Some effects of fertilization on revegetation of coal-mine spoils in south eastern Montana
by James Buchholz

A thesis submitted to the Graduate Faculty in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE in Range Management
Montana State University

Abstract:
Reclamation research on coal-mine spoils at Colstrip, Montana, was initiated in 1968. The purpose of this work was to determine methods and procedures of reclaiming mine spoils and to identify and evaluate species adapted for reclamation in this area.

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Statistical analyses of the data from the greenhouse study showed that 112 kilograms of nitrogen per hectare was optimum. Phosphorus and potassium did not produce significant results. Analyses of the data from the fLfiId study indicated that the combination of 84 kilograms pet hectare of nitrogen and 179 kilograms per hectare of phosphorus produced optimum results. Potassium fertilization did not yield significant differences.

The study must be continued for several more years before enough information about residual effects can be accumulated to estimate the total effects of fertilization on coal-mine spoils.

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Date 18 September 1972

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OF COAL-MINE SPOILS IN SOUTH EASTERN MONTANA

by

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ABSTRACT

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INTRODUCTION

Much of Eastern Montana is underlain with extensive soft coal deposits. The increasing demand for electrical power has led several utility companies to mine this coal to fire steam-driven generators. The most economical method of mining is to strip off the over-lying layer of soil and expose the coal, which is then removed. The economically retrievable coal underlies overburden varying in thickness from almost none to over 100 feet. The process of removing the overburden leaves the material, called spoils, in various shaped piles, depending on the combination of machinery used (Hodder, *et al.*, 1971).

These "spoils" are a combination of surface soil, subsurface material and coal slack. The surface soil is present in various thicknesses, depending upon the topographical location. The subsurface material is variable in thickness, texture and composition. The coal slack is a mixture of the material immediately adjacent to the coal seam and some raw coal (Thompson, 1969).

The strip-mining of coal by the Northern Pacific Railroad in the Colstrip area began in 1924. Although the railroad did not practice any reclamation, neither did it disturb much land. By 1956, after 30 years of mining, less than three sections had been mined. Western Energy Company, a subsidiary of Montana Power Company, began moving coal in 1968 and moving overburden in August of 1970. Since 1970, they have disturbed approximately 50 to 100 acres per year in their operations.

Western Energy Company contracted with the Montana Agricultural Experiment Station in the Spring of 1968 to initiate applied research studies to help determine the best reclamation practices to follow in the Colstrip area. Identifying species adapted for reclamation and developing planting procedures were two main goals of this research. Chemical analyses of the overburden indicated fertilization was a necessary practice for optimum plant establishment and growth.

The purpose of this fertilization research study was to find guidelines for the use of commercial fertilizers as a means of aiding the reclamation process of coal spoil banks at Colstrip, Montana. This study was conducted in two parts; the first a greenhouse study to find general trends in nutrient requirements, the second a field study to further identify these nutrient requirements. The greenhouse portion of the study was conducted during the late winter and spring of 1971. The field fertilizer study, the second part of the research, was initiated in April of 1971 and the data were collected in July of 1971. The field study was conducted at the Western Energy Mine on shaped spoil banks.

LITERATURE REVIEW

Problems Involved

Most of the reclamation of strip-mined spoils has taken place in the eastern portion of the United States where the precipitation exceeds 30 inches annually. In contrast, much of the western United States receives less than 15 inches annually, with some areas receiving less than four inches annually. Most areas being mined in the East have generous amounts of topsoil, with which reclamation is much easier. Depth of topsoil in the West ranges from none to several inches. The lack of topsoil complicates the problem of reclamation (Sullivan, 1967).

Reclamation of strip-mined spoils in the western United States is rather limited and is quite recent. The Knife River Coal Mining Company initiated a reclamation program in 1963 for its sites at Beulah and Cascoyne in North Dakota and Savage in eastern Montana. The purpose of this reclamation was to revegetate these strip-mined areas for game management. In these areas, as in other arid regions, it was found to take several years before any conclusions regarding results as to success or failure could be made (Gwynn, 1966).

