The specific study site was a capped cell of the landfill called Area C. Although Area C is approximately 17 acres (6.8 hectares) in size, much of it consists of side slopes of a constructed hill. Therefore only 0.5 acre (0.2 hectare) near the top of this area was used to avoid variations in slope (Figure 1).

Area C was capped in 1994. First a layer of foundry sand was placed on the material in the landfill, followed by two different clay layers as required by Iowa State regulations. These sand and clay layers were then covered with a six-inch (15.2 cm) layer of previously stockpiled topsoil so that vegetation could be planted to reduce erosion. Eight to twelve inches (20.3-30.5 cm) of coarse compost and sewage sludge were disked into the topsoil to produce a total 14-18 inch (35.6-45.7 cm) thick substrate which is fairly uniform. However, the sludge was not evenly placed on Area C. The northeast side received more sludge than the rest of the site (personal communication Dennis Ehns 1995).



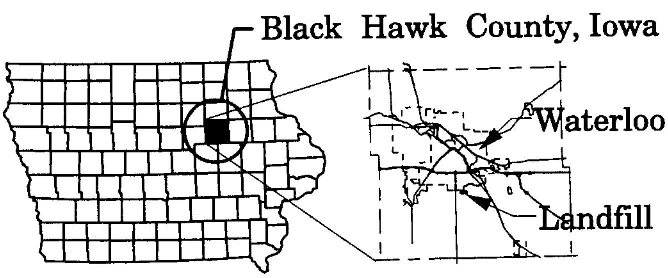


Figure 1
Project Location
Black Hawk County Landfill
Black Hawk County, Iowa

Landfill Seeding

In September 1994, a mixture of Regreen® (*Agropyron* x *Triticum*) a sterile fast-growing hybrid, timothy (*Phleum pratense*), rye (*Lolium perenne*), and annual oats (*Avena sativa*) was seeded on Area C. The following seeding rates were used for the cover crop: Regreen®- 20 lbs/acre (17.8 kg/ha), oats- 1.5 bushels/acre (42.8 kg/ha), rye- 2.5 lbs/acre (2.2 kg/ha) and timothy- 0.5 lbs/acre (0.45 kg/ha). They each grew to approximately 3 inches (7.6 cm) before the first frost. The Regreen®, timothy, and rye are perennials and regrew in the spring. The Regreen® and rye persisted through 1996. The timothy continues to persist on the site.

On May 18, 1995 a native prairie seed mixture was planted with Black Hawk County's native seed drill on the study site. It contained big bluestem (*Andropogon gerardii*), little bluestem (*Schizachyrium scoparium*), Indian grass (*Sorghastrum nutans*), sideoats grama (*Bouteloua curtipendula*) and 49 species of forbs. The seeding rate for this mixture was 12.5 lbs/acre (11.1 kg/ha). The mixture was obtained from a nursery called Ion Exchange that specializes in harvesting local Iowa ecotypes. The forbs in this mix are listed in Table 1 below.

Table 1. Black Hawk County Landfill Study Site

Species List

Common Name	**Scientific Name**
Leadplant	*Amorpha canescens*
Thimbleweed	*Anemone cylindrica*
Columbine	*Aquilegia canadensis*
Butterfly Milkweed	*Asclepias tuberosa*
Whorled Milkweed	*Asclepias verticillata*
Sky Blue Aster	*Aster azureus*
Canada Milkvetch	*Astragalus canadensis*
False Boneset	*Brickellia eupatorioides*
Tall Bellflower	*Campanula americana*
Partridge Pea	*Chamaecrista fasciculata*
Lanceleaf Coreopsis	*Coreopsis lanceolata*
Prairie Coreopsis	*Coreopsis palmata*
Purple Prairie Clover	*Dalea purpurea*
Illinois Bundleflower	*Desmanthus illinoensis*
Pale Purple Coneflower	*Echinacea pallida*
Purple Coneflower	*Echinacea purpurea*
Rattlesnake Master	*Eryngium yuccifolium*
Tall Boneset	*Eupatorium altissimum*
Flowering Spurge	*Euphorbia corollata*
Cream Gentian	*Gentiana alba*
Stiff Gentian	*Gentiana quinquefolia*
Showy Sunflower	*Helianthus rigidus*
Western Sunflower	*Helianthus occidentalis*
Ox-eye Sunflower	*Heliopsis helianthoides*
Roundheaded Bushclover	*Lespedeza capitata*
Rough Blazingstar	*Liatris aspera*
Dwarf Blazingstar	*Liatris cylindracea*
Wild Bergamont	*Monarda fistulosa*
Dotted Mint	*Monarda punctata*
Evening Primrose	*Oenothera biennis*
Small-Flowered Primrose	*Oenothera parviflora*
Large-Flowered Beardtongue	*Penstemon grandiflorus*
Prairie Cinquefoil	*Potentilla arguta*

Common Name	Scientific Name
Slender Mountain Mint	*Pycnanthemum tenuifolium*
Mountain Mint	*Pycnanthemum virginianum*
Drooping Yellow Coneflower	*Ratibida pinnata*
Early Wild Rose	*Rosa blanda*
Black-eyed Susan	*Rudbeckia hirta*
Brown-eyed Susan	*Rudbeckia triloba*
Maryland Senna	*Senna marilandica*
Medsger's Senna	*Senna medsgeri*
Rosinweed	*Silphium integrifolium*
Compass Plant	*Silphium laciniatum*
Old Field Goldenrod	*Solidago nemoralis*
Stiff Goldenrod	*Solidago rigida*
Showy Goldenrod	*Solidago speciosa*
Ohio Spiderwort	*Tradescantia ohiensis*
Hoary Vervian	*Verbena stricta*
Heartleaf Alexanders	*Zizia aptera*
Big Bluestem	*Andropogon gerardii*
Sideoats Grama	*Bouteloua curtipendula*
Little Bluestem	*Schizachyrium scoparium*
Indiangrass	*Sorghastrum nutans*

Mowing

The original plan called for the study site along with the rest of Area C to be mowed two to three times in 1995 and 1996. It was mowed according to plan in 1995. In 1996, mowing was delayed due to concern for birds nesting on Area C. It was mowed only once in 1996 at a later date than was optimum for weed control (late July). In 1997 all of Area C was mowed except the study site. The mowing operator was concerned about running over the permanent transect stakes and the possibility of causing damage to the mower and/or the stakes.

Sludge Application

Municipal liquid sewage sludge from the city of Cedar Falls, Iowa was applied to the experimental plots in July 1996 and April-May 1997. Before this sludge could be applied, permission had to be obtained from the Iowa Department of Natural Resources. Generally an application to apply sludge very near to steep slopes, would require a permit providing an exception to the regulations under IAC 567-67. Since this project was for education and research for a limited time, a permit was not required. The only requirement was a letter to Iowa DNR informing them of the project plans. An information letter was submitted to them each year.

The 0.5 ac (0.2 ha) site was divided into four non-replicated plots oriented north-south side by side near the top of Area C. The site measured 100 ft. (30 m) by 250 ft (76 m). Each plot measured 59 ft. by 100 ft. (18 m by 30 m) with a buffer between each plot of about 4-5 ft. (1.2-1.5 m). Due to limitations in available space the plots were configured in this way and not replicated. The top of Area C is relatively narrow with steep side slopes and I wanted the plots to be on fairly level ground. The truck that applies the sludge is large and making more plots (i.e., 8 plots in a randomized design) would be even more difficult for the truck to maneuver around than with just four plots.

The method to apply the sludge is inaccurate and several smaller plots would make the application method even less accurate. Given the available area on top of Area C, the layout of the four plots was the best use of the land.

Sludge was applied in 1996 and 1997. One plot (Treatment 1) received 1/2 truck load of liquid sludge each year. The second plot (Treatment 2) received 1 load, and the third plot (Treatment 3) received 1 1/2 loads of sludge each year. See Figure 1 for plot locations and designations. A fourth plot of equal size served as an unamended control. One truck load of sludge contains about 2000 gallons (7570 liters). The sludge was analyzed for nutrient and metal content at a local laboratory facility. Copies of the results of the sludge analyses for 1996 and 1997 are shown in Appendix A.

The amount of nitrogen in a load can be calculated fairly easily if the analytical information is available. For example, the amount of N for Treatment 1 which received 1/2 load of sludge or about 1000 gallons (3785 liters) is calculated as follows: sludge weighs about 8.5 lbs/gallon (4.9 kg/liter). In 1997, the percentage total solids was 4.17%. Therefore 8.5 lbs x 1000 gal. x 0.0471 = 400.35 lbs solids/1000 gallons. Ammonia nitrogen (NH3) in this sludge sample (dry weight) was 15,700 ppm. To obtain the rate of NH3/1000 gallons; 15,700 ppm = 1.57%. Then 400.35 x 0.0157

= 6.29 lbs NH3/1000 gal. This gives a rate of 6.29 lbs NH3/1000 gallons. The same calculations have been done for 1996. Table 2 illustrates the amount of ammonia nitrogen applied to the three treatments each year:

Table 2. Rates of Ammonia Nitrogen (NH3) Application to Research Plots

	1996 (lbs/ac)	1997 (lbs/ac)
Treatment 1	60	44
Treatment 2	119	89
Treatment 3	179	133
Control	0	0

To apply the sludge, a truck containing the sludge was driven to the study site at the top of Area C. The plots were clearly marked with flags for the driver. The sludge was sprayed over the plots from the back of the truck. In order to cover each plot, several passes were made over them. This method of application is not precise and did not allow determination of an even distribution of sludge on each plot. The driver uses a gauge in the cab of the truck to assist him in determining the amount of sludge remaining in the tank. However, from experience he observed that the gauge does not accurately indicate the amount of sludge remaining. Specifically it tended to be less accurate as the amount of sludge in the tank decreased. He could estimate about how much actually remained by comparing the length of time and the speed at which he'd been applying to the gauge reading (personal communication Bill Keith 1996).

Monitoring

Each plot was sampled monthly one year after seeding, June through September for 1996 and 1997. In 1996, monitoring started one month prior to the sludge application. In 1997, sludge was applied in the early spring, so monitoring began about 1 to 1½ months after the application.

Within each plot, two 98-foot (30-meter) permanent transects were established. A quadrat was sampled every other meter along each transect so a total of 30 quadrats were sampled per plot. In each quadrat, species present and percent coverage of each of those species were recorded. Percent coverage was estimated to fall within one of the following ranges: 0-5%, 5-25%, 25-50%, 50-75%, 75-95% or 95-100%. Total coverage in any quadrat could total more than 100% given these ranges and plants overlapping coverage areas. The midpoint of each of these ranges (2.5%, 15%, 37.5%, 62.5%, 85%, 97.5%) was converted to a real area in square meters per m^2 (0.025, 0.15, 0.375, 0.625, 0.85, 0.975 m^2) and used in calculating coverage, instead of percent coverage for each transect (Daubenmire 1959). From these data, coverage (area per square meter), relative coverage, frequency, relative frequency, and importance value could be determined for each species. Coverage is defined as the area of the ground occupied by a vertical projection 1-2 inches above the ground from the aerial parts of the plant. Relative coverage for a species is the coverage for that species expressed as a proportion of the total coverage for all species. Frequency is the number of samples out of 30 in which a species occurs. Relative frequency is the frequency of a given species as a proportion of the sum of the frequencies for all species (Brower and Zar 1977). Importance value is the sum of the relative coverage and relative frequency and provides a means of combining the two for determining the relationship within the community.

The species were categorized into three groups including cover crop (timothy (*Phleum pratense*)), weeds, and native prairie species. Timothy was in its own group because it was planted as part of a cover crop and did not appear on the site voluntarily. Native prairie is of primary interest in this study, but timothy and weeds warrant study because they could be competing with prairie species and sludge could effect them also. Thus there are three groups discussed throughout this paper.

Data Analysis

Following data collection, a statistical analysis was conducted. Each data entry is equal to one observation of coverage and frequency for one species. There was potential to have a maximum of 30 observations for each species per plot. The number of observations for each species ranged from one per plot to 29 per plot. Thus the data set was made up of unequal samples. Note that the data entered into the statistical analysis is from non-replicated plots. Limited or no extrapolation to other studies from the statistical analysis can be made because of this. Because plot location is confounded with plot treatment, it is not possible to say whether differences between plots are due to treatments.

Using Microsoft Excel 7.0, descriptive and summary statistics such as mean, median, standard error, sum, count and range were determined. Determinations were made on the following: all species for September 1996 and September 1997, weed species, prairie species, timothy (*Phleum pratense*) and individual prairie species that appeared in more than two plots in September 1997. A 95% confidence interval was also calculated with the summary statistics.

The subsample mean for a group or individual species in each plot treatment was graphed. Error bars were added to show the 95% confidence interval about the mean. Thus the variability within a plot can be shown and compared to other plots of the same group or individual species. Some individual species were observed only one time in a plot and therefore no error bars could be added.

September 1997 data represent the culmination of the 1996 and 1997 growing seasons. Since prairie develops and matures over several years, the 1997 data would represent the most developed prairie for which data are available. Note two species, Black-eyed Susan (*Rudbeckia hirta*) and Illinois bundleflower (*Desmanthus illinoensis*), did not appear in September, but had appeared earlier in the year.

Soil Sampling

In March 1998, a composite soil sample for each plot was collected. Ten soil samples were collected within each of the four plots. The samples for a plot were placed into a clean bucket and the contents were thoroughly mixed. One sample for the plot was collected for analysis from this composite. This technique was repeated for each plot. The samples were analyzed at a commercial laboratory in Eagle Grove, Iowa. The samples were analyzed for available nitrogen (nitrate nitrogen), total (Kjeldahl) nitrogen, potassium, phosphorus, pH and organic matter. The method used to analyze nitrate nitrogen and total nitrogen was Lachet. The method used to analyze the potassium was exchangeable potassium/ammonium acetate. Phosphorus was analyzed using Bray-1 and organic matter was analyzed using loss of ignition method.

CHAPTER 4

RESULTS AND DISCUSSION

Results from this study include data on coverage, frequency and the number of individual prairie species. Also presented is frequency on the four research plots and soil composition data.

General Observations

The prairie seed mix was planted on May 18, 1995. During the first three to four weeks after planting, rainfall events allowed the seeds to germinate and grow to approximately an inch or so in height. Starting in late June and through much of July, there was little precipitation for extended periods. The plants that had germinated were then experiencing very dry conditions. The precipitation data show that July 1995 received less than 2 inches (5.08 cm) of rainfall (NOAA-NCDC 1995). This is 3 inches (7.6 cm) below the 30-year normal for this month (NOAA-NCDC 1995). In early July 1995 the contractor on site, Denver Construction, watered the top of Area C at my request. Precipitation data from May through September 1995-1997 is included in Appendix B. The data show that all three years had below normal rainfall for most of the months recorded (May-September). The year 1996 was the driest of the three. Each month from May through September 1996 received less than the 30-year normal precipitation for a total shortage of over 6 inches (15.2 cm).

