SOIL REPLACEMENT DEPTH AND DEEP RIPPING TO RECLAIM SURFACE-MINED LAND

by

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TABLE OF CONTENTS

LIST OF TABLES

Chapter 1

Chapter 2

APPENDIX

LIST OF FIGURES

Chapter 1

Chapter 2

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LITERATURE REVIEW

HISTORY AND LEGISLATION

In the United States, coal is the most abundant, widely distributed fuel resource (Doyle, 1976), and as such is vital to our ever-increasing demand for energy. Mining of coal has been practiced since the early 1700's in the United States (Brenner, 1984) with these early operations mainly falling in the category of surface mining. Exposed coal seams along river banks were mined using picks and shovels, and in some cases shallow seams near the surface were exposed with hand tools. By the mid-1800's horse-drawn plows and scrapers were being used to remove the overlying soil and other strata (Paone et al., 1978; Ramani and Grim, 1978), and in 1877, the first steam shovel was introduced into the coal fields near Pittsburg, Kansas (Brenner, 1984). Because these early surface mines were of such a small scale, their effects on surface soil disturbance went practically unnoticed and little attention was given to reclamation. However, technological improvements in material handling and earth-moving equipment combined with an increasing demand for coal fueled expansion of surface mining into more valuable land areas (Doyle, 1976).

As environmental effects of mining became more apparent, calls for legislation to mitigate environmental effects began. The first state to pass legislation dealing with surface mined land reclamation was West Virginia in 1939. This law imposed only nominal requirements on the mine operator, but it did serve as a base to begin recognizing the disruptive environmental impacts of surface mining (Bowling, 1978). Other states soon followed with reclamation laws in the 1940's and 1950's, most of which were quite mild and contained numerous exceptions and exemptions (Fridirici, 1982). Consequently, confrontations between concerned citizens and the mining industry continued. In Kansas concerned citizens acted to insure the restoration of lands disturbed by mining, and in 1968 the Kansas Mined Land Conservation and Reclamation Act was enacted. However, the act provided only for those lands disturbed after January 1, 1969, and not the nearly 50,000 acres disturbed prior to that date (Camin et al., 1971).

In the period between 1960 and 1980 coal production in the United States nearly doubled and the proportion produced by surface mining also doubled (Macinko, 1983). Although surface mining and its related activities used less than 0.2% of the U.S. total land mass during the 41 year period 1930-1971 (Paone et.al., 1978), the glaring nature and destructive methods employed created the perception of mining as a national environmental threat. It became evident that an increased need for coal would have to be weighed against the impact of surface mining on the land.

The result was passage of the Surface Mining Control and Reclamation Act of 1977 (SMCRA), also known as Public Law 95-87 (Macinko, 1983).

In their statement of findings and policy (U.S. Congress, 1977, sec. 101), congress concluded that many surface mining operations result in a landscape that is subject to soil erosion, landslides, water pollution, destruction of wildlife habitat and natural beauty, and damage to the property and the quality of life in local communities. These disturbances affect public welfare by diminishing or destroying the utility of the land, making it unfit for commercial, residential, or agricultural uses. The resulting law was designed to strike a balance between protection of the environment and agricultural productivity, and the need for coal as an essential source of energy (U.S. Congress, 1977, sec. 102). The act recognized the diversity of environmental and biological conditions between areas subject to mining and placed primary responsibility for development and enforcement of surface mining and reclamation regulations with the states (U.S. Congress, 1977, sec. 101). It also created the Office of Surface Mining Reclamation and Enforcement to oversee development of state regulations, and to make inspections to insure that surface mining activities are in compliance with the act (U.S. Congress, 1977, sec. 201).

Stated in simplest terms, surface mining is removal of soil material, rock and other strata overlying a mineral deposit and removal of that mineral (Doyle, 1976). Overburden is used to describe materials overlying a minable deposit up to and including rock and other materials but excluding soil horizons that are to be removed separately for reclamation purposes (Bituminous Coal Research, Inc., 1983). Strip mining is a term commonly used to describe the surface mining method for mining coal (Paone et al., 1978). Area stripping is generally used in areas that have relatively flat terrain, characteristic of much of the midwestern U.S. The process (Paone et al., 1978; Law, 1984) involves making an initial trench (box cut), exposing the seam of coal. The excavated overburden is placed on unmined land adjacent to the initial box cut and the coal is removed. A second cut is then made parallel to the first, and overburden is placed into the previously excavated trench, the process being repeated as mining advances. The resulting landscape is visually unpleasing, unproductive, and subject to erosion (U.S. Congress, sec.101). Thus surface mining will drastically alter the environment of the area disturbed through vegetative removal, topography alteration, and destruction of the original geologic overburden and soil profiles (Doyle, 1976).

An important part of the reclamation process is the separate removal and replacement of soil materials over recontoured overburden and spoil materials (Hargis and Redente, 1984). Public Law 95-87 requires that post-mining land use is to be restored to a condition capable of supporting the uses to which the land was capable prior to any mining, or to higher or better uses (U.S. Congress, 1977, sec. 515). This is to be achieved through grading of the land to the approximate original contour, stabilizing and protecting the land from erosion, and replacement of topsoil or the best available subsoil capable of supporting vegetation. Special requirements exist for those lands designated as prime farmlands. These lands, as defined in the Federal Register, have the best combinations of physical and chemical properties for producing food, feed, fiber and oilseed crops, and have historically been used for such purposes. In general, they are characterized as having an adequate and dependable source of water, favorable growing season and climate, acceptable levels of alkalinity, acidity, accumulated salts, and sodium content, and few or no rocks (Federal Register, 31 Jan. 1978). Present regulations require that prime soils be segregated by the defined A (topsoil), B, and C (subsoil) horizons during removal, and during subsequent reconstruction the sequence of horizons must have topsoil over subsoil over graded overburden (U.S. Congress, 1977, sec. 515). Both the topsoil and the subsoil materials are to be stockpiled separately from one another and from the spoil if immediate respreading is not feasible.