Reclamation at Soda Springs, Idaho was begun in 1966 on lands that had been strip-mined for phosphorus. Annual precipitation on this area averages 14 inches. Vegetational response was positive, but was not a spectacular success (Thompson, 1969).

Western Energy Company funded the initiation of pilot studies at Colstrip, Montana, in the fall of 1968. The purpose of this reclamation was twofold: to create grazing for livestock and enhance habitat for wildlife. The results of these pilot studies showed that vegetation could be established with the use of commercial fertilizers. Species adapted to the growing conditions of the spoils were identified and selected for further study (Hodder, *et al.*, 1971).

Every revegetation attempt is faced with similar types of problems. Often the pH is not desirable for germination and establishment of plants. The pH may be as low as two or as high as ten (Thompson, 1969; Jacoby, 1969). Texture of spoils is often clayey, which makes vegetation establishment difficult. Toxicity due to excesses of certain elements, such as sodium or sulphur, creates problems in most reclamation attempts (Hodder, 1972).

The shape of the spoils left by the mining operation is of great concern. If the spoils are left in steep-sided, pointed piles, they are usually mechanically unstable and unsuited for supporting permanent vegetation. The spoils are subject to both wind and water erosion, which dictates that cover of some type be established as quickly as possible to prevent erosion (Hodder, *et al.*, 1971).

<u>Methods of Reclamation</u>

Several procedures have been used to reclaim mine wastes. Chemical stabilization has been used when the substrate is toxic to the point of preventing growth of vegetation (Loomis, 1970). Revegetation is a much more desirable method of reclamation, as it brings the land back into production. Shaping the spoils in some manner provides a more suitable seed bed as well as aiding in preventing water erosion. Eliminating steep slopes prevents sloughing due to mechanical instability and aids in establishment of vegetation (Hodder, *et al.*, 1970).

Selection of species for revegetational purposes must be accomplished for each area and often differs within each mine site. Variability of the substrate creates differing growing conditions within rather small areas (Thompson, 1969). The intended use of the area being reclaimed will affect the selection of species used (Gwynn, 1966; Reilly, 1965). Wildlife habitat often requires a different composition of species than vegetation to be used as grazing for domestic stock.

Jacoby (1960) experimented with snowfence, jute netting and straw mulch to aid in establishment of vegetation at Kemmerer Coal Fields in southwestern Wyoming. Jute netting and straw mulch applied together resulted in the highest seedling density of all methods tried.

Fertilization

Fertilization is often used as an aid to revegetating mine spoils. Mine wastes are usually deficient in one or more of the plant nutrients, and the addition of chemical fertilizers is an economical method of correcting nutrient deficiencies (Hodder, 1970; Jacoby, 1969).

Many factors, including time, rate and placement of fertilizers, as well as soil pH have long been recognized as important for successful use of fertilizers (Cole, *et al.*, 1963; Follett and Reichman, 1972; Lorenz and Johnson, 1953). Olson and Dreier (1956a) pointed out that time of fertilizer application is important as it affects the temperature of the soil, which is a controlling factor for soil microbial activity. Early spring weather is often cool, which inhibits the activities of the soil microbes. Release of organic nitrogen and conversion to the nitrate form is dependent upon the activity of the soil microorganisms.

An adequate supply of nitrogen early in the growing season enhances the uptake and translocation of phosphorus (Olson and Drier, 1956b; Thien and McFee, 1970). This enhancement effect is not due to a companion effect of both nutrients in the soil solution simultaneously but rather due to an increased need for phosphorus because of higher nitrogen metabolism within the plant cells (Cole, *et al.*, 1963; Thien and McFee, 1970).

Warm weather enhances fixation of phosphates and reduces the effectiveness of added phosphorus fertilizers. Beaton and Read (1963), found that temperatures of 16° to 27° C. increased the solubility and mobility of phosphates, which led to a rapid fixation of these ions into relatively insoluble compounds such as dicalcium phosphates and iron and aluminum phosphates. Phosphorus is not subject to leaching loss and may be beneficially applied either late in the fall, just before planting or at planting (Ensminger and Pearson, 1957).

