Effect of amendments on revegetation of gravel pits
by E Susan Hellier

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Land Rehabilitation
Montana State University
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Abstract:
The purpose of this study was to determine if organic amendments (manure, compost or wood chips) or nitrogen-phosphorus-potassium (NPK) amendment had an effect on revegetating a gravel pit where no cover soil materials were available. At two gravel pits in Park County, Montana a randomized complete block design was utilized: the four treatments and a control in three blocks at each pit. Amendment rates were 120-140 Mg/ha of manure, 200 Mg/ha compost, 50 Mg/ha wood chips and 45 kg/ha NPK. Six native grasses and four forbs were seeded. Perennial grass establishment was a goal, since the post-mine land use was wildlife habitat and livestock grazing.

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MONTANA STATE UNIVERSITY
Bozeman, Montana

December 1996

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APPROVAL

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E. Susan Hellier

This thesis has been read by each member of the thesis committee and has been found to be satisfactory regarding content, English usage, format, citations, bibliographic style, and consistency, and is ready for submission to the College of Graduate Studies.

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Date 12-3-96

VITA

E. Susan Hellier was born and raised in New England. She graduated with a Bachelor's degree from Middlebury College, Middlebury, Vermont in 1966. For the past fifteen years Susan has worked for civil engineering firms and has built custom homes in Idaho, Alaska and Montana.

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ABSTRACT

The purpose of this study was to determine if organic amendments (manure, compost or wood chips) or nitrogen-phosphorus-potassium (NPK) amendment had an effect on revegetating a gravel pit where no cover soil materials were available. At two gravel pits in Park County, Montana a randomized complete block design was utilized: the four treatments and a control in three blocks at each pit. Amendment rates were 120-140 Mg/ha of manure, 200 Mg/ha compost, 50 Mg/ha wood chips and 45 kg/ha NPK. Six native grasses and four forbs were seeded. Perennial grass establishment was a goal, since the post-mine land use was wildlife habitat and livestock grazing.

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INTRODUCTION

Sand and gravel are unconsolidated mineral and rock particles resulting from erosion of water, wind and ice. Grain size determines their classification as sand or gravel (Table 1). Sand and gravel occur in and near valleys, terraces and fans of existing and pre-existing rivers (Morris 1982). They are also found in kames, eskers and glacial lake deposits (Mackintosh & Mozuraitus 1982).

Table 1. Classification of Sand and Gravel

Classification	Sand	Gravel
USDA (Brady 1990)	0.05-2.00 mm	2.00-75.0 mm
ASTM-D2487 (Storer 1993)	0.075-4.75 mm	4.75-75.0 mm

In the United States, the demand for gravel is approximately one billion tons per year, or five tons per capita (Luoma 1986). In terms of the number of tons produced, gravel extraction is the second largest mining industry (after coal). In 1982, sand and gravel operations accounted for 17% (3921 km^2) of the total land area disturbed for mining. Only bituminous coal occupied a greater area with 48% of the total land mined (Johnson & Paone 1982). In the early 1980s, 4500 producers of sand and gravel operated 6200 mines. In the second quarter of 1995, producers extracted approximately 240.7 million metric tons (Tepordei et al. 1995). The current value of construction sand and gravel is about $4.50 per yard. Transporting these

materials 20 miles from the processing plant increases their cost 2.5 times.

Lack of topsoil is a problem in gravel pit reclamation. Prior to laws requiring topsoil salvage, many operators did not conserve topsoil, mixed it with overburden, or buried it beneath stockpiles (Green 1992). In some cases, gravel producers sold the topsoil. In other cases, very little soil or vegetative cover existed over the gravel resource prior to excavation. Topsoil greatly enhances re-establishment of plants because it usually possesses more organic matter, nutrients, plant propagules, and has greater water-holding capacity, aggregate stability and cation exchange capacity than gravel. Compared to coarse-textured soils, topsoil has lower bulk density and provides a better balance of macropores and micropores.

Studying the effects of amendments on gravel pit revegetation is important for two reasons. First, because of the cost of hauling sand and gravel relative to the production cost, many operations are near urban centers. Open space, wildlife habitat and scenic views are under intense development pressure in these areas. Most gravel pits will experience sequential land development. After gravel extraction, this disturbed land has the potential for agricultural production, fish and wildlife habitat, recreation, residential or commercial uses.

Second, only one study (Hornick 1986) exists in the literature on organically amending a gravel pit although researchers have experimented with organic and fertilizer amendments on other types of mine spoils. A few studies are available on reclaiming sand and gravel pits, but a cover soil resource was salvaged in each case.

The purpose of this study is to determine if organic or nitrogen-phosphorus-potassium (N-P-K) amendments have an effect on revegetating a gravel pit where no cover soil materials are available. The null hypothesis is that the amendments have no effect.

LITERATURE REVIEW

Problems of Reclaiming Coarse-textures Soils

In a study of the Great Sand Hills in Saskatchewan, Walker (1983) found limitations on revegetation to be high sand content, low water-holding capacity and low organic matter. Results from his three-year study showed that vegetation cover on plots with 15 cm of topsoil was double the cover on plots without topsoil.

Johnson (1987) studied the impacts of the construction of the Trans Alaska Pipeline System. Forty per cent of the land (78,500 ha) disturbed as a result of construction was created for material borrow sites. Impacts at these gravel pits were numerous. They included compaction by heavy equipment, spills or disposal of petroleum products or salts, stability problems over permafrost, loss of existing vegetation and topsoil, and gravel substrates low in moisture- and nutrient-holding capacities. He recommended proper siting of gravel pits to enhance reinvasion of native plants, the salvage of topsoil, fertilizing, and planting native species.

In eastern Montana, Surbrugg (1986) cited reclamation problems due to low annual precipitation, poorly developed soils and little vegetation cover or topsoil. The sites with little topsoil are more economical to develop but much more difficult to reclaim. As a regulator for the

Department of State Lands in Montana, he also noted that multiple operators in the same site make reclamation liability hard to assess.

In the province of Ontario, landowners and gravel pit operators have explored a variety of post-mine land uses. Mackintosh and Mozuraitis (1982) reported on a study of 63 sand and gravel sites reclaimed to agricultural crops. Problems encountered during rehabilitation included the absence of topsoil and subsoil. Poor drainage occurred due to extraction to or below the water table or to an impermeable silty or clayey layer, and failure to design outlets for surface runoff. Soil compaction, stony deposits and poor crop choice also hindered reclamation. The authors included a ten-page section on steps to successful rehabilitation and addressed the problems noted above.

Borgegard (1990) looked at primary succession on abandoned sand and gravel pits in Sweden, primarily on eskers and on sand deltas in former coastal zones. Nothing of the original soil remained on the 68 study sites. In general, the number of species in the pits was lower than in surrounding habitat. Borgegard found a mean of twelve plant species in pits adjoining pine heaths and dry coniferous forests with sandy, well-drained soils and poor nutrient budgets. He identified the same number of species in the surroundings although only five species were common to both. On excavations in broad-leaved forests with higher clay

content in the soil, a mean of 47 plant species occurred, 30 in common with the surroundings.

For 6-8 years, Gaffney and Dickerson (1987) studied grass species for optimal reclamation of sand and gravel mines in the northeastern U.S. Soil problems in the study areas included excessive drainage, low organic matter content, hot surface temperatures and low percentage of soil fines. They experimented with warm- and cool-season grasses, amended only with lime and mulched all of their plots. The authors found that long-term performance of cool-season grasses was poor when fines (<2mm) constituted less than 20% of the soil. Warm-season grasses such as switchgrass, big bluestem and little bluestem persisted well regardless of the soil texture. Gaffney and Dickerson hypothesized that the success of warm-season grasses was a result of adaptation to hot, dry, infertile conditions and development of deep root systems and photosynthetic mechanisms that function well at elevated temperatures.

Unusual Post-Mine Land Uses

Unusual post-mine land uses for gravel pits include "tender fruit" (peaches, cherries, grapes and apples) production in Ontario (Mackintosh & Hoffman 1985), a 500-acre leisure park for the Greater London, England area (Tiffen 1983), lakes and a golf course along the Bow River in Calgary, Alberta (Badke 1982), and orchards (peaches,

almonds, walnuts and grapes) in California (Mackintosh & Hoffman 1985). Gravel pits in Ontario have become valuable recreational and residential properties.

Many gravel pits in the U.S. now serve as ponds and wetland sites for fish and wildlife habitat. Creating aquatic habitat from gravel extraction areas, a large field with numerous references, is beyond the scope of this thesis.

Effectiveness of Organic Amendments on Mine Spoils

Organic matter has many functions in the soil. It is a storage reservoir for anions essential for plant growth, such as nitrates, phosphates, sulfates, chlorides, etc., and it increases the cation exchange capacity (CEC) by 5-10 times that of clay. Organic materials buffer the soil against rapid changes and make phosphorus and micronutrients available over a broader range of pH. Organic matter, which decreases bulk density in soil, protects the soil surface against erosion by wind and water and increases infiltration. It supplies small quantities of all essential plant nutrients and food for microorganisms (Follett et al. 1981).

Researchers have used various animal manures to amend mine spoils. In a study relevant to this thesis, Sharon B. Hornick (1986) examined the effects of cattle feedlot manure and the effects of composted sewage sludge

(undigested municipal sewer sludge plus wood chips) in restoring corn productivity of sand and gravel spoils. Her randomized block design consisted of three replications, two treatments, three rates (40, 80, and 160 Mg/ha) for each amendment, plus a control. Control plots were fertilized at 179 kg N/ha, 122 kg P/ha and 112 kg K/ha. Dolomitic limestone was applied to control plots, the plots with 40 Mg/ha manure and 40 Mg/ha sewage sludge.

After three years, Hornick found that increases in nutrient levels were directly proportional to the initial macronutrient levels in the organic amendment and to the rate applied. A significant difference in grain nitrogen resulted in the third year with the highest nitrogen levels on the highest rates of compost and manure and the control plot. Although she found no consistent treatment effects for grain yields, significant differences in stalk or vegetative growth existed in the first and third years. Manure at all three rates and 80 and 160 Mg/ha compost outperformed 40 Mg/ha compost and the control plot. She concluded, "addition of lime and chemical fertilizers alone is not adequate to restore these sand and gravel spoils to an acceptable level of productivity and stability over the short term."

Chicken manure produced the largest biomass of the three seeded species (weeping lovegrass, Pensacola bahiagrass and sericea lespedeza) on pyritic spoils at a U.S. Corps of Engineers construction site in northeastern

Mississippi (Lee et al. 1983). On mined prime farmland in southern Illinois, Jones and Olsen (1985) found higher crop yields (corn and soybeans) on organically amended spoil than on the replaced topsoil treatment on unmined land. The amendments were animal manure, green manure and a forage-grass-legume crop, and the comparison was to topsoil replacement only.

Dollhopf et al. (1990) worked on abandoned bentonite-mined lands near Belle Fourche, South Dakota. They studied the effects of chemical amendments (H_2SO_4, $CaCl_2$ and gypsum), organic amendments (wood chips and manure), straw mulch, gouging, topsoil and irrigation. Two treatments, H_2SO_4 plus gypsum or manure and $CaCl_2$ plus gypsum, reduced sodium absorption ratios from 38 to 8 and electrical conductivity from 7.0 to 1.8 dS/m. These treatments also had greater plant production (1936-3169 kg/ha) than the control plots (416 kg/ha).

Norland (1994) examined the fractionation of heavy metals in organically amended mine (lead-zinc) lands that are part of the Cherokee County Superfund Site in southeast Kansas. Organic wastes were composted cattle manure, composted yard waste, spent mushroom compost and turkey litter, each applied at three different rates (22.4, 44.8 and 89.6 Mg/ha dry weight). For all of the organic residue plots, concentrations of Cd, Pb and Zn increased in the Fe-Mn oxide bound and the organically bound fractions as the

rate of organic matter increased; concentrations of these metals in exchangeable and dilute-acid extractable fractions decreased.

Manure has proven to be a beneficial soil amendment on gravel pits, pyritic soils, prime farmland restoration, bentonite mines and on lead-zinc mine tailings. In general, animal manures enhance plant growth on rehabilitated cropland soils and pastures because of an increase in organic matter, nutrients and infiltration and a decrease in bulk density (Follett et al. 1981). Compost and wood chips as organic amendments will be discussed next.

Composting is the aerobic, thermophyllic decomposition of organic residues to a relatively stable, humus-like material (Follett et al. 1981). Aeration is necessary for bacteria, actinomycetes and fungi to achieve rapid decomposition. Organic residues contain all the essential microbes, so special inoculum is not necessary. The kinds of residues used for composts will determine the speed of decomposition and the quality of the finished product. Generally, materials with a carbon to nitrogen (C:N) ratio of less than 10:1 are ideal.

Several researchers have demonstrated improved cover and production with the use of compost as an organic amendment on mine spoils. Norland et al. (1993) found that litter, total plant cover, and production increased on coarse taconite iron ore tailings (northern Minnesota) with

the addition of composted yard waste, reed/sedge peat and municipal solid waste. Loebel et al. (1982) assessed the effects of sewage sludge and leaves on a road construction waste pile in Guelph, Ontario. Production of herbaceous species was five to eight times the non-amended control, and plant cover increased 65-100% that of the control.

Compost from the Bozeman, Montana landfill is one of the amendments for this gravel pit study. It was also used by Vodehnal (1993) for the revegetation of gravelly and sandy loams at a high elevation gold mine near Helena. At that time, the makeup of the compost was 30% grass clippings, 30% leaves and 40% straw, hay, manure, hedge trimmings and wood chips. Vodehnal applied both the Bozeman compost and EKO sludge compost at rates of 76 Mg/ha and 152 Mg/ha. After two growing seasons, the plots with these organic amendments had significantly greater plant density, cover and production than plots with two rates of commercial nitrogen fertilizer and with unamended topsoil.

Wood chips have been demonstrated to improve texture and structure, enhance infiltration, reduce raindrop erosion and protect new seedlings. However, when the C:N ratio in the organic matter exceeds 20:1, microbes absorb the available nitrogen, and the plants experience a nitrogen deficiency.

In a number of studies wood chips have been used in combination with municipal sewage sludge. These two

ingredients provide all the necessary nutrients, a source of decomposing microorganisms, and enough organic carbon to sustain the microbes for a number of years without additional inputs. At Hanford, Washington, Brandt and Hendrickson (1991) experimented with wood chip/municipal sludge compost on arid soils. The compost, incorporated 7% by volume into the top 15 cm of soil, had beneficial effects on revegetation exceeding those from mulch or fertilizers alone or in combination. Plant survival and growth on composted plots were twice that of plots with no amendments, and grass density was 3 to 5 times the controls.

Wood by-products have been effective amendments in the establishment of loblolly pines in the South. Schoenholtz et al. (1992) compared three treatments (a control, 50 Mg/ha of whole-tree wood chips and 500 Mg/ha of native topsoil) on newly exposed mine soil in central Appalachia. The growth of a pitch x loblolly hybrid pine was greatest on the wood chip plots. Early revegetation success was more a function of moisture retention than soil nutrient availability. Berry and Marx (1980) experimented with loblolly pine and Kentucky-31 fescue on borrow pits in South Carolina. They used deep subsoil applications of nine different inorganic and organic amendments. They found a significant difference in pine seedling growth and fescue biomass for the amendments that were combinations of sewage sludge, bark and ash versus the non-sludge amendments. The

sewage sludge plots had more nitrogen, phosphorus and organic matter and a higher CEC than the non-sludge plots.

Microorganisms are an important component to the efficacy of wood by-product mulches and amendments. Rothwell (1986) studied how mine-soil microorganisms in Kentucky degrade woody mulches. Rothwell also determined that woody materials aid in stabilizing the soil surface, provide microclimatic conditions for seedlings and may be an important long-term source of structural units for humus formation.

In some cases, a wood by-product is contra-indicated. Composted conifer-tree bark inhibited grass seedling establishment at the Emery coal field in Utah (Ferguson & Frischknecht 1985). Most organic amendments, however, improve mine soils both physically and chemically, protect the soil from erosion, and supply some nutrients to the plants and microorganisms.

Effectiveness of N-P-K Amendment on Mine Spoils

Nitrogen, phosphorus and potassium are important macronutrients for plants, but have shown mixed effects on establishment of native range. Nitrogen is a component of chlorophyll, enzymes and amino acids; it stimulates root development and above-ground vegetative growth. The most readily available form of nitrogen for plants is nitrate, although ammonium is directly absorbed by many plants. Of

the total soil nitrogen only 1-2% is plant available (Brady 1990).

Phosphorus is a component of adenosine diphosphate and adenosine triphosphate, used for energy transformations in plants. Phosphorus is also important for photosynthesis, nitrogen fixation, crop maturation and root development. The amount of phosphorus in available form seldom exceeds 0.01% of the total in the soil. Unlike phosphorus, potassium is found in comparatively high levels in most mineral soils, except sandy soils. It is essential for photosynthesis, protein synthesis, starch formation and translocation of sugars (Brady 1990). Potassium is rarely deficient in disturbed soils in semiarid regions of the West.

Native perennial vegetation in the West has evolved under low nutrient conditions. Nitrogen fertilizer is not necessary on disturbed soils when organic matter in the root zone is adequate, i.e. greater than 2%. In southeastern Montana, the main response to nitrogen fertilization in one study was increased annual grass or annual weed production and decreased diversity (Hertzog 1983).

Ratliff and Westfall (1992) experimented with restoring shorthair sedge by sod plugs to a high elevation gravelly site in Sequoia National Park, California. Nitrogen-phosphorus-potassium fertilizer had negative effects regardless of plug size and transplant method.

McKendrick et al. (1992) found that the type of vegetation could be completely altered with different fertilizer rates on gravelly sites in the National Petroleum Reserve in Alaska. A fertilizer spill on an abandoned aircraft runway caused dense stands of tanacetum and northern tansy mustard.

In a study of tailings sand slopes, Rowell (1978) found that the yield of above-ground vegetation related to the amount of fertilizer added, rather than to the use of peat or overburden soil amendments. He also concluded that fertilizer rate determined the plant community. The unfertilized or minimally fertilized areas had more diversity (71% cover of creeping red fescue and 11% cover of legumes) than the heavily fertilized areas, which were almost entirely covered by brome grass and devoid of legumes.

Macronutrients are essential to plant growth. However, excessive N-P-K fertilization can result in diminished performance by desirable perennials, proliferation of weedy species or annual plants, or an undesirable plant community. Many introduced grasses and forbs benefit from higher fertilizer rates and thus out-compete native species.

SITE DESCRIPTION

Location

The experimental locations for this study are two gravel pits owned by the Montana Department of Transportation; the gravel pits are in Park County. Figure 1 shows the location of the study sites in the State and Figure 2, the location within Park County.

South Pit

The South Pit is in the northwest corner of a six hectare parcel in the East 1/2, Section 27 and the West 1/2, Section 26, Township 1 South, Range 10 East, P.M.M. The parcel occupies the southeast corner of the intersection of Convict Grade Road and State Highway 89 (Figure 3). The elevation at the northwest corner is approximately 1347 m (4420 ft). The test plots face S36°48'22"E, and the slope across the plots is 7% - 11%. The topographic map (Figure 4) shows that the confluence of the Shields and Yellowstone Rivers is about 1 km to the southeast of the pit.

Bedrock under this gravel pit came from the Livingston Group formed during the Upper Cretaceous and Paleocene ages (Thom 1957). The Livingston formation consists of moderately hard sandstones with soft gray shales (Veseth & Montagne 1980). The coastal floodplain deposits came from volcanic activity in western Montana at the same



Figure 1. State of Montana and Site Locations

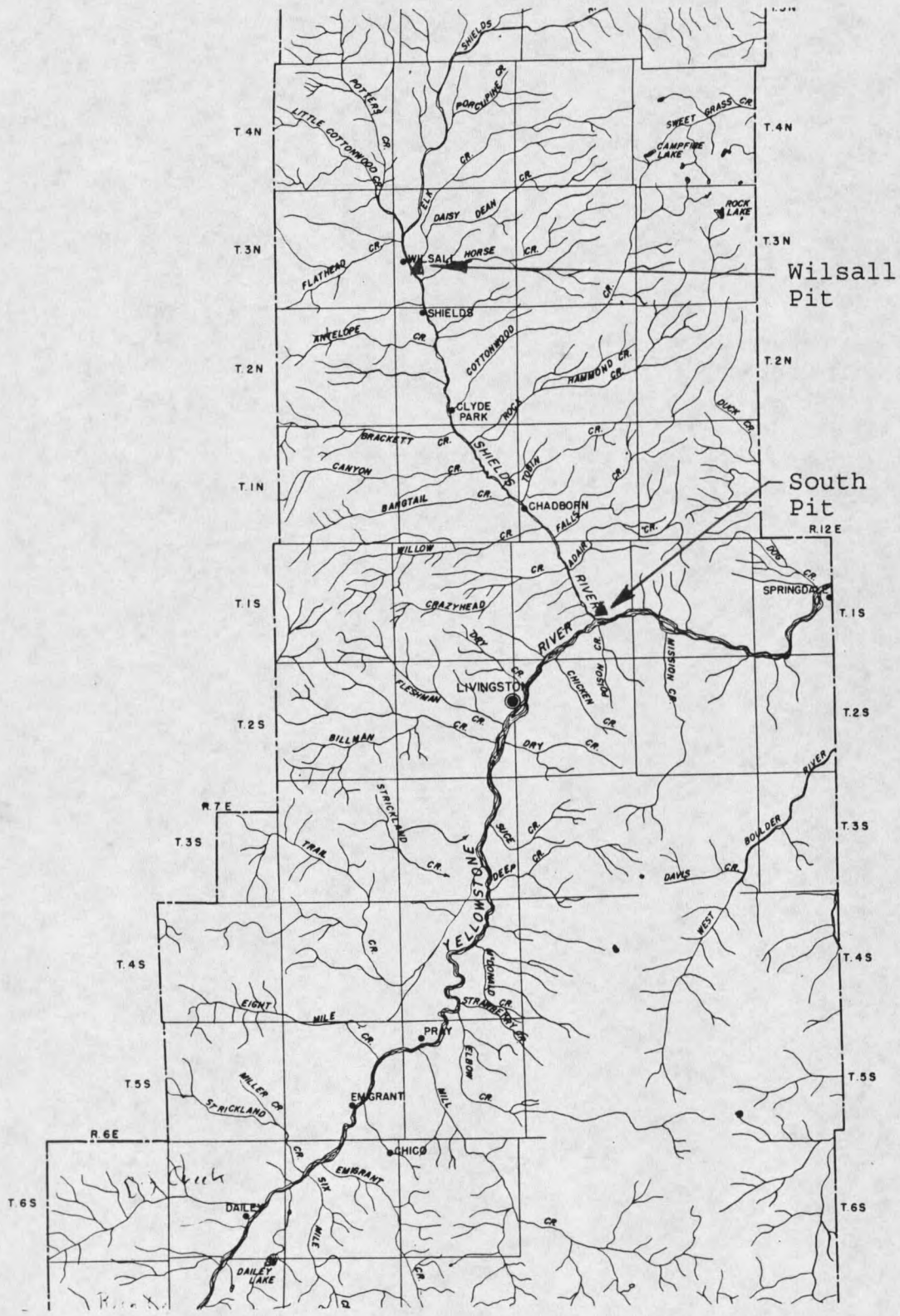
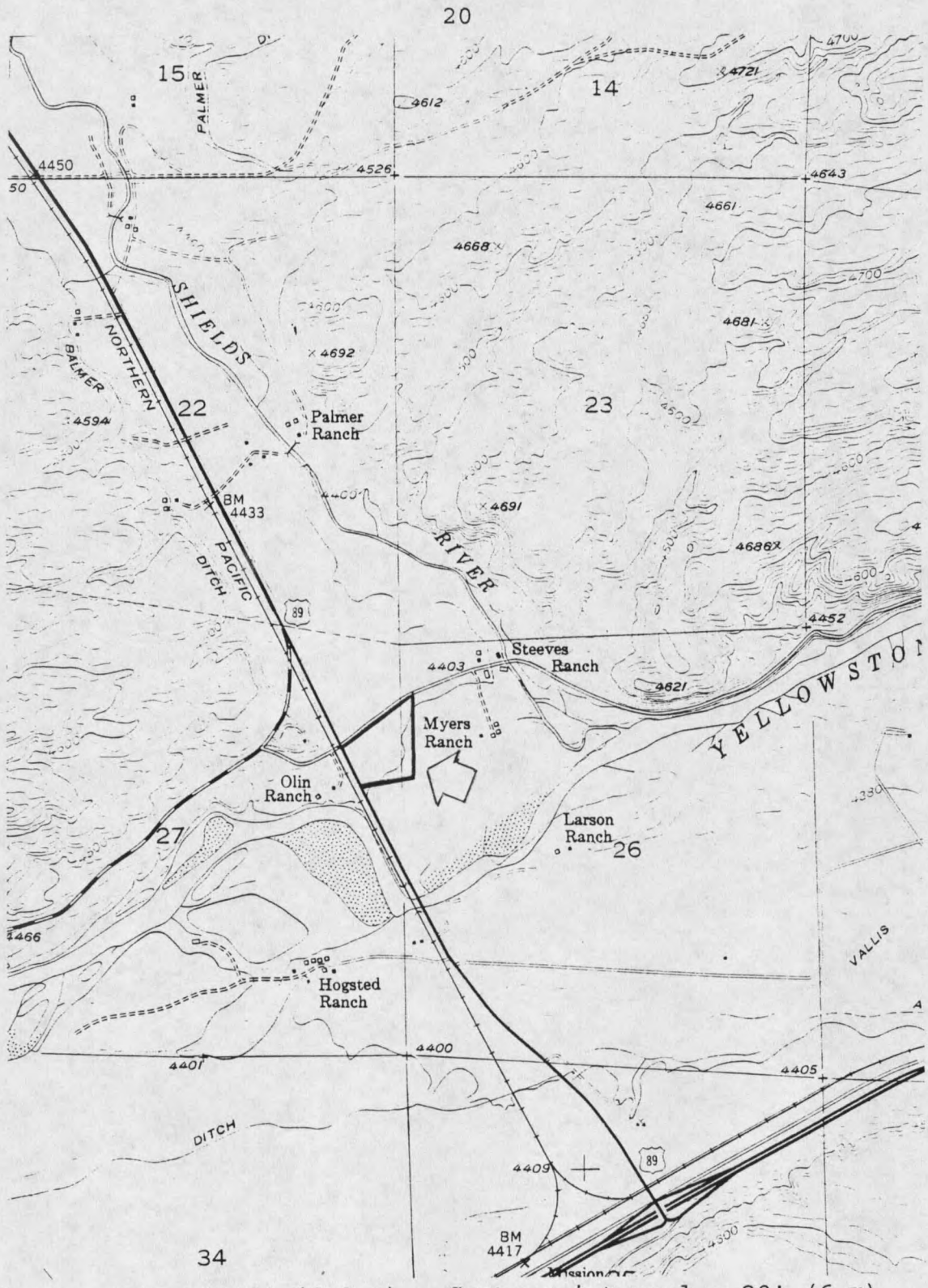