The reconstructed profile should have a root zone of similar depth and quality to that of the original soil, with topsoil and subsoil graded to a uniform depth over the spoil. On lands not considered prime farmland, the A horizon or best available subsoil is to be replaced to "an approximate uniform, stable thickness consistent with the approved post-mining land use" (Federal Register, 16 May 1983). The final productivity of reconstructed prime and non-prime croplands must be shown to be equal or better than that prior to mining before final liability can be released by the regulatory body (Vories, 1985).

PROBLEMS ASSOCIATED WITH RECLAMATION

Reclamation success will be directly related to the nature of the spoil material (Doll et al., 1984). Spoil consists of the broken overburden, below the topsoil and subsoil, that has been removed to gain access to the coal seam (Bituminous Coal Research, Inc., 1983). Minespoil characteristics can potentially limit the effectiveness of reclamation methods and subsequent post-mine land use (Doyle, 1976). Of equal importance is the amount and quality of soil materials available for replacement (Doll et al., 1984). Reconstructed spoil and soil chemical and physical properties, as well as surface topography, affect the potential for plant growth, erosion, and degradation of surface and groundwaters (Massey and Barnhisel, 1972; Doyle, 1976; Mays and Bengtson, 1978; Power et al., 1979; Byrnes et al., 1980; Merrill et al., 1985). A knowledge of physical and chemical characteristics of spoil material as well as those soil materials that are to be used in reconstruction is essential to development of a successful reclamation plan (Vogel, 1987).

There are several soil chemical properties that can potentially reduce or even prevent the establishment of vegetation on reclaimed surface mined land. In the more humid eastern coal regions many coal-bearing strata contain varying amounts of iron pyrite (FeS_2), a sulfur-bearing mineral which is of considerable importance because of potential for generation of acid in exposed pyrite-containing coal mine spoils (Caruccio and Geidel, 1978; Hill, 1978; Vogel and Curtis, 1978; Barnhisel et al., 1984). Certain elements, mainly copper, lead, nickel, cadmium, and zinc become more soluble as pH decreases and can interfere with revegetation of reclaimed minesoils (Foy, 1984). Saline and sodic spoils and soils are more of a problem in the arid and semi-arid regions of the western half of the U.S. (Doyle, 1976; Merrill et al., 1985) The quantity and kinds of soluble salts are especially important because they can interfere with water uptake by plants (Sandoval and Gould, 1978; Power et al., 1979), and toxicities of molybdenum, boron, and selenium may be a problem in strongly alkaline soils (pH

8.5-9.5) (Vogel, 1987). Minesoils containing excess sodium typically show poor physical structure and are prone to surface sealing and water transmission problems in replaced subsoil and spoil materials (Omodt et al., 1975; Holmberg, 1983).

One of the most troublesome aspects of reconstructing surface mined lands is that of creating a compact physical condition within the new soil. Soil compaction is viewed as an unavoidable consequence of grading and shaping the spoil material and replacement of topsoil (Philo et al., 1982). In soils reconstructed following surface mining, root development is generally less than in nearby unmined soils (Fehrenbacher et al., 1982), although there are exceptions. On a reclaimed minesoil in Texas, measured forage rooting mass was found to be almost three times greater than rooting masses observed on similar unmined soils in the region (Hons et al., 1979). This was partially attributed to the destruction of a native claypan during the mining and reclamation process. The observation made by Fehrenbacher et al., (1982), however, is almost always the case. On a recently constructed soil in Illinois, McSweeney and Jansen (1984) found the subsoil to be compact and structurally massive which promoted extensive lateral rooting at the base of the topsoil. Vertical root penetration was limited to cracks, and roots appeared flattened and compressed. In another study Jansen et al. (1984) suggested that high soil strength as a result of compaction during soil reconstruction increased both corn (Zea mays L.) and soybean (Glycine max (L.) Merr.) susceptibility to drought stress. A zone of high bulk density (1.7-1.9 g cm^{-3}) beneath the tillage layer was responsible for restricting root access to stored soil moisture in the subsoil. In eastern Oklahoma, bulk densities of a reclaimed minesoil were higher at any given depth than similar undisturbed soils in the area (Silburn and Crow, 1984), attributable to compaction of topsoil and spoil during the reclamation process. In a study of five newly reconstructed soils in Illinois, Indorante et al. (1981) found that resulting soils had higher bulk densities and lacked structure when compared to undisturbed soils. They concluded that the combination of high bulk density, poor structure, and moderately fine textures would result in compacted and poorly aerated soils.

Soil compaction can have a deleterious effect on plant growth by limiting the volume of soil that can be exploited by the roots (Ide et al., 1984; Dickey et al., 1985), thereby depriving plants of subsoil moisture and nutrients (Rosenberg, 1964; Lamond, 1984; Dunker and Jansen, 1987). In addition, compaction results in a reduction in non-capillary soil pore space (Meredith and Patrick, 1961; Hillel, 1982) which combined with a higher soil density increases the mechanical impedance to roots, alters moisture availability, reduces aeration in the root zone, and reduces infiltration and internal movement of water in the soil (Hillel, 1982; Lamond, 1984; Vepraskas et al., 1986). The ability of plant roots to effectively penetrate into and through dense zones in the soil profile is affected by many factors. Soil physical properties such as bulk density, mechanical impedance (soil strength), texture, and structure affect the rate of root expansion in the soil (Meredith and Patrick, 1961; Taylor, 1974; Gerard et al.,1982). Dense soil layers such as tillage pans have high bulk densities, few macropores, and a mechanical impedance sufficient to reduce root growth rates. However, at the same bulk density, mechanical impedance will be less as the moisture content of the soil increases (Vepraskas et al., 1986) which could result in greater root penetration in a wet year than in a dry year. Martin et al. (1979) found that irrigating soybeans allowed some roots to penetrate a hardpan and extract some water from the subsoil. Similarly, dense soil layers may not restrict root growth if natural voids, shrinkage cracks, and root and worm channels are present for roots to grow through (Ellis and Barnes, 1980), bypassing the zones of high mechanical impedance (Vepraskas and Miner, 1986)