Potassium fertilization often results in greater yields if applied just prior to planting (Ignatieff and Page, 1958). Potassium fertilizers are usually very soluble and are subject to considerable leaching loss over a period of time.

Olson and Dreier (1956a) found small amounts of nitrogen fertilizer (22 kg/ha) to be very beneficial to germination. Grunes, *et al.*, (1963) found that rates as high as 400 pounds per acre would produce increasing yields for many grasses. Stanford and Nelson (1949), and Olsen and Gardner (1949), found small amounts of phosphorus beneficial. Luxury amounts were not detrimental to growth, but neither did they produce higher yields. Potassium was necessary in moderate amounts (90 to 120 kg/ha), but heavier applications were detrimental to dry weight yield and seed production (Wolton, *et al.*, 1968; Gately, 1968; Boswell and Parks, 1957).

Nitrogen applied with the seed can inhibit seed germination by creating an environment with excess soluble salts. Nitrogen fertilization was more efficient and less damaging when applied either before planting or as a side dressing after germination. Phosphorus alone was found to be more efficient when applied with the seed and not mixed in with the soil (Olson and Dreier, 1956a). Heslep and Black (1954) found that phosphorus movement within the soil was limited to two-to-three centimeters. Nitrogen and phosphorus were both more effective when applied before seeding (Lorenz and Johnson, 1953; Rennie and Soper, 1958). Potassium fertilization was more effective when applied with the seed (Baver, 1943).

The effectiveness or the possibility of damage by applied fertilizers is related to the amount of moisture in the soil. Olson and Dreier (1956a) concluded that low levels of moisture coupled with fertilization was likely to cause low rates of germination.

The pH of the soil solution also affects the availablility of plant nutrients through its effect on nutrient solubility (Murrmann and Peech, 1969; Estermann and McLaren, 1961; Ensminger and Pearson, 1957). The optimum pH varies for different nutrients and not all researchers agree on the optimum pH for each nutrient.

The source of nitrogen may have a slight effect on pH of the soil immediately adjacent to the absorbing root surface (Riley and Barber, 1971). If nitrogen is applied in the ammonium form (NH_4^+), pH tended to be lower than if nitrogen was applied in the nitrate form (NO_3^-). In this study the ammonium form of nitrogen tended to induce a higher uptake of phosphorus than did the nitrate form.

Fertilization Response

Response to nitrogen fertilization is often rapid and more pronounced than the effects of phosphorus and potassium fertilization. Its effect on the plant is a higher protein content and a lush, succulent vegetative growth. Excess nitrogen may delay maturation (Buckman and Brady, 1960). However, nitrogen is easily leached from the soil profile and thus not available to the plant. Legumes need little if any additional nitrogen. Rates as high as 400 pounds per acre (357 kilograms per hectare) have been found to produce increased yields of grasses (Grunes, *et al.*, 1963).

Phosphorus has the effect of hastening maturation and thus tends to offset the effect of excess nitrogen. Phosphorus is important in the strengthening of the straw in grasses and small grains and the development of the root structure. Walton, *et al.*, (1968) found 56 to 110 kilograms per hectare optimum for three grasses on sodded pastures. Phosphorus fertilizers are insoluble and are not subject to leaching loss.

Most soils have sufficient quantities of potassium for normal plant growth. However, cropping or disturbance of the surface which exposes the sub-soil may create conditions that require application of potash for optimum growth. Excessive quantities of potassium may decrease dry weight yields and kernal weight (Gately, 1968).

DESCRIPTION OF STUDY AREA

Location and Topography

The site on which this research was conducted is located at the Western Energy Company's strip-mine operation five miles southeast of Colstrip in Rosebud County, Montana (Section 17, T1N, R42E of the Montana Principle Meridian).