Figure 2. Park County and Site Locations



Figure 3. South Pit Property and Test Plot Location



Scale : 1" = 2000' (610 m) Contour interval : 20' (6 m)

Figure 4. Topographic Map - South Pit

time as the building of the Rocky Mountains. The most abundant mineral of volcanic origin in the Livingston Group is plagioclase feldspar. Most of the sandstone was cemented by silica or calcite. The soil in this gravel pit is calcareous and has very little clay. During the Ice Age glaciers occupied the Yellowstone and Shields Valleys and deposited moraines, kames and eskers. Finally, streams carried fine gravel, sand and alluvium down from the mountains to form the terraces and floodplains (Willard 1935).

The A and B horizons and a portion of the C horizon were removed during the operation of the pit. The soil for the test plots was entirely in the C horizon or parent material. The test plots are located in a loamy sand with 66% rock fragments (by weight). A test pit, 1.5 m (5 ft) deep and 60 m (200 ft) to the East of the pit area, indicated that the original soil was a sandy, mixed Typic Calciboroll. Figure 5 shows the soil profile description for the undisturbed soil.

The climax vegetation for the South Pit is a grassland community consisting of bluebunch, western and thickspike wheatgrasses, Idaho fescue, Columbia needlegrass and basin wildrye (Montagne et al. 1982). At some time prior to gravel extraction, the parcel was plowed and seeded with crested wheatgrass. The gravel pit has not been in use for 12 years. Either topsoil was not salvaged, or it was removed

Soil Type	Typic Calciboroll, sandy, mixed		Date 10-8-95
Area	Confluence of Shields and Yellowstone Rivers		
Location	NE-NE, Section 27, Township 1 S., Range 10 E., P.M.M.		
Vegetation	Crested wheatgrass		Climate . frigid, ustic
Parent Material	Sandstone		
Physiography	Alluvial terrace; broad open valley		
Relief	Straight slope	Drainage Well-drained	Salt or alkali no
Elevation	1345 m	Gr. water 8+ m deep	Erosion none
Slope	5%	Aspect SSE	
Additional notes			

Hor.	Depth (cm)	Color dry/ moist	Text.	Struc.	Consistence dry	moist	wet	CaCo3 equiv.	Bndy.	Rock frag.	pH	E.C. mmhos /cm
Ap	0-18	10YR 4/4 10YR 3/3	loamy sand	strong fine gran.	slight hard	very friable	non-sticky	0	smooth abrupt	21.3% (by wt.)	7.4	1.05
Bk1	18-76	10YR 5/2 10YR 3/2	loamy sand	mod. med. sub-ang.	slight hard	very friable	slightly sticky	14	wavy clear	14.5%	7.6	0.42
Bk2	76-152	10YR 5/4 10YR 3/2	sand	weak fine blocky	soft	very friable	non-sticky	10		0.0%	7.9	0.50

Figure 5. South Pit - Soil Profile Description for Undisturbed Ground

from the property. Seed of plant species from communities around the pit have germinated on the disturbed soil, although approximately 50% of the ground is bare.

Climatic factors include a mean average air temperature of 6.7° C. (44° F.), mean summer soil temperature of 17.7° C. (63.9° F.), mean annual precipitation of 35.6-40.6 cm (14 in-16 in) and mean annual snowfall of 63.5-127.0 cm (25 in-50 in). Slightly more than half of the annual precipitation falls between April and July (Roche 1994).

Wilsall Pit

The Wilsall Pit is a five hectare parcel in the SW 1/4 and SE 1/4 of Section 19, Township 3 North, Range 9 East, P.M.M. The pit is located on the northeast corner of State Highway 89 and Horse Creek Road, near the south edge of the town of Wilsall (Figure 6). The test plots face S 35°38" E; their elevation is approximately 1533 m (5030 ft). The slope across the plots varies from 10% to 12%. The topographic map (Figure 7) shows that the property is part of a floodplain terrace created by the Shields River.

The Wilsall Pit is also in the geologic formation called the Livingston Group, and the pit was subject to the same surficial events as the South Pit (Veseth & Montagne 1980). The C horizon material in the pit reacted strongly to hydrochloric acid. The climax vegetation would be similar to

A TRACT OF LAND LOCATED IN THE
SW 1/4 & SE 1/4, SECTION 19
TOWNSHIP 3N., RANGE 9E., P.M.M.
PARK COUNTY, MONTANA

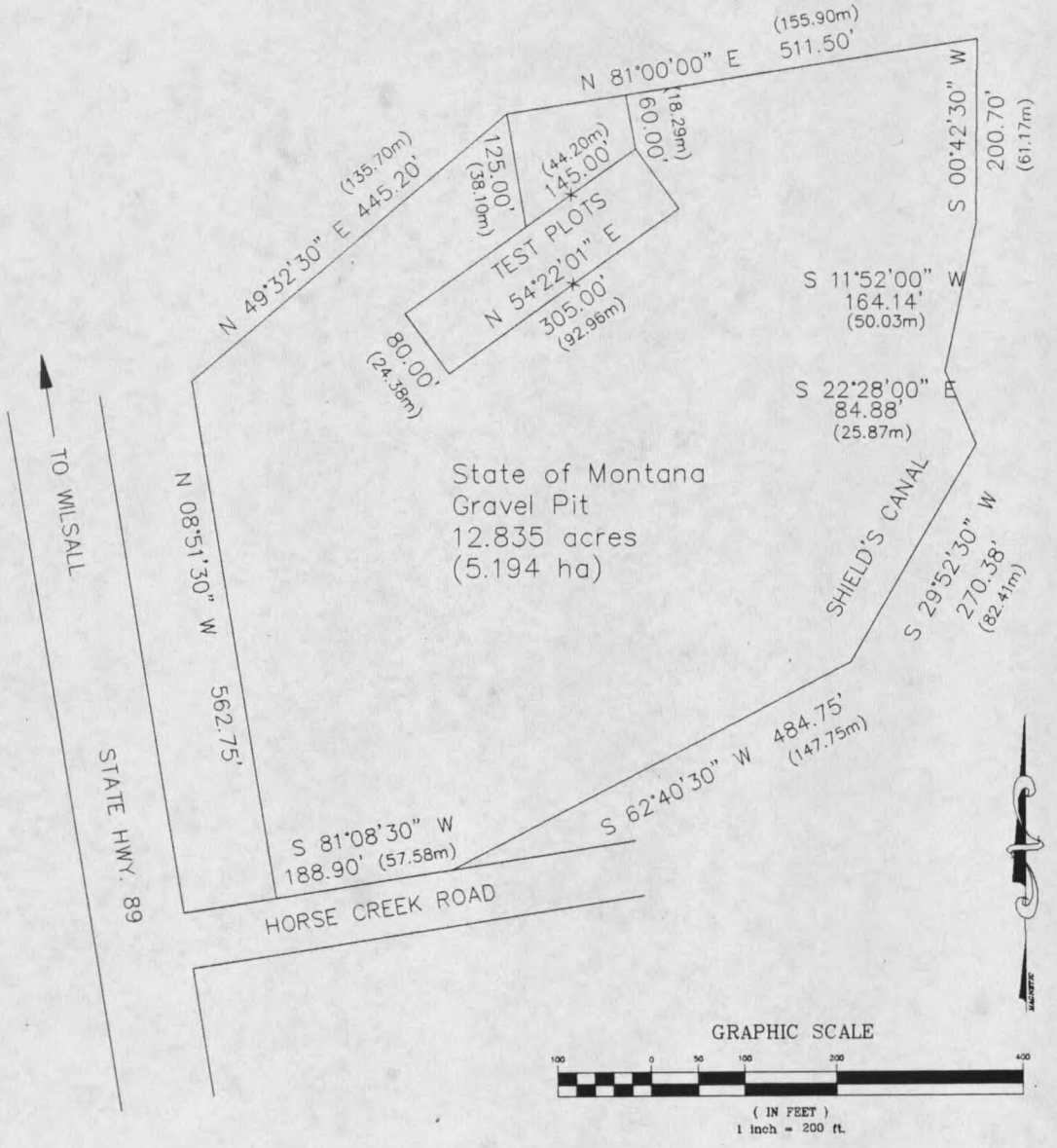
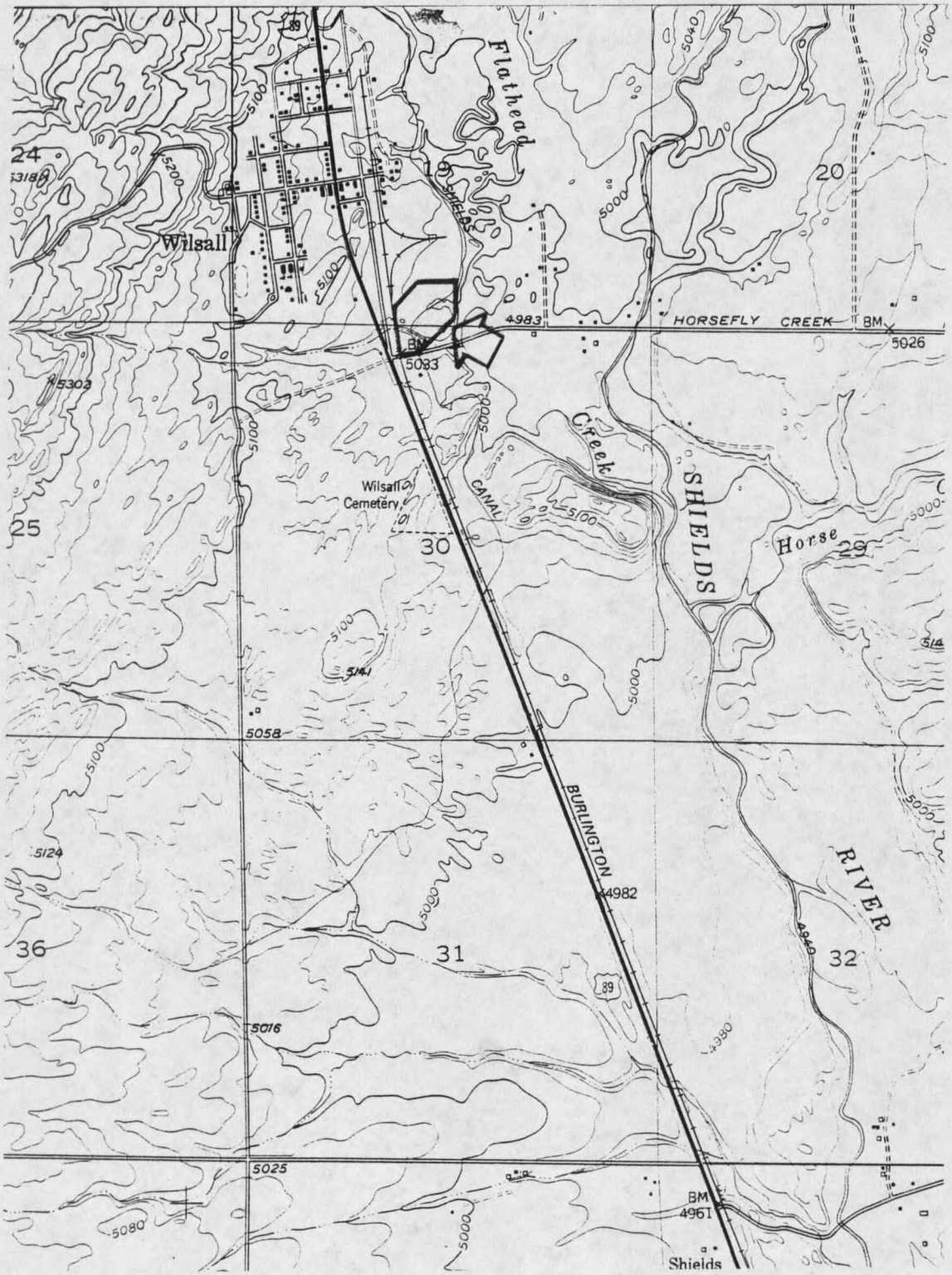


Figure 6. Wilsall Pit Property and Test Plot Location



Scale: 1" = 2000' (610m) Contour interval: 20' (6 m)

Figure 7. Topographic Map - Wilsall Pit

the South pit. In late 1995, the Highway Department closed the pit, and a contractor re-contoured the area. Some topsoil had been salvaged. The material on the test plots consists of topsoil and "reject material", sand and gravel with a clay content higher than desirable for road construction purposes.

Climatic factors (Roche 1994) at this pit are similar to those at the South Pit with the exception of snowfall. Mean average air temperature is 5° C. (41° F.), mean annual precipitation 35.5-40.6 cm (14 in-16 in) and mean annual snowfall 127-154 cm (50 in-100 in).

METHODS AND MATERIALS

Experimental Design

The study design included four amendments and a control at two gravel pits. The treatments were randomly located within each of three blocks at each pit. Soil materials at both sites dictated the layout of the blocks. At the South Pit the blocks were designed from west to east to avoid the greater concentration of cobbles found in the eastern part of the study area. At the Wilsall Pit more smectite-like (highly plastic) clay occurred in the eastern part of the pit, and more "reject" material was found on the west end. Plots at both sites were 7.6 m x 7.6 m (25 ft x 25 ft) with 4.6 m (15 ft) between plots. Plot corners were marked with 2.3 m (7.5 ft) offset stakes (Figures 8 and 9). The plots were arranged in a similar manner at both pits. Only plots 3 and 4, N-P-K and control (CTL), were reversed at the two pits.

The soil amendments were cow manure (MAN), compost (COM), wood chips (WC) and N-P-K fertilizer. Each of the organically treated plots was also fertilized with nitrogen, phosphorus and potassium at the same rate as the N-P-K plots. The commercial fertilizer was considered part of the organic treatments. Five centimeters (2 in) of organic amendments were added to the top 15 cm (6 in) of soil in

BLOCK 1

Plot 1 wood chips (WC)
Plot 2 manure (MAN)
Plot 3 control (CTL)
Plot 4 nitr.,phos.,pot. (NPK)
Plot 5 compost (COM)

BLOCK 2

Plot 6 WC
Plot 7 COM
Plot 8 CTL
Plot 9 NPK
Plot 10 MAN

BLOCK 3

Plot 11 WC
Plot 12 COM
Plot 13 MAN
Plot 14 CTL
Plot 15 NPK

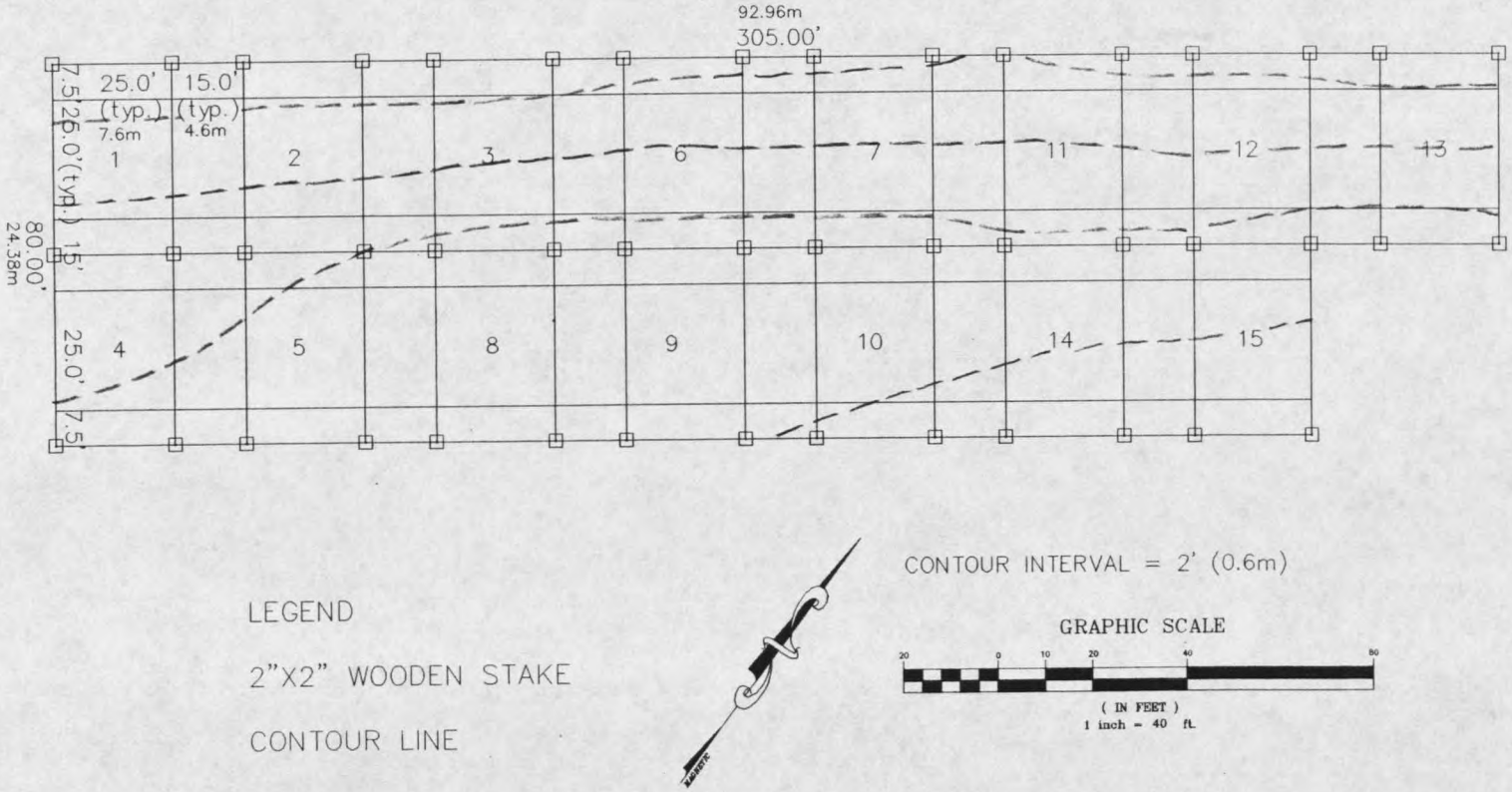


Figure 8. South Pit Experimental Design.