Researchers have attributed the massive, compacted condition of reconstructed soils to use of rubber-tired scrapers and bulldozers during grading and soil replacement (McSweeney et al., 1987; Dunker and Jansen, 1987; Philo et al., 1982; Fehrenbacher et al., 1982). Moisture content of soil at the time of replacement is also of importance because wetter soils are more subject to compaction than drier soils (Lamond, 1984). In some mining operations, however, soil replacement may occur on a nearly continuous basis (Vogel, 1987), and the chances for severe compaction at these sites is increased. Use of a bucket wheel excavator-conveyor-spreader system of mining and reclamation has been shown to reduce the degree of compaction in reconstructed soils (McSweeney and Jansen, 1984). This method employs a conveyor which transports excavated soil materials directly to the site of reclamation for subsequent spreading by bulldozers. The trundling action of the conveyor results in a soil structure, termed fritted (McSweeney and Jansen, 1984), consisting of smoothed, rounded aggregates loosely compressed together which create a subsoil containing extensive voids suitable for root proliferation and water and air movement within the profile.

In mining operations where there is excessive grading by rubber-tired scrapers, subsoiling may be one way to alleviate some of the problems caused by compaction (Philo et al., 1982), although little is known of the effects of subsoiling on reconstructed mined land (Jansen, 1981). Subsoiling, deep chiseling, and ripping are similar operations accomplished by pulling a vertical blade through the soil to loosen compacted layers in the subsoil or spoil, thereby allowing for exploitation of a greater soil volume by plant roots.

Much of the research on subsoiling has been on undisturbed soils possessing either a natural or tillage-induced hard pan in the Ap or EB horizon. Subsoiling puts cracks in dense soil layers to allow for deeper root penetration into the subsoil (Sene et al., 1985; Vepraskas et al., 1987), with the possible benefits of reducing mechanical impedance and oxygen stress, and increasing utilization of subsoil moisture and nutrients by growing plants (Cassel and Edwards, 1985). Earlier researchers had concluded that root growth was restricted in dense layers because of reduced aeration (Bertrand and Kohnke, 1957; Flocker et al., 1959), while others found mechanical impedance of the small pores to be the major limiting factor (Veihmeyer and Hendrickson, 1948; Taylor and Burnett, 1964). Subsoiling was shown to result in yield increases where these root restricting hardpans existed (Robertson et al., 1957; Patrick et.al., 1959).

More recent research has yielded similar results. In Belgium, Ide et al. (1984) compared the effects of subsoiling two soils; one a well-drained silt loam with a distinct plow pan (field 1), and the other a poorly drained silt loam lacking a distinct pan but with relatively high bulk densities below 50 cm depth (field 2). Subsoiling effectively removed the hard pan in field 1, increasing rooting depth and root density deeper in the profile, and higher yields of winter barley (Hordeum vulgare L.) were obtained. However, in field 2, subsoiling did not significantly affect rooting characteristics or yields, even though bulk density was decreased and aeration increased below the 50 cm depth. Because the poorly drained soil maintained a high subsoil moisture content, subsoiling did not reduce the penetrometer resistance at this depth and root growth was not restricted. They concluded that the main beneficial effect of subsoiling was an increase in effective soil volume for rooting exploration by removal of a root restrictive layer in the subsoil and not an increase in aeration (Ide et al., 1984).

Researchers in Egypt, on the other hand, did not see any improvement in soil physical condition as a result of subsoiling heavy textured, montmorillonitic soils (El-Araby et al, 1987). Although bulk densities of the soils were high (> 1.6 g cm^{-3}), they developed numerous deep cracks upon drying, extending as deep as 80 cm into the subsoil, thus allowing for considerable water and air infiltration deep into the profile.

In North Carolina, on sandy, coastal plain soils, researchers found that under irrigation, corn on subsoiled plots required less irrigation water than on non-subsoiled plots because of the disruption of a tillage pan 25 cm below the surface (Cassel and Edwards, 1985). Lowest corn grain yields were taken from non-subsoiled, dryland plots while subsoiling increased yields from 124 to 337 percent, with the highest increases occurring in the driest year. Martin et al. (1979) also found that during a dry growing season subsoiling a coarse-textured coastal plain soil increased soybean yields over those of conventionally tilled, irrigated plots, and that irrigation had no positive effect on yields from the subsoiled plots. They suggested that there might be other advantages to subsoiling in addition to increasing moisture availability. One such benefit might be the utilization of nutrients in the subsoil (Cassel and Edwards, 1985). Excessive rainfall after topdressing corn plots with nitrogen fertilizer leached nitrogen out of the root zone early in the growing season, consequently, much of the nitrogen utilized by the crop came from the subsoil. Plant roots on non-subsoiled, irrigated plots were restricted to the Ap horizon, resulting in lower grain yields than on subsoiled, dryland plots. Vepraskas et al. (1987) found that the largest relative yield increases of tobacco (Nicotiana tabacum L.) because of subsoiling occurred during years of poorly distributed rainfall on sites exhibiting poor water retention. Kamprath et al. (1979) compared soybean response to conventional moldboard plowing, chiseling (27 cm depth), and subsoiling (45 cm depth) of two coarse-textured soils containing subsurface hardpans. Breaking the tillage pan by subsoiling or chisel-plowing increased top growth at full bloom, and root growth and moisture utilization in the subsoil. Grain yields were also increased by subsoiling and chisel-plowing, but only in years with sub-normal precipitation during late-flowering and early pod set.

In Morocco on a well drained clay loam soil with a subsurface compacted layer, Oussible and Crookston (1987) observed that the soil in the area of the subsoiler slits had a reduction in bulk density of 11 percent and increases in total porosity and air-filled porosity of 17 and 50 percent, respectively. Root length:root weight ratio was increased in the area of the compact layer by 54 percent over those in the check plots. They attributed significant increases in wheat straw and grain yields to improved moisture availability during two relatively dry years, and to the production of finer roots in the previously compacted zone (more root surface area for moisture and nutrient absorption).