The topography of the general area is rolling, with alternating ridges and draws. Much of the land is covered with timber. While there are several drainages in the immediate area of the mining operation, there is no runoff from the mine into these drainages and therefore, stream pollution is not a problem.

The topography at the strip-mined area consists mainly of steep-banked overburden piles, nearly vertical highwalls, and deep pits. The steepness of the slopes is conducive to sloughing and water erosion. The site for the study was prepared by partially leveling the overburden piles so that farm epuipment could be used to prepare a seedbed for planting. The slope ranged from nearly level to approximately a 3:1 grade.

Climate

Climate of the study area is variable with temperature extremes of 60° C in normal years, often ranging from -22° C to 43° C. July is generally the hottest month and December is the coldest. Mean annual precipitation for the area is 37.8 centimeters, with snow melt contributing approximately 11.4 cm. to the annual total. Rains normally begin in April and reach their peak in May and June. The growing season extends from March through June, with May being the most critical month for major forage production. Summers are hot and relatively dry. The average frost-free period is 125 days; the average date of last freeze is May 15 - 25 and the first fall freeze is expected about September 15 - 22 (Hodder, *et al.*, 1971). Monthly climatological data for Colstrip in 1971 are presented in Table 1.

Table 1. Monthly climatological data for Colstrip, Montana for 1971.

	Temperature (°C)		Precipitation (cm)	
	Avg. for Month	Deviation from Normal	Total for Month	Deviation from Normal
January	-7.8	-2.1	5.97	+4.50
February	-3.8	+0.4	2.5	+0.64
March	1.2	+1.0	1.60	-0.94
April	7.8	+0.7	2.87	-1.30
May	13.3	+0.5	4.55	-1.19
June	18.8	+1.3	6.48	-0.99
July	21.0	-1.6	1.19	-1.92
August	24.5	+3.1	4.65	+1.55
September	13.5	-1.9	13.00	+10.44
October	6.7	-2.5	15.85	+12.75
November	2.4	+1.2	0.46	-1.32
December	-6.7	-3.8	1.80	+0.30

1/ Normal based on thirty years observations.

Soils

The soils material in this area is of sedimentary rock origin with the surface layer mostly loamy sands and sandy loams. There are layers within the overburden profile classified as clays. These layers are rather thin and do not contribute much to the total volume of overburden.

Table II. Soil chemical analysis of raw spoils material at the Western Energy Site, Colstrip, Montana.

Variable	Value	Variable	Value
pH	8.62	Calcium (meg/100g)	12.0
Organic matter (%)	0.15 vl[1/]	Magnesium (meg/100g)	3.25
Phosphorus (ppm)	8.0 vl	Sodium (meg/100g)	0.22
Potassium (ppm)	37.5 vl	Salt hazard (mmhos/cm)	0.7

1/ very low

The spoil material tends to be slightly alkaline, with pH's averaging 8.6 (Table II). The organic matter is quite low, less than 0.2 percent. Both phosphorus and potassium are very low, eight ppm. and 37.5 ppm. respectively. The trace minerals are present in acceptable levels, being neither too high nor too low. The salt hazard, often a problem in spoils revegetation, was very low at 0.7 mmhos per centimeter.[1/] Four mmhos per centimeter is considered toxic to "average" plants (Soil Survey Staff, 1951). The texture of the spoils material ranged from sandy to sandy loam.

1/ Montana Soil Testing Laboratory Report.

METHODS AND PROCEDURES

Greenhouse Experiment

The mining process used to remove the overburden from above the coal seam involved dynamiting and stripping the overburden and dumping it, thus forming spoils piles. The stripping procedure thoroughly mixed the spoils material. In November of 1970, new mine spoils material became available for study. A representative sample of this material was transported from Colstrip to Bozeman to be used in the greenhouse fertilizer studies.