BLOCK 1

Plot 1 wood chips (WC)
Plot 2 manure (MAN)
Plot 3 nitr.,phos.,pot.(NPK)
Plot 4 control (CTL)
Plot 5 compost (COM)

BLOCK 2

Plot 6 WC
Plot 7 COM
Plot 8 CTL
Plot 9 NPK
Plot 10 MAN

BLOCK 3

Plot 11 WC
Plot 12 COM
Plot 13 MAN
Plot 14 CTL
Plot 15 NPK

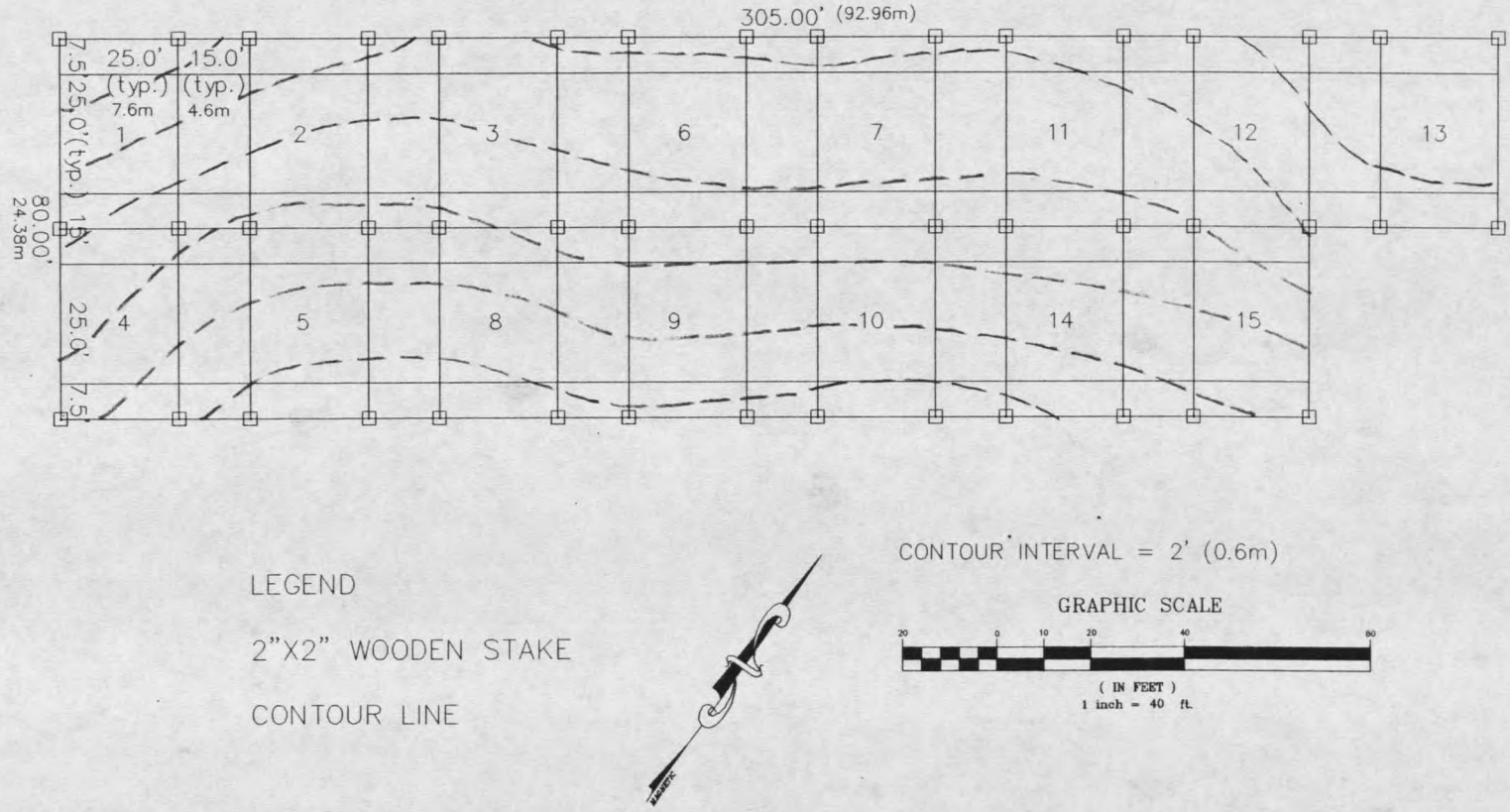


Figure 9. Wilsall Pit Experimental Design

each plot. They represented 33% by volume (3.33 cu yd or 2.54 m^3 per plot).

Because the organic matter had different textures, the amendment rates by dry weight were dissimilar. The cow manure came from a cattle ranch on Convict Grade Road, east of the South Pit. It had been stored in a pile at the ranch for several months. The rate of dry manure was 120 Mg/ha (110,000 lb/a) at the Wilsall Pit and 140 Mg/ha (132,000 lb/a) at the South Pit.

The compost material came from the City of Bozeman landfill. It consisted of grass clippings, leaves, straw, manure, shrub and tree branches (Vodehnal 1993) and Bozeman silt loam soil. The amendment rate of dry compost was 200 Mg/ha (180,000 lb/a) at each pit.

Brand S Lumber in Livingston supplied the wood chips for this study. At the South Pit the "chips" came from a log-yard waste pile and included wood chips, bark and larger pieces to (15 cm). At the Wilsall Pit the chips were typical of landscaping material, 2.5 cm (1 in) square and fairly green. The dry amendment rate was 50 Mg/ha (43,000 lb/a).

Urea (46-0-0 fertilizer) was added to the wood chips in addition to the standard N-P-K fertilizer used on all the amended plots. The objective was to add enough nitrogen to achieve a 20:1, C:N ratio. In order to determine the urea rate, several assumptions were made: 1) nitrogen

was 0.25% by weight of the chips; 2) carbon was 25% by weight; 3) four cubic yards of chips weighed 1 ton (Dollhopf 1993). The urea rate was 1.3 Mg/ha (1160 lb/a).

Nitrogen-phosphorus-potassium fertilizer rates were calculated for native rangeland conditions. Table 2 shows the existing nutrients (mean value at each pit) in the soil prior to plot construction, and the target rates for each macronutrient. Based on these data, 17-17-17 (N-P_2O_5-K_2O) commercial fertilizer was applied at 44.8 kg/ha (40 lb/a) to the plots at each site.

Table 2. Existing Soil Nutrients and Target Rates.

Nutrient	South Pit	Wilsall Pit	Target rate
nitrogen	2.9 mg/kg	2.6 mg/kg	23 mg/kg (46 lb/a)
phosphorus	2.5 mg/kg	3.5 mg/kg	8 mg/kg (16 lb/a)
potassium	69.6 mg/kg	143.3 mg/kg	85 mg/kg (170 lb/a)

On March 20-21, 1995 the amendments were incorporated into the plots. The fertilizer was applied to the plots with a mechanical spreader. The amendments were end-dumped from a truck at a rate of approximately 3.33 cu yd (2.54 m^3) per plot. An operator using a motor grader with a 4.3 m (14 ft) blade spread the amendment evenly over the surface of the plot. Then the amendments were plowed into the top 15 cm of soil by working along the contour in an east-west direction. In order to mitigate compaction caused by the grader, the operator ripped the soil at the South Pit to a 15 cm depth with the machine's scarifiers. The Wilsall

Pit was not ripped at the end because the soil was too wet. The north and south edges of the plots had less effective incorporation, so vegetation measurements were made in the 6 m (20 ft) square area centered within the 7.6 m (25 ft) square plot.

Both pits were seeded in late March and early April, 1995. The seed was hand-broadcast and raked. The South Pit was rolled with a standard lawn roller. The Wilsall Pit was too uneven to roll. Table 3 shows the species seeded and seed rates at both pits.

Table 3. Species and Seed Rates

Species/ Common name	variety	kg/ha PLS	seeds per ha
Agropyron spicatum bluebunch wheatgrass	Secar	2.2 *	617,750**
A. dasystachyum thickspike wheatgrass	Critana	4.4	1,522,136
A. trachycaulum slender wheatgrass	Pryor	2.2	479,374
Elymus cinerus Basin wildrye	Magnar	2.2	617,750
Poa compressa Canada bluegrass	Reubens	.6	3,088,750
Sporobolus cryptandrus sand dropseed		.6	6,177,500
Achillea millefolium western yarrow		.1	855,584
Linum lewesii blue flax	Appar	1.1	724,003
Lotus corniculatus birdsfoot trefoil	Empire	.6	502,848
Lupinus sericeus common lupine		2.2	63,752
TOTAL		16.2	14,649,447

Total number of seeds: 1465/m^2 (136/ft^2)

* Multiply (kg/ha) (0.892) = lb/a
** Multiply (seeds/ha) (0.405) = seeds/a

Soil Tests

Soil tests were performed prior to plot construction (October 1994 to March 1995) and after incorporation of amendments (May to June 1996). Objectives in collecting data for pH, electrical conductivity, texture and bulk density were to characterize the soil. Water content at field capacity, organic matter content, nitrogen, phosphorus and potassium were statistically analyzed for treatment differences. Because cobbles to 10 cm (4 in) were common in both test areas, soil samples were taken with a 15 cm (6 in) post-hole digger to a depth of 15 cm. A single random sample per plot was taken with the post-hole digger to characterize the soil for particle-size analysis, pH, electrical conductivity (EC) and water content at field capacity. A composite sample was formed from three random locations per plot by digging with a garden trowel to a depth of 15 cm. The composite samples were used for analysis of nitrogen, phosphorus, potassium and organic matter.

The samples collected for physical analyses were dried at 105°C. for 24 hours, ground with a mortar and rubber-tipped pestle where necessary (Storer 1993), and sieved through a 2 mm screen. The composite samples were air-dried, sieved and analyzed for N-P-K. Nitrate-nitrogen was extracted by the KCl method (Keeney & Nelson 1982), phosphorus by the Olsen method (Olsen & Sommers 1982) and

potassium by ammonium acetate (Knudsen et al. 1982). The organic amendments were air-dried, sieved (2 mm) and tested for N-P-K using the same methods as the soil samples for these factors. Organic matter was determined by the Walkley-Black method (Nelson & Sommers 1982) for the soils and loss-on-ignition (Ball 1964) for the amendments.

Particle size distribution was determined by the hydrometer method with the sand determination made at 40 seconds and the clay at 6.5 hours (Bouyoucos 1936, Day 1965). Saturated paste extracts were made according to L.A. Richards (1969) for measurement of pH and EC.

Water content of the soil at field capacity was determined under natural rainfall. A more or less continuous rainfall with a total accumulation of 2.5 cm (1 in) was required for the in-situ field capacity test, followed by a 24 hr drying period (Klute 1982). Rainfall prior to the field capacity tests is listed in Table 4. The reporting weather stations were the Livingston Airport, ten miles west of the South Pit, and "Wilsall 8 [mi] ENE".

To approximate pre-construction conditions (for baseline information), on June 11, 1995, both pits were tested for water content/ field capacity of the bulk soil at one random location slightly off each plot with a Troxler 3411 B surface nuclear gauge. The probe was set to a 15 cm (6 in) depth. In 1996 gravimetric water content samples were taken (15 cm deep, one per plot) on May 21 at the South Pit

and May 31 at the Wilsall Pit. These samples were analyzed to determine treatment differences of water content in the bulk soil (includes coarse fragments).

Table 4. Precipitation Prior to In-situ Field Capacity Test.

Date	Livingston	Wilsall	Date	Livingston	Date	Wilsall
6/4/95	0.00cm	1.68cm	5/12/96	0.48cm	5/28/96	0.69cm
6/5/95	0.89	0.64	5/13/96	0.41	5/29/96	1.19
6/6/95	trace	2.84	5/14/96	0.20	5/30/96	0.64
6/7/95	0.36	0.00	5/15/96	0.08	5/31/96	0.00
6/8/95	0.43	0.13	5/16/96	0.66		
6/9/95	0.08	0.46	5/17/96	0.36		
6/10/95	0.00	0.46	5/18/96	0.41		
			5/19/96	0.15		
Total	1.76cm	6.21cm		2.75cm		2.52cm
	0.69in	2.44in		1.08in		0.99in

Vegetation Measurements

Cover and standing crop biomass were measured to determine plant performance in these experimental areas. Canopy cover and biomass were measured on a transect from the northwest offset stake to the southeast stake (Figure 10). Ten 20 x 50 cm frames per plot were read for canopy cover (Daubenmire 1959) in mid-July of the second growing season. Cover was read by species; bare ground, litter and total foliar cover were also measured.

Standing crop biomass, biomass measured on one day at the height of the growing season, was collected from five 20 x 20 cm frames per plot. Collection categories included perennial cool season grasses, perennial warm season

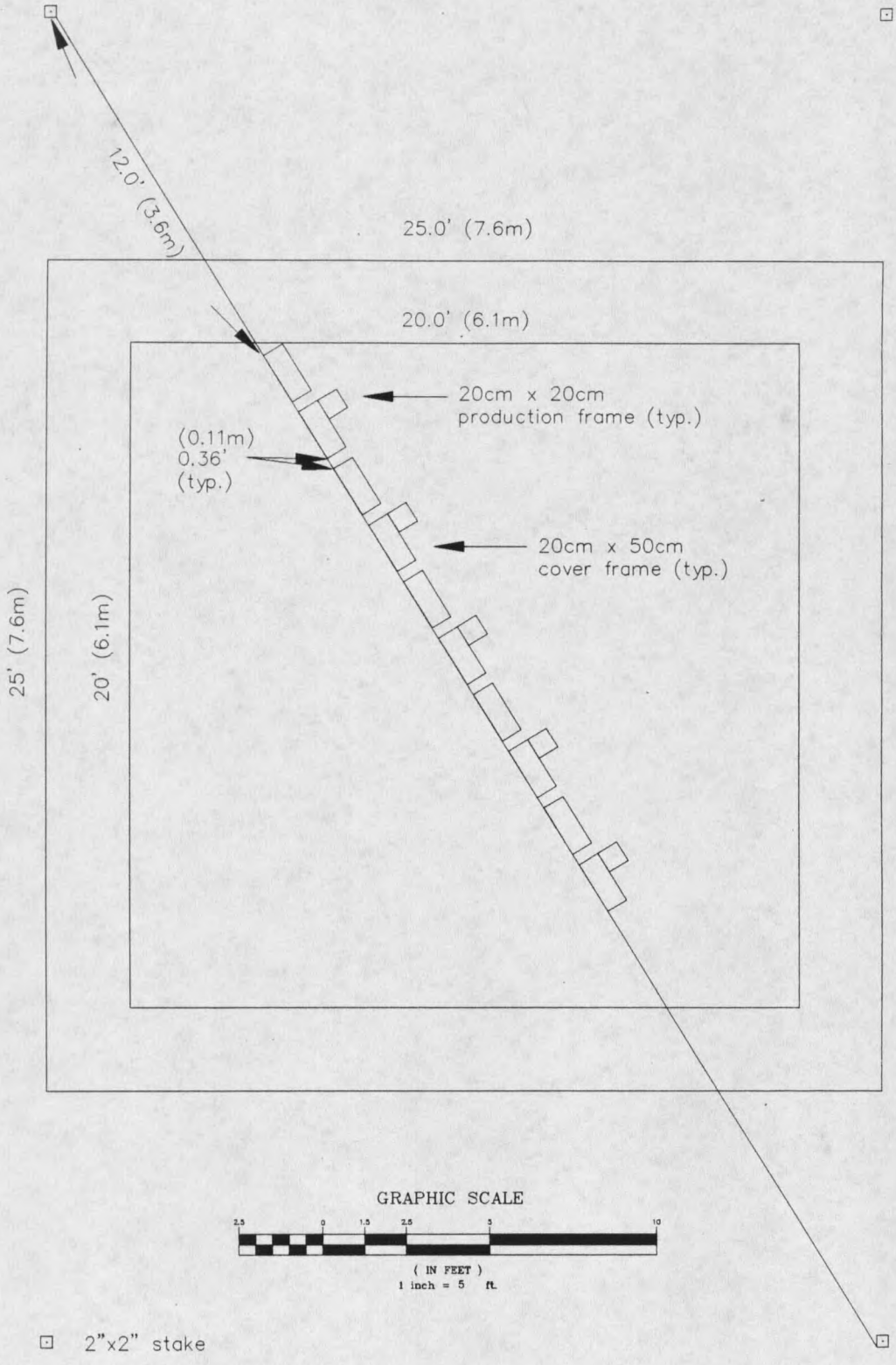


Figure 10. Location of Cover and Production Frames.

grasses, annual grasses, legumes and other forbs. Plants were clipped 1 cm above the ground, dried at 49°C. (120°F.) in an oven and then weighed. A list of all plant species on the plots at each pit was used to indicate species richness.

Quality Control and Statistics

Quality control procedures for the soil tests were: 1) one sample split of the less than 2 mm fraction was analyzed for every 15 tests; 2) one analysis of a Reclamation Research Unit control soil was conducted for every 15 tests. The split or control soil result was expected to be within 25% of the other half or the mean recorded value for the control soil. The Montana State University (MSU) Soil Analytical Lab's quality control protocol included one split for every 10 samples. A method blank and an internal standard were analyzed for every 40 samples. For vegetation, quality control was submission of voucher plant specimens to the MSU Herbarium.

The design for this experiment was a randomized complete block. One-way analysis of variance (ANOVA) was performed; all statistical tests were made at the 0.10 level of significance. Least significant difference tests between treatments were only used if the F-test from the ANOVA was significant.

RESULTS AND DISCUSSION

The post-mine land use for the two gravel pits is livestock grazing and wildlife habitat. Perennial grass establishment is a major goal for these land uses; therefore, grass establishment is emphasized in the results for vegetative cover, standing crop biomass and species richness.

Cover data by plot are located in Appendix A and ANOVA tables in Appendix C. All data sets were normally distributed ($p > .05$) according to the Kolmogorov-Smirnov test. Approximately one-third of the data sets did not have equal variances from the mean according to Bartlett's test ($p > .05$). Data transformations using log- base 10 or reciprocal (1/y) were applied to remedy this problem. Transformations failed to remedy the problems of normality and equal variance for the data set for organic matter at the Wilsall Pit. A Kruskal Wallis ANOVA on ranks was used to test significant treatment differences for this data set.

At the end of each ANOVA table in Appendix C, results of the tests for normality and equal variance are shown. In the table title the data transformation, if required, is noted. If a transformation was used, the ANOVA table displays information for the transformed data.

In Appendix C significant treatment differences at $p < 0.10$ level are denoted by an asterisk(*). If the F-test from the ANOVA was significant, then a least significant

difference test was applied. In the tables the various treatments are noted as control - CTL, compost - COM, manure - MAN, nitrogen-phosphorus-potassium fertilizer - NPK and wood chip - WC plots. The life forms are noted as cool season perennial grasses - per gr cool, warm season perennial grasses - per gr warm, annual grasses - ann gr, and forbs.

Vegetation Cover

The most prevalent grass at the South Pit was *Agropyron spicatum*, bluebunch wheatgrass. The NPK fertilizer, manure and compost plots had significantly higher cover than plots amended with wood chips (Table 5). *Agropyron spicatum* is excellent forage for cattle and horses and good for sheep, elk and deer (Stubbendieck et al. 1994). It is a key species on southcentral Montana rangeland, and it produces considerable forage (Taylor & Lacey 1994).

Table 5. Vegetation Cover (%) for the South Pit.

Treatment	*Agropyron spicatum*	Per gr cool	Per gr warm	Total per gr	Forb	Total cover
CTL	13.7 AB*	17.9	3.7**	21.5	54.3 A	59.8
COM	16.4 B	25.9	5.8	31.7	29.7 C	62.0
MAN	17.6 B	23.0	6.4	29.3	21.9 D	66.8
NPK	18.6 B	24.4	1.3	25.7	42.0 AB	57.4
WC	9.8 A	30.4	7.2	37.5	32.3 BC	65.1

* Means followed by different letters in the same column are significantly different at $p < 0.10$.
** The absence of letters indicates no significant differences at $p < 0.10$.

Although there were not significant treatment differences in cool-season perennial grass cover the means indicate that any amendment was better than none (Table 5). A visual examination of the study site suggested better establishment of cool-season perennial grasses on the amended plots. *Sporobolus cryptandrus*, sand dropseed, was common in this pit area, and it was part of the seed mix. Sand dropseed provides forage to all classes of livestock. It is especially adapted to dry habitats because the lower part of the panicle is enclosed in the leaf sheath, which promotes self-pollination (Taylor & Lacey 1994). This warm-season grass increases with over-grazing or drought (Stubbendieck et al. 1994).

Significant treatment differences existed in forb cover (Table 5). The control plots had higher forb cover than plots amended with compost, manure or wood chips, but they were not different from the NPK plots. The most common forbs on the control plots were the nitrogen fixers, *Melilotus officinalis*, yellow sweetclover, and *Medicago lupulina*, black medic. Both are good forage for livestock and wildlife; they are preferred over grasses (Taylor & Lacey 1994). They are aggressive and competitive pioneers on disturbed lands, particularly in areas with low nutrient budgets like the control plots. Because of its low growth form, black medic allows better grass growth than yellow sweetclover (Munshower 1991). The means for total foliar

cover indicate that the organic treatments may be producing higher cover and less bare ground than the control or NPK plots.

Cover data by plot for the Wilsall Pit are located in Appendix A and ANOVA tables in Appendix C. Table 6 shows the per cent cover for the Wilsall Pit. Again the most common grass was *Agropyron spicatum* (14.8% average cover/ plot), followed by *Hordeum jubatum*, foxtail barley (11.5% average cover/plot). The latter grass is poor forage for livestock and wildlife because of its long awns. It can be grazed prior to the development of the inflorescence (Stubbendieck et al. 1994). For *Agropyron spicatum*, compost and manure plots had significantly higher cover than NPK, wood chip or control plots. All treatments had significantly higher cover of total perennial grasses than the control plots. Note that plots amended with compost had the highest cover for both *Agropyron spicatum* and total perennial grasses. *Sporobolus cryptandrus* was found in only one cover frame at this site although it was in the seed mix. Unlike the South Pit, sand dropseed was not found in the surrounding area.

On two of the manure plots, *Chenopodium album*, goosefoot, and *Sisymbrium loeselii*, tumble mustard, comprised most of the forb cover. Both are weedy annuals, common on disturbed rangeland and waste areas (Whitson 1996). On the control plots over 86% of the forb cover was

Melilotus officinalis, a common biennial legume of this region.

Table 6. Vegetation Cover (%) for the Wilsall pit.

Treatment	*Agropyron spicatum*	Per gr cool	Forbs	Total cover
CTL	5.5 A*	8.8 A	75.3**	78.3
COM	33.9 C	52.5 B	64.0	82.7
MAN	17.3 B	32.3 B	86.7	87.9
NPK	9.4 A	36.8 B	60.4	76.7
WC	8.2 A	31.8 B	50.3	66.1

* Means followed by different letters in the same column are significantly different at $p < 0.10$.
** The absence of letters indicates no significant differences at $p < 0.10$.

In total foliar cover the manure and compost means were somewhat higher than control, NPK, and wood chip plots. The Wilsall Pit total cover was very similar in ranking of the treatments to that of the South Pit; however, the Wilsall pit had greater foliar coverage.

Standing-crop Biomass

At the South Pit no significant treatment differences for biomass were found for any of the life forms evaluated. Biomass data are located in Appendix B and the ANOVA tables in Appendix C. Table 7 shows the results for the South pit.

At the Wilsall Pit, once again no significant treatment differences were found. Table 8 displays the results for standing crop biomass at the Wilsall pit.

Table 7. Standing-crop Biomass (g/400cm²) for the South Pit.

Treatment	Ann gr	Per gr cool	Per gr warm	Total per gr	Forb	Total g/400cm²	prod. kg/ha
CTL	0.45*	1.13	0.18	1.31	2.17	3.93	980
COM	0.79	1.98	0.45	2.44	1.55	4.78	1195
MAN	1.18	1.88	0.38	2.27	1.06	4.51	1130
NPK	0.16	1.99	0.08	2.07	1.85	4.08	1020
WC	0.62	4.21	0.04	4.26	1.24	6.12	1530

* The absence of letters indicates no significant differences at $p < 0.10$.

Table 8. Standing-crop Biomass (g/400 cm²) for the Wilsall Pit.

Treatment	Ann gr	Per gr cool	Forb	Total g/400cm²	prod. kg/ha
CTL	0.00*	0.41	15.24	15.65	3910
COM	0.12	6.11	5.25	11.49	2870
MAN	0.05	1.88	11.89	13.82	3455
NPK	0.01	4.63	8.53	13.17	3290
WC	0.06	4.79	8.25	13.11	3280

* The absence of letters indicates no significant differences at $p < 0.10$.

Species Richness

There were no significant differences among treatments for the mean number of species present at the South Pit (Table 9). Thirty species were found in the experimental area; nine species were perennial grasses. Cheatgrass was more abundant on the plots at lower elevations. Spotted knapweed was common in Block 3, even though it had been hand-pulled during both growing seasons.

Thirty-three species were found in the experimental area at the Wilsall Pit (Table 10); eight

Table 9. Species Richness for the South Pit.