In South Carolina, Reicosky et al. (1976) examined effects of chiseling and irrigation of a sandy, coastal plain soil on corn plant water status when stressed by withholding moisture at tasseling. Results showed corn grain yields significantly increased when irrigation water was applied, but only on those plots that did not receive the chiseling treatment. No yield increase was observed on the chiseled treatments. They suggested that when water was not a limiting factor there was no benefit from chiseling.

In Texas, Heilman (1988) studied effects of in-row subsoiling on soil bulk density, water infiltration, and cotton (Gossypium hirsutum L.) lint yields. The soil had a very high montmorillonitic clay content (60-65 percent) which caused serious soil physical and management problems from slow internal drainage and restricted crop rooting. Typical rooting depth for most crops grown on these soils is only about 30 cm. Subsoiling resulted in significant increases in infiltration and decreases in bulk densities beneath the row. In addition, rooting depth was increased to as much as 91 cm, and the crop achieved canopy closure more than one month sooner than on non-subsoiled plots. Resulting cotton lint yields were increased an average of 17 percent during the three year study.

From the above discussion it appears that subsoiling can be expected to increase plant growth and production if a dense soil layer restricts root growth. In almost all of the studies previously mentioned, favorable responses to subsoiling occurred only when plants would otherwise suffer from moisture deficits during periods of below-normal or poorly distributed precipitation as a result of shallow rooting. Unfortunately, amelioration of tillage-induced or clay hardpans by subsoiling may only be temporary as these tend to reform spontaneously (Hillel, 1982).

In many reconstructed soils the entire soil profile is compacted (van Es et al., 1988). Consequently, roots are only able to exploit the soil to the depth of tillage, unlike natural soils containing hardpans in which roots can normally exploit the subsoil beneath the shattered impervious layer. As stated earlier (Jansen, 1981), little is known of the effects of subsoiling on soil physical condition and crop growth on reclaimed surface mined lands. In the more humid interior regions of the U.S., the need to mitigate the effects of dense reconstructed soils is of considerable importance since it is here that reconstruction of prime soils is a major concern (Albrecht and Thompson, 1982).

Research results in Kentucky suggest that ripping may be beneficial to crop production on reclaimed mined lands. Ripping minesoils to the soil-spoil interface resulted in taller and more vigorous plant growth than on minesoils that had not been ripped (Huntington et al., 1980). Powell et al.(1985) used a bulldozer-drawn ripper on reconstructed prime farmland and saw significant crop yield increases since stored soil moisture was made more accessible. Ripping effects were still apparent after four years. Barnhisel et al. (1988) saw a slight increase in soft red winter wheat (Triticum aestivum L.) yields as a result of ripping reclaimed mined land. The ripping treatment was deep enough to affect the soil-spoil interface, and resulted in lowering the bulk densities in the narrow zone affected by the ripper shank (25-37.5 cm) by about 0.2 g cm^{-3}. They indicated that the change in bulk density of the ripped zone was enough to increase yields.

In addition to improving subsurface plant root-soil moisture relations, ripping may also facilitate moisture retention at the surface. Powell et al.(1980) compared four land preparation treatments for their effect on establishment and growth of tall fescue and red clover on spoil material. They concluded that ripping, which resulted in a rougher soil surface than disking, improved water retention and intake at the surface and offset the slow infiltration rate of the spoil materials. Forage production was significantly higher on the ripped treatments than on the disked treatments. After the second growing season, forage response to surface roughness ceased, attributed to decreases in soil phosphorous levels to the point of affecting yields. Subsoiling, therefore, may reduce runoff and erosion and improve micro-relief, keeping more rainfall on the reclaimed area (Holmberg, 1983).

There are many factors that can interact to make short term tillage experiments yield inconclusive results (Hillel, 1982). Final crop yields may indicate no differences resulting from different tillage methods, in spite of measurable effects of tillage on soil. Crop response tends to be masked by other unpredictable variables such as fertility, moisture excesses, diseases, and pest infestations (Hillel, 1982). On a reclaimed site in Iowa, van Es et al. (1988) found that surface micro-topography differences masked the effects of subsoiling on corn yields. Newly reconstructed mined lands are subject to differential settling of the spoil materials (USDA Forest Service, 1984), because freshly excavated overburden occupies a much larger volume than that of rock prior to excavation (Paone et al., 1978). Over time, spaces between fragments are reduced under the force of gravity. This phenomenon occurred on the site in Iowa, resulting in concave areas on the experimental plots. van Es et al. (1988) concluded that microtopographic variations strongly influenced corn yield distributions to such a degree that subsoiling treatment effects were concealed.

SOIL REPLACEMENT RESEARCH

The ideal objective of modern reclamation is rebuilding of a plant-growth medium that is similar to and equally suited for plant growth and production as the pre-mine soils (Vogel, 1987). However, replacement of segregated soil materials is a relatively recent innovation in surface mined land reclamation. Research prior to the 1970’s was conducted primarily on spoils and concern was given to methods that would make them more favorable for plant growth. Reclamation research in Kansas has occurred primarily on those lands disturbed prior to enactment of reclamation legislation in 1969, and consisted of reforestation, rangeland establishment, and cereal grain production on leveled or recontoured spoil banks (Camin et al., 1972; Geyer, 1972; State Geological Survey of Kansas, 1972).