Cover Crop

The cover crop, planted in September 1994, contained Regreen®, oats, rye and timothy. It grew quickly and provided sparse cover the first year. The cover crop on a landfill is critical to keep the soil in place so the cap does not deteriorate. If the soil is allowed to erode the integrity of the cap can be altered and eventually if this continues, garbage can become exposed. Even though the vegetation was sparse the first year, coarse compost had been incorporated into the soil prior to the planting. The coarse compost aided the vegetation in holding the soil in place until 1995 when the cover crop regrew and was thicker than 1994.

Each cover crop species had a time line for functioning for erosion control. The Regreen® was purported to survive for about three years but not reproduce. As expected, it followed that time line. Oats are an annual species and were not expected to live beyond 1994. They did not persist into 1995. Rye is a perennial species and was anticipated to persist for two to four years. It persisted for about two years before dying out. Timothy is also a perennial that was expected to persist for several years. It has done better than expected and continues to return each year. In some regions on Area C, in general, and the study site in particular, there is almost a solid stand of timothy. Although this is not desirable from a prairie establishment and diversity standpoint, it is beneficial to maintaining the cap at a low maintenance cost. However, it may have interfered with establishment of prairie species. Future cover crop seedings should include a lower seeding rate of timothy (<0.5 lbs/acre (0.45 kg/ha)) than was used at this location or it could be left out altogether. The sludge applied to the study site may have contributed to the abundance of timothy. This is discussed later in this chapter.

Soil Analysis

There was not a clear correlation between the amount of sludge applied and the amount of nutrients found in the soil in the four plots (Appendix C). It was expected that the control would have the lowest levels of nutrients while Plot 3 would have the highest levels since the largest amount of sludge was applied to it. The pH was similar for all four plots ranging from 7.5 to 7.8. Nitrate nitrogen, the available form of nitrogen, was the only nutrient that correlated somewhat to the amount of sludge that was applied. In the control it was 3.2 ppm. In Plot 1 it was 9.45 ppm. Plot 2 had a level of 8.35 ppm and Plot 3 had a nitrate nitrogen level of 11.2 ppm. Total nitrogen and phosphorus were highest in Plot 1. Potassium was highest in the control. Organic matter was the highest in Plot 2.

Soils are variable by nature. But soils that have been stripped and replaced later, often provide highly variable results when sampled. Randy Killorn (1998) Iowa State University Soil Fertility professor, theorizes that when soil is stockpiled it is broken apart and settles out by particle size. The size of the particle affects its cation exchange. When the soil is replaced it is not mixed as a natural soil would be so that large particles are grouped together separate from the small particles. This could create unusual results in the nutrient tests. If the soils within the plots had been sampled prior to the start of the project then this would have provided a reference point for the impact of the sludge on the soils in each of the treatments. In Killorn's opinion, the soil analysis results found in this experiment are not entirely inconsistent with the amount of sludge placed on the plots. However he said without base line information on the soils we can not be certain of the conditions prior to the applications (personal communication Killorn 1998). Nevertheless, it can be assumed that the nutrients of the control are similar to those in the other plots prior to treatment.

Prairie Species Present

Of the 49 forbs and four grass species seeded on the study site, 18 of the forbs and all the grasses were observed. Fourteen of the forbs were found in quadrats during sampling and the remaining four were present, but outside all quadrats. Table 3 lists the prairie species observed in quadrats by month in 1996-1997. Four species observed outside the sampling quadrats were compass plant (*Silphium laciniatum*), blazingstar (*Liatrus* sp.), hoary vervain (*Verbena stricta*) and leadplant (*Amorpha canescens*).

Switch grass (*Panicum virgatum*) was observed in sparse numbers. It was not part of this seeding mix, but was present in a nearby planting and evidently migrated into the study site. Rosinweed (*Silphium integrifolium*) was listed in Ion Exchange's dry site seed mix. This species was not observed. Instead prairie dock (*Silphium terebinthinaceum*) was observed in quadrats. The prairie dock may have been included in the mix accidentally or substituted for the rosinweed without my knowledge.

Table 3. Prairie Species Observed Each Month

Species	1	9	9	6	1	9	9	7
	J	Jy	A	S	J	Jy	A	S
Andropogon gerardii	X	X	X	X	X	X	X	X
Bouteloua curtipendula	X	X	X	X	X	X	X	X
Panicum virgatum				X			X	X
Schizachyrium scoparium	X	X		X	X	X	X	X
Sorghastrum nutans					X	X	X	X
Asclepias verticillata	X		X	X	X	X	X	X
Aster azureus				X		X	X	X
Brickellia eupatorioides		X	X	X	X	X	X	X
Chamaecrista fasciculata			X					
Coreopsis lanceolata	X	X		X	X	X	X	X
Desmanthus illinoensis	X	X		X	X	X	X	
Echinacea pallida			X		X			X
Echinacea purpurea			X	X	X	X	X	X
Helianthus occidentalis		X	X	X			X	X
Heliopsis helianthoides				X				
Ratibida pinnata	X		X		X	X	X	X
Rudbeckia hirta	X	X	X	X	X	X		
Silphium terebinthinaceum							X	X
Solidago rigida	X	X			X	X		

Note: J = June, Jy = July, A = August, S = September

Some species appeared then disappeared as the growing seasons progressed. Species that were not present at the end of the season in 1996 were partridge pea (*Chamaecrista fasciculata*), pale purple coneflower (*Echinacea pallida*), and drooping yellow coneflower (*Ratibida pinnata*). Western sunflower (*Helianthus occidentalis*) was present in July, August and September 1996 and reappeared in August and September 1997. Pale purple coneflower (*Echinacea pallida*) appeared in August 1996 and June and September 1997. Little bluestem (*Schizachyrium scoparium*) and lanceleaf coreopsis (*Coreopsis lanceolata*) were both absent in August, 1996 but present in all other months. Indian grass (*Sorghastrum nutans*) did not appear until 1997, but was present in all four of those months. Prairie dock (*Silphium terebinthinaceum*) did not appear until August and September 1997. Two species were observed only once in the transects, Partridge pea (*Chamaecrista fasciculata*) in August 1996 and Ox-eye sunflower (*Heliopsis helianthoides*) in September 1996. Rigid goldenrod (*Solidago rigida*) appeared only in June and July 1996 and 1997. Two species not present in September 1997 were Illinois bundleflower (*Desmanthus illinoensis*) and black-eyed Susan (*Rudbeckia hirta*). Table 3 is useful for an overall look at the species present in each month.

The species that were observed most often are not surprising given their adaptability. Drooping Yellow coneflower (*Ratibida pinnata*) and black-eyed Susan (*Rudbeckia hirta*) are species listed by Schramm (1976) as low quality and easy to establish. High quality species according to Schramm (1976) are defined as occurring in high numbers in undisturbed areas, occurring in low numbers in disturbed areas, not weedy or aggressive, an important self-reproducing component of a mature prairie and associated with similar species. We can infer that low-quality species do not possess these qualities. Sky blue aster (*Aster azureus*), pale purple coneflower (*Echinacea pallida*) and rigid goldenrod (*Solidago rigida*) are listed as medium to high quality species with varying degrees of success for establishment according to Schramm (1976).

A project conducted by Peven (1985) was successful in establishing native prairie on landfills. Species that were especially successful in the Peven study and appeared in this study include big bluestem (*Andropogon gerardii*), sideoats grama (*Bouteloua curtipendula*), Indian grass (*Sorghastrum nutans*), black-eyed Susan (*Rudbeckia hirta*), drooping yellow coneflower (*Ratibida pinnata*), purple coneflower (*Echinacea purpurea*), ox-eye (*Heliopsis helianthoides*), and false boneset (*Brickellia eupatorioides*).

Other species that did well in the Peven (1985) experiment that were also in the seeding mix for this study but were not observed include wild bergamont (*Monarda fistulosa*), evening primrose (*Oenothera biennis*) and purple prairie clover (*Dalea purpurea*).

A few other species in the Peven (1985) study were common to my seeding mix but did not do well for him. These species were little bluestem (*Schizachyrium scoparium*), stiff goldenrod (*Solidago rigida*) and roundheaded bushclover (*Lespedeza capitata*). Of these three species, little bluestem (*Schizachyrium scoparium*) and stiff goldenrod (*Solidago rigida*) appeared in my study. Little bluestem was observed in all plots and would be considered a successful seeding. Whorled milkweed (*Asclepias verticillata*) appeared in the Peven (1985) study without being seeded. It was included in the seed mix for this study and appeared in all plots and months except July 1996.

Coverage

The coverage of plant species is a common measure used by botanists and field ecologists. Coverage gives an indication of the space occupied by a species. It provides a measure of the success of establishment of a given species.

Graphical Comparison

All the data are presented in square meters per m^2. To obtain percent coverage, multiply the coverage by 100. Note that all following coverage graphs are labeled C, 1, 2 and 3. This stands for the Control plot, Plot 1, Plot 2 and Plot 3.

The 95% confidence interval is indicated on both sides of each mean in each plot. For plots of individual species containing only one observation, no mean and no confidence interval could be shown and only a dot is shown.

Mean coverage data for September 1996 are plotted on the following graph (Figure 2). In 1996, mean coverage for all species combined generally remained constant as the amount of sludge increased. The overlap in confidence intervals show that the amount of variability from place to place within each plot was similar and there is really no difference between plots. When the mean coverage of prairie, timothy and weeds were considered separately, the results were more revealing (Figures 3-5).

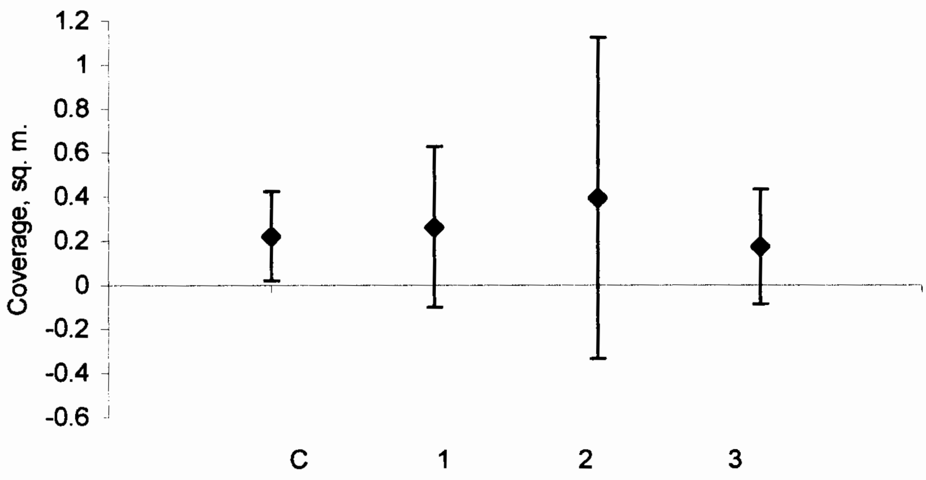


Figure 2. Mean Coverage of All Species in September 1996

Mean prairie coverage was highest in the control plot but varied with each treatment. Mean coverage was lower in all three treatments but only slightly lower in Plot 2. Again, the plot means all fall within overlapping confidence intervals suggesting little difference in the treatments.

The mean coverage of timothy was much higher in Plots 1 and 2 than the control. It was lower in Plot 3 but may have been affected by sludge. The sludge was applied in a fairly thick layer on the fourth plot (Plot 3). Rainfall was not adequate to rinse sludge from the plants. Many plant species including timothy appeared to suffer because of this.

Mean weed coverage was highest in the control plot and generally decreased through increasing sludge amounts. However, the treatment means all fall within overlapping confidence intervals, suggesting that there is little difference between the four treatments.