Scientific binomial	Common name	CTL	COM	MAN	NPK	WC
Perennial grasses - cool						
Agropyron cristatum	crested wheatgrass	x	x	x		x
*A. dasystachyum**	thickspike wheatgr.		x		x	x
*A. spicatum**	bluebunch wheatgr.	x	x	x	x	x
*A. trachycaulum**	slender wheatgrass	x	x	x	x	x
Oryzopsis hymenoides	Indian ricegrass					x
*Poa compressa**	Canada bluegrass	x	x	x	x	x
Poa pratensis	Kentucky bluegrass			x		x
Stipa comata	needle-and-thread	x				x
Perennial grass - warm						
*Sporobolus cryptandrus**	sand dropseed	x	x	x	x	x
Annual grass						
Bromus tectorum	cheatgrass	x	x	x	x	x
Forbs						
Alyssum alyssoides	pale alyssum	x	x	x	x	x
Artemisia campestris	common sagewort	x	x	x	x	x
Chenopodium berlandieri	lambsquarter			x		
Heterotheca villosa	hairy golden aster	x	x	x		x
Kochia scoparia	summer cypress	x		x		
Liatris punctata	dotted gayfeather		x	x		
*Linum lewisii**	blue flax	x	x	x	x	x
*Lotus corniculatus**	birdsfoot trefoil	x	x		x	x
Medicago lupulina	black medic	x	x	x	x	x
Melilotus officinalis	yellow sweetclover	x	x	x	x	x
Salsola kali	Russian thistle	x	x	x		x
Sisymbrium altissimum	tumble mustard	x	x	x		
Tragopogon dubius	salsify					x
Verbascum thapsus	common mullein	x	x		x	x
Verbena bracteata	prostrate vervain	x	x	x	x	x
Also present (but not in cover frames)						
*Achillea millefolium**	yarrow					
Artemisia frigida	fringed sagewort					
Astragalus adsurgens	upright milkvetch					
Centaurea maculosa	spotted knapweed					
Mentzelia decapetala	tenpetal blazingstar					

	CTL	COM	MAN	NPK	WC
Total # of species	19	19	19	14	21
Mean species	12.3	13.7	12.3	10.3	15.0

* seeded species
x present on at least one plot

Table 10. Species Richness for the Wilsall Pit.

Scientific binomial	Common name	CTL	COM	MAN	NPK	WC
Perennial grasses - cool						
*Agropyron spicatum**	bluebunch wheatgr.	x	x	x	x	x
*A. dasystachyum**	thickspike wheatgr.	x	x	x	x	x
*A. trachycaulum**	slender wheatgr.	x	x	x	x	x
*Elymus cinerus**	Basin wildrye		x	x		
Hordeum jubatum	foxtail barley	x	x	x	x	x
*Poa compressa**	Canada bluegrass	x	x			x
Phleum pratense	timothy			x		
Perennial grass - warm						
*Sporobolus cryptandrus**	sand dropseed					x
Annual grasses						
Bromus tectorum	cheatgrass	x	x	x	x	x
Secale cereale	annual rye	x				
Forbs						
Achillea millefolium	yarrow			x		
Alyssum alyssoides	pale alyssum	x	x	x	x	x
Astragalus adsurgens	upright milkvetch					x
Berteroa incana	hoary false alyssum		x	x	x	x
Chenopodium album	goosefoot		x	x	x	x
C. berlandieri	lambsquarter					x
Cirsium arvense	Canada thistle	x				
Cynoglossum officinale	houndstongue				x	
Galium aparine	cleavers		x			
Hyoscyamus niger	black henbane				x	
Kochia scoparia	summer cypress		x	x		x
Lactuca serriola	wild lettuce			x		
*Linum lewisii**	blue flax	x	x	x	x	x
*Lotus corniculatus**	birdsfoot trefoil	x	x	x	x	x
*Lupinus sp.**	lupine				x	
Melilotus officinalis	yellow sweetclover	x	x	x	x	x
Salsola kali	Russian thistle	x	x	x	x	x
Sisymbrium loeselii	tumble mustard	x	x	x	x	x
Tragopogon dubius	salsify	x				
Also present (but not in cover frames)						
Agropyron cristatum	crested wheatgrass					
Centaurea maculosa	spotted knapweed					
Cirsium vulgare	bull thistle					
Trifolium pratense	red clover					

	CTL	COM	MAN	NPK	WC
Total # of species	15	18	18	16	18
Mean species	9.0A**	12.7B	12.3B	11.0AB	12.7B

* seeded species
x present on at least one plot
** Means followed by different letters in the same row are significantly different at $p < 0.10$.

perennial grasses were included among them. The organically amended plots had a significantly higher number of species than the control plots.

Many noxious and other weeds were found throughout the Wilsall plots and the surrounding area: *Salsola kali, Cirsium arvense, C. vulgare* (Russian, Canada and bull thistle), *Centaurea maculosa* (spotted knapweed), *Cynoglossum officinale* (houndstongue), *Carderia pubescens* (whitetop), *Hyoscyamus niger* (black henbane), *Kochia scoparia* (summer cypress), *Chenopodium album* and *C. berlandieri* (lambsquarter and goosefoot). Almost one-third of the Wilsall Pit species were weedy invaders that rob valuable resources from desirable plants.

Soils and Organic Amendments

The results of all the pre- and post-construction soil tests are found in Appendix D. The South Pit was homogeneous across the test plots for each of the physical and chemical characteristics measured in the pre-construction sampling. One-way analysis of variance was used to detect any significant difference ($p < 0.10$) between blocks for the various soil tests. The soil had an average particle-size analysis by weight of 66.2% coarse rock fragments (>2 mm) and a loamy sand texture, i.e. 80.8% sand, 18.2% silt and 1.0% clay in the less than 2 mm fraction of the soil. The bulk density average of 2.0 g/cm^3 was high for

a mineral soil, but ideal for a gravel pit. The pH was 8.0, reflecting the calcareous nature of the parent material. Electrical conductivity was low (0.38 dS/m) as were the values for nitrogen, phosphorus and potassium. The gravimetric water content (kg/kg) at field capacity was 5.0%.

Pre-construction sampling at the Wilsall Pit also revealed a statistically homogeneous site, except for silt in the < 2 mm fraction. There was less silt in Block 1 than the other two blocks. This pit had more variation than the South Pit because it was reclaimed in late 1994 with topsoil, reject gravel and pit waste materials. Textures ranged from loamy sand to silty clay loam. The coarse rock fragments were 43.5% by weight of the samples. The pH at 8.2 was slightly alkaline. The bulk density was 1.7 g/cm^3, reflecting higher clay and organic matter contents than the South Pit. The gravimetric water content at field capacity was 13.2%, more than double that of the South Pit.

In 1996 soils at both pits were analyzed for nitrogen, phosphorus, potassium, organic matter and gravimetric water content at field capacity (θ_mF.C.) of the bulk soil. Table 11 displays these results for the South Pit.

At the South Pit manure plots were significantly higher in nitrogen than wood chip, control or NPK plots, but not significantly different from the compost-amended plots

(Table 11). For phosphorus, potassium and organic matter, manure plots were significantly different from all other treatments and control plots. Generally, these findings are in direct proportion to the inputs of the organic amendments. There were no significant differences in gravimetric water content at field capacity, although manure and compost were highest with 5.0% and 4.3% respectively.

Table 11. Soil Tests for the South Pit.

Treat-ment	N (mg/kg)	P (mg/kg)	K (mg/kg)	O.M. (%)	θ_mF.C. (%)
CTL	5.47 A*	25.90 AB	206.7 A	0.95 C	3.9**
COM	11.90 AB	53.63 B	374.7 B	2.70 B	4.3
MAN	34.47 B	179.70 C	1182.7 C	3.94 A	5.0
NPK	3.13 A	21.83 AB	125.3 A	0.84 C	3.5
WC	6.00 A	19.13 A	193.3 AB	1.68 BC	3.5

* Means followed by different letters in the same column are significantly different at $p < 0.10$.
** The absence of letters indicates no significant differences at $p < 0.10$.

Significantly higher water-holding capacity was anticipated on the compost and manure plots than on the NPK, wood chip and control plots. As the field capacity water contents were quite low for the South Pit in general, the test method may not be suitable for soils as coarse-textured as this gravel pit. The 24 hour drainage period after saturation may be too short, or the natural rainfall in southcentral Montana may not be concentrated in a short enough period of time to saturate the soil.

At the Wilsall Pit (Table 12) no significant treatment differences were found for nitrogen or field-capacity water content. Manure and compost plots were significantly higher in phosphorus content than the other treatments. Manure plots also had higher potassium than the other treatments; compost plots were different from wood chip and control plots. Finally, manure plots had significantly higher organic matter than control plots.

Table 12. Soil Tests for the Wilsall Pit.

Treat-ment	N (mg/kg)	P (mg/kg)	K (mg/kg)	O.M. (%)	θ_mF.C. (%)
CTL	0.40**	5.67 A*	112.7 A	0.25 A C	9.7
COM	2.23	41.50 B	336.0 B	1.90 BC	13.1
MAN	4.00	74.93 B	778.7 C	2.23 B	20.0
NPK	0.90	9.17 A	138.0 AB	0.65 AB	18.2
WC	1.67	7.53 A	121.3 A	0.71 AB	18.3

* Means followed by different letters in the same column are significantly different at $p < 0.10$.
** The absence of letters indicates no significant differences at $p < 0.10$.

The organic amendments were tested for nitrogen, phosphorus, potassium and organic matter. Results are displayed in Table 13. These numbers represent the mean of three composite samples. Note that with the exception of organic matter these results are directly proportional to the results from the post-construction soil tests. The organic matter content of the wood chips (93.8%) did not show up proportionally in the soil tests for those plots.

Table 13. Analysis of Organic Amendments.

Amend-ment	N (mg/kg)	P (mg/kg)	K (mg/kg)	O.M. (%)
MAN	896.0	893.6	22,527	49.8
COM	145.5	269.3	3,893	15.6
WC	1.7	59.4	717	93.8

Comparison of the Two Gravel Pits

A comparison of the two gravel pits indicates that the soils were dissimilar in texture, bulk density, coarse fragment content and water-holding capacity (Table 14). Cover values for *Agropyron spicatum* and perennial grasses were not significantly different at the two pits, whereas forb cover and total cover were different ($p < 0.10$).

Perennial grass production was not significantly different at the two pits, but forb production and total production were significantly greater at the Wilsall pit. The higher cover and production of forbs and total plant species at the Wilsall Pit may be due to the abundance of weeds and *Melilotus officinalis,* higher amounts of clay in the soil, or greater water-holding capacity.

Generally, nitrogen content and organic matter were significantly higher at the South Pit; field capacity water content was higher at the Wilsall Pit. Data for the comparison of the two gravel pits and *t*-test results may be be found in Appendix D.

Table 14. Comparison of the Two Gravel Pits.

Life form	South pit	Wilsall pit
	Cover (%)	
Ag. spic.	15.2 ± 4.3 (S.D.)	14.8 ± 12.5 (S.D.)
Per gr	29.1 ± 6.8	32.5 ± 19.4
Forb	36.0 ±13.7 A*	67.3 ± 23.0 B
Total	62.2 ± 7.6 A	78.3 ± 12.2 B
	Production (g/400 cm^2)	
Per gr	2.47 ± 0.84	3.56 ± 3.07
Ann gr	0.64 ± 0.64 B	0.05 ± 0.08 A
Forb	1.57 ± 0.66 B	9.84 ± 7.29 A
Total	4.68 ± 0.99 B	13.45 ± 6.35 A
	Soil Factors	
Sand (%)**	80.9	57.0
Rock(%)**	66.2	43.5
B.D. (g/cc)**	2.00	1.71
θ_mF.C. (%)	4.0 ± 1.0 A	15.9 ± 6.1 B
N (mg/kg)	12.2 ± 17.2 A	1.8 ± 2.3 B
P (mg/kg)	60.0 ± 71.3	27.8 ± 33.9
K (mg/kg)	416 ± 489	297 ± 319
O.M. (%)	4.0 ± 1.5 A	1.2 ± 1.0 B

* Means followed by different letters in the same row are significantly different at $p < 0.10$.
** Pre-construction

CONCLUSIONS AND RECOMMENDATIONS

For perennial grass establishment in a gravel pit where cover soil materials are not available, any of the four amendments from this study would produce greater cover and production than none. The compost and manure plots in this study provided the highest cover values for *Agropyron spicatum*. The value of manure amendments and composted sewage sludge amendments was supported in Hornick's (1986) study of grain nitrogen content and vegetative growth of corn on reclaimed sand and gravel spoils.

Cow-calf ranches exist within a short distance of many gravel pits in Montana. These ranchers often need a place to dispose of excess manure. Cooperative arrangements between gravel pit owners and ranchers could lead to better reclamation of the pits at a very low cost. One drawback to the use of manure would be possible importation of weed seeds, although weeds specifically imported from the manure were not a problem in this study.

The South Pit disturbance (approximately 7 acres) could be amended in one day (Pierce 1995). Incorporation would require three passes with the grader if the amendment had previously been spread over the site, e.g. with a manure spreader. The first pass would rip and furrow the soil. On the next two passes the grader would blend the amendment into the soil and rip out any compaction.

Suitable compost materials are more difficult to obtain. At the time of this study the City of Bozeman Landfill used all of their compost, either to reclaim their own slopes or to give to homeowners for landscaping or vegetable gardens. Landfill staff are careful in their construction of compost piles, so sufficient heat is generated to support the microbes that compost the organic materials. Most weed seeds are no longer viable as a result of this process.

Weeds can be a serious problem in reclaiming gravel pits. Weed control should be practiced around an active pit or across the entire property if the pit is temporarily not in use. At the time of reclamation and during the early years of plant establishment, weed control should be part of the land management plan. The Montana Opencut Mining Bureau requires weed control until plants get established at a reclaimed pit.

The warm-season grass, *Sporobolus cryptandrus* (sand dropseed), was found primarily at the South Pit where a higher sand content and lower water-holding capacity provided better growth conditions for this species than the Wilsall Pit. Also, the surrounding area may have provided a seed source for this species. Although the *Sporobolus* plants were still small and primarily vegetative in this second growth season, they were likely expending most of their energy developing roots deep in the soil (Miller 1996).

A need exists for further research about the use of warm-season grasses as reclamation species for gravel pits. Many of these grasses are uniquely adapted to coarse-textured soils and dry conditions. Valuable information about grass species' performance could be acquired by planting separate stands of cool-season grasses and separate stands of warm season grasses at a gravel pit. Mixtures of both types of grasses tend to result in poor establishment of warm-season native grasses (Miller 1996).

Finally, this study needs further monitoring to determine whether results for perennial grass survival change from the initial plant establishment. After the second-season cover and biomass measurements were made, the Park County Weed Supervisor sprayed both properties, including the test plots, with a Tordon/ 2,4-D mixture. Treatment differences for grasses may be more significant in the absence of weeds. Also, at the South Pit *Sporobolus cryptandrus* may develop increased cover and production after the plants produce seed.

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APPENDIX A

Vegetation Cover

Table 15 South Pit Cover Plot 1 Wood Chip

July 20-21,1996		20cm x 50cm frame											
Per.gr. cool		1	2	3	4	5	6	7	8	9	10	Mean	Std.dev
Ag cri	*Agropyron cristatum*	2.5	37.5	15.0	37.5	37.5	0.0	0.0	2.5	0.0	0.0	13.3	17.3
Ag das	*A. dasystachyum*								15.0	15.0			
Ag spi	*A. spicatum*	37.5	0.0	0.0	15.0	15.0	2.5	0.0	0.0	37.5	2.5	11.0	15.1
Ag tra	*A. trachycaulum*						15.0				15.0		
Or hy	*Oryzopsis hymenoides*												
Po co	*Poa compressa*		2.5	37.5	2.5							4.3	20.2
Po pr	*P. pratensis*								2.5				
St co	*Stipa comata*												
Sum, per.gr.cool		40.0	40.0	52.5	55.0	52.5	17.5	0.0	20.0	52.5	17.5	34.8	19.5
Per.gr. warm													
Sp cr	*Sporobolus cryptandrus*	0.0	0.0	0.0	15.0	0.0	0.0	37.5	15.0	2.5	37.5	10.8	15.3
Sum, warm+cool gr.		40.0	40.0	52.5	70.0	52.5	17.5	37.5	35.0	55.0	55.0	45.5	14.5
Annual grass													
Br te	*Bromus tectorum*	0.0	2.5	0.0	2.5	2.5	2.5	15.0	15.0	2.5	15.0	5.8	6.5
Forbs & Legumes													
Lo co	*Lotus corniculatus*	2.5	2.5		2.5								
Me of	*Melilotus officinalis*	37.5	2.5	62.5	37.5	15.0	0.0	0.0	0.0	0.0	0.0	15.5	22.5
Me lu	*Medicago lupulina*						15.0	2.5		15.0			
Li le	*Linum lewisii*	15.0	0.0	0.0	0.0	15.0	15.0	0.0	0.0	2.5	37.5	8.5	12.3
He vi	*Heterotheca villosa*		37.5	2.5									
Tr du	*Tragopogon dubius*												
Ve th	*Verbascum thapsus*									2.5			
Si al	*Sisymbrium altissimum*												
Al al	*Alyssum alyssoides*			15.0	2.5								
Li pu	*Liatris punctata*												
Ko sc	*Kochia scoparia*												
Ch be	*Chenopodium berlandieri*												
Sa ka	*Salsola kali*												
Ve br	*Verbena bracteata*												
Ar ca	*Artemisia campestris*	2.5					15.0						
Sum, forb & leg.		57.5	42.5	80.0	42.5	30.0	45.0	2.5	0.0	20.0	37.5	35.8	24.2
Bare ground		37.5	15.0	15.0	15.0	37.5	37.5	37.5	62.5	37.5	15.0	31.0	15.7
Litter		15.0	15.0	2.5	2.5	2.5	37.5	15.0	37.5	15.0	15.0	15.8	12.8
Total foliar cover		62.5	85.0	85.0	85.0	62.5	62.5	62.5	37.5	62.5	85.0	69.0	15.7

Table 16 South Pit Cover Plot 2 Manure
July 20-21,1996 20cm x 50cm frame

Per.gr. cool	1	2	3	4	5	6	7	8	9	10	Mean	Std.dev
Ag cri			37.5		15.0		15.0					
Ag das												
Ag spi	15.0	2.5	0.0	15.0	15.0	15.0	2.5	15.0	15.0	15.0	11.0	6.5
Ag tra												
Or hy												
Po co					15.0	2.5						
Po pr												
St co												
Sum, per.gr.cool	15.0	2.5	37.5	15.0	45.0	17.5	17.5	15.0	15.0	15.0	19.5	12.3
Per.gr. warm												
Sp cr	0.0	15.0	2.5	15.0	2.5	15.0	37.5	15.0	15.0	2.5	12.0	11.1
Sum, warm+cool g	15.0	17.5	40.0	30.0	47.5	32.5	55.0	30.0	30.0	17.5	31.5	13.1
Annual grass												
Br te	37.5	62.5	62.5	2.5	15.0	37.5	37.5	15.0	37.5	85.0	39.3	25.2
Forbs & Legumes												
Lo co												
Me of		15.0						37.5				
Me lu	2.5											
Li le												
He vi												
Tr du												
Ve th												
Si al	2.5			15.0					37.5			
Al al	0.0	2.5	0.0	15.0	15.0	2.5	2.5	0.0	0.0	2.5	4.0	5.9
Li pu												
Ko sc			15.0						2.5		1.8	8.8
Ch be												
Sa ka												
Ve br	2.5	15.0	0.0	15.0	2.5	15.0	15.0	15.0	0.0	0.0	8.0	7.4
Ar ca						2.5						
Sum, forb & leg.	7.5	32.5	15.0	45.0	17.5	20.0	17.5	52.5	40.0	2.5	25.0	16.6
Bare ground	15.0	37.5	15.0	37.5	37.5	37.5	37.5	37.5	37.5	15.0	30.8	10.9
Litter	15.0	15.0	2.5	2.5	15.0	15.0	2.5	2.5	15.0	15.0	10.0	6.5
Total foliar cov	85.0	62.5	85.0	62.5	62.5	62.5	62.5	62.5	62.5	85.0	69.3	10.9

Table 17 South Pit Cover Plot 3 Control
July 20-21,1996 20cm x 50cm frame

Per.gr. cool	1	2	3	4	5	6	7	8	9	10	Mean	Std.d
Ag cri			15.0				15.0	2.5				
Ag das												
Ag spi	15.0	15.0	0.0	15.0	2.5	15.0	15.0	0.0	15.0	37.5	13.0	10.9
Ag tra												
Or hy												
Po co	0.0	0.0	0.0	0.0	0.0	2.5	15.0	2.5	15.0	0.0	3.5	6.1
Po pr												
St co	2.5											
Sum, per.gr.cool	17.5	15.0	15.0	15.0	2.5	17.5	45.0	5.0	30.0	37.5	20.0	13.5
Per.gr. warm												
Sp cr	2.5	15.0	0.0	15.0	15.0	15.0	15.0	2.5	0.0	15.0	9.5	7.1
Sum, warm+cool g	20.0	30.0	15.0	30.0	17.5	32.5	60.0	7.5	30.0	52.5	29.5	16.3
Annual grass												
Br te	15.0	0.0	15.0	37.5	15.0	37.5	2.5	0.0	0.0	0.0	12.3	14.9
Forbs & Legumes												
Lo co	2.5	2.5				2.5						
Me of	0.0	0.0	0.0	0.0	0.0	15.0	15.0	37.5	37.5	15.0	12.0	15.1
Me lu										15.0		
Li le	2.5	2.5	0.0	15.0	15.0	37.5	2.5	15.0	15.0	2.5	10.8	11.4
He vi			62.5									
Tr du												
Ve th							15.0	2.5				
Si al	15.0	0.0	0.0	15.0	37.5	37.5	0.0	0.0	0.0	0.0	10.5	15.5
Al al	2.5	15.0	37.5	15.0	15.0	0.0	2.5	0.0	0.0	15.0	10.3	11.9
Li pu												
Ko sc					2.5							
Ch be												
Sa ka												
Ve br									2.5			
Ar ca						2.5						
Sum, forb & leg.	22.5	20.0	100.0	45.0	70.0	95.0	35.0	55.0	55.0	47.5	54.5	27.3
Bare ground	37.5	62.5	15.0	37.5	37.5	15.0	15.0	37.5	37.5	37.5	33.3	14.8
Litter	2.5	2.5	15.0	2.5	15.0	2.5	2.5	2.5	2.5	2.5	5.0	5.3
Total foliar cov	62.5	37.5	85.0	62.5	62.5	85.0	85.0	62.5	62.5	62.5	66.8	14.8

Table 18	South Pit Cover Plot 4 NPK Fertilizer											
July 20-21,1996	20cm x 50cm frame											
Per.gr. cool	1	2	3	4	5	6	7	8	9	10	Mean	Std.d
Ag cri												
Ag das						15.0						
Ag spi	2.5	15.0	15.0	15.0	15.0	15.0	37.5	15.0	37.5	15.0	18.3	10.9
Ag tra				15.0								
Or hy												
Po co												
Po pr												
St co												
Sum, per.gr.cool	2.5	15.0	15.0	30.0	15.0	30.0	37.5	15.0	37.5	15.0	21.3	11.7
Per.gr. warm												
Sp cr	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.5	0.0	0.0	0.3	0.8
Sum, warm+cool g	2.5	15.0	15.0	30.0	15.0	30.0	37.5	17.5	37.5	15.0	21.5	11.6
Annual grass												
Br te	15.0	0.0	15.0	0.0	0.0	2.5	15.0	2.5	0.0	2.5	5.3	6.8
Forbs & Legumes												
Lo co												
Me of	15.0	62.5	37.5	37.5	37.5	62.5	15.0	2.5	15.0	15.0	30.0	20.9
Me lu								15.0	15.0	2.5	3.3	7.2
Li le	2.5	0.0	0.0	15.0	2.5	0.0	0.0	0.0	0.0	2.5	2.3	4.6
He vi												
Tr du												
Ve th									2.5			
Si al												
Al al					2.5	2.5						
Li pu												
Ko sc												
Ch be												
Sa ka												
Ve br												
Ar ca												
Sum, forb & leg.	17.5	62.5	37.5	52.5	42.5	65.0	15.0	17.5	32.5	20.0	36.3	19.0
Bare ground	62.5	37.5	37.5	37.5	37.5	37.5	62.5	62.5	62.5	62.5	50.0	13.2
Litter	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	0.0
Total foliar cov	37.5	62.5	62.5	62.5	62.5	62.5	37.5	37.5	37.5	37.5	50.0	13.2