The process of soil removal, transport, and subsequent respreading can seriously affect the chemical, physical, and microbial properties of a soil. In addition, many mining operations are forced to stockpile soil materials when immediate respreading is not possible. Stockpiling for extended periods of time can result in changes in soil fungal populations, mycorrhizae infection potential, and losses of other microorganisms (Rives et al., 1980; Schuman and Power, 1981), which may result in lower nutrient cycling rates and reduced nutrient availability (Stark and Redente, 1987). Other possible effects of stockpiling include losses of organic matter and increases in soil density (USDA Forest Service, 1984). In spite of the damage done to the pre-mine soil materials, the A and B horizons will often be the most desirable medium with which to construct a new soil (Jansen, 1981). Replacement of topsoil provides a medium for the relatively rapid reestablishment of favorable soil properties (Doll et al., 1984). Thus, soil replacement, particularly topsoil, is now recognized as one of the best means to restore productivity to surface mined lands (McGinnies and Nicholas, 1980; Merrill et al., 1980; Doll et al., 1984; Halvorson and Doll, 1985).

The question of how much soil material is necessary to achieve the maximum level of productivity on reclaimed surface mined lands has been the subject of many experiments in the Northern Great Plains and in the more humid regions of the midwest, although none are specific to Kansas. However, the information obtained from such experiments is of value because many factors have been identified that can be used to establish general guidelines for soil reconstruction and for interpretation of research results from other geographical regions.

Research in the West

The bulk of the research on reclamation in the west has occurred in the semi-arid Northern Great Plains, of which over half of the mineable land is pasture or rangeland (Hofmann and Ries, 1988). One of the early experiments using soil replacement as a means to increase reclamation success was initiated in 1970 in North Dakota on highly sodic spoils (Power et al., 1974). Their results indicated that gypsum applied to the sodic spoil increased slender wheatgrass (Agropyron trachycaulum (Link) Malte) yields, but much higher yields were obtained when only 5 cm of topsoil was applied. Furthermore, runoff was reduced from 90 percent to 53 percent of intercepted precipitation by the addition of topsoil, thereby increasing water infiltration. Richardson et al. (1975) found that 20 cm topsoil over spoil produced higher native grass yields in southeastern Wyoming than did irrigating non-topsoiled spoil. It is apparent that water was not the limiting factor, rather the nutrient supplying capacity of the spoil (Hargis and Redente, 1984).

A set of experiments, initiated in 1972 by Merrill et al. (1983b), evaluated two topsoil applications (none or 30 cm) combined with two gypsum treatments (0 or 5080 kg ha^{-1}). The topsoil and gypsum treatments were applied at four sites in North Dakota on spoils of differing SAR (sodium absorptive ratio) values. At the highly sodic site (spoil SAR=27) average crested wheatgrass (Agropyron desertorum (Fisch.) Schult.) yields from 1975 to 1978 on bare spoil were less than half of those on topsoiled spoil, with little effect of gypsum on either topsoil treatment. At the moderately sodic sites (spoil SAR=11-12) gypsum did not affect yields on topsoiled plots. However, when gypsum was applied to the plots without topsoil, yields approached those on the topsoiled plots. At the non-sodic site, yields from topsoiled plots tended to be higher than on plots without topsoil. Gypsum additions had no effect on yields with or without topsoil. Overall yields from the four sites were highest for the non-sodic site, intermediate for the moderately sodic sites, and lowest for the highly sodic site. In 1983, yields taken from the four sites tended to be two to three times higher on plots that were topsoiled. These results point to the need to respread topsoil because yields were not maintained when only gypsum was applied (Doll et al., 1984). On more sodic spoils, 30 cm of topsoil is not enough to attain maximum yields (Ries et al., 1978; Merrill et al., 1983b). This implies that the amount of soil necessary for maximum production is related to the quality of underlying spoil material (Doll et al., 1984), with poorer quality spoils requiring deeper replaced soil materials.

An experiment was initiated in 1972 to compare grass yields on sodic spoils covered with 0, 5, 15 and 30 cm of topsoil. Yields on 30 cm of topsoil were highest each year, but the rate of yield increase with increasing depth indicated that maximum productivity had not been achieved on 30 cm of topsoil (Ries et al., 1978). Grass yields declined as the experiment progressed, which was partially attributed to deterioration of topsoil quality resulting from upward movement of sodium into the topsoil from the spoil (Sandoval and Gould, 1978).

Results from preceding experiments indicate that more than 30 cm of good quality soil material may be necessary to achieve maximum productivity, because of unfavorable properties of the spoils. In order to evaluate effects of increased total soil thickness on plant production, experiments were developed using both the topsoil (A horizon) and subsoil (B and favorable portions of the C horizons). In a greenhouse experiment, McGinnies and Nicholas (1980) reported herbage yields of wheat (Triticum aestivum, L.) and intermediate wheatgrass (Agropyron intermedium (Host) Beauv.) increased linearly with replaced soil depth over favorable minespoil. Root production of both species was much greater in soil than spoil, and increased linearly with soil thickness. This low root production in spoil material was attributed to deficient levels of nitrogen and phosphorus in the spoil.

In northwestern Colorado, Redente and Hargis (1985) reported that seeded grass production was greatest on 60 cm replaced topsoil, while seeded forb and shrub production was greatest on only 15 cm of topsoil. Apparently, when only 15 cm of topsoil was applied, perennial grass and weed growth was poor, and forbs and shrubs were able to grow with little competition for water or nutrients. At 60 cm topsoil depth however, vegetation was dominated by the grasses and annual weeds to the near exclusion of the forbs and shrubs.

Fifteen wedge-type experiments were constructed at surface coal mines in Wyoming, Montana, and North Dakota in 1977-1980 (Barth and Martin, 1984). Topsoil (actually a mixture of A, and favorable portions of B, and C horizons) was spread to establish a uniform soil depth gradient ranging from 0 to 152 cm over spoil material. Response of cool-season grass production to increasing soil depths was found to be dependent on chemical and physical traits of underlying spoil materials, of which four types were recognized. Maximum production was achieved at soil depths of 152 cm over acid spoil, 50 cm over generic spoil, 71 cm over sodic spoil, and 0 cm over soil-like spoil which had no adverse properties and was chemically and physically similar to soil. Roots were found to penetrate only 10 cm into either sodic or generic spoils, and penetration stopped abruptly 10-15 cm above the acid spoil. For a detailed description of each spoil type see Barth and Martin (1984).