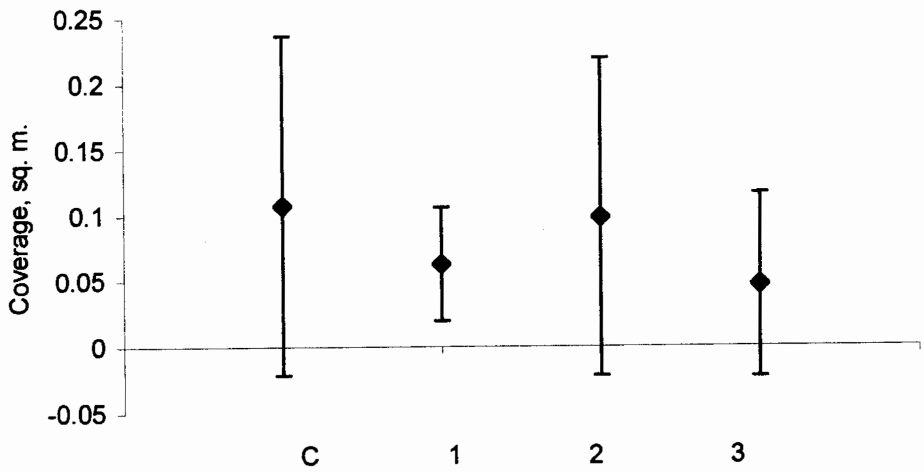


Figure 3. Mean Coverage of Prairie Species in September 1996

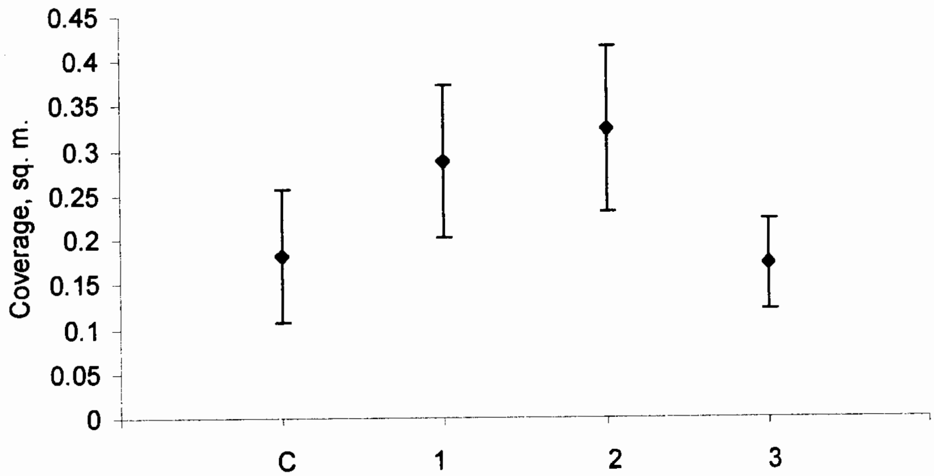


Figure 4. Mean Coverage of Timothy (*Phleum pratense*) in September 1996

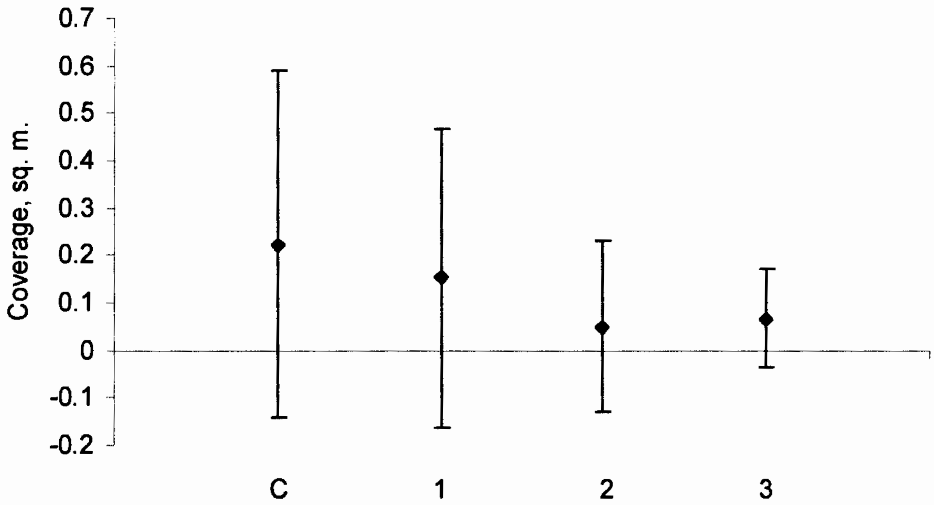


Figure 5. Mean Coverage of Weed Species in September 1996

Mean coverage of all species observed for September 1997 is plotted on the following graph (Figure 6). Mean coverage of all species was numerically higher in each Plot compared to the control plot. Plot 3 had slightly lower mean coverage than Plot 2 including all species, natives and non-natives. However, the treatment means all fall within overlapping confidence intervals suggesting there is no difference between the four treatments.

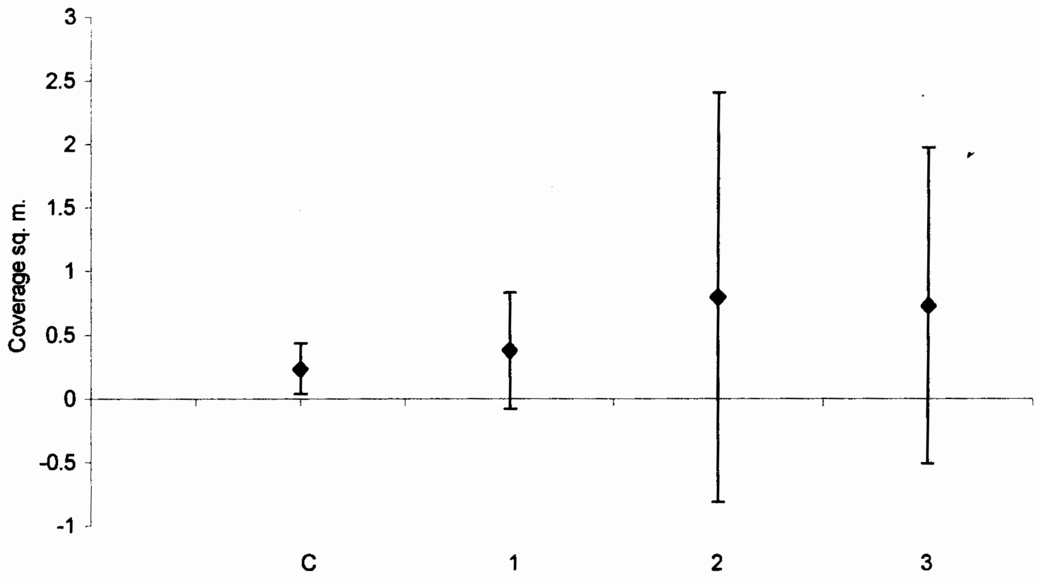


Figure 6. Mean Coverage of All Species in September 1997

To determine if the mean coverage was different between plots for weeds and native prairie, these groups were analyzed separately. Prairie species mean coverage was highest in the control and decreased with each increment of sludge (Figure 7). It showed distinctive declines between Plots 1 and 2. There was a small decline between Plots 2 and 3. From this, it appears that a small amount of sludge may cause some decline in native prairie coverage. A larger amount of sludge may cause further decline, but a threshold is reached where the prairie coverage is about as low as it can be without disappearing. Therefore, a trend toward declining coverage with increasing sludge application appears to be present. Again, the confidence intervals of the plots are overlapping, suggesting little difference in the treatments.

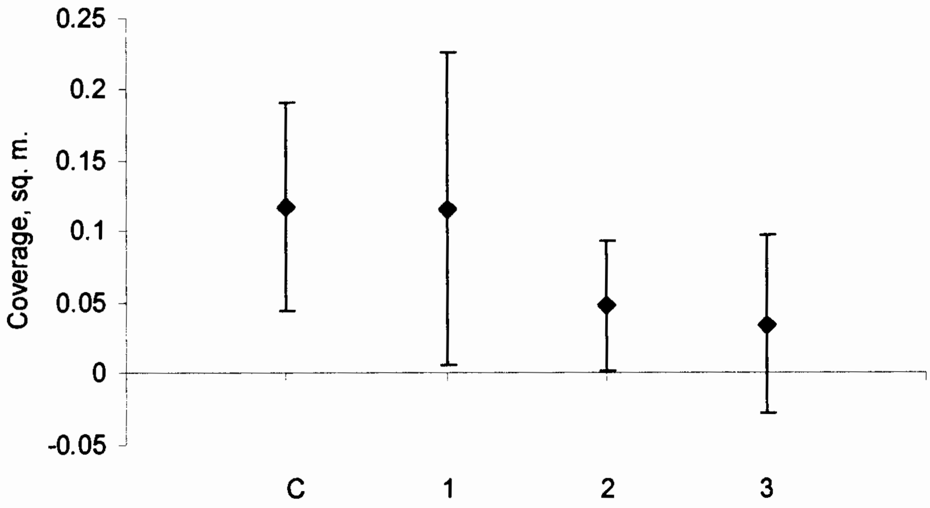


Figure 7. Mean Coverage of Prairie Species in September 1997

Timothy is plotted separately on Figure 8 for comparison. Timothy's mean coverage is very high compared to the other species and increases with each treatment. Its coverage appears to have an effect on the overall coverage shown in Figure 6. Differences between plots are meaningful as the confidence intervals overlap very little.

When the weeds (without timothy) are plotted (Figure 9), the results look quite different from Figure 6. Mean weed coverage varies from plot to plot. There is no clear trend in weed coverage as shown by the graph. Given that the confidence intervals are overlapping, there is no meaningful difference between plots. There is not an increase in coverage as is commonly thought to occur when a prairie reconstruction has a fertilizer applied such as sludge.

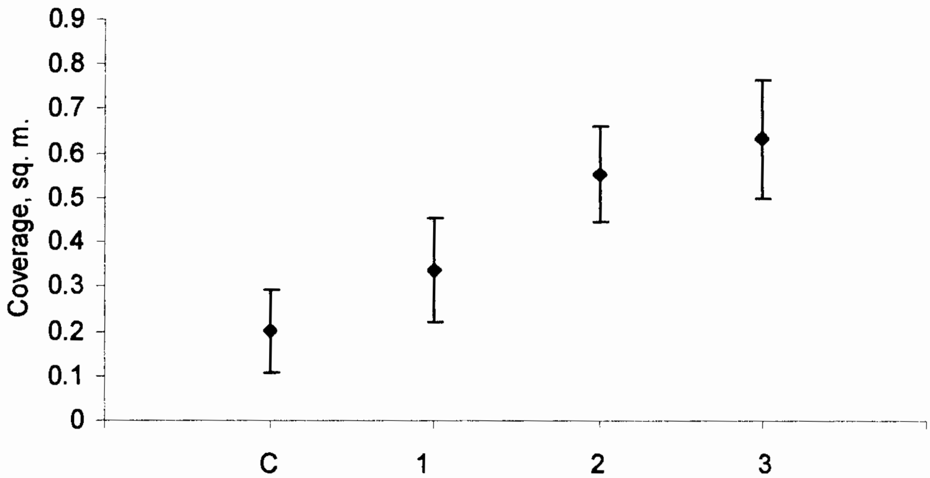


Figure 8. Mean Coverage of Timothy (*Phleum pratense*) in September 1997

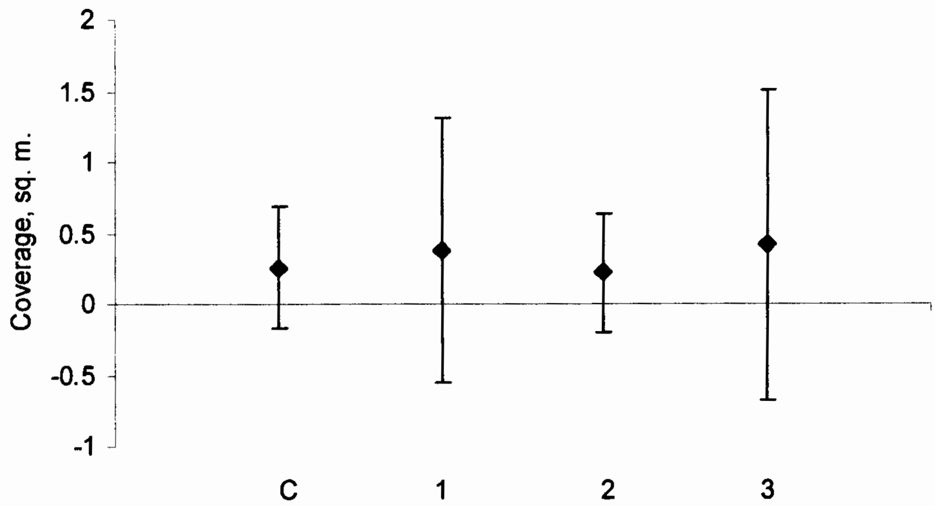


Figure 9. Mean Coverage of Weed Species in September 1997

The mean coverage of individual species in each treatment is interesting. Native species are graphed below in Figures 10-20 with the exception of those that were observed only in the control. These species include Indian grass (*Sorghastrum nutans*), switch grass (*Panicum virgatum*), prairie dock (*Silphium terebinthinaceum*), pale purple coneflower (*Echinacea pallida*), Illinois bundleflower (*Desmanthus illinoensis*) (last appeared in August 1997) and rigid goldenrod (*Solidago rigida*) (last appeared in July 1997). This is a total of six species out of a total of 19 observed over the two years. These species may be intolerant of sludge.

Several species decreased in mean coverage in the treatment plots compared to the control plot. These species include big bluestem (*Andropogon gerardii*), sky blue aster (*Aster azureus*), lanceleaf coreopsis (*Coreopsis lanceolata*), and black-eyed Susan (*Rudbeckia hirta*) (Figures 10, 14, 16). Some of these species did not appear in all plots. For example, sky blue aster appeared in the control plot, Plot 1 and Plot 3 but not Plot 2. Coverage for species in these plots generally decreased with increasing sludge application.

Some species had an increase in coverage in the treated plots. Species that showed no change or an increase in coverage include sideoats grama (*Bouteloua curtipendula*) and false boneset (*Brickellia eupatorioides*), (Figures 11 and 15). All the species in this group had an increase or no change in coverage in Plot 1 only.

A third group of species showed no clear trend either increasing or decreasing coverage. These species include little bluestem (*Schizachyrium scoparium*), whorled milkweed (*Asclepias verticillata*), purple coneflower (*Echinacea purpurea*), western sunflower (*Helianthus occidentalis*) and drooping yellow coneflower (*Ratibida pinnata*) (Figures 12-13, 17-19).

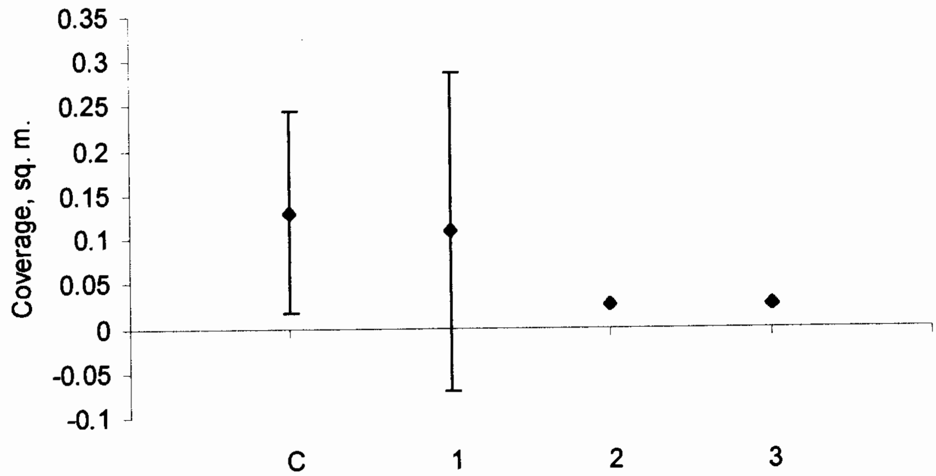


Figure 10. Mean Coverage of Big Bluestem (*Andropogon gerardii*) September 1997

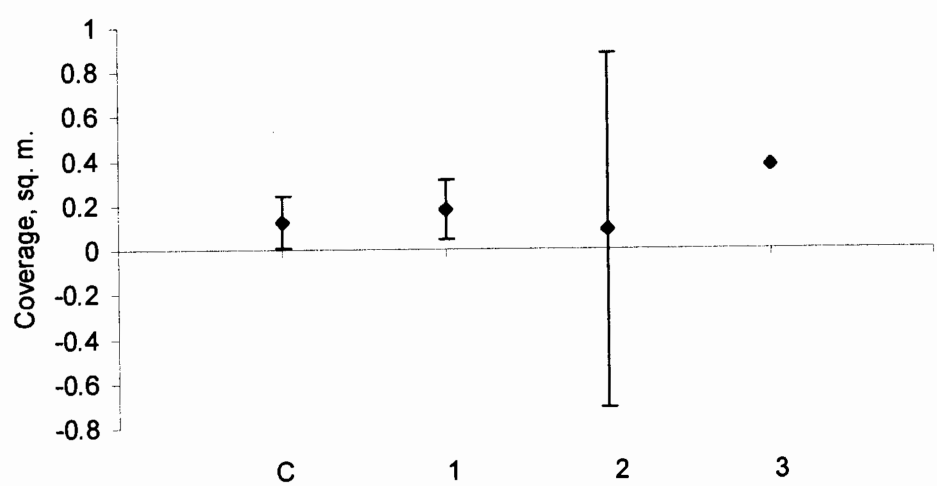


Figure 11. Mean Coverage of Sideoats Grama (*Bouteloua curtipendula*) September 1997