Table 19 South Pit Cover Plot 5 Compost
July 20-21,1996 20cm x 50cm frame

Per.gr. cool	1	2	3	4	5	6	7	8	9	10	Mean	Std.dev
Ag cri												
Ag das				2.5	37.5							
Ag spi	15.0	37.5	37.5	15.0	37.5	37.5	0.0	0.0	15.0	15.0	21.0	15.3
Ag tra									2.5			
Or hy												
Po co									2.5			
Po pr												
St co												
Sum, per.gr.cool	15.0	37.5	37.5	17.5	75.0	37.5	0.0	0.0	20.0	15.0	25.5	22.4
Per.gr. warm												
Sp cr	0.0	0.0	2.5	0.0	0.0	2.5	15.0	0.0	0.0	0.0	2.0	4.7
Sum, warm+cool g	15.0	37.5	40.0	17.5	75.0	40.0	15.0	0.0	20.0	15.0	27.5	21.2
Annual grass												
Br te	15.0	2.5	0.0	0.0	0.0	0.0	0.0	15.0	0.0	2.5	3.5	6.1
Forbs & Legumes												
Lo co												
Me of	15.0	15.0	15.0	37.5	15.0	15.0	15.0	15.0	37.5	15.0	19.5	9.5
Me lu												
Li le	0.0	15.0	0.0	2.5	2.5	0.0	0.0	0.0	2.5	2.5	2.5	4.6
He vi							2.5	2.5				
Tr du												
Ve th												
Si al												
Al al	2.5	0.0	0.0	2.5	0.0	2.5	37.5	15.0	0.0	0.0	6.0	12.0
Li pu												
Ko sc												
Ch be												
Sa ka								2.5				
Ve br				2.5								
Ar ca	15.0											
Sum, forb & leg.	32.5	30.0	15.0	45.0	17.5	17.5	55.0	35.0	40.0	17.5	30.5	13.6
Bare ground	37.5	37.5	62.5	37.5	37.5	37.5	62.5	62.5	15.0	62.5	45.3	16.3
Litter	2.5	2.5	2.5	2.5	15.0	2.5	2.5	15.0	2.5	2.5	5.0	5.3
Total foliar cov	62.5	62.5	37.5	62.5	62.5	62.5	37.5	37.5	85.0	37.5	54.8	16.3

Table 20	South Pit Cover	Plot 6	Wood Chip									
July 20-21,1996	20cm x 50cm frame											
Per.gr. cool	1	2	3	4	5	6	7	8	9	10	Mean	Std.dev
Ag cri	15.0	0.0	2.5	0.0	15.0	37.5	0.0	62.5	62.5	0.0	19.5	25.5
Ag das						15.0						
Ag spi	15.0	15.0	2.5	15.0	2.5	15.0	2.5	0.0	0.0	37.5	10.5	11.7
Ag tra				2.5								
Or hy			15.0									
Po co							2.5					
Po pr												
St co												
Sum, per.gr.cool	30.0	15.0	20.0	17.5	17.5	67.5	5.0	62.5	62.5	37.5	33.5	22.9
Per.gr. warm												
Sp cr	2.5	2.5	2.5	0.0	2.5	0.0	2.5	15.0	15.0	15.0	5.8	6.5
Sum, warm+cool g	32.5	17.5	22.5	17.5	20.0	67.5	7.5	77.5	77.5	52.5	39.3	27.0
Annual grass												
Br te	2.5	85.0	15.0	0.0	37.5	2.5	2.5	2.5	2.5	2.5	15.3	27.0
Forbs & Legumes												
Lo co												
Me of	0.0	0.0	0.0	0.0	15.0	0.0	2.5	15.0	15.0	37.5	8.5	12.3
Me lu				2.5			2.5		15.0			
Li le	15.0	0.0	15.0	15.0	15.0	15.0	37.5	2.5	2.5	15.0	13.3	10.6
He vi												
Tr du												
Ve th												
Si al												
Al al	0.0	0.0	2.5	2.5	2.5	0.0	0.0	2.5	0.0	2.5	1.3	1.3
Li pu												
Ko sc												
Ch be												
Sa ka												
Ve br												
Ar ca		2.5										
Sum, forb & leg.	15.0	2.5	17.5	20.0	32.5	15.0	42.5	20.0	32.5	55.0	25.3	15.4
Bare ground	15.0	15.0	37.5	37.5	37.5	37.5	37.5	37.5	37.5	15.0	30.8	10.9
Litter	15.0	15.0	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	5.0	5.3
Total foliar cov	85.0	85.0	62.5	62.5	62.5	62.5	62.5	62.5	62.5	85.0	69.3	10.9

Table 21 South Pit Cover Plot 7 Compost
July 20-21,1996 20cm x 50cm frame

Per.gr. cool	1	2	3	4	5	6	7	8	9	10	Mean	Std.dev
Ag cri								2.5	2.5			
Ag das												
Ag spi	15.0	15.0	15.0	37.5	2.5	62.5	2.5	2.5	2.5	15.0	17.0	19.3
Ag tra								2.5				
Or hy				15.0								
Po co	2.5	15.0	15.0	0.0	15.0	15.0	2.5	0.0	0.0	0.0	6.5	7.4
Po pr												
St co												
Sum, per.gr.cool	17.5	30.0	30.0	52.5	17.5	77.5	5.0	7.5	5.0	15.0	25.8	23.3
Per.gr. warm												
Sp cr	15.0	0.0	2.5	15.0	15.0	2.5	2.5	15.0	2.5	2.5	7.3	6.7
Sum, warm+cool g	32.5	30.0	32.5	67.5	32.5	80.0	7.5	22.5	7.5	17.5	33.0	23.7
Annual grass												
Br te	15.0	37.5	15.0	15.0	15.0	2.5	15.0	37.5	62.5	62.5	27.8	21.2
Forbs & Legumes												
Lo co												
Me of		15.0				2.5						
Me lu					15.0			15.0				
Li le	15.0	2.5	0.0	15.0	15.0	2.5	15.0	15.0	0.0	0.0	8.0	7.4
He vi												
Tr du												
Ve th						2.5						
Si al									15.0			
Al al	2.5	15.0	2.5	2.5	2.5	2.5	2.5	15.0	0.0	2.5	4.8	5.5
Li pu			15.0									
Ko sc												
Ch be												
Sa ka												
Ve br												
Ar ca			2.5	2.5			15.0					
Sum, forb & leg.	17.5	32.5	20.0	20.0	32.5	10.0	32.5	45.0	15.0	2.5	22.8	12.7
Bare ground	15.0	15.0	37.5	15.0	37.5	37.5	37.5	37.5	37.5	37.5	30.8	10.9
Litter	15.0	15.0	2.5	2.5	2.5	15.0	15.0	15.0	15.0	15.0	11.3	6.0
Total foliar cov	85.0	85.0	62.5	85.0	62.5	62.5	62.5	62.5	62.5	62.5	69.3	10.9

Table 22	South Pit Cover	Plot 8	Control								
July 20-21,1996	20cm x 50cm frame										
Per.gr. cool	1	2	3	4	5	6	7	8	9	10	Mean	Std.dev
Ag cri												
Ag das												
Ag spi	15.0	15.0	15.0	0.0	2.5	15.0	15.0	15.0	2.5	37.5	13.3	10.6
Ag tra												
Or hy												
Po co	15.0											
Po pr												
St co												
Sum, per.gr.cool	30.0	15.0	15.0	0.0	2.5	15.0	15.0	15.0	2.5	37.5	14.8	11.9
Per.gr. warm												
Sp cr												
Sum, warm+cool g	30.0	15.0	15.0	0.0	2.5	15.0	15.0	15.0	2.5	37.5	14.8	11.9
Annual grass												
Br te					2.5							
Forbs & Legumes												
Lo co												
Me of	37.5	37.5	37.5	37.5	15.0	37.5	62.5	62.5	62.5	62.5	45.3	16.3
Me lu	0.0	0.0	0.0	2.5	15.0	15.0	0.0	2.5	0.0	0.0	3.5	6.1
Li le	15.0	15.0	15.0	2.5	0.0	0.0	2.5	0.0	0.0	0.0	5.0	7.0
He vi												
Tr du												
Ve th												
Si al												
Al al										2.5		
Li pu												
Ko sc												
Ch be												
Sa ka												
Ve br												
Ar ca									15.0			
Sum, forb & leg.	52.5	52.5	52.5	42.5	30.0	52.5	65.0	65.0	77.5	65.0	55.5	13.4
Bare ground	37.5	62.5	62.5	62.5	62.5	37.5	37.5	62.5	37.5	37.5	50.0	13.2
Litter	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	0.0
Total foliar cov	62.5	37.5	37.5	37.5	37.5	62.5	62.5	37.5	62.5	62.5	50.0	13.2

Table 23 South Pit Cover Plot 9 NPK Fertilizer
July 20-21,1996 20cm x 50cm frame

Per.gr. cool	1	2	3	4	5	6	7	8	9	10	Mean	Std.dev
Ag cri												
Ag das												
Ag spi	15.0	15.0	15.0	15.0	37.5	15.0	37.5	15.0	15.0	15.0	19.5	9.5
Ag tra												
Or hy												
Po co										15.0		
Po pr												
St co												
Sum, per.gr.cool	15.0	15.0	15.0	15.0	37.5	15.0	37.5	15.0	15.0	30.0	21.0	9.9
Per.gr. warm												
Sp cr												
Sum, warm+cool g	15.0	15.0	15.0	15.0	37.5	15.0	37.5	15.0	15.0	30.0	21.0	9.9
Annual grass												
Br te	2.5	0.0	0.0	2.5	0.0	2.5	0.0	2.5	2.5	2.5	1.5	1.3
Forbs & Legumes												
Lo co												
Me of	37.5	62.5	37.5	15.0	15.0	62.5	37.5	37.5	15.0	0.0	32.0	20.7
Me lu			15.0							2.5	1.8	8.8
Li le	0.0	2.5	0.0	0.0	15.0	0.0	0.0	15.0	15.0	0.0	4.8	7.1
He vi												
Tr du												
Ve th												
Si al												
Al al	0.0	0.0	0.0	15.0	0.0	2.5	2.5	0.0	2.5	2.5	2.5	4.6
Li pu												
Ko sc												
Ch be												
Sa ka												
Ve br												
Ar ca			15.0		2.5							
Sum, forb & leg.	37.5	65.0	67.5	30.0	32.5	65.0	40.0	52.5	32.5	5.0	42.8	19.8
Bare ground	62.5	37.5	37.5	37.5	37.5	37.5	37.5	37.5	37.5	62.5	42.5	10.5
Litter	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	0.0
Total foliar cov	37.5	62.5	62.5	62.5	62.5	62.5	62.5	62.5	62.5	37.5	57.5	10.5

Table 24	South Pit Cover	Plot 10	Manure								
July 20-21,1996	20cm x 50cm frame										
Per.gr. cool	1	2	3	4	5	6	7	8	9	10	Mean	Std.dev
Ag cri												
Ag das												
Ag spi	37.5	37.5	2.5	37.5	37.5	15.0	37.5	15.0	15.0	15.0	25.0	13.7
Ag tra												
Or hy												
Po co					15.0	2.5	37.5					
Po pr	2.5											
St co												
Sum, per.gr.cool	40.0	37.5	2.5	37.5	52.5	17.5	75.0	15.0	15.0	15.0	30.8	21.9
Per.gr. warm												
Sp cr	15.0	2.5	0.0	0.0	0.0	2.5	0.0	0.0	2.5	15.0	3.8	6.0
Sum, warm+cool g	55.0	40.0	2.5	37.5	52.5	20.0	75.0	15.0	17.5	30.0	34.5	22.0
Annual grass												
Br te	15.0	15.0	15.0	15.0	15.0	0.0	15.0	15.0	15.0	2.5	12.3	5.8
Forbs & Legumes												
Lo co												
Me of	15.0	15.0		15.0								
Me lu					2.5					15.0		
Li le	0.0	0.0	0.0	0.0	2.5	15.0	0.0	0.0	2.5	15.0	3.5	6.1
He vi						2.5	2.5					
Tr du												
Ve th												
Si al												
Al al	15.0	15.0	15.0	15.0	2.5	2.5	2.5	15.0	2.5	0.0	8.5	6.9
Li pu												
Ko sc												
Ch be												
Sa ka												
Ve br			37.5									
Ar ca										2.5		
Sum, forb & leg.	30.0	30.0	52.5	30.0	7.5	20.0	5.0	15.0	5.0	32.5	22.8	15.2
Bare ground	37.5	37.5	62.5	62.5	15.0	37.5	15.0	62.5	37.5	37.5	40.5	17.6
Litter	2.5	15.0	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	3.8	4.0
Total foliar cov	62.5	62.5	37.5	37.5	85.0	62.5	85.0	37.5	62.5	62.5	59.5	17.6

Table 25 South Pit Cover Plot 11 Wood Chip
July 20-21,1996 20cm x 50cm frame

Per.gr. cool	1	2	3	4	5	6	7	8	9	10	Mean	Std.dev
Ag cri	37.5			15.0					15.0			
Ag das		15.0		15.0				15.0				
Ag spi	0.0	15.0	0.0	0.0	15.0	15.0	15.0	2.5	2.5	15.0	8.0	7.4
Ag tra					2.5							
Or hy									15.0			
Po co								15.0				
Po pr												
St co					2.5							
Sum, per.gr.cool	37.5	30.0	0.0	30.0	20.0	15.0	15.0	32.5	32.5	15.0	22.8	11.6
Per.gr. warm												
Sp cr	2.5	0.0	15.0	0.0	2.5	0.0	0.0	0.0	15.0	15.0	5.0	7.0
Sum, warm+cool g	40.0	30.0	15.0	30.0	22.5	15.0	15.0	32.5	47.5	30.0	27.8	11.0
Annual grass												
Br te	2.5	15.0	2.5	0.0	2.5	37.5	2.5	2.5	2.5	15.0	8.3	11.6
Forbs & Legumes												
Lo co												
Me of	0.0	0.0	62.5	15.0	0.0	0.0	15.0	2.5	0.0	0.0	9.5	19.6
Me lu	0.0	15.0	15.0	15.0	15.0	0.0	15.0	0.0	0.0	0.0	7.5	7.9
Li le	0.0	2.5	0.0	2.5	15.0	0.0	0.0	15.0	0.0	2.5	3.8	6.0
He vi												
Tr du			15.0									
Ve th												
Si al												
Al al									15.0	15.0	3.0	0.0
Li pu												
Ko sc												
Ch be												
Sa ka						2.5				2.5		
Ve br			85.0		15.0							
Ar ca												
Sum, forb & leg.	0.0	17.5	177.5	32.5	45.0	2.5	30.0	17.5	15.0	20.0	35.8	51.6
Bare ground	62.5	37.5	15.0	37.5	37.5	37.5	62.5	62.5	62.5	15.0	43.0	18.9
Litter	2.5	2.5	2.5	2.5	2.5	2.5	2.5	15.0	15.0	15.0	6.3	6.0
Total foliar cov	37.5	62.5	85.0	62.5	62.5	62.5	37.5	37.5	37.5	85.0	57.0	18.9

Table 26	South Pit Cover	Plot 12	Compost								
July 20-21,1996	20cm x 50cm frame										
Per.gr. cool	1	2	3	4	5	6	7	8	9	10	Mean	Std.dev
Ag cri	85.0	0.0	0.0	15.0	0.0	15.0	15.0	0.0	15.0	0.0	14.5	25.9
Ag das												
Ag spi	15.0	0.0	2.5	2.5	15.0	0.0	37.5	37.5	2.5	0.0	11.3	15.0
Ag tra					2.5							
Or hy												
Po co					2.5				2.5			
Po pr												
St co												
Sum, per.gr.cool	100.0	0.0	2.5	17.5	20.0	15.0	52.5	37.5	20.0	0.0	26.5	30.7
Per.gr. warm												
Sp cr	0.0	0.0	2.5	0.0	0.0	0.0	0.0	2.5	37.5	37.5	8.0	15.6
Sum, warm+cool g	100.0	0.0	5.0	17.5	20.0	15.0	52.5	40.0	57.5	37.5	34.5	30.0
Annual grass												
Br te	15.0	0.0	15.0	0.0	37.5	15.0	2.5	15.0	37.5	85.0	22.3	25.8
Forbs & Legumes												
Lo co			2.5									
Me of	15.0	0.0	15.0	0.0	0.0	2.5	2.5	15.0	0.0	0.0	5.0	7.0
Me lu	37.5	0.0	37.5	15.0	15.0	0.0	0.0	0.0	0.0	0.0	10.5	15.5
Li le	15.0	0.0	0.0	15.0	15.0	15.0	0.0	15.0	15.0	0.0	9.0	7.7
He vi												
Tr du												
Ve th			15.0				2.5					
Si al												
Al al	2.5	0.0	2.5	2.5	15.0	0.0	2.5	15.0	15.0	15.0	7.0	7.0
Li pu												
Ko sc												
Ch be												
Sa ka												
Ve br					15.0		2.5				1.8	8.8
Ar ca	2.5			2.5							0.5	0.0
Sum, forb & leg.	72.5	0.0	72.5	35.0	60.0	17.5	10.0	45.0	30.0	15.0	35.8	26.1
Bare ground	15.0	37.5	37.5	37.5	37.5	62.5	62.5	37.5	37.5	15.0	38.0	15.8
Litter	2.5	2.5	2.5	15.0	2.5	2.5	2.5	15.0	2.5	15.0	6.3	6.0
Total foliar cov	85.0	62.5	62.5	62.5	62.5	37.5	37.5	62.5	62.5	85.0	62.0	15.8

Table 27 South Pit Cover Plot 13 Manure
July 20-21,1996 20cm x 50cm frame

Per.gr. cool	1	2	3	4	5	6	7	8	9	10	Mean	Std.dev
Ag cri	15.0											
Ag das												
Ag spi	2.5	15.0	2.5	0.0	2.5	37.5	15.0	15.0	15.0	62.5	16.8	19.5
Ag tra							2.5					
Or hy												
Po co										2.5		
Po pr												
St co												
Sum, per.gr.cool	17.5	15.0	2.5	0.0	2.5	37.5	17.5	15.0	15.0	65.0	18.8	19.5
Per.gr. warm												
Sp cr	0.0	0.0	15.0	15.0	0.0	0.0	0.0	2.5	0.0	0.0	3.3	6.2
Sum, warm+cool g	17.5	15.0	17.5	15.0	2.5	37.5	17.5	17.5	15.0	65.0	22.0	17.3
Annual grass												
Br te	15.0	2.5	62.5	85.0	85.0	62.5	37.5	85.0	85.0	15.0	53.5	33.3
Forbs & Legumes												
Lo co												
Me of	15.0											
Me lu	2.5											
Li le												
He vi												
Tr du												
Ve th												
Si al				2.5		15.0						
Al al												
Li pu	15.0											
Ko sc	0.0	0.0	0.0	15.0	0.0	2.5	2.5	0.0	2.5	0.0	2.3	4.6
Ch be									2.5			
Sa ka	0.0	0.0	2.5	15.0	2.5	0.0	15.0	0.0	0.0	0.0	3.5	6.1
Ar ca	0.0	15.0	15.0	0.0	0.0	2.5	0.0	37.5	0.0	0.0	7.0	12.3
Sum, forb & leg.	32.5	15.0	17.5	32.5	2.5	20.0	17.5	37.5	5.0	0.0	18.0	13.1
Bare ground	37.5	37.5	37.5	15.0	15.0	37.5	37.5	15.0	15.0	37.5	28.5	11.6
Litter	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	15.0	2.5	3.8	4.0
Total foliar cov	62.5	62.5	62.5	85.0	85.0	62.5	62.5	85.0	85.0	62.5	71.5	11.6

Table 28	South Pit Cover	Plot 14	Control								
July 20-21,1996	20cm x 50cm frame										
Per.gr. cool	1	2	3	4	5	6	7	8	9	10	Mean	Std.dev
Ag cri												
Ag das												
Ag spi	15.0	15.0	2.5	15.0	37.5	15.0	15.0	15.0	15.0	2.5	14.8	9.5
Ag tra		2.5							2.5	2.5		
Or hy												
Po co	2.5					15.0	15.0					
Po pr												
St co												
Sum, per.gr.cool	17.5	17.5	2.5	15.0	37.5	30.0	30.0	15.0	17.5	5.0	18.8	11.0
Per.gr. warm												
Sp cr	2.5	2.5	2.5	0.0	2.5	0.0	0.0	2.5	2.5	0.0	1.5	1.3
Sum, warm+cool g	20.0	20.0	5.0	15.0	40.0	30.0	30.0	17.5	20.0	5.0	20.3	11.0
Annual grass												
Br te	2.5						2.5			2.5	0.8	0.0
Forbs & Legumes												
Lo co												
Me of	15.0	37.5	2.5	15.0	15.0	15.0	15.0	37.5	15.0	15.0	18.3	10.9
Me lu	37.5	0.0	37.5	15.0	15.0	15.0	37.5	15.0	15.0	62.5	25.0	18.3
Li le	2.5	0.0	15.0	15.0	0.0	2.5	0.0	15.0	0.0	0.0	5.0	7.0
He vi												
Tr du												
Ve th				15.0								
Si al												
Al al	2.5	0.0	0.0	0.0	0.0	0.0	2.5	0.0	2.5	2.5	1.0	1.3
Li pu												
Ko sc												
Ch be												
Sa ka										2.5		
Ar ca			2.5		15.0	2.5						
Sum, forb & leg.	57.5	37.5	57.5	60.0	45.0	35.0	55.0	67.5	32.5	82.5	53.0	15.7
Bare ground	37.5	37.5	37.5	37.5	37.5	37.5	37.5	37.5	37.5	37.5	37.5	0.0
Litter	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	0.0
Total foliar cov	62.5	62.5	62.5	62.5	62.5	62.5	62.5	62.5	62.5	62.5	62.5	0.0

Table 29 South Pit Cover Plot 15 NPK Fertilizer
July 20-21,1996 20cm x 50cm frame

Per.gr. cool	1	2	3	4	5	6	7	8	9	10	Mean	Std.dev
Ag cri												
Ag das	0.0	15.0	0.0	15.0	0.0	15.0	0.0	15.0	0.0	0.0	6.0	7.7
Ag spi	37.5	0.0	0.0	37.5	37.5	15.0	37.5	15.0	0.0	0.0	18.0	17.7
Ag tra								2.5	15.0		1.8	8.8
Or hy												
Po co			37.5	15.0								
Po pr												
St co												
Sum, per.gr.cool	37.5	15.0	37.5	67.5	37.5	30.0	37.5	32.5	15.0	0.0	31.0	18.2
Per.gr. warm												
Sp cr	2.5	0.0	15.0	0.0	15.0	0.0	0.0	0.0	0.0	2.5	3.5	6.1
Sum, warm+cool g	40.0	15.0	52.5	67.5	52.5	30.0	37.5	32.5	15.0	2.5	34.5	20.0
Annual grass												
Br te	15.0	2.5	0.0	0.0	0.0	2.5	15.0	0.0	2.5	2.5	4.0	5.9
Forbs & Legumes												
Lo co							2.5					
Me of	15.0	15.0	37.5	0.0	62.5	15.0	0.0	15.0	2.5	15.0	17.8	19.1
Me lu	37.5	0.0	15.0	0.0	15.0	15.0	0.0	15.0	37.5	15.0	15.0	13.7
Li le					15.0		15.0	2.5				
He vi												
Tr du												
Ve th												
Si al												
Al al	0.0	15.0	0.0	2.5	2.5	15.0	15.0	15.0	2.5	0.0	6.8	7.2
Li pu												
Ko sc												
Ch be												
Sa ka												
Ve br		2.5										
Ar ca	0.0	15.0	0.0	2.5	0.0	0.0	0.0	0.0	2.5	15.0	3.5	6.1
Sum, forb & leg.	52.5	47.5	52.5	5.0	95.0	45.0	32.5	47.5	45.0	45.0	46.8	22.0
Bare ground	37.5	37.5	37.5	37.5	37.5	15.0	37.5	37.5	37.5	37.5	35.3	7.1
Litter	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	0.0
Total foliar cov	62.5	62.5	62.5	62.5	62.5	85.0	62.5	62.5	62.5	62.5	64.8	7.1