In another wedge experiment, Power et al. (1981) spread subsoil from 0 to 210 cm deep over sodic spoil. Topsoil was then spread at either 0, 20, or 60 cm over subsoil. A fourth treatment of mixed topsoil and subsoil was also established during plot construction. Plant species included in the study were crested wheatgrass (Agropyron desertorum (Fisch.) Schult.), spring wheat (Triticum aestivum L.), alfalfa (Medicago sativa L.), and native grasses. Maximum yields of all crops equaled or exceeded those expected with adequate management on similar type soils in the surrounding area. Alfalfa yields tended to increase up to about 70 cm subsoil for each topsoil depth, and 110 cm when topsoil and subsoil were mixed. Maximum yields were at 20 cm topsoil over 70 cm subsoil giving a total soil depth of 90 cm. Native grass yields tended to increase up to 70 to 90 cm of subsoil but these increases were generally not significant past 30 cm subsoil. There were no significant differences between yields on any soil treatment at subsoil depths over 50 cm.

Crested wheatgrass yields again increased up to about 70 to 90 cm subsoil, but were generally not significant past 30 cm for any soil treatment. However, except for 10 to 30 cm subsoil depth, yields on subsoil only were significantly lower than on either topsoiled or mixed treatments. Spring wheat yields increased significantly up through 50 cm subsoil, and tended to reach a maximum at about the 70 to 90 cm subsoil depth. Wheat yields on mixed and subsoil only plots were always significantly less than when topsoil was applied at all subsoil depths except at 190 cm, where topsoiled and mixed treatments produced statistically equivalent yields. Alfalfa, wheat, and crested wheatgrass yields were lowest for plots receiving only subsoil, followed by plots with topsoil and subsoil mixed, and highest yields were taken from plots with either 20 or 60 cm of topsoil over subsoil. Yields at which responses leveled off, therefore, increased as quality of replaced soil materials increased. Differences between soil materials were not as apparent for native grasses.

Yields in general tended to decrease at subsoil depths over 90 to 110 cm, attributed to increased vehicular traffic at the top of the wedge (compaction), and better soil moisture at the midslope resulting from more snowmelt and run-on from the summit. Similar topographic and slope effects reported by Merrill et al. (1982) were summarized by Doll et al. (1984, p.10-12). On mixed topsoil and subsoil, at least 90 percent of maximum yields were obtained for all three forage species (Power et al., 1981). Spring wheat yields, on the other hand, were significantly higher on segregated A-B soils than on mixed soils.

For all crops, there was little difference in yield between 20 and 60 cm topsoil at the same subsoil depth. However, at equal total soil depths, yields were consistently higher with 20 cm topsoil than with 60 cm of topsoil. Halvorson and Doll (1985) attributed this to the more droughty nature of the sandy loam topsoil when compared to the clay loam subsoil. It was concluded that 90 cm total soil thickness (20 cm topsoil over 70 cm subsoil) was required to obtain maximum yields of most crops under the conditions encountered in the experiment (Power et al., 1981).

At the same site, Merrill et al. (1985) obtained crested wheatgrass yields two to three times higher on 20 cm topsoil over 100 cm subsoil as compared to 20 cm topsoil over 25 cm subsoil. Roots were able to penetrate at least 25 cm into the spoil, and root densities (root weight per unit soil volume) through the 50 cm depth under 25 cm subsoil were not significantly different from those at the same depth in the subsoil of the 50, 75, or 100 cm subsoil depth treatments. However, measured root water uptake was much less from the minespoil than from the subsoil, attributed to the very low hydraulic conductivity of the sodic spoil. With the assumption that root densities (root number per unit volume of soil) were correlated with functional root length density (root length per unit volume of soil), they concluded that reduced yields resulting from restricted water uptake was not due to inhibition of root growth, but of root function in the spoil. Highest relative yield differences between soil depth treatments were observed when early spring precipitation distribution was less than favorable.

Researchers in southwest Canada constructed plots of various depths of silty clay subsoil plus 15 cm clay loam topsoil over sodic sandy clay loam spoil (Oddie and Bailey, 1988). Both barley (Hordeum vulgare L.) and alfalfa-smooth bromegrass (Medicago sativa, L., Bromus inermis Leyss.) yields were significantly lower on plots with topsoil over spoil than on plots which received subsoil plus topsoil. Generally, annual yields increased up to 55 cm of subsoil and tended to reach a maximum at about 95 cm, although the differences between 55 cm and 95 cm were not statistically significant. Yields on 95 cm subsoil plus 15 cm topsoil were reported to compare favorably with those obtained on non-mined land in the surrounding area. Barley root penetration into the sodic spoil was observed only on the "no subsoil" treatment to a depth of about 24 cm. Alfalfa-bromegrass roots, on the other hand, penetrated into the spoil much more readily, even when as much as 135 cm subsoil covered the spoil. A combination of less water depletion and shallower rooting by barley led to an accumulation of water above the spoil-soil interface. Minesoils in this condition are predisposed to the movement of sodium from the spoil into the lower portion of the overlying soil (Sandoval and Gould, 1978; Merrill et al. 1983a), which could decrease minesoil productivity if replaced soil depth is insufficient to allow for topsoil deterioration.

On non-sodic spoils, Halvorson et al. (1986) and Halvorson et al. (1987) found differences in soil depth requirements depending on the texture and available water holding capacity of both the spoil and replaced soil materials. Root density measurements indicated that the majority of roots occurred in the replaced soil material over coarser textured spoils. In a later experiment Schroeder and Halvorson (1988) found that lower amounts of stored available water in reconstructed profiles over gravelly loamy sand spoil resulted in significantly lower yields three out of four years when compared to underlying spoils of finer textures. As either replaced soil thickness increased or spoil texture became finer, soil water depletion values generally increased with profile depth. Thus, finer textured, non-sodic spoil materials with adequate moisture holding capacity were able to serve as the lower portion of the root zone, thereby reducing the amount of replaced soil required for desired productivity. Crop yields obtained on the reclaimed soils were generally comparable to those on nearby undisturbed soils when growing season precipitation was favorable. However, in years with inadequate or poorly distributed precipitation, yields on reclaimed soils were significantly lower, which was attributed to deeper rooting in the undisturbed soils.