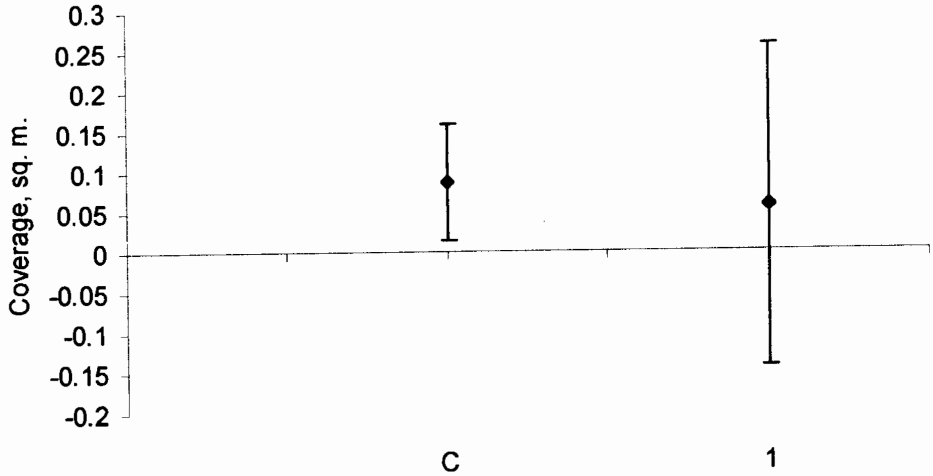


Figure 12. Mean Coverage of Little Bluestem (*Schizachyrium scoparium*) September 1997

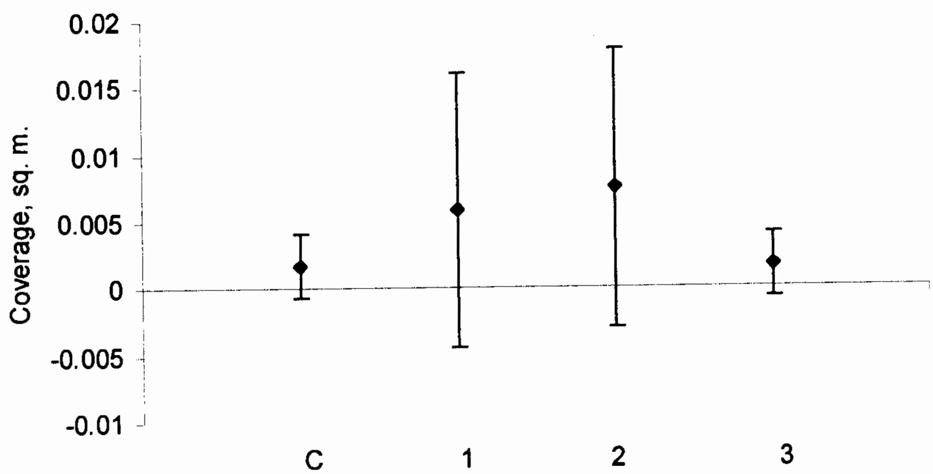


Figure 13. Mean Coverage of Whorled Milkweed (*Asclepias verticillata*) September 1997

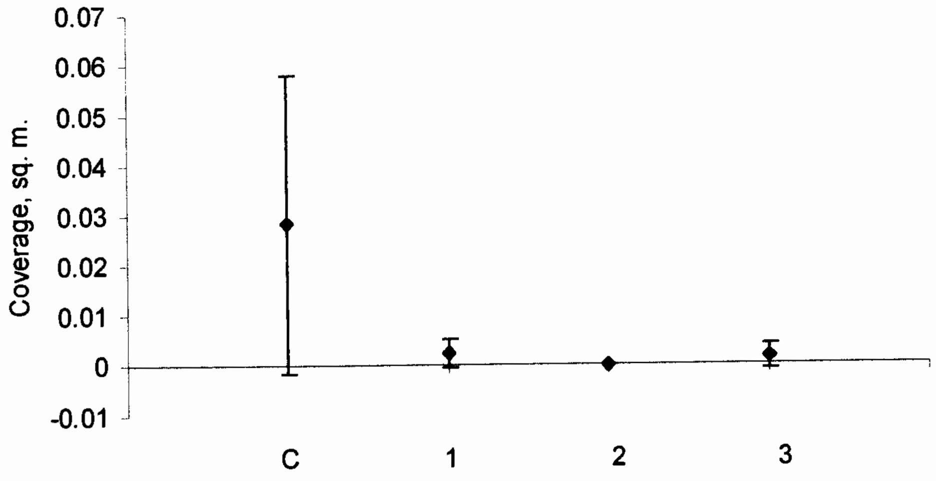


Figure 14. Mean Coverage of Sky Blue Aster (*Aster azureus*) September 1997

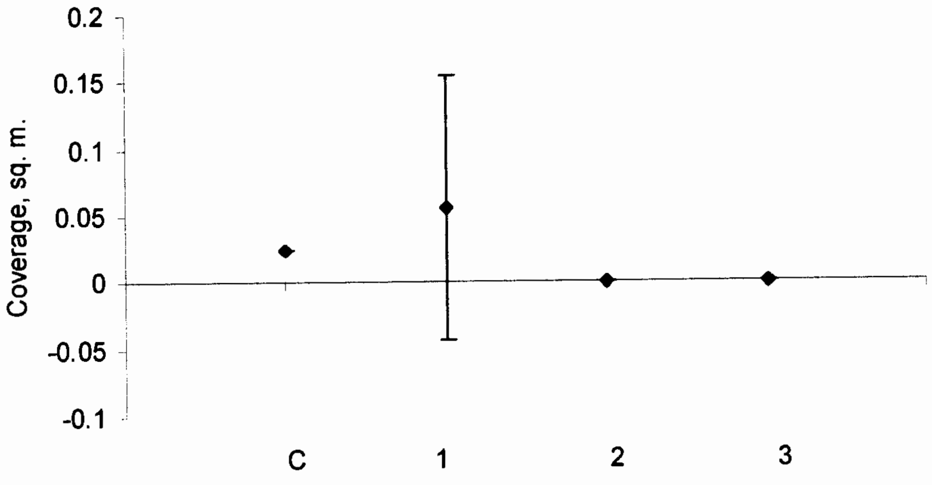


Figure 15. Mean Coverage of False Boneset (*Brickellia eupatorioides*) in September 1997

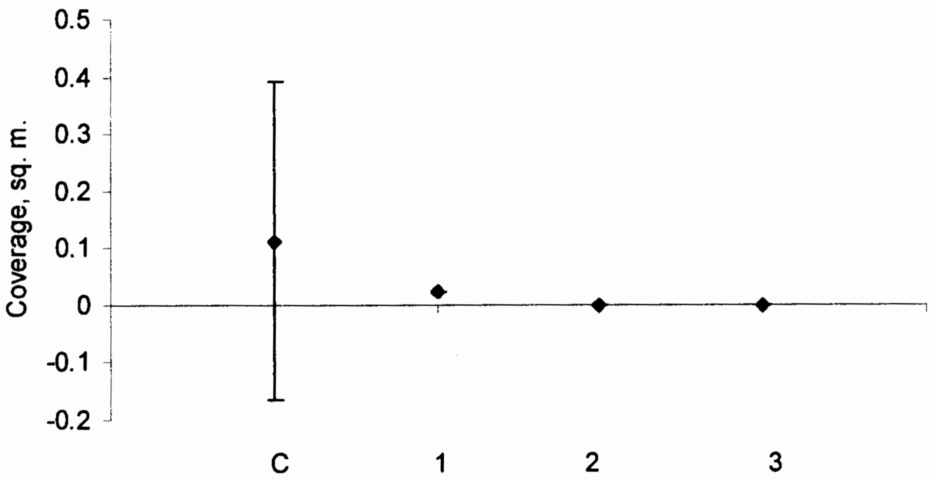


Figure 16. Mean Coverage of Lanceleaf Coreopsis (*Coreopsis lanceolata*) in September 1997

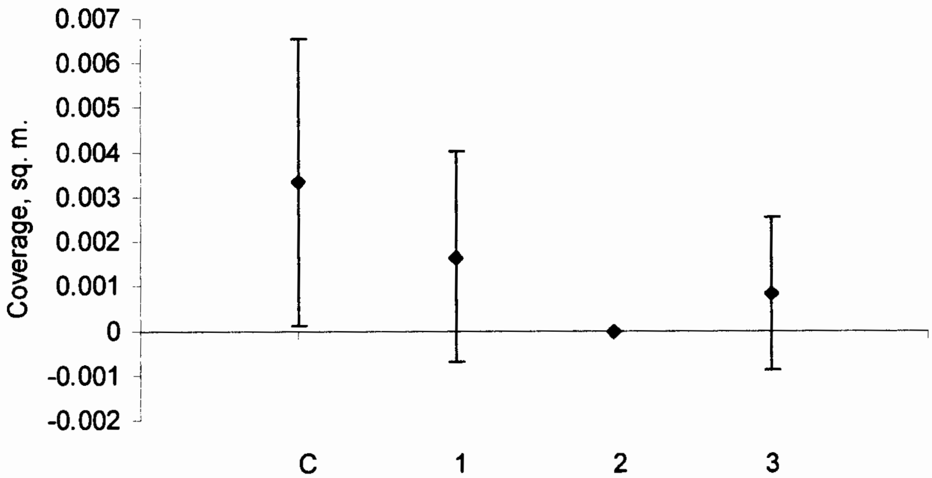


Figure 17. Mean Coverage of Purple Coneflower (*Echinacea purpurea*) in September 1997

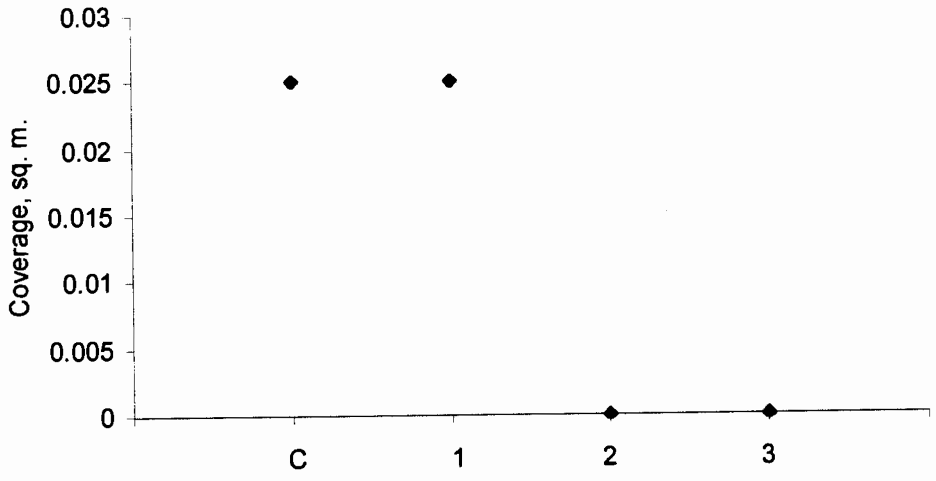


Figure 18. Mean Coverage of Western Sunflower (*Helianthus occidentalis*) in September 1997

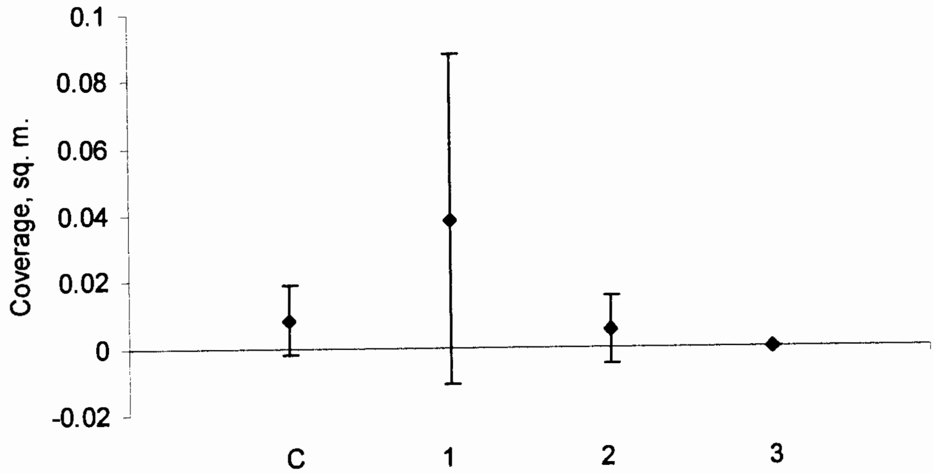


Figure 19. Mean Coverage of Drooping Yellow Coneflower (*Ratibida pinnata*) in September 1997

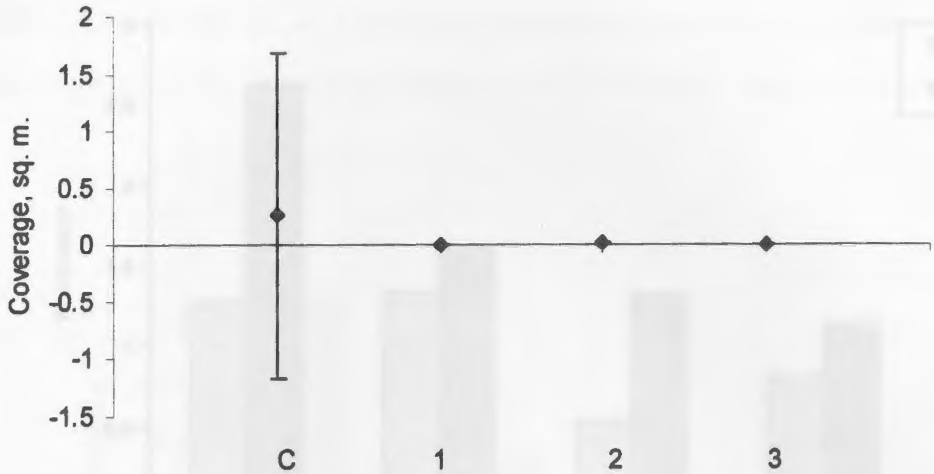


Figure 20. Mean Coverage of Black-eyed Susan (*Rudbeckia hirta*) in July 1997

<u>Frequency</u>

Frequency was calculated for all plots from data collected in the field. The frequency for native prairie species and weeds was plotted for September 1996 and 1997 (Figures 21 and 22).