Table 30 Wilsall Pit Cover Plot 1 Wood Chip

July 11-12,1996 20cm x 50cm frame

Per.gr. cool		1	2	3	4	5	6	7	8	9	10	Mean	Std.dev
Ag das	*Agropyron dasystachyum*												
Ag spi	*A. spicatum*	15.0	0.0	2.5	0.0	0.0	0.0	0.0	2.5	15.0	0.0	3.5	6.1
Ag tra	*A. trachycaulum*	2.5											
El ci	*Elymus cinerus*												
Ho ju	*Hordeum jubatum*	15.0	85.0	62.5	62.5	0.0	37.5	0.0	0.0	0.0	0.0	26.3	33.0
Po co	*Poa compressa*						15.0						
Ph pr	*Phleum pratense*												
Sum, per.gr.		32.5	85.0	65.0	62.5	0.0	52.5	0.0	2.5	15.0	0.0	31.5	32.5
Per.gr. warm													
Sp cr	*Sporobolus cryptandrus*			2.5									
Annual grass													
Br te	*Bromus tectorum*	2.5											
Forbs & Legumes													
Cy of	*Cynoglossum officinale*												
Be in	*Berteroa incana*												
Me of	*Melilotus officinalis*	0.0	0.0	2.5	15.0	85.0	15.0	0.0	0.0	37.5	0.0	15.5	27.3
Li le	*Linum lewisii*	0.0	0.0	15.0	2.5	0.0	15.0	0.0	0.0	15.0	2.5	5.0	7.0
Al al	*Alyssum alyssoides*												
Ko sc	*Kochia scoparia*	2.5											
Lo co	*Lotus corniculatus*	15.0	2.5	2.5	0.0	0.0	62.5	0.0	2.5	0.0	15.0	10.0	19.4
Ch be	*Chenopodium berlandieri*	2.5											
Ch al	*C. album*												
Ac mi	*Achillea millefolium*												
Si lo	*Sisymbrium loeselii*								2.5				
La se	*Lactuca serriola*												
Sa ka	*Salsola kali*						15.0	37.5	15.0				
Ci ar	*Cirsium arvense*												
Tr du	*Tragopogon dubius*												
Hy ni	*Hyoscyamus niger*												
Sum,forb & leg.		20.0	2.5	20.0	17.5	85.0	107.5	37.5	20.0	52.5	17.5	38.0	33.9
Bare ground		62.5	15.0	2.5	15.0	2.5	15.0	62.5	15.0	2.5	85.0	27.8	30.3
Litter		37.5	15.0	15.0	15.0	15.0	37.5	37.5	85.0	62.5	85.0	40.5	28.0
Total foliar cov.		37.5	85.0	85.0	85.0	97.5	85.0	37.5	37.5	62.5	15.0	62.8	28.6

Table 31	Wilsall Pit Cover		Plot 2	Manure							
July 11-12,1996	20cm x 50cm frame										
Per.gr. cool	1	2	3	4	5	6	7	8	9	10	Mean	Std.dev
Ag das												
Ag spi	0.0	15.0	2.5	37.5	15.0	0.0	0.0	37.5	0.0	2.5	11.0	15.1
Ag tra												
El ci												
Ho ju	15.0	0.0	2.5	0.0	15.0	15.0	37.5	0.0	37.5	15.0	13.8	14.3
Po co												
Ph pr		15.0										
Sum, per.gr.	15.0	30.0	5.0	37.5	30.0	15.0	37.5	37.5	37.5	17.5	26.3	12.1
Per.gr. warm												
Sp cr												
Annual grass												
Br te						2.5						
Forbs & Legumes												
Be in												
Caderia			62.5	2.5	15.0	2.5						
Me of	85.0	85.0	0.0	15.0	62.5	37.5	15.0	37.5	15.0	62.5	41.5	30.8
Li le	0.0	15.0	0.0	15.0	0.0	0.0	0.0	37.5	15.0	2.5	8.5	12.3
Al al			2.5									
Ko sc												
Lo co	0.0	0.0	15.0	2.5	0.0	0.0	0.0	0.0	85.0	15.0	11.8	26.5
Ch be												
Ch al					2.5	15.0	15.0	2.5	2.5	37.5	7.5	13.7
Ac mi					2.5							
Si lo	15.0		2.5	2.5								
La se	15.0											
Sa ka												
Ci ar												
Tr du												
Hy ni										15.0		
Sum,forb & leg.	115.0	100.0	82.5	37.5	82.5	55.0	30.0	77.5	117.5	132.5	83.0	34.4
Bare ground	2.5	2.5	15.0	37.5	2.5	2.5	15.0	2.5	2.5	2.5	8.5	11.4
Litter	15.0	15.0	37.5	37.5	15.0	37.5	37.5	15.0	15.0	15.0	24.0	11.6
Total foliar cov.	97.5	97.5	85.0	37.5	97.5	85.0	85.0	97.5	97.5	97.5	87.8	18.6

Table 32 Wilsall Pit Cover Plot 3 NPK Fertilizer

July 11-12,1996

Per.gr. cool	1	2	3	4	5	6	7	8	9	10	Mean	Std.dev.
Ag das					62.5							
Ag spi	0.0	0.0	2.5	2.5	0.0	0.0	2.5	0.0	0.0	15.0	2.3	4.6
Ag tra		15.0										
El ci												
Ho ju	85.0	85.0	62.5	62.5	0.0	85.0	97.5	85.0	15.0	15.0	59.3	35.8
Po co												
Ph pr												
Sum, per.gr.	85.0	100.0	65.0	65.0	62.5	85.0	100.0	85.0	15.0	30.0	69.3	28.3
Per.gr. warm												
Sp cr												
Annual grass												
Br te								2.5	2.5	2.5		
Se ce												
Forbs & Legumes												
Be in				2.5								
Caderia												
Me of	37.5	0.0	62.5	0.0	37.5	37.5	2.5	15.0	15.0	15.0	22.3	20.7
Li le	0.0	2.5	2.5	2.5	2.5	0.0	0.0	15.0	0.0	0.0	2.5	4.6
Al al												
Ko sc												
Lo co	2.5	15.0	2.5	2.5	0.0	0.0	0.0	2.5	2.5	0.0	2.8	4.5
Ch be												
Ch al									2.5			
Ac mi												
Si lo									2.5			
La se												
Sa ka									2.5	2.5		
Ci ar												
Tr du												
Hy ni												
Sum,forb & leg.	40.0	17.5	67.5	7.5	40.0	37.5	2.5	32.5	25.0	17.5	28.8	19.0
Bare ground	15.0	2.5	15.0	37.5	15.0	2.5	2.5	15.0	62.5	62.5	23.0	23.2
Litter	37.5	15.0	15.0	15.0	15.0	37.5	15.0	15.0	2.5	2.5	17.0	11.9
Total foliar cov.	85.0	97.5	85.0	62.5	85.0	97.5	97.5	85.0	37.5	37.5	77.0	23.2

Table 33	Wilsall Pit Cover Plot 4 Control											
July 11-12,1996	20cm x 50cm frame											
Per.gr. cool	1	2	3	4	5	6	7	8	9	10	Mean	Std.dev.
Ag das								15.0				
Ag spi	0.0	15.0	15.0	0.0	2.5	0.0	0.0	0.0	2.5	2.5	3.8	6.0
Ag tra									2.5	37.5		
El ci												
Ho ju									2.5			
Po co												
Ph pr												
Sum, per.gr.	0.0	15.0	15.0	0.0	2.5	0.0	0.0	15.0	7.5	40.0	9.5	12.6
Per.gr. warm												
Sp cr												
Annual grass												
Br te												
Se ce										15.0		
Forbs & Legumes												
Be in												
Caderia												
Me of	62.5	85.0	85.0	37.5	85.0	62.5	0.0	0.0	0.0	0.0	41.8	38.7
Li le	0.0	0.0	0.0	2.5	0.0	15.0	2.5	37.5	0.0	0.0	5.8	12.1
Al al												
Ko sc												
Lo co												
Ch be												
Ch al												
Ac mi												
Si lo									2.5			
La se												
Sa ka		2.5				2.5			2.5			
Ci ar												
Tr du												
Hy ni												
Sum,forb & leg.	62.5	87.5	85.0	40.0	85.0	80.0	2.5	37.5	5.0	0.0	48.5	36.4
Bare ground	37.5	15.0	15.0	62.5	15.0	37.5	97.5	62.5	62.5	15.0	23.0	23.2
Litter	2.5	15.0	15.0	2.5	2.5	2.5	2.5	2.5	2.5	2.5	17.0	11.9
Total foliar cov.	62.5	85.0	85.0	37.5	85.0	62.5	2.5	37.5	37.5	85.0	77.0	23.2

Table 34 Wilsall Pit Cover Plot 5 Compost
July 11-12,1996 20cm x 50cm frame

Per.gr. cool	1	2	3	4	5	6	7	8	9	10	Mean	Std.dev.
Ag das	15.0								37.5			
Ag spi	2.5	15.0	15.0	0.0	15.0	2.5	15.0	62.5	15.0	62.5	20.5	23.0
Ag tra		2.5			37.5				37.5			
El ci												
Ho ju	0.0	0.0	0.0	15.0	2.5	15.0	2.5	15.0	0.0	0.0	5.0	7.0
Po co	37.5							2.5	2.5			
Ph pr												
Sum, per.gr.	55.0	17.5	15.0	15.0	55.0	17.5	17.5	80.0	92.5	62.5	42.8	29.8
Per.gr. warm												
Sp cr												
Annual grass												
Br te						2.5			2.5			
Forbs & Legumes												
Ga ap	2.5	2.5										
Caderia												
Me of	2.5	0.0	85.0	85.0	85.0	62.5	62.5	37.5	0.0	37.5	45.8	35.6
Li le	0.0	15.0	15.0	2.5	2.5	0.0	15.0	0.0	15.0	15.0	8.0	7.4
Al al						2.5						
Ko sc												
Lo co			2.5					2.5		15.0		
Ch be												
Ch al		2.5										
Ac mi												
Si lo		2.5										
Lupinus								2.5		2.5		
Sa ka			2.5									
Ci ar												
Tr du												
Hy ni												
Sum,forb & leg.	5.0	22.5	105.0	87.5	87.5	65.0	77.5	42.5	15.0	70.0	57.8	34.4
Bare ground	37.5	37.5	15.0	15.0	15.0	15.0	37.5	15.0	15.0	2.5	20.5	12.3
Litter	15.0	15.0	15.0	15.0	15.0	37.5	15.0	15.0	37.5	15.0	19.5	9.5
Total foliar cov.	62.5	62.5	85.0	85.0	85.0	85.0	62.5	85.0	85.0	97.5	79.5	12.3

Table 35	Wilsall Pit Cover Plot 6 Wood Chip											
July 11-12,1996	20cm x 50cm frame											
Per.gr. cool	1	2	3	4	5	6	7	8	9	10	Mean	Std.dev
Ag das				15.0								
Ag spi	37.5	15.0	0.0	0.0	2.5	15.0	15.0	2.5	0.0	15.0	10.3	11.9
Ag tra	0.0	15.0	15.0	0.0	15.0	0.0	15.0	0.0	0.0	0.0	6.0	7.7
El ci												
Ho ju	37.5	2.5	62.5	62.5	37.5	37.5	0.0	2.5	0.0	0.0	24.3	26.2
Po co										2.5		
Ph pr												
Sum, per.gr.	75.0	32.5	77.5	77.5	55.0	52.5	30.0	5.0	0.0	17.5	42.3	29.5
Per.gr. warm												
Sp cr												
Annual grass												
Br te	2.5	15.0	15.0									
Forbs & Legumes												
Ga ap												
Caderia		85.0										
Me of	0.0	0.0	62.5	0.0	85.0	97.5	85.0	85.0	37.5	85.0	53.8	40.6
Li le	0.0	0.0	15.0	2.5	15.0	15.0	0.0	0.0	0.0	15.0	6.3	7.6
Al al												
Ko sc												
Lo co				15.0								
Ch be									2.5			
Ch al												
Ac mi												
Si lo	37.5											
Lupinus												
Sa ka									2.5	2.5		
Ci ar												
Tr du												
Hy ni												
Sum,forb & leg.	37.5	85.0	77.5	17.5	100.0	112.5	85.0	85.0	42.5	102.5	74.5	31.4
Bare ground	15.0	2.5	2.5	2.5	2.5	2.5	15.0	15.0	62.5	15.0	13.5	18.3
Litter	15.0	15.0	15.0	37.5	15.0	15.0	15.0	15.0	2.5	15.0	16.0	8.5
Total foliar cov.	85.0	97.5	97.5	97.5	97.5	97.5	85.0	85.0	37.5	85.0	86.5	18.3

Table 36 Wilsall Pit Cover Plot 7 Compost
July 11-12,1996 20cm x 50cm frame

Per.gr. cool	1	2	3	4	5	6	7	8	9	10	Mean	Std.dev.
Ag das												
Ag spi	37.5	15.0	37.5	62.5	0.0	62.5	15.0	0.0	62.5	85.0	37.8	29.7
Ag tra												
El ci												
Ho ju	37.5	37.5	0.0	0.0	15.0	0.0	0.0	0.0	0.0	0.0	9.0	15.7
Po co												
Ph pr												
Sum, per.gr.	75.0	52.5	37.5	62.5	15.0	62.5	15.0	0.0	62.5	85.0	46.8	28.5
Per.gr. warm												
Sp cr												
Annual grass												
Br te				2.5	15.0	15.0	15.0					
Forbs & Legumes												
Be in												
Caderia				2.5	37.5							
Me of	0.0	15.0	85.0	2.5	15.0	0.0	85.0	0.0	15.0	37.5	25.5	33.4
Li le	15.0	0.0	15.0	2.5	15.0	0.0	15.0	0.0	2.5	37.5	10.3	11.9
Al al				2.5								
Ko sc								2.5				
Lo co				2.5	2.5							
Ch be												
Ch al												
Ac mi												
Si lo				2.5				15.0	2.5			
La se												
Sa ka				2.5				2.5				
Ci ar												
Tr du												
Hy ni												
Sum,forb & leg.	15.0	15.0	100.0	17.5	70.0	0.0	100.0	20.0	20.0	75.0	43.3	38.6
Bare ground	37.5	15.0	15.0	37.5	15.0	37.5	15.0	62.5	15.0	15.0	26.5	16.5
Litter	15.0	15.0	15.0	15.0	15.0	15.0	2.5	15.0	15.0	15.0	13.8	4.0
Total foliar cov.	62.5	85.0	85.0	62.5	85.0	62.5	85.0	37.5	85.0	85.0	73.5	16.5

Table 37	Wilsall Pit Cover Plot 8 Control											
July 11-12,1996	20cm x 50cm frame											
Per.gr. cool	1	2	3	4	5	6	7	8	9	10	Mean	Std.dev.
Ag das												
Ag spi	0.0	15.0	0.0	2.5	0.0	0.0	37.5	2.5	2.5	2.5	6.3	11.9
Ag tra	15.0											
El ci												
Ho ju												
Po co			2.5									
Ph pr												
Sum, per.gr.	15.0	15.0	2.5	2.5	0.0	0.0	37.5	2.5	2.5	2.5	8.0	11.8
Per.gr. warm												
Sp cr												
Annual grass												
Br te								2.5				
Forbs & Legumes												
Be in												
Caderia												
Me of	85.0	37.5	62.5	62.5	97.5	85.0	97.5	85.0	85.0	85.0	78.3	18.6
Li le	0.0	0.0	0.0	15.0	0.0	0.0	0.0	2.5	2.5	2.5	2.3	4.6
Al al												
Ko sc												
Lo co												
Ch be												
Ch al												
Ac mi												
Si lo												
La se												
Sa ka	0.0	15.0	2.5	0.0	2.5	2.5	0.0	15.0	0.0	2.5	4.0	5.9
Ci ar												
Tr du										15.0		
Hy ni												
Sum,forb & leg.	85.0	52.5	65.0	77.5	100.0	87.5	97.5	102.5	87.5	105.0	86.0	17.0
Bare ground	15.0	62.5	37.5	37.5	2.5	15.0	2.5	15.0	15.0	15.0	21.8	18.6
Litter	2.5	2.5	2.5	2.5	15.0	2.5	2.5	15.0	2.5	15.0	6.3	6.0
Total foliar cov.	85.0	37.5	62.5	62.5	97.5	85.0	97.5	85.0	85.0	85.0	78.3	18.6

Table 38 Wilsall Pit Cover Plot 9 NPK Fertilizer
July 11-12, 1996 20cm x 50cm frame

Per.gr. cool	1	2	3	4	5	6	7	8	9	10	Mean	Std.dev.
Ag das												
Ag spi	0.0	15.0	15.0	15.0	0.0	0.0	0.0	37.5	0.0	2.5	8.5	12.3
Ag tra	0.0	2.5	0.0	2.5	15.0	0.0	0.0	0.0	15.0	0.0	3.5	6.1
El ci												
Ho ju	2.5	0.0	15.0	0.0	15.0	15.0	15.0	2.5	15.0	2.5	8.3	7.2
Po co												
Ph pr												
Sum, per.gr.	2.5	17.5	30.0	17.5	30.0	15.0	15.0	40.0	30.0	5.0	20.3	12.0
Per.gr. warm												
Sp cr												
Annual grass												
Br te	2.5				2.5							
Forbs & Legumes												
Be in		2.5	2.5							15.0		
Caderia		2.5										
Me of	85.0	97.5	37.5	85.0	37.5	62.5	97.5	37.5	85.0	85.0	71.0	25.0
Li le	0.0	0.0	0.0	0.0	0.0	15.0	0.0	15.0	2.5	2.5	3.5	6.1
Al al												
Ko sc												
Lo co						2.5						
Ch be												
Ch al												
Ac mi												
Si lo												
La se												
Sa ka	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	0.0	2.3	0.8
Ci ar												
Tr du												
Hy ni					15.0							
Sum,forb & leg.	87.5	105.0	42.5	87.5	55.0	82.5	100.0	55.0	90.0	102.5	80.8	22.1
Bare ground	15.0	2.5	37.5	15.0	15.0	15.0	2.5	15.0	2.5	15.0	13.5	10.3
Litter	37.5	15.0	15.0	15.0	15.0	15.0	15.0	15.0	37.5	37.5	21.8	10.9
Total foliar cov.	85.0	97.5	62.5	85.0	85.0	85.0	97.5	85.0	97.5	85.0	86.5	10.3

Table 39	Wilsall Pit Cover Plot 10 Manure											
July 11-12, 1996	20cm x 50cm frame											
Per.gr. cool	1	2	3	4	5	6	7	8	9	10	Mean	St.dev.
Ag das	15.0	0.0	0.0	2.5	62.5	0.0	0.0	2.5	0.0	0.0	8.3	19.6
Ag spi	15.0	15.0	15.0	15.0	0.0	2.5	15.0	2.5	15.0	37.5	13.3	10.6
Ag tra	2.5											
El ci				15.0								
Ho ju								37.5	15.0			
Po co												
Ph pr												
Sum, per.gr.	32.5	15.0	15.0	32.5	62.5	2.5	15.0	42.5	30.0	37.5	28.5	17.3
Per.gr. warm												
Sp cr												
Annual grass												
Br te							2.5	15.0		2.5		
Forbs & Legumes												
Be in												
Caderia												
Me of	37.5	15.0	15.0	2.5	37.5	2.5	0.0	0.0	15.0	15.0	14.0	14.0
Li le	0.0	37.5	2.5	15.0	0.0	0.0	0.0	0.0	15.0	0.0	7.0	12.3
Al al					2.5					2.5	0.5	
Ko sc			15.0									
Lo co												
Ch be												
Ch al	0.0	15.0	15.0	2.5	2.5	85.0	62.5	85.0	62.5	62.5	39.3	35.3
Ac mi												
Si lo	0.0	2.5	0.0	0.0	85.0	0.0	0.0	0.0	15.0	15.0	11.8	26.5
La se												
Sa ka	15.0		2.5									
Ci ar												
Tr du												
Hy ni												
Sum,forb & leg.	52.5	70.0	50.0	20.0	127.5	87.5	62.5	85.0	107.5	95.0	75.8	31.3
Bare ground	15.0	37.5	37.5	15.0	15.0	2.5	15.0	15.0	37.5	2.5	19.3	13.5
Litter	15.0	37.5	15.0	15.0	62.5	37.5	15.0	15.0	37.5	15.0	26.5	16.5
Total foliar cov.	85.0	62.5	62.5	85.0	85.0	97.5	85.0	85.0	62.5	85.0	79.5	12.3

Table 40 Wilsall Pit Cover	Plot 11 Wood Chip											
July 11-12,1996	20cm x 50 cm frame											
Per.gr. cool	1	2	3	4	5	6	7	8	9	10	Mean	Std.dev.
Ag das	15.0	62.5										
Ag spi	15.0	0.0	37.5	0.0	0.0	37.5	15.0	0.0	0.0	2.5	10.8	15.3
Ag tra												
El ci												
Ho ju				2.5				15.0	15.0			
Po co												
Ph pr												
Sum, per.gr.	30.0	62.5	37.5	2.5	0.0	37.5	15.0	15.0	15.0	2.5	21.8	19.9
Per.gr. warm												
Sp cr												
Annual grass												
Br te				2.5								
Forbs & Legumes												
Ga ap												
Caderia												
Me of	0.0	62.5	2.5	37.5	15.0	15.0	15.0	2.5	85.0	0.0	23.5	29.3
Li le	2.5	0.0	2.5	0.0	0.0	37.5	37.5	0.0	0.0	0.0	8.0	15.6
Al al						2.5						
Ko sc												
Lo co							15.0					
Ch be												
Ch al	2.5											
Ac mi												
Si lo			15.0	15.0								
La se												
Sa ka										2.5		
Ci ar												
Tr du												
As ad									15.0			
Sum,forb & leg.	5.0	62.5	20.0	52.5	15.0	55.0	67.5	2.5	100.0	2.5	38.3	33.8
Bare ground	37.5	15.0	37.5	37.5	85.0	62.5	37.5	85.0	15.0	97.5	51.0	29.7
Litter	37.5	15.0	37.5	37.5	37.5	62.5	37.5	97.5	85.0	62.5	51.0	25.4
Total foliar cov.	62.5	85.0	62.5	62.5	15.0	37.5	62.5	15.0	85.0	2.5	49.0	29.7