Research in the Interior Coal Province

The Interior Coal Province occupies all or part of ten states: Michigan, Illinois, Indiana, western Kentucky, Iowa, Missouri, Kansas, Oklahoma, Arkansas, and central Texas (Grandt, 1978a). A major portion of lands disturbed by surface mining in this region are well suited for, and have historically been used for small grain and row crop production. In Illinois, for instance, approximately 60 percent of the land area is considered prime farmland

(Jansen, 1981). Reclamation objectives in many of these areas must not only provide for swift land stabilization and erosion control, but must create new soils capable of supporting intensive agricultural production in the short term as dictated by state and federal regulations.

Like the Northern Great Plains, studies in the Interior Coal Province have established soil replacement as the most effective means to restore productivity to most surface mined lands. Grandt (1978b) reported on a study in Illinois which compared corn (Zea Mays, L.) production on 38 cm silt loam topsoil over spoil and on spoil only. Corn yields were nearly 40 percent higher when topsoil was replaced in all three years of the study, although they were still less than those on the undisturbed control soil.

Dunker and Jansen (1987) established experimental plots by replacing 45 cm of good quality topsoil over graded wheel spoil of favorable quality. Under irrigation, corn yields were generally significantly increased by the addition of topsoil compared to bare spoil. Without irrigation, yields were significantly increased by topsoil in moisture deficient years, and were significantly reduced in years with little moisture stress. Differences in dates of pollination between corn on topsoil and bare spoil allowed the latter to pollinate under conditions of cooler temperatures and beneficial precipitation, resulting in better yields. Topsoil replacement produced significantly higher soybean yields both with and without irrigation. They concluded that when reconstructed minesoils have favorable chemical and physical characteristics, yields of row crops will compare favorably to those in undisturbed soils of similar character. They also noted that temperature and moisture stress adversely affected crops grown on mine soils more than those on undisturbed soils. A wedge experiment conducted concurrently at the same site resulted in maximum corn and soybean yields at 60-80 cm of replaced soil. Increases in yield were not observed beyond 80 cm soil thickness, likely due to increased soil strength from compaction by scrapers during soil reconstruction (Jansen et al., 1984). Few roots were found to penetrate beyond 60 cm at this site, hence, shallow rooting limited crop growth and production, especially during years of temperature and moisture stress.

In Kentucky, researchers compared soft red winter wheat yields when grown on 25, 50, or 75 cm of topsoil placed over graded spoil (Barnhisel et al., 1988). In two of three years, yields from 50 and 75 cm soil were not significantly different, but both were greater than those from the thinnest soil treatment. However, in a drought year, yields from the thickest soil treatment were significantly lower than the other two treatments. This was attributed to greater vegetative growth early in the season, depleting soil moisture to a level incapable of sustaining grain-fill during the drought. It was concluded that when spoils possess no serious growth limiting characteristics, at least 50 cm of good quality soil material should be sufficient to produce wheat on reclaimed mined land in Kentucky.

A study in western Illinois by Fehrenbacher et al. (1982) compared corn root development in four different soil treatments constructed from silt loam spoil, silty clay loam subsoil, and silt loam topsoil. Treatments were spoil only, 77 cm subsoil over spoil (B-spoil), 55 cm topsoil over spoil (A-spoil), and 55 cm topsoil plus 77 cm subsoil over spoil (A-B-spoil). An undisturbed Clarksdale silt loam (fine, montmorillonitic, mesic Udollic Ochraqualf) was used as a control.

At depths greater than 54 cm, bulk densities of graded spoil were significantly higher than replaced subsoil. In both the A-spoil, and A-B-spoil profiles bulk densities tended to be higher than the control in a zone about 20-40 cm below the soil surface. Depth of root penetration, measured directly under the corn plant, was 163, 120, 74, 64, and 36 cm for the control, A-B-spoil, A-spoil, B-spoil, and spoil only, respectively. Thus, roots penetrated the subsoil to about a 65 cm depth whether topsoil was replaced or not. Root length densities (root length per unit soil volume) below the topsoil were significantly higher in the A-B-spoil than in the A-spoil, attributed partially to the higher bulk densities of the graded spoil below the A-spoil.

With the exception of the spoil only, corn yields the first year following profile construction showed no significant differences among replaced soil treatments. However, in the following year yields from the A-B-spoil were statistically equivalent to the undisturbed control, and significantly greater than both A-spoil, B-spoil, and spoil only. The results of this experiment illustrate the benefits of separate topsoil and subsoil spreading on leveled spoil, but it must be noted that scraper-pan traffic was not allowed directly on the plots during construction, thereby avoiding possible excess compaction.

Researchers in Kentucky (Barnhisel et al. , 1987) obtained higher yields of grain sorghum (Sorgum bicolor (L.) Moench) on spoils covered with 20 cm topsoil and either 40 or 80 cm subsoil than on 20 cm topsoil over spoil. Overall, the best yields were obtained on 80 cm limed subsoil plus 20 cm topsoil which had previously been cropped to tall fescue (Festuca arundinacea Schreb.) or alfalfa.

SUMMARY

As stated earlier, the primary goal of reclamation is to build a new soil able to support land uses in existence prior to mining, or some other use of equal value. The actual amount of soil necessary to achieve the desired post-mine productivity is a function of many factors which vary according to specific regions, and even sites within regions. In some cases, albeit very few, soil replacement may not be required to achieve maximum plant production as found by Barth and Martin (1984) on very favorable spoil materials. Conversely, on highly unfavorable (acidic) spoils, they saw linear increases in yields with soil depths, with no sign of leveling off, even at their thickest soil treatment. Texture of both the soil and spoil are also important parameters affecting productivity of reconstructed mine soils, mainly because of its effect on the water holding capacity of the newly constructed root zone (Halvorson et al., 1986; Doll et al., 1984).