Figure 21 shows a steady decline in frequency of prairie species from the control plot to Plot 3. Frequency of weeds are very similar in the control plot and Plot 1, declines markedly in Plot 2 and rises slightly in Plot 3. Overall native prairie has a higher frequency than weeds in any plot.

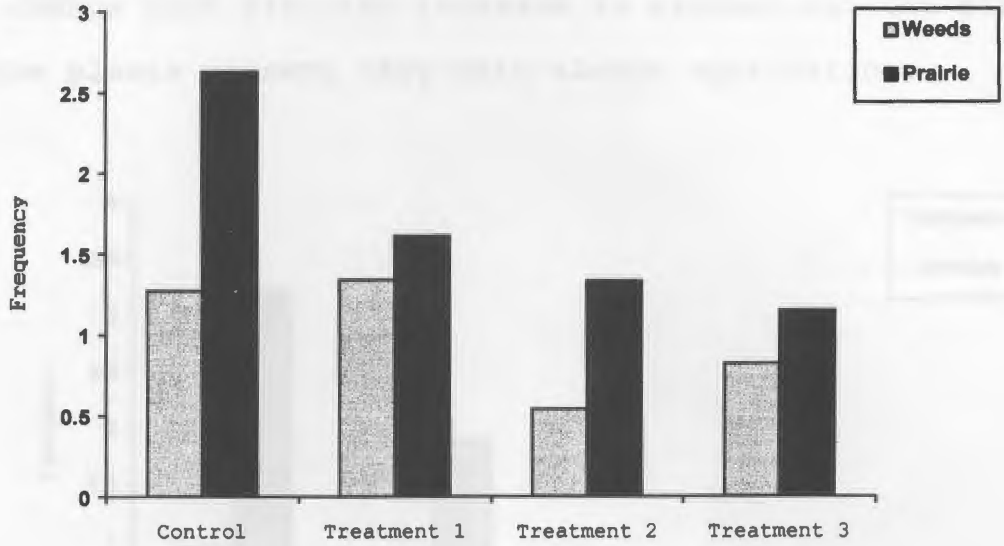


Figure 21. Frequency of Weeds and Prairie in September 1996

In September 1997, frequency of prairie species was also highest in the control plot(Figure 22). It decreased to Plot 2 then remained about the same through Plot 3. Frequency of weed species was nearly constant for the control plot and all treatment plots. This suggests that weeds may not be affected by the amount of sludge applied to them.

Coverage and frequency of prairie species this month (September 1997) are very similar in that both were less than the control plot. However, coverage for weeds varied between all plots, while the decrease in frequency was fairly constant. This implies that weed species numbers do not change much with the increase in sludge, but the sizes of the plants present vary with sludge applications.

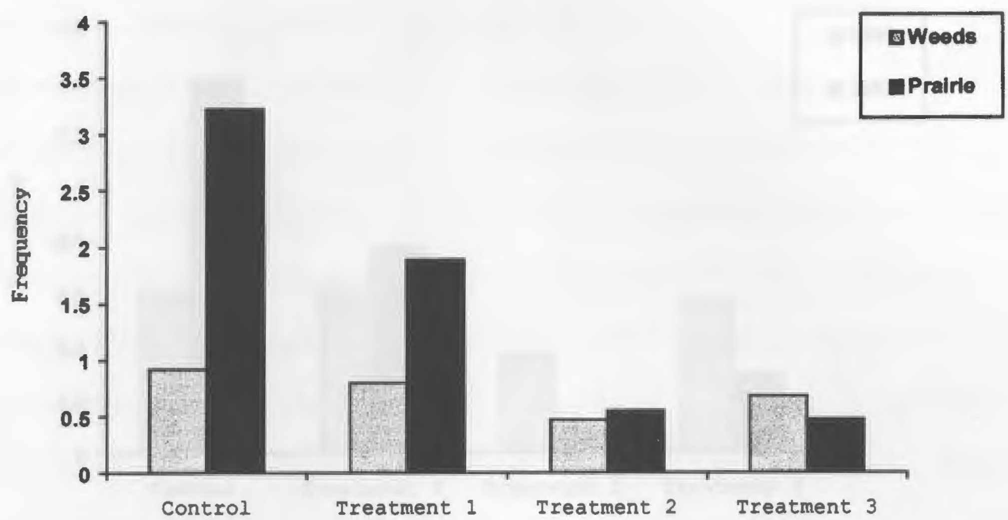


Figure 22. Frequency of Weeds and Prairie in September 1997

The graph below (Figure 23) shows the average frequency of native species for each plot for 1996 and 1997. To get average frequency, frequency of native prairie species was averaged over the four months that monitoring was conducted. Average frequency did not vary much in 1996. It was lowest in Plot 2 and similar in the control plot, Plots 1 and 3. In 1997, the control had the highest average frequency. Average frequency declined steadily until Plot 2. Plot 3 had a higher average frequency than Plot 2.

Overall Plot 2 had the lowest average frequency in both years. The results indicated by this graph are interesting to observe trends, but are speculative and should be viewed as such.

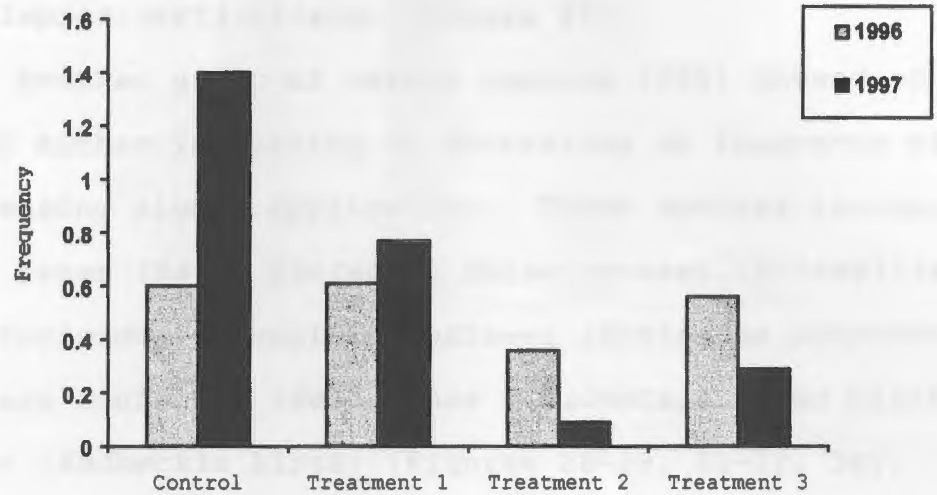


Figure 23. Average Frequency of Native Prairie Species in 1996 and 1997

Frequency of individual species was graphed to determine how different species respond to the treatments. Figures 24-34 show the frequencies of individual prairie species except those that were observed only in the control.

Frequency of approximately 29% of the native species decreased with an increase in sludge application. Species that showed this negative response include big bluestem (*Andropogon gerardii*), sideoats grama (*Bouteloua curtipendula*), little bluestem (*Schizachyrium scoparium*), lanceleaf coreopsis (*Coreopsis lanceolata*), drooping yellow coneflower (*Ratibida pinnata*) (Figures 24-26, 30, 33).

One native species showed an increase in frequency (6%) or maintained about the same frequency with an increase in sludge application. This species is whorled milkweed (*Asclepias verticillata*) (Figure 27).

Another group of native species (29%) showed no clear trend either increasing or decreasing in frequency with increasing sludge application. These species include sky blue aster (*Aster azureus*), false boneset (*Brickellia eupatorioides*), purple coneflower (*Echinacea purpurea*), Western sunflower (*Helianthus occidentalis*) and black-eyed Susan (*Rudbeckia hirta*) (Figures 28-29, 31-32, 34). Western sunflower and false boneset did not appear in Plots 2 and 3.

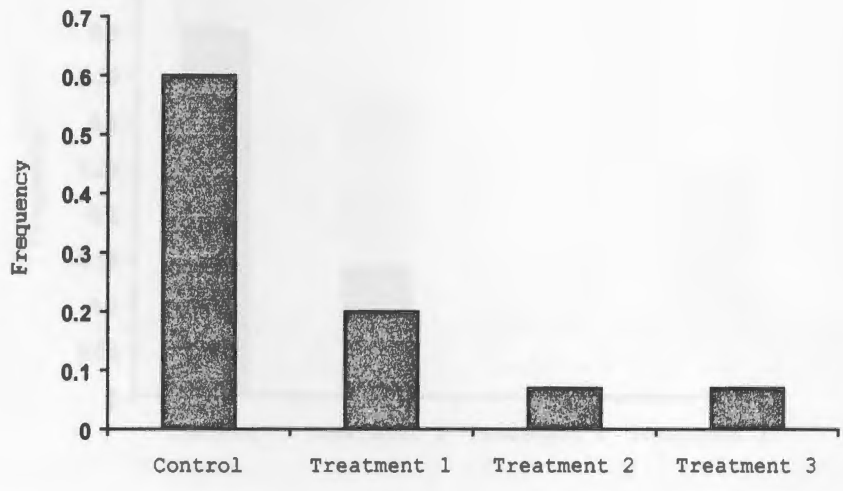


Figure 24. Frequency of Big Bluestem (*Andropogon gerardii*) in September 1997

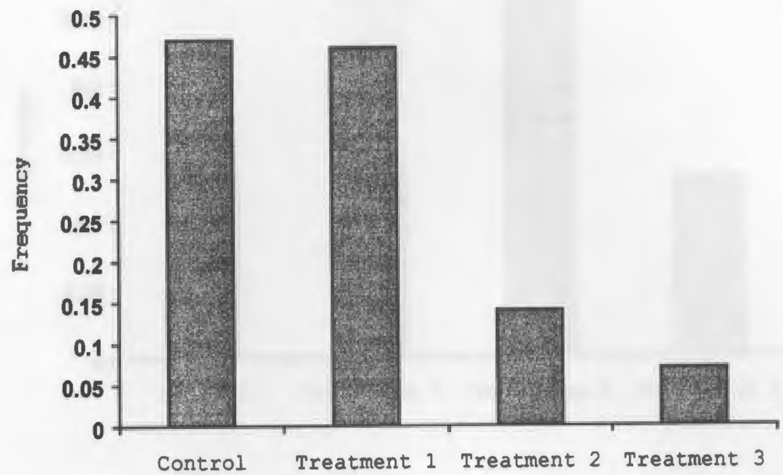


Figure 25. Frequency of Sideoats Grama (*Bouteloua curtipendula*) in September 1997

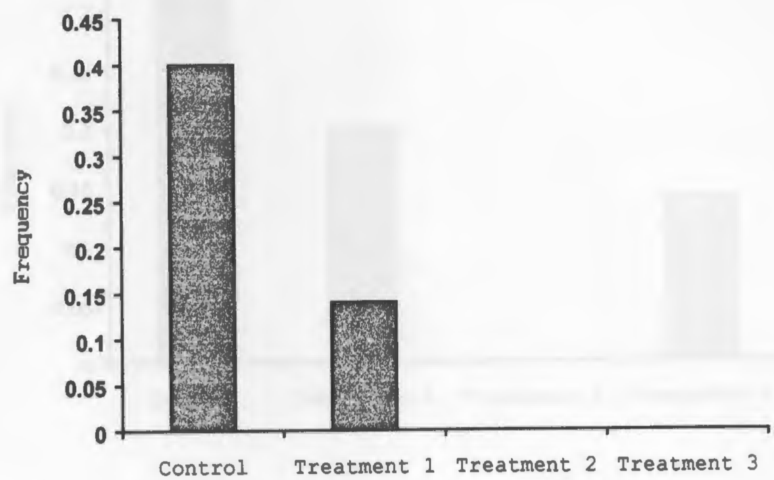


Figure 26. Frequency of Little Bluestem (*Schizachyrium scoparium*) in September 1997

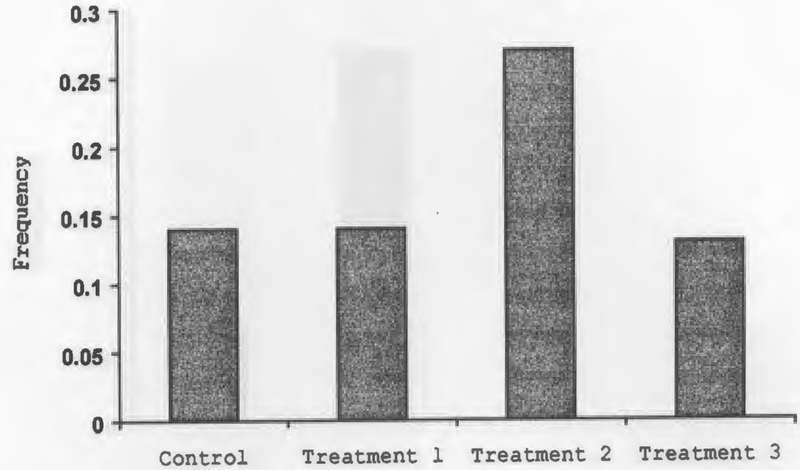


Figure 27. Frequency of Whorled Milkweed (*Asclepias verticillata*) in September 1997