Table 41	Wilsall Pit Cover Plot 12 Compost											
July 11-12,1996	20cm x 50cm frame											
Per.gr. cool	1	2	3	4	5	6	7	8	9	10	Mean	Std.dev.
Ag das	85.0									15.0		
Ag spi	0.0	62.5	0.0	97.5	37.5	15.0	2.5	85.0	97.5	37.5	43.5	39.8
Ag tra												
El ci						15.0				15.0		
Ho ju			85.0									
Po co				15.0			15.0					
Ph pr												
Sum, per.gr.	85.0	62.5	85.0	112.5	37.5	30.0	17.5	85.0	97.5	67.5	68.0	31.0
Per.gr. warm												
Sp cr												
Annual grass												
Br te												
Forbs & Legumes												
Ga ap						37.5						
Caderia												
Me of	37.5	37.5	0.0	37.5	37.5	0.0	0.0	0.0	0.0	15.0	16.5	18.6
Li le	0.0	0.0	0.0	0.0	2.5	2.5	2.5	37.5	0.0	0.0	4.5	11.7
Al al	0.0	2.5	2.5	2.5	2.5	37.5	0.0	0.0	0.0	2.5	5.0	11.5
Ko sc												
Lo co	15.0			2.5	2.5							
Ch be												
Ch al	37.5	15.0	37.5	0.0	85.0	0.0	62.5	15.0	15.0	15.0	28.3	27.6
Ac mi												
Si lo	0.0	2.5	2.5	2.5	37.5	85.0	62.5	37.5	15.0	62.5	30.8	31.0
La se												
Sa ka												
Ci ar												
Tr du												
As ad												
Sum,forb & leg.	90.0	57.5	42.5	45.0	167.5	162.5	127.5	90.0	30.0	95.0	90.8	49.0
Bare ground	15.0	15.0	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	5.0	5.3
Litter	15.0	37.5	15.0	15.0	37.5	37.5	37.5	37.5	37.5	37.5	30.8	10.9
Total foliar cov.	85.0	85.0	97.5	97.5	97.5	97.5	97.5	97.5	97.5	97.5	95.0	5.3

Table 42 Wilsall Pit Cover Plot 13 Manure
July 11-12,1996 20cm x 50cm frame

Per.gr. cool	1	2	3	4	5	6	7	8	9	10	Mean	Std.dev.
Ag das												
Ag spi	15.0	62.5	15.0	37.5	2.5	37.5	85.0	15.0	2.5	2.5	27.5	28.0
Ag tra			37.5									
El ci												
Ho ju	2.5	37.5	0.0	0.0	0.0	0.0	0.0	0.0	15.0	37.5	9.3	15.6
Po co												
Ph pr	15.0											
Sum, per.gr.	32.5	100.0	52.5	37.5	2.5	37.5	85.0	15.0	17.5	40.0	42.0	30.5
Per.gr. warm												
Sp cr												
Annual grass												
Br te												
Forbs & Legumes												
Be in												
Caderia							2.5					
Me of	37.5	2.5										
Li le	0.0	0.0	0.0	0.0	2.5	15.0	15.0	0.0	0.0	0.0	3.3	6.2
Al al							2.5					
Ko sc												
Lo co							2.5					
Ch be												
Ch al	85.0	85.0	85.0	97.5	37.5	97.5	62.5	85.0	85.0	97.5	81.8	18.6
Ac mi												
Si lo	15.0	0.0	0.0	0.0	2.5	62.5	2.5	15.0	15.0	2.5	11.5	19.1
La se												
Sa ka												
Ci ar												
Tr du												
Hy ni												
Sum,forb & leg.	137.5	87.5	85.0	97.5	42.5	175.0	87.5	100.0	100.0	100.0	101.3	34.7
Bare ground	25.0	2.5	2.5	2.5	2.5	2.5	2.5	2.5	15.0	2.5	6.0	7.7
Litter	37.5	37.5	37.5	62.5	37.5	37.5	15.0	37.5	15.0	15.0	33.3	14.8
Total foliar cov.	97.5	97.5	97.5	97.5	97.5	97.5	97.5	97.5	85.0	97.5	96.3	4.0

Table 43	Wilsall Pit Cover Plot 14 Control											
July 11-12,1996	20cm x 50cm frame											
Per.gr. cool	1	2	3	4	5	6	7	8	9	10	Mean	Std.dev.
Ag das									15.0			
Ag spi	0.0	2.5	0.0	15.0	2.5	0.0	37.5	2.5	0.0	2.5	6.3	11.9
Ag tra			2.5	2.5					2.5			
El ci												
Ho ju							2.5	2.5				
Po co												
Ph pr												
Sum, per.gr.	0.0	2.5	2.5	17.5	2.5	0.0	40.0	5.0	17.5	2.5	9.0	12.7
Per.gr. warm												
Sp cr												
Annual grass												
Br te												
Forbs & Legumes												
Be in												
Caderia												
Me of	85.0	85.0	62.5	62.5	85.0	85.0	97.5	85.0	62.5	85.0	79.5	12.3
Li le	2.5	0.0	2.5	0.0	0.0	15.0	0.0	0.0	15.0	0.0	3.5	6.1
Al al									2.5	2.5		
Ko sc												
Lo co										2.5		
Ch be												
Ch al												
Ac mi												
Si lo												
La se												
Sa ka	2.5	15.0	15.0	2.5	15.0	2.5	2.5	2.5	2.5	2.5	6.3	6.0
Ci ar								15.0				
Tr du												
Hy ni												
Sum,forb & leg.	90.0	100.0	80.0	65.0	100.0	102.5	100.0	102.5	82.5	92.5	91.5	12.4
Bare ground	15.0	15.0	37.5	37.5	15.0	15.0	2.5	15.0	37.5	15.0	20.5	12.3
Litter	2.5	15.0	15.0	15.0	37.5	2.5	15.0	15.0	2.5	2.5	12.3	10.8
Total foliar cov.	85.0	85.0	62.5	62.5	85.0	85.0	97.5	85.0	62.5	85.0	79.5	12.3

Table 44 Wilsall Pit Cover	Plot 15 NPK Fertilizer											
July 11-12,1996	20cm x 50cm frame											
Per.gr. cool	1	2	3	4	5	6	7	8	9	10	Mean	Std.dev.
Ag das												
Ag spi	37.5	15.0	15.0	62.5	37.5	0.0	2.5	2.5	0.0	0.0	17.3	21.6
Ag tra		15.0							15.0	2.5		
El ci												
Ho ju						2.5						
Po co												
Ph pr												
Sum, per.gr.	37.5	30.0	15.0	62.5	37.5	2.5	2.5	2.5	15.0	2.5	20.8	20.5
Per.gr. warm												
Sp cr												
Annual grass												
Br te												
Forbs & Legumes												
Be in												
Caderia												
Me of	2.5	37.5	0.0	2.5	37.5	62.5	37.5	62.5	85.0	62.5	39.0	29.7
Li le	15.0	0.0	0.0	15.0	15.0	15.0	2.5	0.0	0.0	0.0	6.3	7.6
Al al						2.5						
Ko sc												
Lo co	2.5											
Ch be												
Ch al												
Ac mi												
Si lo		2.5										
La se												
Sa ka	15.0	2.5	37.5	62.5	15.0	37.5	15.0	15.0	15.0	37.5	25.3	17.9
Ci ar												
Tr du												
Lupinus sp.								2.5				
Sum,forb & leg.	35.0	42.5	37.5	80.0	67.5	117.5	55.0	80.0	100.0	100.0	71.5	28.9
Bare ground	37.5	37.5	62.5	15.0	15.0	37.5	62.5	15.0	15.0	37.5	33.5	18.6
Litter	2.5	15.0	2.5	37.5	15.0	2.5	2.5	2.5	2.5	2.5	8.5	11.4
Total foliar cov.	62.5	62.5	37.5	85.0	85.0	62.5	37.5	85.0	85.0	62.5	66.5	18.6

APPENDIX B

Standing Crop Biomass

Table 45. SOUTH PIT STANDING CROP BIOMASS - Grasses
7/20-21/96 Weight in grams for a 20cm x 20 cm frame

Perennial grasses - cool

	CTL1	CTL2	CTL3	COM1	COM2	COM3	MAN1	MAN2	MAN3	NPK1	NPK2	NPK3	WC1	WC2	WC3
	1.32	1.81	1.20	4.02	3.59	1.03	0.74	0.35	1.93	0.00	0.31	0.19	2.41	10.99	0.87
	0.98	0.09	1.65	1.22	2.29	2.51	1.25	0.00	0.00	3.70	4.49	0.74	0.81	5.94	0.17
	3.64	1.01	0.50	3.29	2.87	0.28	0.84	2.27	0.00	3.87	4.23	1.79	0.71	36.39	0.28
	2.77	0.97	0.71	0.00	1.40	2.92	1.58	3.84	5.08	1.72	2.62	4.41	0.26	0.56	0.00
	0.26	0.00	0.00	3.39	0.93	0.00	0.37	0.38	9.58	1.26	0.48	0.00	1.73	1.25	0.85
Mean	1.79	0.78	0.81	2.38	2.22	1.35	0.96	1.37	3.32	2.11	2.43	1.43	1.18	11.03	0.43
Std.dev	1.38	0.75	0.64	1.70	1.08	1.31	0.47	1.64	4.07	1.65	1.99	1.81	0.87	14.78	0.40

Perennial grasses - warm

	CTL1	CTL2	CTL3	COM1	COM2	COM3	MAN1	MAN2	MAN3	NPK1	NPK2	NPK3	WC1	WC2	WC3
	0.79	0.00	0.00	0.09	2.79	0.00	0.47	0.00	0.15	0.00	0.00	0.00	0.00	0.00	0.00
	0.42	0.00	0.12	0.12	1.01	0.00	1.62	0.62	0.63	0.00	0.00	0.50	0.36	0.01	0.00
	0.28	0.00	0.39	0.00	0.00	0.18	0.00	0.00	0.00	0.00	0.00	0.56	0.00	0.00	0.00
	0.54	0.00	0.18	0.00	0.85	0.56	1.01	0.00	0.15	0.00	0.14	0.00	0.30	0.00	0.00
	0.01	0.00	0.00	0.00	0.12	1.10	1.05	0.00	0.09	0.00	0.00	0.00	0.05	0.00	0.00
Mean	0.41	0.00	0.14	0.04	0.95	0.37	0.83	0.12	0.20	0.00	0.03	0.21	0.14	0.00	0.00
Std.dev	0.29	0.00	0.16	0.06	1.12	0.47	0.62	0.28	0.25	0.00	0.06	0.29	0.17	0.00	0.00

Annual grasses

	CTL1	CTL2	CTL3	COM1	COM2	COM3	MAN1	MAN2	MAN3	NPK1	NPK2	NPK3	WC1	WC2	WC3
	0.36	0.00	0.24	0.21	1.02	0.25	2.04	1.43	0.46	0.42	0.14	0.18	0.32	0.60	0.72
	2.10	0.00	0.27	0.00	1.25	0.24	0.25	0.97	2.49	0.00	0.21	0.14	0.47	0.40	0.22
	3.47	0.00	0.02	0.00	0.27	0.19	0.60	0.07	1.68	0.00	0.00	0.14	0.21	0.29	0.93
	0.00	0.00	0.00	0.00	0.65	0.18	0.80	0.33	2.09	0.00	0.00	0.91	0.33	0.14	0.15
	0.14	0.00	0.11	0.00	2.11	5.50	1.14	0.92	2.48	0.00	0.09	0.25	0.37	0.15	3.97
Mean	1.21	0.00	0.13	0.04	1.06	1.27	0.97	0.74	1.84	0.08	0.09	0.32	0.34	0.32	1.20
Std.dev	1.52	0.00	0.12	0.09	0.70	2.36	0.68	0.54	0.84	0.19	0.09	0.33	0.09	0.19	1.58

Table 46. SOUTH PIT STANDING CROP BIOMASS - Forbs, Total
7/20-21/96 Weight in grams for a 20cm x 20 cm frame

Forbs

	CTL1	CTL2	CTL3	COM1	COM2	COM3	MAN1	MAN2	MAN3	NPK1	NPK2	NPK3	WC1	WC2	WC3
	0.88	0.20	0.36	0.00	0.25	0.25	0.56	0.15	0.00	0.00	0.19	1.42	1.11	0.25	0.00
	2.39	0.27	1.62	0.00	1.30	0.88	1.23	0.32	0.16	0.00	0.00	0.65	1.52	1.92	1.70
	0.00	0.00	0.82	0.00	0.14	0.38	0.00	0.48	2.11	1.89	0.00	3.18	0.62	0.00	1.39
	0.00	0.14	0.40	1.58	2.15	2.16	0.10	0.56	1.69	0.00	0.05	0.48	0.00	0.96	0.57
	1.28	0.05	0.50	0.38	1.53	0.16	1.84	0.50	0.19	0.00	0.00	0.20	1.90	0.35	0.75
Mean	0.91	0.13	0.74	0.39	1.07	0.77	0.75	0.40	0.83	0.38	0.05	1.19	1.03	0.70	0.88
Std.dev	1.00	0.11	0.52	0.68	0.86	0.83	0.78	0.17	0.99	0.85	0.08	1.20	0.75	0.77	0.67

Legumes

	CTL1	CTL2	CTL3	COM1	COM2	COM3	MAN1	MAN2	MAN3	NPK1	NPK2	NPK3	WC1	WC2	WC3
	0.78	6.14	1.48	1.74	0.00	0.00	0.24	0.81	0.00	0.38	1.38	0.84	1.07	0.00	0.00
	0.00	0.78	0.29	0.58	0.00	0.00	0.00	1.36	0.00	1.41	0.00	6.57	0.00	0.18	0.40
	0.00	0.37	3.30	2.18	0.35	3.43	0.00	0.00	0.98	0.32	0.47	2.25	0.00	0.00	0.36
	0.00	1.87	3.21	2.96	0.00	0.00	1.47	0.00	0.00	0.90	2.17	1.64	0.00	1.04	0.17
	0.72	2.40	2.32	0.90	0.00	0.00	0.00	1.13	0.00	0.51	0.38	0.38	0.00	2.32	0.00
Mean	0.30	2.31	2.12	1.67	0.07	0.69	0.34	0.66	0.20	0.70	0.88	2.34	0.21	0.71	0.19
Std.dev	0.41	2.29	1.26	0.96	0.16	1.53	0.64	0.63	0.44	0.45	0.88	2.47	0.48	1.00	0.19

Total

	CTL1	CTL2	CTL3	COM1	COM2	COM3	MAN1	MAN2	MAN3	NPK1	NPK2	NPK3	WC1	WC2	WC3
Mean	4.62	3.22	3.94	4.52	5.37	4.45	3.85	3.29	6.39	3.27	3.48	5.49	2.90	12.76	2.70

Table 47. WILSALL PIT STANDING CROP BIOMASS - Grasses
7/11-12/96 Weight in grams for a 20cm x 20 cm frame
Perennial grasses - cool

	CTL1	CTL2	CTL3	COM1	COM2	COM3	MAN1	MAN2	MAN3	NPK1	NPK2	NPK3	WC1	WC2	WC3
	0.50	0.20	0.25	1.34	14.90	21.05	0.19	0.58	4.07	4.41	2.06	5.03	1.84	1.18	40.60
	0.00	0.00	1.21	1.98	0.00	1.89	0.37	0.00	4.45	8.79	7.89	3.90	0.00	6.71	0.00
	0.00	0.00	0.00	15.21	7.88	1.51	0.85	0.03	0.07	9.22	0.00	0.17	0.00	13.04	0.00
	2.14	0.00	0.59	0.48	0.00	1.58	2.11	1.39	1.03	16.88	1.74	0.00	0.00	0.60	0.00
	0.75	0.16	0.34	0.00	0.19	23.71	2.27	10.78	0.00	0.32	9.01	0.00	4.52	3.41	0.00
Mean	0.68	0.07	0.48	3.80	4.59	9.95	1.16	2.56	1.92	7.92	4.14	1.82	1.27	4.99	8.12
Std.dev	0.88	0.10	0.46	6.42	6.68	11.39	0.97	4.63	2.18	6.18	4.03	2.45	1.98	5.10	18.16

Annual grasses

CTL1	CTL2	CTL3	COM1	COM2	COM3	MAN1	MAN2	MAN3	NPK1	NPK2	NPK3	WC1	WC2	WC3
			0.00	0.40			0.00		0.03	0.01			0.00	0.78
			0.00	0.00			0.00		0.01	0.00			0.12	0.00
			0.00	0.00			0.00		0.17	0.00			0.00	0.00
			0.66	0.01			0.36		0.00	0.00			0.00	0.00
			0.38	0.39			0.44		0.00	0.00			0.00	0.00
Mean			0.21	0.16			0.16		0.04	0.00			0.02	0.16
Std.dev.			0.30	0.21			0.22		0.07	0.00			0.05	0.35

Table 48. WILSALL PIT STANDING CROP BIOMASS - Forbs, Total
7/11-12/96 Weight in grams for a 20cm x 20 cm frame

Forbs

	CTL1	CTL2	CTL3	COM1	COM2	COM3	MAN1	MAN2	MAN3	NPK1	NPK2	NPK3	WC1	WC2	WC3
	0.00	0.36	0.36	1.89	0.00	6.65	0.13	0.05	8.43	0.00	0.00	0.44	0.00	20.00	0.00
	0.00	0.00	2.07	0.41	0.38	9.44	15.28	5.70	4.31	0.65	0.00	0.70	0.00	0.00	0.50
	0.00	0.00	0.19	0.00	0.00	3.84	6.93	5.89	13.57	0.00	0.00	1.35	0.00	0.00	0.00
	6.75	0.00	2.01	2.65	0.76	5.54	0.09	1.35	16.83	0.00	0.00	0.50	0.00	0.00	0.00
	0.15	0.00	1.41	0.03	0.92	0.43	2.79	0.51	16.17	0.00	3.93	0.00	0.00	0.00	0.00
Mean	1.38	0.07	1.21	1.00	0.41	5.18	5.04	2.70	11.86	0.13	0.79	0.60	0.00	4.00	0.10
Std.dev	3.00	0.16	0.89	1.20	0.42	3.35	6.37	2.86	5.36	0.29	1.76	0.49	0.00	8.94	0.22

Legumes

	CTL1	CTL2	CTL3	COM1	COM2	COM3	MAN1	MAN2	MAN3	NPK1	NPK2	NPK3	WC1	WC2	WC3
	0.00	0.00	0.00	0.00	0.68	1.60	13.70	0.00	0.00	0.08	8.30	0.00	0.00	0.85	0.00
	0.00	0.00	1.47	3.85	0.22	25.06	3.35	0.00	0.00	0.11	5.57	4.21	27.64	0.00	0.33
	23.75	0.00	29.38	0.69	0.00	8.36	27.90	0.00	0.00	0.00	0.00	0.00	17.66	35.81	0.00
	0.00	42.42	48.30	0.32	0.00	0.00	7.46	0.00	0.00	0.27	12.39	11.13	0.00	12.24	0.00
	0.00	67.27	2.73	0.00	3.34	1.72	24.48	3.46	0.00	4.34	21.90	52.03	0.00	8.75	0.00
Mean	4.75	21.94	16.38	0.97	0.85	7.35	15.38	0.69	0.00	0.96	9.63	13.47	9.06	11.53	0.07
Std.dev	10.62	31.30	21.59	1.63	1.42	10.41	10.60	1.55	0.00	1.89	8.20	22.03	12.90	14.53	0.15

Total

	CTL1	CTL2	CTL3	COM1	COM2	COM3	MAN1	MAN2	MAN3	NPK1	NPK2	NPK3	WC1	WC2	WC3
Mean	6.81	22.08	18.07	5.98	6.01	22.48	21.58	6.11	13.78	9.05	14.56	15.89	10.33	20.54	8.45

APPENDIX C

ANOVA Tables

Table 49. ANOVA South Pit Cover - *Agropyron spicatum* - log(10) transformation.

Source	DF	SS	MS	F-ratio	p-value
Total	14	.2621			
Block	2	.0208	.0104		
Treatment	4	.1453	.0363	3.03	.0854*
Residual	8	.0960	.0120		

Bartlett's test for equal variance[1] p =.0657
Kolmogorov-Smirnov test for normality[2] p > .20

Table 50. ANOVA South Pit Cover - cool perennial grasses.

Source	DF	SS	MS	F-ratio	p-value
Total	14	504.97			
Block	2	6.48	3.24		
Treatment	4	247.44	61.86	1.97	.1921
Residual	8	251.05	31.38		

Bartlett's test for equal variance p = .1110
Kolmogorov-Smirnov test for normality p > .20

Table 51. ANOVA South Pit Cover - warm perennial grasses.

Source	DF	SS	MS	F-ratio	p-value
Total	14	217.42			
Block	2	33.97	16.98		
Treatment	4	68.71	17.18	1.20	.3823
Residual	8				

Bartlett's test for equal variance p = .7750
Kolmogorov-Smirnov test for normality p > .20

Table 52. ANOVA South Pit Cover - total perennial grasses.

Source	DF	SS	MS	F-ratio	p-value
Total	14	941.54			
Block	2	29.84	14.92		
Treatment	4	440.38	110.10	1.87	.2094
Residual	8	471.31	58.91		

Bartlett's test for equal variance p = .8724
Kolmogorov-Smirnov test for normality p > .148

[1] variances considered equal for Bartlett's test p > .05
[2] data considered to be normally distributed for K-S > .05
* significant treatment differences at p < 0.10 level

Table 53. ANOVA South Pit Cover - forbs - reciprocal transformation.

Source	DF	SS	MS	F-ratio	p-value
Total	14	.001810			
Block	2	.000053			
Treatment	4	.001415	.000354	8.27	.0061*
Residual	8	.000342	.000043		
Bartlett's test for equal variance p = .7567					
Kolmogorov-Smirnov test for normality p > .072					

Table 54. ANOVA South Pit Cover - total foliar cover.

Source	DF	SS	MS	F-ratio	p-value
Total	14	720.86			
Block	2	15.32	7.66		
Treatment	4	173.80	43.45	0.65	.6406
Residual	8	531.75	66.47		
Bartlett's test for equal variance[1] p = .9963					
Kolmogorov-Smirnov test for normality[2] p > .196					

Table 55. ANOVA South Pit Biomass - annual grass.

Source	DF	SS	MS	F-ratio	p-value
Total	14	4.71			
Block	2	.74	.37		
Treatment	4	1.75	.44	1.58	.2702
Residual	8	2.21	.28		
Bartlett's test for equal variance p = .4949					
Kolmogorov-Smirnov test for normality p > .20					

Table 56. ANOVA South Pit Biomass - cool perennial grasses - log(10) transformation.

Source	DF	SS	MS	F-ratio	p-value
Total	14	1.49			
Block	2	.21	.11		
Treatment	4	.15	.04	.27	.8884
Residual	8	1.13	.14		
Bartlett's test for equal variance p = .1027					
Kolmogorov-Smirnov test for normality p >.20					

[1] variances considered equal for Bartlett's test p > .05
[2] data considered to be normally distributed for K-S > .05
* significant treatment differences at p < 0.10 level

Table 57. ANOVA South Pit Biomass - warm perennial grasses.

Source	DF	SS	MS	F-ratio	p-value
Total	14	1.25			
Block	2	.02	.01		
Treatment	4	.39	1.00	.96	.4810
Residual	8	.83	.10		

Bartlett's test for equal variance[1] p = .1936
Kolmogorov-Smirnov test for normality[2] p > .20

Table 58. ANOVA South Pit Biomass - total perennial grasses - log(10) transformation.

Source	DF	SS	MS	F-ratio	p-value
Total	14	1.42			
Block	2	.19	.09		
Treatment	4	.16	.04	.31	.8646
Residual	8	1.07	.13		

Bartlett's test for equal variance p = .0668
Kolmogorov-Smirnov test for normality p > .05

Table 59. ANOVA South Pit Biomass- forbs- reciprocal transformation.