The spoils material was screened to remove aggregates larger than five centimeters in diameter. Approximately 1.6 kilograms of spoils material were weighed into each of 192 clay pots. The pots were placed in watering benches in three replicates of 64 pots each. Four levels each of nitrate (NO_3^-), phosphorus (P_2O_5), and potassium (K_2O) were applied in a factorial arrangement. The levels of nitrogen and/or potassium used were 0, 56, 112, and 224 kilograms of actual nutrient per hectare. The levels of phosphorus used were 0, 112, 224, 448 kilograms of actual nutrient per acre. All combinations of the selected fertilizer levels were used, giving a total of 64 treatments in each of three replicates.

The amounts of fertilizer applied to each pot were calculated on a weight basis. The weight of a furrow slice per hectare was considered to weigh 2.24×10^6 kilograms. Each pot contained approximately

1.6 kilograms of spoils material. Thus, an application of 56 kilograms per hectare would be equivalent to 0.040 grams per pot. The fertilizer used was analyzed as being 34 percent available nitrate. Therefore, 0.117 grams of nitrogen fertilizer were applied to the pots that contained the treatment of 56 kilograms of nitrate per hectare. The phosphorus fertilizer was 45 percent available phosphate, and the potassium fertilizer was 60 percent available potash.

The watering system used was automated, with each pot having an individual watering tube. The system was activated by a spring-loaded mechanism calibrated to the weight difference between the lowest level of soil moisture desired and the optimum soil moisture content of an indicator pot. The labor required to water all the pots was much less with the automatic system than with hand watering. One disadvantage of the automatic watering system was that the watering tubes became plugged by minerals precipitating out of the water.

Fifty-five days after planting, one-third of all plants were fully headed out and the remaining plants were at least in the boot stage. The height of the tallest plant in each pot was measured to the nearest millimeter. The shoots were clipped at ground level. Soil was washed from the roots with a stream of water under low pressure. The vegetation and roots from each individual pot were sacked separately and dried for 24 hours at 100° C. The weight data were recorded upon removal from the drying oven.

Field Study

The site chosen for the field fertilizer study, located at Colstrip, Montana, was a west-facing slope with an overall 3:1 gradient which was part of a previous slope-and-exposure study. The previous study had been band-seeded to thickspike wheatgrass *(Agropyron dasystachyum)* to determine the relative advantages of spring and fall seeding and the effect of slope on seedling establishment. Each fertilizer treatment plot included both a spring and a fall grass seeding block (Figure 1). Each spring and fall treatment plot measured six feet by thirty feet.

Three levels of nitrogen (0, 84, and 168 kg/ha), two levels of phosphorus (0 and 179 kg/ha) and two levels of potassium (0 and 67 kg/ha of actual nutrient) were applied using a factorial arrangement. The design was a randomized complete block with three replications. The fertilizer was weighed and mixed with an inert filler so it could be applied uniformly over the plot. A hand-operated broadcast seeder was used to apply the treatments.

The fertilizer treatments were applied April 11, 1971 and the data were collected the second week of July, 1971. Four types of data: aerial and basal cover, dry weight yield, and percent soil moisture were collected. Aerial and basal cover data were obtained by using a point frame with ten vertical points spaced five centimeters apart. The first aerial foliage contacted by a point was recorded as an aerial hit. Whatever the point touched at the soil surface level was recorded as the basal hit. Only the first aerial hit with each pin was recorded. Each plot was gridded and five sample locations were selected at random using a table of random numbers. At each location the point frame was placed perpendicular to the seeded rows.

The total frequency was obtained by dividing the number of hits by the number of samples. This term will be referred to as total frequency in this thesis. Each plot had fifty sample observations. The relative frequency was obtained by dividing the number of hits by the number of times vegetation, either live or dead, was recorded as hits. This term will be referred to as relative frequency in this thesis.

The production data were obtained by placing a one-tenth square meter circular hoop at each sample site where the center of the point frame was located. The total vegetation rooted within the hoop was clipped by hand, separated by species and sacked for weighing. The sacks were transported to Bozeman to be dried at 100^{o} C. for 24 hours and then cooled in a desiccator until weighing.