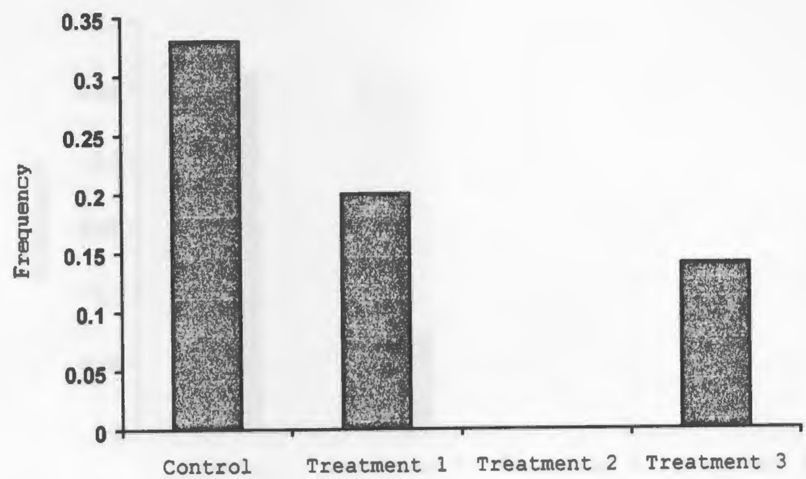


Figure 28. Frequency of Sky Blue Aster (*Aster azureus*) in September 1997

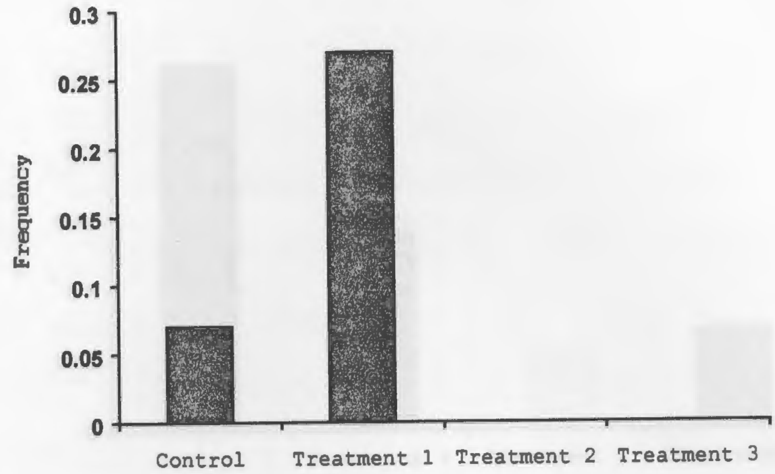


Figure 29. Frequency of False Boneset (*Brickellia eupatorioides*) in September 1997

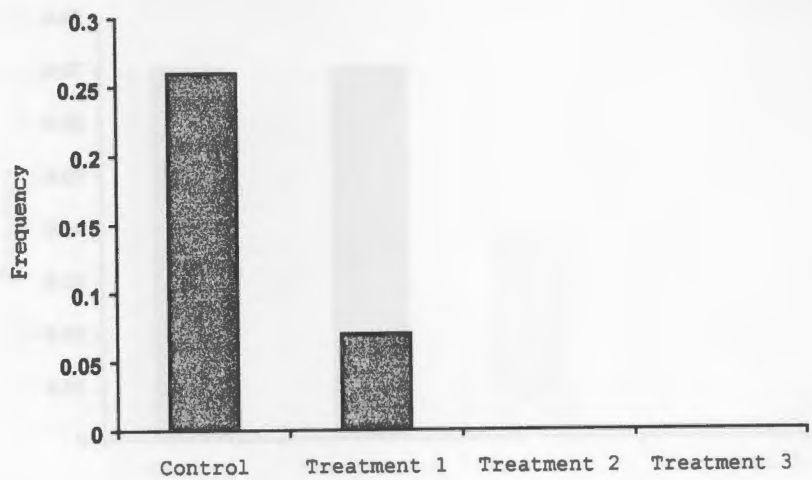


Figure 30. Frequency of Lanceleaf Coreopsis (*Coreopsis lanceolata*) in September 1997

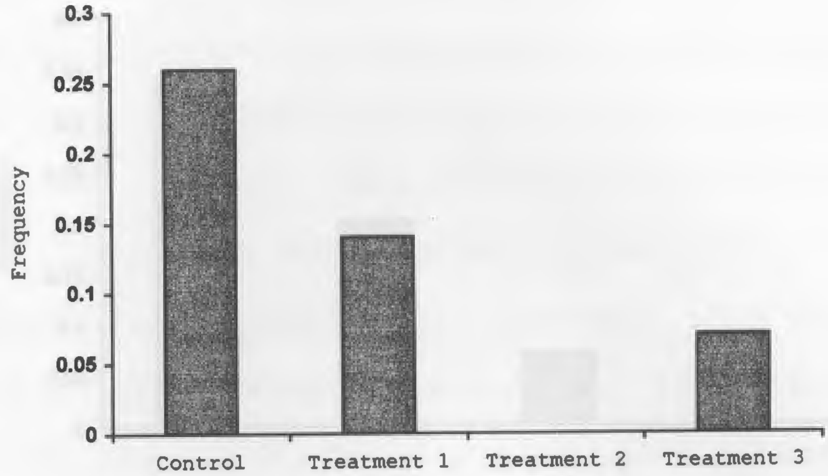


Figure 31. Frequency of Purple Coneflower (*Echinacea purpurea*) in September 1997

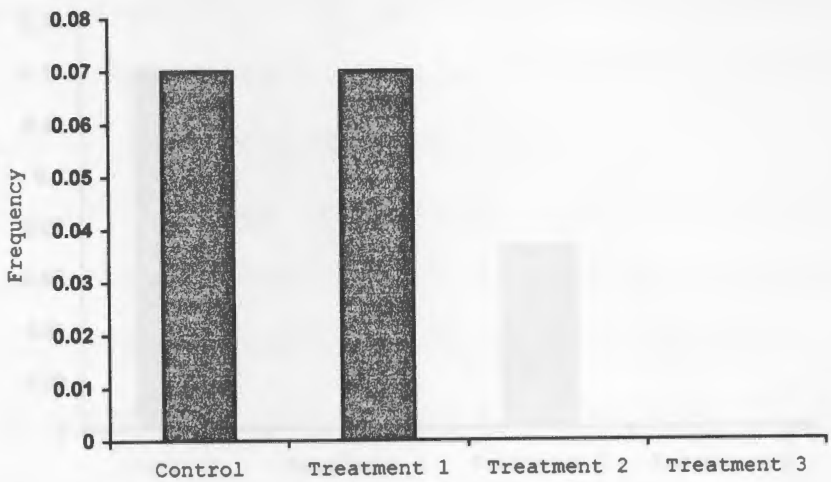


Figure 32. Frequency of Western Sunflower (*Helianthus occidentalis*) in September 1997

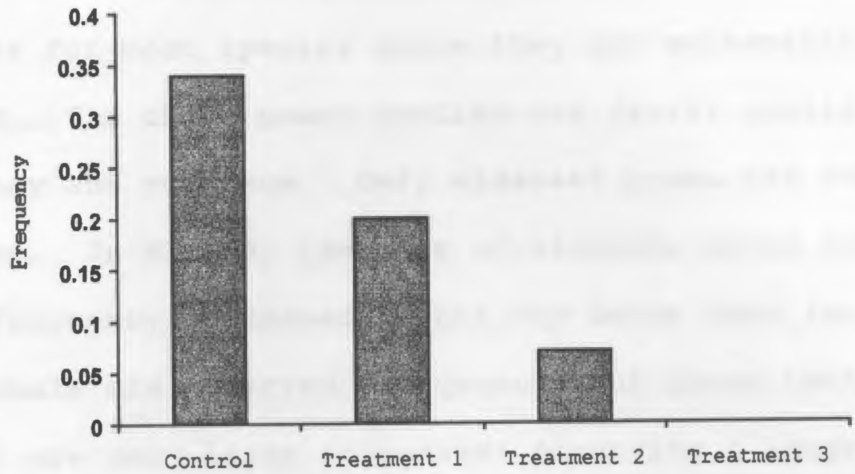


Figure 33. Frequency of Drooping Yellow Coneflower (*Ratibida pinnata*) in September 1997

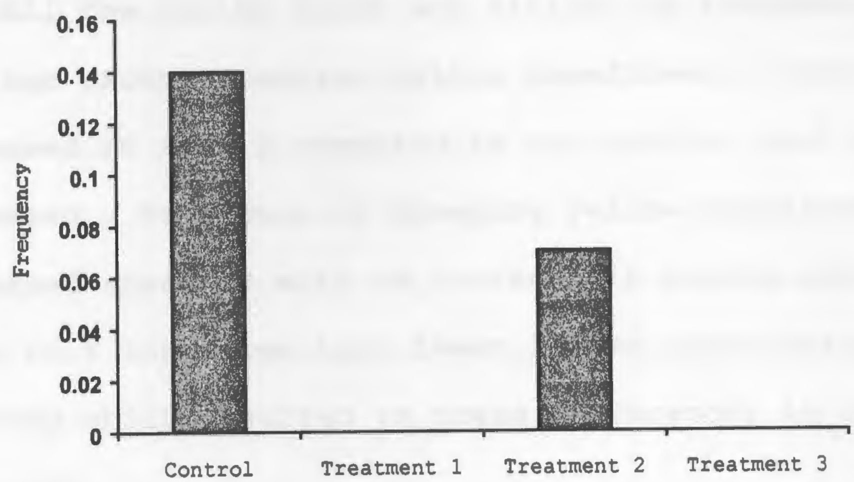


Figure 34. Frequency of Black-Eyed Susan (*Rudbeckia hirta*) in July 1997

The trends for frequency and coverage follow consistent patterns for most species since they are mathematically related. The three grass species are fairly similar between frequency and coverage. Only sideoats grama has some variance. In Plot 3, coverage of sideoats grama increased while frequency decreased. This can occur when few individuals are observed (frequency) but those that are present are very large (coverage) occupying a larger area than several smaller individuals. The inverse can also occur when many observations of very small individuals are made. This can cause a species to have a high frequency with low coverage.

All the native forbs are similar in frequency and coverage except drooping yellow coneflower. Coverage increased in Plot 1 compared to the control plot and then decreased. Frequency of drooping yellow coneflower decreased steadily with an increase in sludge application. Again this indicates that fewer larger individuals were observed which resulted in these differences in coverage and frequency.

Importance Value

The importance value of each native species was calculated from the September 1996 and 1997 data with a few exceptions. For species that were not observed in September, importance values are given for the last month for which there is an observation. Importance value gives an overall estimate of the status of a particular species in the community. Table 4 compares the importance values for each species in 1996 and 1997. Three species included in Table 4 were not observed in September. The last month for which there are data for these species is included instead. However, none of them were considered for determining the top three species of each year since importance value is relative to the time of data collection. For this reason, it would not make sense to include them.

In the control plot, the top three species by importance value in 1996 were big bluestem (*Andropogon gerardii*), little bluestem (*Schizachyrium scoparium*) and sideoats grama (*Bouteloua curtipendula*). The top three in 1997 were big bluestem (*Andropogon gerardii*), sideoats grama (*Bouteloua curtipendula*) and sky blue aster (*Aster azureus*).

In Plot 1, the top three species by importance value in 1996 were sideoats grama (*Bouteloua curtipendula*),

Table 4. Comparison of September 1996 and 1997 Importance Values of Prairie Species

Species	Control		Treatment 1		Treatment 2		Treatment 3	
	1996	1997	1996	1997	1996	1997	1996	1997
Andropogon gerardii	0.16	0.19	0.05	0.07	0.09	0.02	0.04	0.03
Bouteloua curtipendula	0.05	0.15	0.09	0.19	0.17	0.05	0.04	0.04
Panicum virgatum	0.01	0.02	0.0	0.0	0.0	0.0	0.0	0.0
Schizachyrium scoparium	0.09	0.11	0.0	0.04	0.0	0.0	0.0	0.0
Sorghastrum nutans	0.0	0.01	0.0	0.0	0.0	0.0	0.0	0.0
Asclepias verticillata	0.01	0.03	0.05	0.04	0.0	0.10	0.04	0.05
Aster azureus	0.01	0.12	0.03	0.05	0.0	0.0	0.0	0.05
Brickellia eupatorioides	0.04	0.01	0.06	0.08	0.0	0.0	0.04	0.0
Coreopsis lanceolata	0.01	0.08	0.06	0.02	0.02	0.0	0.0	0.0
Desmanthus illinoensis	0.0	0.01**	0.0	0.0**	0.02	0.0**	0.0	0.0**
Echinacea pallida	0.0	0.01	0.0	0.0	0.0	0.0	0.0	0.0
Echinacea purpurea	0.04	0.05	0.03	0.04	0.0	0.0	0.02	0.03
Helianthus occidentalis	0.01	0.01	0.02	0.02	0.0	0.0	0.02	0.0
Heliopsis helianthoides	0.04	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ratibida pinnata	0.0	0.08	0.0	0.12	0.0	0.03	0.0	0.0
Rudbeckia hirta	0.0	0.05*	0.0	0.0*	0.0	0.03*	0.02	0.0*
Silphium integrifolium	0.0	0.04	0.0	0.0	0.0	0.0	0.0	0.0
Solidago rigida	0.0	0.02*	0.03	0.0*	0.0	0.0*	0.0	0.0*

*July 1997 data

**August 1997 data

false boneset (*Brickellia eupatorioides*) and lanceleaf coreopsis (*Coreopsis lanceolata*). In 1997, the top three species were sideoats grama (*Bouteloua curtipendula*), drooping yellow coneflower (*Ratibida pinnata*) and false boneset (*Brickellia eupatorioides*).

In Plot 2, the species with the highest importance value in 1996 were sideoats grama (*Bouteloua curtipendula*), big bluestem (*Andropogon gerardii*), lanceleaf coreopsis (*Coreopsis lanceolata*) and Illinois bundleflower (*Desmanthus illinoensis*) (tied). In 1997 the top species were whorled milkweed (*Asclepias verticillata*), sideoats grama (*Bouteloua curtipendula*), and drooping yellow coneflower (*Ratibida pinnata*).

In Plot 3, the top species by importance value in 1996 were big bluestem (*Andropogon gerardii*), little bluestem (*Schizachyrium scoparium*), whorled milkweed (*Asclepias verticillata*) and false boneset (*Brickellia eupatorioides*) (four-way tie). In 1997, the top three species were whorled milkweed (*Asclepias verticillata*), sky blue aster (*Aster azureus*) and sideoats grama (*Bouteloua curtipendula*).

Generally, the grasses appear to have a strong presence in the community across treatments and years which may influence the community. A few forbs also have a strong presence in the community. The forbs that are especially noteworthy include false boneset (*Brickellia eupatorioides*), whorled milkweed (*Asclepias verticillata*), lanceleaf coreopsis (*Coreopsis lanceolata*), drooping yellow coneflower (*Ratibida pinnata*) and sky blue aster (*Aster azureus*).

Weed Coverage

Weeds can play a significant role in the establishment of prairie. It is a topic discussed in nearly every North American Prairie Conference since it began. Often asked is "how can we best rid a site of weeds before and/or after a seeding?" This project makes no attempt at addressing that issue. However, observations on the coverage of weeds were made as part of the monitoring of all species within a quadrat each month of monitoring.

Weeds are defined in this project as any plant other than timothy (*Phleum pratense*) or native prairie species. Weeds were present in all plots in all months and years. Table 5 below summarizes the number of weed species observed in each month of data collection for 1996 and 1997.