Source	DF	SS	MS	F-ratio	p-value
Total	14	.88			
Block	2	.08	.04		
Treatment	4	.29	.07	1.11	.4136
Residual	8	.51	.06		

Bartlett's test for equal variance p = .0731
Kolmogorov-Smirnov test for normality p > .20

Table 60. ANOVA South Pit Biomass - total production - log(10) transformation.

Source	DF	SS	MS	F-ratio	p-value
Total	14	.41			
Block	2	.03	.01		
Treatment	4	.02	.005	.11	.9757
Residual	8	.36	.04		

Bartlett's test for equal variance p = .0787
Kolmogorov-Smirnov test for normality p > .20

[1] variances considered equal for Bartlett's test p > .05
[2] data considered to be normally distributed for K-S > .05
* significant treatment differences at p < 0.10 level

Table 61. ANOVA South Pit Species Richness.

Source	DF	SS	MS	F-ratio	p-value
Total	14	96.93			
Block	2	22.53	11.27		
Treatment	4	36.27	9.07	1.90	.2036
Residual	8	38.13			

Bartlett's test for equal variance[1] p = .0676
Kolmogorov-Smirnov test for normality[2] p > .109

Table 62. ANOVA South Pit Soils - nitrogen - log(10) transformation.

Source	DF	SS	MS	F-ratio	p-value
Total	14	3.12			
Block	2	.059	.029		
Treatment	4	1.84	.46	3.03	.0850*
Residual	8	1.22	.15		

Bartlett's test for equal variance p = .6676
Kolmogorov-Smirnov test for normality p > .20

Table 63. Anova South Pit Soils - phosphorus.

Source	DF	SS	MS	F-ratio	p-value
Total	14	61606			
Block	2	1963.7	981.9		
Treatment	4	55999	14000	30.74	.0001*
Residual	8	3643.3	455.4		

Bartlett's test for equal variance p = .1207
Kolmogorov-Smirnov test for normality p > .20

Table 64. ANOVA South Pit Soils - potassium - log(10) transformation.

Source	DF	SS	MS	F-ratio	p-value
Total	14	2.72			
Block	2	1.77	.088		
Treatment	4	2.02	.505	7.73	.0075*
Residual	8	.52	.065		

Bartlett's test for equal variance p = .0897
Kolmogorov-Smirnov test for normality p > .20

[1] variances considered equal for Bartlett's test p > .05
[2] data considered to be normally distributed for K-S > .05
* significant treatment differences at p < 0.10 level

Table 65. ANOVA South Pit Soils - organic matter.

Source	DF	SS	MS	F-ratio	p-value
Total	14	24.73			
Block	2	.54	.27		
Treatment	4	20.32	5.08	10.51	.0028*
Residual	8	3.87	.48		
Bartlett's test for equal variance[1] p = .4165					
Kolmogorov-Smirnov test for normality[2] p > .20					

Table 66. ANOVA South Pit Soils - water content/ field capacity.

Source	DF	SS	MS	F-ratio	p-value
Total	14	12.99			
Block	2	.84	.42		
Treatment	4	4.59	1.15	1.21	.3762
Residual	8	7.56	.94		
Bartlett's test for equal variance p = .1975					
Kolmogorov-Smirnov test for normality p > .20					

Table 67. ANOVA Wilsall Pit Cover - *Agropyron spicatum*.

Source	DF	SS	MS	F-ratio	p-value
Total	14	2194.8			
Block	2	414.61	207.30		
Treatment	4	1597.1	399.26	17.44	.0005*
Residual	8	183.10	22.89		
Bartlett's test for equal variance p = .2094					
Kolmogorov-Smirnov test for normality p > .20					

Table 68. ANOVA Wilsall Pit Cover - cool perennial grasses - log(10) transformation.

Source	DF	SS	MS	F-ratio	p-value
Total	14	1.2554			
Block	2	.0183	.0091		
Treatment	4	.9804	.2451	7.64	.0077*
Residual	8	.2566	.0321		
Bartlett's test for equal variance p = .1945					
Kolmogorov-Smirnov test for normality p > .185					

[1] variances considered equal for Bartlett's test p > .05
[2] data considered to be normally distributed for K-S > .05
* significant treatment differences at p < 0.10 level

Table 69. ANOVA Wilsall Pit Cover - forbs.

Source	DF	SS	MS	F-ratio	p-value
Total	14	7415.5			
Block	2	2054.6	1027.3		
Treatment	4	2370.6	592.66	1.59	.2680
Residual	8	2990.3	373.78		

Bartlett's test for equal variance[1] p = .9239
Kolmogorov-Smirnov test for normality[2] p > .151

Table 70. ANOVA Wilsall Pit Cover - total foliar cover.

Source	DF	SS	MS	F-ratio	p-value
Total	14	2096.3			
Block	2	49.12	24.56		
Treatment	4	786.29	196.57	1.25	.3650
Residual	8	1260.9	157.62		

Bartlett's test for equal variance p = .1219
Kolmogorov-Smirnov test for normality p > .20

Table 71. ANOVA Wilsall Pit Biomass - annual grasses.

Source	DF	SS	MS	F-ratio	p-value
Total	14	.085			
Block	2	.003	.002		
Treatment	4	.028	.007	1.03	.4462
Residual	8	.054	.007		

Bartlett's test for equal variance p = .3825
Kolmogorov-Smirnov test for normality p > .20

Table 72. ANOVA Wilsall Pit Biomass- cool perennial grasses.

Source	DF	SS	MS	F-ratio	p-value
Total	14	131.82			
Block	2	6.22	3.11		
Treatment	4	65.77	16.44	2.20	.1593
Residual	8	59.83	7.48		

Bartlett's test for equal variance p = .0630
Kolmogorov-Smirnov test for normality p > .20

[1] variances considered equal for Bartlett's test p > .05
[2] data considered to be normally distributed for K-S > .05
* significant treatment differences at p < 0.10 level

Table 73. ANOVA Wilsall Pit Biomass - forbs.

Source	DF	SS	MS	F-ratio	p-value
Total	14	743.63			
Block	2	34.36	17.18		
Treatment	4	176.03	44.01	.66	.6366
Residual	8	533.24	66.66		

Bartlett's test for equal variance[1] p = .9945
Kolmogorov-Smirnov test for normality[2] p > .20

Table 74. ANOVA Wilsall Pit Biomass - total production.

Source	DF	SS	MS	F-ratio	p-value
Total	14	564.24			
Block	2	63.37	31.69		
Treatment	4	27.10	6.78	.11	.9738
Residual	8	473.76	59.22		

Bartlett's test for equal variance p = .8381
Kolmogorov-Smirnov test for normality p > .20

Table 75. ANOVA Wilsall Pit Species Richness.

Source	DF	SS	MS	F-ratio	p-value
Total	14	45.73			
Block	2	5.73	2.87		
Treatment	4	29.73	7.43	5.79	.0172*
Residual	8	10.27	1.28		

Bartlett's test for equal variance p = .5874
Kolmogorov-Smirnov test for normality p > .20

Table 76. ANOVA Wilsall Pit Soils - nitrogen - log(10) transformation.

Source	DF	SS	MS	F-ratio	p-value
Total	14	2.82			
Block	2	0.23	.12		
Treatment	4	1.28	.32	1.94	.1967
Residual	8	1.31	.16		

Bartlett's test for equal variance p = .3121
Kolmogorov-Smirnov test for normality p > .20

[1] variances considered equal for Bartlett's test p > .05
[2] data considered to be normally distributed for K-S > .05
* significant treatment differences at p < 0.10 level

Table 77. ANOVA Wilsall Pit Soils - phosphorus - log(10) transformation.

Source	DF	SS	MS	F-ratio	p-value
Total	14	3.344			
Block	2	.404	.020		
Treatment	4	2.716	.679	9.24	.0043*
Residual	8	.588	.073		

Bartlett's test for equal variance[1] p = .5368
Kolmogorov-Smirnov test for normality[2] p > .20

Table 78. ANOVA Wilsall Pit Soils - potassium - log(10) transformation.

Source	DF	SS	MS	F-ratio	p-value
Total	14	1.892			
Block	2	.056	.028		
Treatment	4	1.391	.348	6.26	.0139
Residual	8	.445	.055		

Bartlett's test for equal variance p = .3661
Kolmogorov-Smirnov test for normality p > .20

Table 79. ANOVA Wilsall Pit Soils - organic matter - Kruskal Wallis ANOVA on ranks.

Treatment	Median	25%	75%	p-value
CTL	0.21	0.135	0.375	
COM	2.17	0.715	3.025	
MAN	2.22	1.410	3.045	.0904*
NPK	0.70	0.513	0.775	
WC	0.57	0.450	1.005	

Bartlett's test for equal variance p = .0279
Kolmogorov-Smirnov test for normality p > .20

Table 80. ANOVA Wilsall Pit Soils - water content/ field capacity.

Source	DF	SS	MS	F-ratio	p-value
Total	14	520.83			
Block	2	13.12	6.56		
Treatment	4	221.85	55.46	1.55	.2762
Residual	8	285.87	35.73		

Bartlett's test for equal variance p = .6219
Kolmogorov-Smirnov test for normality p > .099

[1] variances considered equal for Bartlett's test p > .05
[2] data considered to be normally distributed for K-S > .05
* significant treatment differences at p < 0.10 level

APPENDIX D

Soil Characteristics

Table 81. SOUTH PIT SOIL CHARACTERISTICS

1995 - preconstruction

Plot #	Treat-ment	sand % (by wt.)	silt of < 2mm	clay	texture	coarse frag.% (by wt.)	pH	E.C. mmhos/cm	N mg/kg	P mg/kg	K mg/kg	B.D. gm/cc	F.C. gravim. water %
SP1	WC	83.9	15.1	1.0	l-s	70.7	8.3	0.05	2.5	1.8	74	1.80	4.6
SP2	MAN						8.2	2.26	0.1	0.2	50	2.12	4.8
SP3	CTL	77.6	22.2	0.2	l-s	67.3	8.2	1.87	0.1	1.4	74	2.06	5.6
SP4	NPK						8.4	0.00	0.4	1.1	46	1.94	4.3
SP5	COM	79.9	20.1	0.0	l-s	61.8	8.4	0.30	7.1	6.0	54	1.98	4.5
SP6	WC						8.1	1.06	0.8	2.4	64	1.99	4.9
SP7	COM	80.0	20.0	0.0	l-s	58.0	8.3	1.03	0.3	3.3	82	2.05	5.3
SP8	CTL						8.5	0.05	1.5	1.4	48	2.01	4.4
SP9	NPK	77.4	20.2	2.4	l-s	63.0	8.4	0.08	2.1	1.9	48	1.97	5.4
SP10	MAN	81.5	18.5	0.0	l-s	68.2	8.5	0.16	2.7	3.0	62	2.06	4.8
SP11	WC	80.8	16.2	3.0	l-s	63.1	8.4	0.04	2.2	0.7	38	2.00	6.2
SP12	COM						8.5	0.22	7.2	5.3	148	2.09	6.4
SP13	MAN	85.8	14.2	0.0	l-s	70.2	8.5	0.12	4.0	1.8	50	2.18	4.1
SP14	CTL						8.4	0.06	5.1	4.1	74	2.02	5.4
SP15	NPK	80.8	17.2	2.0	l-s	73.4	8.4	0.19	7.8	2.5	132	1.99	4.2
Mean		80.9	18.2	1.0		66.2	8.4	0.50	2.9	2.5	69.6	2.0	5.0
Std. dev.		2.7	2.7	1.2		5.0	0.1	0.72	2.7	1.6	31.4	0.1	0.7

5/21/96 - post-construction

Plot #	Treat-ment	sand % (by wt.)	silt of < 2mm	clay	texture	coarse frag.% (by wt.)	pH	E.C. mmhos/cm	N mg/kg	P mg/kg	K mg/kg	O.M. %	F.C. gravim. water %
SP1	WC	75.1	18.3	6.6	l-s	71.1	7.6	1.07	4.2	14.0	154	1.66	3.2
SP2	MAN	78.3	15.5	6.2	l-s	68.8	7.7	1.02	41.4	221.2	1552	4.35	3.7
SP3	CTL	75.3	16.5	8.2	s-l	63.1	8.0	1.18	12.4	59.1	494	2.21	5.1
SP4	NPK	74.3	17.5	8.2	s-l	63.6	7.8	0.62	2.6	31.6	182	1.18	3.4
SP5	COM	76.4	17.0	6.6	l-s	66.7	7.9	0.40	3.5	52.4	310	2.05	3.1
SP6	WC	75.3	21.0	3.6	l-s	77.3	7.6	1.13	9.8	12.9	194	1.71	4.3
SP7	COM	75.0	21.4	3.6	l-s	68.7	7.7	1.14	20.4	59.9	480	3.56	5.1
SP8	CTL	85.1	14.3	0.6	l-s	60.3	8.0	0.51	1.3	4.7	48	0.13	3.0
SP9	NPK	80.0	19.4	0.6	l-s	64.5	8.1	0.69	2.2	25.9	102	0.66	3.4
SP10	MAN	80.7	19.3	0.0	l-s	58.5	8.0	0.93	9.7	139.4	790	3.33	5.1
SP11	WC	88.5	11.5	0.0	s	60.0	7.9	0.42	4.0	30.5	232	1.68	3.1
SP12	COM	78.7	21.3	0.0	l-s	64.4	8.1	1.04	11.8	48.6	334	2.48	4.7
SP13	MAN	80.1	19.9	0.0	l-s	65.4	8.1	1.37	52.3	178.6	1206	4.13	6.1
SP14	CTL	82.5	17.5	0.0	l-s	61.8	8.1	0.69	2.7	13.9	78	0.52	3.6
SP15	NPK	81.4	18.6	0.0	l-s	66.4	8.0	0.82	4.6	8.0	92	0.68	3.6

Table 82. WILSALL PIT SOIL CHARACTERISTICS

1995 - pre-construction

Plot #	Treat-ment	sand % (by wt.)	silt of < 2mm	clay	texture	coarse frag.% (by wt.)	pH	E.C. mmhos/cm	N mg/kg	P mg/kg	K mg/kg	B.D. gm/cc	F.C gravim. water %
W1	WC	57.3	6.8	35.9	s-c	40.6	8.6	0.0	0.3	1.9	114	1.84	9.8
W2	MAN	78.6	14.4	7.0	l-s	53.6	7.6	2.9	0.2	2.4	114	1.84	9.7
W3	NPK	46.8	21.9	31.3	s-c-	37.5	8.7	0.8	0.2	4.9	180	1.76	9.3
W4	CTL	70.4	18.7	10.9	s-l	44.0	8.2	1.9	0.2	2.4	120	1.78	8.9
W5	COM	69.4	19.8	10.8	s-l	43.0	8.2	1.8	0.1	2.2	116	1.83	10.8
W6	WC	50.9	24.6	24.5	s-c-	53.6	8.3	1.3	2.7	4.9	170	1.70	11.2
W7	COM	65.5	18.8	15.7	s-l	36.4	8.2	3.8	2.7	2.9	142	1.82	11.4
W8	CTL	70.4	14.9	14.7	s-l	44.2	8.3	0.5	0.7	1.4	92	1.74	10.9
W9	NPK	63.2	16.9	19.9	s-l	38.4	7.7	4.0	3.4	3.5	138	1.86	10.0
W10	MAN	41.3	26.9	31.8	c-l	41.9	8.4	0.8	7.4	4.1	186	1.56	17.7
W11	WC	60.1	21.9	18.0	s-l	40.8	8.1	3.4	1.4	2.7	130	1.74	17.2
W12	COM	38.3	28.9	32.8	c-l	38.2	8.2	1.5	1.7	6.8	192	1.52	17.4
W13	MAN	39.2	30.3	30.5	c-l	53.9	8.4	2.1	10.0	7.1	194	1.52	22.6
W14	CTL	48.3	24.9	26.8	s-c-	48.3	8.2	1.9	6.3	3.9	152	1.61	13.8
W15	NPK	55.1	22.3	22.6	s-c-	37.5	8.1	3.6	1.5	0.9	110	1.54	16.9
Mean		57.0	20.8	22.2		43.5	8.2	2.0	2.6	3.5	143	1.71	13.2
Std. dev.		12.6	6.1	9.2		6.2	0.3	1.3	3.0	1.8	34	0.13	4.2

5/31/96 - post-construction

Plot #	Treat-ment	sand % (by wt.)	silt of < 2mm	clay	texture	coarse frag.% (by wt.)	pH	E.C. mmhos/cm	N mg/kg	P mg/kg	K mg/kg	O.M. %	F.C. gravim. water %
W1	WC	57.1	20.9	22.0	s-c-l	48.1	8.0	0.61	2.3	9.4	140	0.57	14.6
W2	MAN	71.0	20.0	9.0	s-l	42.6	8.3	1.59	2.0	81.7	796	2.22	14.9
W3	NPK	23.2	37.9	38.9	c-l	31.9	8.3	0.59	1.8	9.8	150	0.80	26.4
W4	CTL	75.1	15.9	9.0	s-l	44.7	8.4	0.39	0.2	4.5	72	0.11	9.3
W5	COM	76.0	16.0	8.0	s-l	47.6	8.2	0.50	1.0	14.4	114	0.23	9.4
W6	WC	49.4	29.7	20.9	l	48.7	8.2	0.91	1.4	8.4	130	1.15	25.1
W7	COM	49.1	31.5	19.4	l	42.4	8.4	1.48	3.2	74.9	508	3.31	9.6
W8	CTL	69.1	17.3	13.6	s-l	45.9	8.4	0.28	0.5	6.2	98	0.21	8.1
W9	NPK	52.7	23.8	23.5	s-c-l	44.9	8.0	0.73	0.3	13.6	156	0.70	13.6
W10	MAN	49.9	25.5	24.6	s-c-l	46.6	8.2	1.88	0.4	32.0	342	1.14	21.3
W11	WC	55.7	22.9	21.4	s-l	48.4	8.2	0.77	1.3	4.8	94	0.41	15.2
W12	COM	34.4	31.4	34.2	c-l	46.1	8.4	1.63	2.5	35.2	386	2.17	20.4
W13	MAN	29.3	34.3	36.4	c-l	53.6	8.3	1.54	9.6	111.1	1198	3.32	23.8
W14	CTL	53.0	23.6	23.4	s-c-l	40.3	8.4	0.66	0.5	6.3	168	0.43	11.7
W15	NPK	43.7	25.9	30.4	c-l	44.8	8.2	1.13	0.6	4.1	108	0.45	14.6

Table 83. Comparison of two gravel pits

SOUTH PIT - Cover (%)

Treatm't	Ag sp	Per.gr	Forb	Total
CTL	13.0	29.5	54.5	66.8
CTL	13.3	14.8	55.5	50.0
CTL	14.8	20.3	53.0	62.5
COM	21.0	27.5	30.5	54.8
COM	17.0	33.0	22.8	69.3
COM	11.3	34.5	35.8	62.0
MAN	11.0	31.5	25.0	69.3
MAN	25.0	34.5	22.8	59.5
MAN	16.8	22.0	18.0	71.5
NPK	18.3	21.5	36.3	50.0
NPK	19.5	21.0	42.8	57.5
NPK	18.0	34.5	46.8	64.8
WC	11.0	45.5	35.8	69.0
WC	10.5	39.3	25.3	69.3
WC	8.0	27.8	35.8	57.0
Mean	15.2	29.1	36.0	62.2
Std.dev.	4.3	6.8	13.7	7.6

SOUTH PIT - Production (g)

Per.gr	Ann.gr	Forb	Total
2.20	1.21	1.21	4.62
0.78	0.00	2.44	3.22
0.95	0.13	2.86	3.94
2.42	0.04	2.06	4.52
3.17	1.06	1.14	5.37
1.72	1.27	1.46	4.45
1.79	0.97	1.09	3.85
1.49	0.74	1.06	3.29
3.52	1.84	1.03	6.39
2.11	0.08	1.08	3.27
2.46	0.09	0.93	3.48
1.64	0.32	3.53	5.49
1.32	0.34	1.24	2.90
11.03	0.32	1.41	12.76
0.43	1.20	1.07	2.70
2.47	0.64	1.57	4.68
0.84	0.64	0.66	0.99

SOUTH PIT - Soils

N(mg/kg)	P(mg/kg)	K(mg/kg)	O.M.(%)	F.C. Water (%)
12.4	59.1	494	2.21	5.1
1.3	4.7	48	0.13	3.0
2.7	13.9	78	0.52	3.6
3.5	52.4	310	2.05	3.1
20.4	59.9	480	3.56	5.1
11.8	48.6	334	2.48	4.7
41.4	221.2	1552	4.35	3.7
9.7	139.4	790	3.33	5.1
52.3	178.6	1206	4.13	6.1
2.6	31.6	182	1.18	3.4
2.2	25.9	102	0.66	3.4
4.6	8.0	92	0.68	3.6
4.2	14.0	154	1.66	3.2
9.8	12.9	194	1.71	4.3
4.0	30.5	232	1.68	3.1
12.2	60.0	417	2.02	4.0
17.2	71.3	489	1.49	1.0

WILSALL PIT - Cover (%)

Treatm't	Ag sp	Per.gr	Forb	Total
CTL	3.8	9.5	48.5	77.0
CTL	6.3	8.0	86.0	78.3
CTL	6.3	9.0	91.5	79.5
COM	20.5	42.8	57.8	79.5
COM	37.8	46.8	43.3	73.5
COM	43.5	68.0	90.8	95.0
MAN	11.0	26.3	83.0	87.8
MAN	13.3	28.5	75.8	79.5
MAN	27.5	42.0	101.3	96.3
NPK	2.3	69.3	28.8	77.0
NPK	8.5	20.3	80.8	86.5
NPK	17.3	20.8	71.5	66.5
WC	3.5	31.5	38.0	62.8
WC	10.3	42.2	74.5	86.5
WC	10.8	21.8	38.3	49.0
Mean	14.8	32.5	67.3	78.3
Std.dev.	12.5	19.4	23.0	12.2
t-test	0.12	0.64	4.52	4.34

WILSALL PIT - Production (g)

Per.gr	Ann.gr	Forb	Total
0.68	0.00	6.13	6.81
0.07	0.00	22.01	22.08
0.48	0.00	17.59	18.07
3.80	0.21	1.97	5.98
4.59	0.16	1.26	6.01
9.95	0.00	12.53	22.48
1.16	0.00	20.42	21.58
2.56	0.16	3.39	6.11
1.92	0.00	11.86	13.78
7.92	0.04	1.09	9.05
4.14	0.00	10.42	14.56
1.82	0.00	14.07	15.89
1.27	0.00	9.06	10.33
4.99	0.02	15.53	20.54
8.12	0.16	0.17	8.45
3.56	0.05	9.83	13.45
3.07	0.08	7.29	6.35
1.33	3.54	4.37	5.28

WILSALL PIT - Soils

N(mg/kg)	P(mg/kg)	K(mg/kg)	O.M.(%)	F.C. Water (%)
0.2	4.5	72	0.11	9.3
0.5	6.2	98	0.21	8.1
0.5	6.3	168	0.43	11.7
1.0	14.4	114	0.23	9.4
3.2	74.9	508	3.31	9.6
2.5	35.2	386	2.17	20.4
2.0	81.7	796	2.22	14.9
0.4	32.0	342	1.14	21.3
9.6	111.1	1198	3.32	23.8
1.8	9.8	150	0.80	26.4
0.3	13.6	156	0.70	13.6
0.6	4.1	108	0.45	14.6
2.3	9.4	140	0.57	14.6
1.4	8.4	130	1.15	25.1
1.3	4.8	94	0.41	15.2
1.8	27.8	297	1.15	15.9
2.3	33.9	319	1.09	6.1
2.32	1.58	0.80	1.82	7.46

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