Fall / Spring	N2P2K2	N2P1K2	N2P1K1	N3P2K2	
Fall / Spring	N3P1K1	N1P2K1	N3P2K1	N3P1K2	Block 1
Fall / Spring	N1P2K2	N1P1K1	N2P2K1	N1P1K2	
Fall / Spring	N1P2K2	N1P1K1	N2P1K2	N3P2K1	
Fall / Spring	N3P1K2	N3P2K2	N1P1K2	N2P2K1	Block 2
Fall / Spring	N2P1K1	N2P2K2	N1P2K1	N3P1K1	
Fall / Spring	N2P1K2	N3P1K1	N2P2K2	N2P1K1	
Fall / Spring	N1P2K2	N3P1K2	N1P1K1	N2P2K1	Block 3
Fall / Spring	N3P2K2	N1P1K2	N3P2K1	N1P2K1	

Treatment codes:

N1 = 0 kg/ha	P1 = 0 kg/ha	K1 = 0 kg/ha
N2 = 84 kg/ha	P2 = 179 kg/ha	K2 = 67 kg/ha
N3 = 168 kg/ha		

Figure 1. Plot design of the field fertilizer study, Colstrip, Montana.

The soil moisture data were obtained by driving a King Tube into the soil profile and extracting a core of soil. Five levels, 0 to 15 cm., 15 to 30 cm., 30 to 60 cm., 60 to 90 cm., and 90 to 120 cm. of the soil profile were sampled and placed into separate cans for soil moisture determination. The cans were transported to Bozeman to be weighed, dried for 24 hours at 100° C. and reweighed to determine the soil moisture.

RESULTS AND DISCUSSION

Greenhouse Experiment

Of the three nutrients studied (nitrogen, phosphorus and potassium), only nitrogen produced significant differences among various levels of application (Appendix Table I). While there is a lack of significant response to phosphorus, the trend is for higher production with higher rates of application. The lack of significant response may have been due to the fact that when applied to the soil, it reverts to a rather insoluble dicalcium phosphate form (Buckman and Brady, 1960). Potassium is rather soluble and may have been lost by leaching. The lack of response may also have been the result of insufficient levels of applied nutrients.

The shoot-height data revealed a difference in plant response between 56 kg/ha and 112 kg/ha of nitrogen (Table III). Plants grown with 112 kg/ha and 168 kg/ha of nitrogen were significantly taller than those grown with 0 kg/ha and 56 kg/ha of nitrogen. Shoot weight and root weight data showed similar results to shoot height data.

Field Fertilization Study

Soil Moisture Results

The soil moisture data from the field fertilizer study at Colstrip showed significant variation in moisture content for blocks, treatments, and depths of sampling (Appendix Table II). Block one, at the top of the slope, had a higher moisture content than the lower two blocks (Table IV). The higher water content may have been due to

Table III. Treatment means for shoot height, shoot weight, and root weight; Greenhouse Experiment.

Treatments	Shoot Height (cm)	Shoot Weight (g)	Root Weight (g)
NITROGEN			
0 kg/ha	24.0a[1/]	0.50a	1.72a
56 kg/ha	26.2a	0.67a	1.94ab
112 kg/ha	29.5b	1.12b	2.32bc
168 kg/ha	28.8b	1.27b	2.50c
PHOSPHORUS			
0 kg/ha	27.5a	0.78a	2.37a
112 kg/ha	26.3a	0.87a	2.06a
224 kg/ha	26.5a	0.91a	2.04a
448 kg/ha	28.1a	1.00a	2.20a
POTASSIUM			
0 kg/ha	27.6a	0.96a	2.05a
56 kg/ha	27.2a	0.81a	1.93a
112 kg/ha	26.5a	0.87a	2.13a
168 kg/ha	27.2a	0.91a	2.38a

1/ Means followed by the same letter or letters are not significantly different (P .05) according to Duncan's New Multiple Range Test.