In June 1996 the greatest number of different weed species was observed. Ten weed species were present in each of the following: control, Plot 1 and Plot 2. Plot 3 had nine weed species. The number of weed species in each treatment declined thereafter. In the last sampling month the number of weed species in each treatment was 4 in the control plot and Plot 3 and 3 in Plots 1 and 2.

In 1997, overall, the number of different weed species was lower than in 1996. The highest number of weed species was six which is four fewer than in 1996.

Table 5. Number of Different Weed Species Observed Each Month

Year	Month	Control	Plot 1	Plot 2	Plot 3
1996	June	10	10	10	9
	July	4	3	2	2
	August	7	4	1	6
	September	6	6	4	6
1997	June	6	5	4	5
	July	5	1	2	6
	August	3	1	1	4
	September	4	3	3	4

Although the number of species is interesting, the coverage of these species is more important. Coverage gives an indication of the amount of competition for space the native prairie species had from weed species. Table 6 summarizes the coverage of weeds by plot and month. In 1996, June had the highest average coverage of weed species at 0.08 (m^2). It is not surprising that June 1996 had the highest weed coverage and a large number of different species. Weeds are often most abundant early in the establishment of a prairie. The remainder of months in 1996 had a lower coverage with no clear relation between rate of sludge application and plot. This is similar to the results of the graphical comparison. It did not show a very large increase in treatment means for weeds.

In 1997, September had the highest average coverage of weeds at 0.12 m^2. Weed coverage in the control plot was higher in September 1996 than September 1997. However, all the other plots in 1997 had weed coverages higher than the previous year. The increase in weed coverage for the plots in 1997 indicates that the sludge may be promoting their growth. Weeds may only be aided by very high nutrients in this experiment and lower rates of sludge application have no effect on them. Also the topsoil on the landfill cap was mostly inert because it had been stockpiled for many years and therefore devoid of an abundant weed seed bank.

Table 6. Coverage of Weeds By Month For 1996 And 1997

Month	Control	Plot 1	Plot 2	Plot 3	Average
1996					
June	0.08	0.06	0.10	0.07	0.08
July	0.02	0.002	0.001	0.001	0.006
August	0.03	0.006	0.001	0.005	0.01
September	0.11	0.08	0.02	0.03	0.06
Average	0.06	0.04	0.03	0.03	0.04
1997					
June	0.03	0.01	0.01	0.05	0.03
July	0.05	0.002	0.01	0.05	0.03
August	0.06	0.001	0.01	0.10	0.07
September	0.11	0.12	0.07	0.17	0.12
Average	0.06	0.03	0.03	0.09	

Sludge was applied to the three treatments during July 1996. Weed coverage decreased and remained low in August. Monitoring took place about 2 weeks after the application. This pattern was repeated in 1997. Sludge was applied over a few days in late May and early June. Monitoring occurred about 3 weeks after this application. Coverage was quite low for the months of June, July and August. This indicates that weeds may be affected directly by the sludge application. It is possible that the weight of the liquid sludge may be too much for the weeds. The sludge dried into a crusted layer on the plants, covering them and apparently reducing their exposure to sunlight. This response is similar to that of the native species. Figure 7 which shows the September 1997 data on prairie species, also demonstrates this trend. The mean coverage of native species decreases from the control to Plot 3.

The weed species present were those common to waste areas and agricultural fields. In June 1996, species with the highest coverage included, foxtail barley (*Hordeum jubatum*), sweet clover (*Melilotus officinalis*), common ragweed (*Ambrosia artemisiifolia*), and prickly lettuce (*Lactuca scariola*). In July 1996, those highest coverage species were dandelion (*Taraxacum officinale*), sweet clover, common ragweed, and prickly lettuce. In August 1996, the species with the highest coverage were sweet clover, common ragweed and dandelion. In September 1996, barnyard grass (*Echinochloa crusgalli*), giant foxtail (*Setaria faberi*), and common ragweed had the highest coverage.

In 1997 the species with high coverage differed somewhat from 1996. The common species observed in June 1997 included quackgrass (*Agropyron repens*), common ragweed (*Ambrosia artemisiifolia*), and prickly lettuce (*Lactuca scariola*). In July 1997 the weed species with the highest coverage were common ragweed, giant ragweed (*Ambrosia trifida*), and quackgrass. In August 1997, common ragweed and quackgrass had the highest coverage. In September 1997, giant foxtail (*Setaria faberi*), quackgrass and common ragweed had the highest coverages.

In general, weed species did not appear to overwhelm the plots to a point of becoming a serious competition problem for the prairie species. Evidence of this is the low coverage of weed species and the results of the graphical comparison (September 1997 data).

Timothy was so thick in areas of some plots that it alone probably had more effect on the prairie species than the weeds. Christiansen (1967) reported that competition from weeds is less severe than competition from a cover crop. In his study, one year after seeding in a heavy cover crop, 37.5% of the species were present compared to 62% present in the weedy treatment. Both weeds and prairie species had to compete with timothy in this study. Sludge did not appear to promote weed growth as anticipated but did promote timothy. Timothy may have been more tolerant of sludge or it may be because it was already established that it benefited from the sludge. Immediately after an application, weeds were found in fewer numbers and lower coverage in the three plots with sludge treatments than they were prior to the application. The control plot had similar coverage of weed species as any treatment in 1996 and 1997 except Plot 3 (September 1997). In some months, weed species coverage was actually higher in the control than some of the plot treated with sludge.

Summary of Results

Prairie

Of the four native grasses and 49 native forbs planted at the landfill study site, four grasses plus switch grass and 19 forbs were observed (17 forbs were observed in 1997). The number of forbs is low, less than half the number planted. Including all native species observed in 1997, approximately 39% were found in quadrats. Often, only about 40% of the species in the seed mix appear in the first few years following planting (personal communication Gerald Wilhelm 1998). I plan to informally monitor the study site at least one time per growing season over the next three or more years to observe what species are present. Hopefully, more species will appear in future years. If no other species have entered the site by this time it becomes less likely they will do so.

Frequencies of prairie species were measured as part of this research. The average frequency of all prairie species was reported for 1996 and 1997. The frequencies for groups of species were also plotted by treatment for September 1996 and 1997 (Figures 21-22). Overall, average frequencies of prairie species in 1996 and 1997 were highest in the control plot, decreased in Plot 1 and further decreased in Plot 2.

Plot 3 frequency was slightly lower than Plot 2 in 1996 and 1997. The decrease in frequency with increasing sludge indicates that sludge may inhibit growth of some prairie species at higher application rates.

Frequencies of individual prairie species indicate that big bluestem (*Andropogon gerardii*), sideoats grama (*Bouteloua curtipendula*), yellow coneflower (*Ratibida pinnata*), purple coneflower (*Echinacea purpurea*), black-eyed Susan (*Rudbeckia hirta*), false boneset (*Brickellia eupatorioides*), whorled milkweed (*Asclepias verticillata*) and Illinois bundleflower (*Desmanthus illinoensis*) were among the most adaptive or tolerant of those seeded. These species were observed more frequently than others. This suggests that they would do the best to get established in a reconstruction project.

Overall, mean coverage of prairie species in September 1996 and 1997, although more variable than frequency, also showed a general decline in the treated plots versus the control plot. However, the coverage means had overlapping confidence intervals indicating there is no difference between the treatments. It showed no meaningful difference in treatment plot means for any treatment in September 1997. This is evidence that sludge has no effect on prairie reconstruction. When coverage from September 1997 of individual species of prairie are looked at there is an almost even split in their responses. Six species were observed only in the control plot, four species had a decline in coverage with an increase in sludge application and two had an increase or no change in coverage. Another group of species showed no clear trend either decreasing or increasing in coverage. There were five in this group. Each group is a combination of grasses and forbs. The forbs do not fall into taxanomical family groups.

Importance value of each species observed was calculated as part of the data analysis. A few native prairie species had high importance values across both years, 1996 and 1997, and across treatment plots. The species with high importance values include sideoats grama (*Bouteloua curtipendula*), big bluestem (*Andropogon gerardii*), whorled milkweed (*Asclepias verticillata*), lanceleaf coreopsis (*Coreopsis lanceolata*), drooping yellow coneflower (*Ratibida pinnata*) and sky blue aster (*Aster azureus*). Other species that also had high importance values, but appeared at the top of the list for native species only once or twice, include little bluestem (*Schizachyrium scoparium*), false boneset (*Brickellia eupatorioides*), black-eyed Susan (*Rudbeckia hirta*) and Illinois bundleflower (*Desmanthus illinoensis*). Many of these species are the same ones that had the highest frequencies and coverages of the prairie species observed.

Schramm (1990) categorized the succession process of prairie species into stages. Many of the species mentioned above with high importance values and frequencies are included on Schramm's list. Some of the species that are on his developmental stage list appeared in this study but did not have high coverage, frequency or importance value. Betz (1984) also listed native species at Fermilab in Illinois. Many species are common to both authors. Species common to this study, Betz (1984) and Schramm (1990) include big bluestem (*Andropogon gerardii*), little bluestem (*Schizachyrium scoparium*), Indian grass (*Sorghastrum nutans*), switch grass (*Panicum virgatum*), sky blue aster (*Aster azureus*), pale purple coneflower (*Echinacea pallida*), purple coneflower (*Echinacea purpurea*), ox-eye sunflower (*Heliopsis helianthoides*), drooping yellow coneflower (*Ratibida pinnata*), black-eyed Susan (*Rudbeckia hirta*), prairie dock (*Silphium terebinthinaceum*) and rigid goldenrod (*Solidago rigida*). According to Schramm (1990), all the species listed above should persist into Stage IV (13 to 20+ years) except black-eyed Susan (*Rudbeckia hirta*), drooping yellow coneflower (*Ratibida pinnata*) and ox-eye sunflower (*Heliopsis helianthoides*). Two species were not on the Betz (1984) list including sky blue aster (*Aster azureus*) and purple coneflower (*Echinacea purpurea*).

<u>Weeds</u>

Weeds were present throughout the project. Species observed were typical of yards and agricultural fields. Some of the species include giant foxtail (*Setaria faberi*), foxtail barley (*Hordeum jubatum*), barnyard grass (*Echinochloa crusgalli*), quackgrass (*Agropyron repens*), common ragweed (*Ambrosia artemisiifolia*), giant ragweed (*Ambrosia trifida*), prickly lettuce (*Lactuca scariola*) and dandelion (*Taraxacum officinale*).

No more than 10 different species of weeds were observed in quadrats in any month during monitoring. The highest number of different species was observed in June 1996, the first time monitoring occurred. This was also early in the project when weeds are most abundant. Weed numbers generally decreased during a growing season but increased in coverage in September 1996 and 1997. Monitoring was continued after both sludge applications. Weed coverage declined in July and August but increased in September. This may be a result of the sludge application or it may be typical of weed species to be less abundant in the mid-summer since it is usually dry and was during this study.

Differences in weed coverage between plots were interesting to observe. In September 1996 weed coverage generally decreased in each treatment. Weed coverage was lower than prairie coverage in Plot 3. In September 1997, weed coverage was highly variable and there is no clear trend. Based on this, it is not absolutely clear that sludge promotes weed growth.

Timothy (*Phleum pratense*)

Frequency and coverage of timothy was very high, especially in Plots 2 and 3. The fertilization from sludge seems to be beneficial to timothy. In some areas it was nearly a monoculture of this species. If native species eventually encroach on these areas, it will take many years. The results of the graphical comparison indicate that there was a difference between the control plot and each treatment plot. Timothy alone probably had as much effect on the prairie and the weeds by way of competition as sludge. Without sludge, timothy would not have grown as abundantly in two years and the prairie and weeds would have had different coverage and frequency results.

CHAPTER 5

RECOMMENDATIONS FOR FUTURE PROJECTS

Plant Species and Sludge

Native Species

Based on the results of this project, there are some suggestions for future projects I would make. The first is that the species listed below in Table 7 are likely to give the best results in a prairie reconstruction project.

Table 7. Recommended Species for Future Reconstruction Projects

Big bluestem	(*Andropogon gerardii*)
Little bluestem	(*Schizachyrium scoparium*)
Sideoats grama	(*Bouteloua curtipendula*)
Indian grass	(*Sorghastrum nutans*)
Whorled milkweed	(*Asclepias verticillata*)
Sky blue aster	(*Aster azureus*)
False boneset	(*Brickellia eupatorioides*)
Lanceleaf coreopsis	(*Coreopsis lanceolata*)
Illinois bundleflower	(*Desmanthus illinoensis*)
Purple coneflower	(*Echinacea purpurea*)
Western sunflower	(*Helianthus occidentalis*)
Yellow coneflower	(*Ratibida pinnata*)
Black-eyed Susan	(*Rudbeckia hirta*)

Schramm (1976) and Peven (1985) both reported that rigid goldenrod (*Solidago rigida*) is easy to establish and could be expected to do well in a reconstruction project. Other species were observed but less frequently than the list of species above (see discussion in Chapter 4). These species are partridge pea (*Chamaecrista fasciculata*), pale purple coneflower (*Echinacea pallida*), ox-eye sunflower (*Heliopsis helianthoides*), and prairie dock (*Silphium terebinthinaceum*). These should also be included in a reconstruction project. With the results of this study and supported by the Schramm (1976), Betz (1984) and Peven (1985) studies, these species should do well in a seed mix for future projects.

Other species that were observed during monthly monitoring, but were not present in a quadrat, include compass plant (*Silphium laciniatum*), prairie blazingstar (*Liatris pycnostachya*), hoary vervain (*Verbena stricta*) and leadplant (*Amorpha canescens*). In another project they may do better than in this study. It remains to be seen whether they will increase in frequency and coverage over time at the Black Hawk County Landfill, too.

<u>Sludge Recommendations</u>

Sludge was applied in three different amounts once a year for two years. As summarized above, native prairie species frequency and coverage showed no effect with the application of sludge. It appears that sludge is not necessary to native prairie species establishment. At the two highest quantities, sludge appears to promote timothy and weeds somewhat but not native prairie. If the project involved promoting grasses such as timothy, then sludge would be an excellent choice to aid in their establishment. It not only provides nutrients, but also supplies much needed moisture.

Applying sludge in the fall may be better than in the spring or summer. Once fall has begun, the growing season is over so the physical properties of sludge would not have an effect on any of the plants.

Finally, planting prairie on a landfill is a cost saving measure. It requires little maintenance and has long-term survival. Using sludge on native prairie had a negative impact on coverage and frequency in this study. However, without further testing it is difficult to determine if this same result would occur elsewhere. Given the limited amount of prairie remaining in Iowa today, it is best not to compromise the integrity of existing prairie by subjecting it to another stress such as sludge application. At the Black Hawk County Landfill, the areas with thick growths of timothy may hopefully be invaded by prairie over time. One day there may be other uses for sludge but not likely application to prairies.

Research Design Refinements

After going through the process of a field experiment and the write up of results, there are some improvements that I would make on the research design if I were to start again. These are discussed in the following paragraphs.

Initially, the plot layout could be designed differently to enable statistical analysis. The layout was four 1/8 acre plots side by side. This was relatively easy for the sludge truck to access for applying different amounts to each area. A randomized design with eight smaller plots containing two replicates of each treatment and the control would be better from a statistical standpoint. This layout would help to remove the effects of the soil on the plant species. This layout would require more space to allow the truck hauling sludge to maneuver in and around them. It would also become much more difficult to divide one and one-half loads between two plots that are several hundred feet away from each other, for example. An inaccurate application method would become even less accurate to a point of possibly being impossible to undertake.

The soils were sampled as part of this experiment. A composite soil sample was taken from each plot. A better method would have been to take several samples from each plot instead. Had the plots been in a randomized layout, then the soil samples would also be from varied locations. It may have been easier to determine whether the results shown were due to the sludge or were part of the original soil constituents.

Permanent stakes were placed in each plot to mark the location of transect lines. A total of four stakes were in each plot. Maintaining the location of these stakes was difficult. Occasionally trucks or other heavy equipment would drive over the stakes, bending them down in place or popping them up out of the ground. They were replaced as close to their original location as possible. Over the course of the fall, winter and early spring the top layer of the landfill cap would shift slightly. This slight shift was enough to cause the stakes to sometimes come loose and fall down.

To prevent the possibility of replacing the stakes in the wrong location it would be a good idea to use GPS with accuracy of 0.5 meters or better. Global positioning system would allow the researcher to know exactly where the stakes were originally placed. When they become dislocated through various means, they could be replaced more easily and accurately. Another method to maintain permanent stakes is to drive metal stakes into the ground flush with the surface. By using a metal detector, the stakes can be relocated.

Future Research Recommendations

Future studies could include a continuation of this research to track the long-term effects of applying sludge early in a prairie establishment. The accumulation of more data could help support existing results or contradict them. In any case, more knowledge than the two short years of data collected for this research would be of value.

Other studies that look into landfill-tolerant species would be beneficial. Evaluation of root development in a landfill setting where the soils are shallow would be useful. Other conditions such as extreme dryness, alternating with wet conditions is another area to consider when selecting species for a landfill.

There would be opportunity for a researcher to use the data I have collected to run make more comparisons. There are numerous subsets of prairie and weeds that could be investigated. The three prairie groups that responded differently to the treatments could be interesting subsets to analyze. I selected September 1997 data for this report to analyze for reasons stated earlier however, I have data for each month for two years. Therefore, any number of graphical comparisons could be made. Looking at the trends in coverage closely over several months of data would be one comparison. Another comparison that could be made would be to compare June 1996 to June 1997 and so on for each month through September of each year.

Finally, research that focuses on the soils would be a benefit as well. Determining how soils develop in a landfill setting with deep rooted vegetation and alternating wet and dry conditions could help address basic questions on soil development. Also testing could focus on the sludge amendments to determine what effect it had on the soil such as an increase in heavy metals or nutrients.

CHAPTER 6

SUMMARY AND CONCLUSIONS

Summary of Results

In general the results are what was expected. The coverage of native plants did not vary greatly among plots. Weed species also were not affected with an increase in sludge application except at very high amounts. Weed coverage marginally increased with an increase in sludge application but showed no clear trends.

Timothy (*Phleum pratense*) dominated in all the plots and was particularly abundant in Plots 1-3. It averaged coverage of over 60% of the area in Plot 3. This was shown using graphical comparison. Prairie and weeds both had to compete for space with timothy.

Sludge application did not clearly promote weed growth. In fact, the number of different weeds and the coverage of weed species decreased in each month after an application with the exception of September 1997. This decrease may be a result of the sludge blocking out the sunlight to allow growth and competition for space with timothy.

Timothy became more abundant with an increase of sludge, especially at the highest application rate. There is one clear conclusion to draw from this research: sludge is beneficial to timothy. It may have little or no effect on prairie species and may not promote weed growth.

Based on the data on the nutrients in the soil, it is possible the soil was too nutrient-rich for some species of prairie. Since nutrients in the control were high as well, it is difficult to determine whether it was the high nutrients or the physical application, weight and light filtering aspects of the sludge that caused a decrease in coverage of some native prairie species. The decrease could also be due to the competition for space with timothy. It is also possible that the differences are due to random variation among plots since there is no treatment replication.

This study was limited in terms of its length of monitoring time (2 years) and size (0.5 acre (0.2 ha)). In order to make more definitive statements more years of data collection at the Black Hawk County Landfill are required. The effects of sludge application on prairie establishment should be addressed at other sites as well. It is recommended that the sludge be applied in the fall using replicated plots.

Conclusions

The primary question was to address the effects of sludge application on prairie establishment. Secondary questions were how sludge affects timothy (*Phleum pratense*) and weed species.

Sludge did not seem to affect prairie species coverage. The graphs showed trends of some species to decrease and some an increase and others had little change in coverage with an increase in sludge application. Several species appeared only in the control plot suggesting an intolerance to sludge. Frequency of several native species showed a decrease as well.

Timothy (*Phleum pratense*) showed an increase in coverage with an increase in sludge application. Given the relatively small and in some cases non-overlapping 95% confidence intervals, and the consistent, upward trend in timothy coverage with increasing sludge application, there is strong evidence that it responds positively to sludge. This should be confirmed in a replicated experiment.

Weed species did not show a clear increase in coverage with an increase in sludge application from the results of the graphical comparison.

Although the results of this study were interesting, it is important that these results not be extrapolated to other sites. The apparent treatment effects may be due to differences in soils, between plots or random variation. The use of non-replicated plots is an experimental design flaw that does not allow us to make statements beyond the scope of this study or about treatment effects in this

study.

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APPENDIX A

CITY OF CEDAR FALLS SLUDGE ANALYSIS

1996 AND 1997

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NET® NATIONAL ENVIRONMENTAL TESTING, INC.

Cedar Falls Division
704 Enterprise Drive
Cedar Falls, IA 50613
Tel: (319) 277-2401
Fax: (319) 277-2425

ANALYTICAL REPORT

Lyle Krueger
CEDAR FALLS
WATER RECLAMATION FACILITY
501 E. 4th
Cedar Falls, IA 50613

04/08/1997

Sample No.: 389905
Job Number: 97.03532

Sample ID: Digester #1 3-31

Date Taken: 03/31/1997

Date Received: 03/31/1997

Analyte	Results	Units	Analysis Method	Regulatory Limits
pH	7.3	units	E-150.1	
Ammonia Nitrogen (dist)	15,700	mg/kg dw	SM 4500-NH3 B	NR
Kjeldahl Nitrogen	51,000	mg/kg dw	SM 4500-N B,E	NR
Nitrate Nitrogen	<42	mg/kg dw	SM 4500-NO3 D	NR
Phosphorus, Total (as P)	20,400	mg/kg dw	E-365.2	NR
Solids, Total	4.71	%	SM 2540 G	NR
Solids, Total Volatile	3.10	%	SM 2540 G	NR
Arsenic, GFAA	4.33	mg/kg dw	S-7060A	75
Mercury, CVAA	11	mg/kg dw	E-245.5	57
Selenium, GFAA	6.28	mg/kg dw	S-7740	100
ICP Metals Prep (Solid)	Complete	g		
ICP Metals-Solid	Complete	mg/kg	S-6010A	
Cadmium, ICP	4.4	mg/kg dw	S-6010A	85
Chromium, ICP	55	mg/kg dw	S-6010A	3000
Copper, ICP	1,100	mg/kg dw	S-6010A	4300
Iron, ICP	19,300	mg/kg dw	S-6010A	
Lead, ICP	98	mg/kg dw	S-6010A	840
Molybdenum, ICP	51	mg/kg dw	S-6010A	75
Nickel, ICP	44	mg/kg dw	S-6010A	420
Potassium, ICP	1,300	mg/kg dw	S-6010A	NR
Zinc, ICP	1,500	mg/kg dw	S-6010A	7500

NOTE: The final column contains the regulatory limits for Class II sludge.
dw = dry weight NR = Not Regulated
To convert mg/kg to % divide mg/kg result by 10,000.

Kristin Voigts for
Cheryl L. Wilson
Operations Manager
Iowa Lab Certification - 007

Diges. #1 empty
during all of June 1997

07/10/97 09:24 FAX 3192685566 003

NET® NATIONAL ENVIRONMENTAL TESTING, INC.

Cedar Falls Division
704 Enterprise Drive
Cedar Falls, IA 50613
Tel: (319) 277-2401
Fax: (319) 277-2425

ANALYTICAL REPORT

Lyle Krueger
CEDAR FALLS
WATER RECLAMATION FACILITY
501 E. 4th
Cedar Falls, IA 50613

06/26/1997

Sample No.: 404006
Job Number: 97.07651

Sample ID: Digester #2 6-13

Date Taken: 06/13/1997

Date Received: 06/16/1997

Analyte	Results	Units	Analysis Method	Regulatory Limits
pH	7.2	units	E-150.1	
Ammonia Nitrogen (dist)	14,100	mg/kg dw	SM 4500-NH3 B	NR
Kjeldahl Nitrogen	54,400	mg/kg dw	SM 4500-N B,E	NR
Nitrate Nitrogen	<50	mg/kg dw	SM 4500-NO3 D	NR
Phosphorus, Total (as P)	18,600	mg/kg dw	E-365.2	NR
Solids, Total	4.04	%	SM 2540 G	NR
Solids, Total Volatile	59.07	%	SM 2540 G	NR
Arsenic, GFAA	4.26	mg/kg dw	S-7060A	75
Mercury,CVAA	14	mg/kg dw	E-245.5	57
Selenium, GFAA	57	mg/kg dw	S-7740	100
ICP Metals Prep (Solid)	Complete	g		
ICP Metals-Solid	Complete		S-6010A	
Cadmium, ICP	6.36	mg/kg dw	S-6010A	85
Chromium, ICP	69	mg/kg dw	S-6010A	3000
Copper, ICP	1,200	mg/kg dw	S-6010A	4300
Iron, ICP	21,800	mg/kg dw	S-6010A	
Lead, ICP	92	mg/kg dw	S-6010A	840
Molybdenum, ICP	64	mg/kg dw	S-6010A	75
Nickel, ICP	47	mg/kg dw	S-6010A	420
Potassium, ICP	2,400	mg/kg dw	S-6010A	NR
Zinc, ICP	1,600	mg/kg dw	S-6010A	7500

NOTE: The final column contains the regulatory limits for Class II sludge.
dw = dry weight NR = Not Regulated
To convert mg/kg to % divide mg/kg result by 10,000.

Kristin Voigts for

Cheryl L. Wilson
Operations Manager
Iowa Lab Certification - 007

08/27/96 08:08 FAX 001

NET® NATIONAL ENVIRONMENTAL TESTING, INC.

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ANALYTICAL REPORT

Lyle Krueger
CEDAR FALLS
WATER RECLAMATION FACILITY
501 E. 4th
Cedar Falls, IA 50613

07/12/1996

Sample No.: 354669
Job Number: 96.08026

Sample ID: Digester #1 6-24

Date Taken: 06/24/1996 Date Received: 06/25/1996

Analyte	Results	Units	Analysis Method	Regulatory Limits
pH	7.6	units	E-150.1	
Ammonia Nitrogen (dist)	19,200	mg/kg dw	SM 4500-NH3 B	NR
Kjeldahl Nitrogen	50,300	mg/kg dw	SM 4500-N B	NR
Nitrate Nitrogen	<110	mg/kg dw	SM 4500-NO3 D	NR
Phosphorus, Total	420	mg/kg dw	E-365.2	NR
Solids, Total	4.57	%	SM 2540 G	NR
Solids, Total Volatile	53.88	%	SM 2540 G	NR
Arsenic, GFAA	3.48	mg/kg dw	S-7060A	75
Mercury, CVAA	15.7	mg/kg dw	S-7471A	57
Selenium, GFAA	2.41	mg/kg dw	S-7740	100
ICP Metals Prep (Solid)	Complete	g		
ICP Metals-Solid	Complete	mg/kg	S-6010A	
Cadmium, ICP	4.8	mg/kg dw	S-6010A	85
Chromium, ICP	48	mg/kg dw	S-6010A	3000
Copper, ICP	920	mg/kg dw	S-6010A	4300
Iron, ICP	14,200	mg/kg dw	S-6010A	
Lead, ICP	81	mg/kg dw	S-6010A	840
Molybdenum, ICP	35	mg/kg dw	S-6010A	75
Nickel, ICP	42	mg/kg dw	S-6010A	420
Potassium, ICP	1,300	mg/kg dw	S-6010A	NR
Zinc, ICP	1,200	mg/kg dw	S-6010A	7500

NOTE: The final column contains the regulatory limits for Class II sludge.
dw = dry weight NR = Not Regulated
To convert mg/kg to % divide mg/kg result by 10,000.

Cheryl L. Wilson
Operations Manager

APPENDIX B

PRECIPITATION DATA

Table 8. Precipitation Data for Waterloo, Iowa

For May Through September, 1995-1997

Year	Month	Total Monthly Precip (in)	30-year Normal (in)	Departure From Normal (in)
1995	May	3.15	4.08	-0.93
	June	4.99	4.47	0.52
	July	1.83	4.83	-3.00
	August	4.97	3.64	1.33
	September	2.44	3.51	-1.07
1996	May	2.26	4.08	-1.82
	June	4.42	4.47	-0.05
	July	2.38	4.83	-2.45
	August	1.77	3.64	-1.87
	September	3.50	3.51	-0.01
1997	May	2.68	4.08	-1.40
	June	5.92	4.45	1.47
	July	1.99	4.83	-2.84
	August	4.63	3.64	1.02
	September	3.15	3.51	-0.36

Note: in = inches

Source: NOAA-NCDC. May to September, 1995-1997.

APPENDIX C

SOIL ANALYSIS RESULTS

Table 9. Soil Analysis Results

	pH	%OM	P	K	N	NO_3
Control	7.5	7.2	29	237	0.33	3.20
Treatment 1	7.8	5.8	63	204	0.59	9.45
Treatment 2	7.7	8.9	37	210	0.44	8.35
Treatment 3	7.7	5.1	53	225	0.49	11.2

Note: P, K and NO_3 in ppm. N is reported as percent.