In the Northern Great Plains, efficient use of limited precipitation is seen as the major constraint to increased crop yields (Power et al., 1979), and any spoil or soil trait that might reduce this efficiency will adversely affect plant growth. When available, at least 30 cm topsoil should always be respread over root zone materials that are of favorable quality. On sodic spoils the root zone should consist of at least 90 to 120 cm subsoil (Halvorson and Doll, 1985) to ensure adequate root zone moisture supplying capabilities, and to buffer the root zone from the adverse effects of the sodic material. In the same manner, coarser textured spoils should be covered with finer textured subsoil material. Spoil materials with no adverse properties may serve as the lower portion of the root zone, thereby decreasing the amount of salvaged soil required to restore productivity. Halvorson et al. (1986) recommended total soil thickness of at least 70 cm for highest yields over non-sodic, gravelly loamy sand spoil, while as little as 46 cm of soil was sufficient for maximum productivity on clay loam and silty clay loam spoils.

Optimum soil thicknesses in the more humid Interior Coal Province do not appear to differ greatly from those in the more arid West. Jansen et al. (1984) saw maximum corn and soybean yields when 80 cm good quality soil was placed over favorable spoil. There was no benefit to replacing more than 80 cm, attributed to excessive compaction from repeated passes of scrapers required to construct the deeper soils. In Kentucky, Barnhisel et al. (1987) and Barnhisel et al. (1988) obtained highest yields of wheat on at least 50 cm topsoil, and highest grain sorghum yields between 40 and 80 cm subsoil plus 20 cm topsoil placed over limed acid spoils.

As in the west, textural properties of spoils and soils are of considerable importance. However, the major contributor to increased climatic stress appears to be the effective creation of shallow soils through compaction during the soil construction operation (Jansen et al., 1984; Dunker and Jansen, 1987). Plant roots are then unable to fully exploit the total soil volume, and are prone to succumb to extreme in climatic conditions sooner than those on undisturbed soils. Jansen et al. (1984) suggested that at many sites, the physical condition of the root zone may be more important to establishing successful rowcrop production than the precise replacement of soil horizons.

Many of the previously mentioned studies encountered varying responses to replaced soil treatments with varying climatic conditions. In years with abundant and favorably distributed precipitation, measured plant parameters might indicate mere non-significant trends, while stressful conditions elicit highly significant responses to the soil depth treatments (Merrill et al., 1985), or in some cases, total crop failure (Jansen et al., 1984). Thus, in order to insure continued productivity of reclaimed surface mined lands, soil reconstruction must allow for changes such as sodium movement, or erosive soil loss which might adversely affect plant growth in the future. The ultimate goal of a stable soil environment, implies that a soil should be created to sustain plant growth and production through the range of environmental extremes that might be encountered, not just the average.

I. FORAGE RESPONSE TO REPLACED SUBSOIL DEPTH AND RIPPING OF RECONSTRUCTED SURFACE-MINED LAND IN SOUTHEAST KANSAS

ABSTRACT

An experiment was initiated to evaluate the effects of different depths of replaced soil on fescue (Festuca arundinacea Schreb.) and alfalfa (Medicago sativa L.) production by constructing plots with 30 cm of topsoil plus 0, 30, 60, or 90 cm of subsoil placed over leveled minespoil. Deep ripping of the new profiles was also evaluated to determine if it could improve forage yields. Fescue yields were measured for three years, 1987-1989, and it was generally observed that yields were not significantly increased by increasing subsoil depth. There was , however, a significant effect of subsoil depth in 1988. Yields were significantly lower on 30 cm topsoil plus 30 cm subsoil than on any of the other treatments, while the 'topsoil only' plots compared favorably with the two deepest treatments. Ripping did not significantly affect yields in any of the three years, but a significant interaction with subsoil depth was observed in 1987. On the ripped treatments, fescue yields increased up to 30 cm topsoil plus 60 cm subsoil, then tended to level off, or decrease. Yields on the unripped treatments were not as responsive to subsoil depth, and tended to reach a maximum at 30 cm topsoil plus 30 cm subsoil. Two cuttings of alfalfa were taken in 1988, and two in 1989. Depth of subsoil did not significantly affect yields in 1988. Yields from the second cutting were signif-

icantly higher on the ripped than on the unripped treatments. In 1989, yields from the first cutting were not significantly increased by increasing subsoil depth. Yields from the second cutting were significantly higher on 30 cm topsoil plus 90 cm subsoil than on topsoil plus either 0, or 30 cm subsoil. Ripping did not significantly affect yields from either cutting. At least 60 cm of subsoil plus 30 cm of topsoil should be respread for optimum forage production at this site, while at the same time guarding against long-term effects of erosion and settling. Ripping of newly constructed soils did not greatly improve forage yields and is not an essential part of reclamation if the post-mining land use is fescue or alfalfa production.

INTRODUCTION

In 1977, congress enacted the Surface Mining Control and Reclamation Act which requires that all lands disturbed by surface mining be reclaimed to a condition of equal or greater value than that which existed prior to mining (U.S. Congress, 1977). According to the law, lands must be reclaimed by replacing soil materials over recontoured overburden and spoil materials. Numerous studies have shown that the most important aspect of the soil replacement process is the separate spreading of good quality topsoil over favorable subsoil materials (Doll et al., 1984). Topsoil generally has a more favorable structure, and contains higher amounts of organic matter, nitrogen, and other plant available nutrients, which encourage the reestablishment of microbial activity and nutrient cycling (Doll et al., 1984). Halvorson and Doll (1985) recommended that at least 30 cm of good quality topsoil should always be respread when reclaiming mined soils. Freshly replaced soil materials, however, are susceptible to erosion , and must be revegetated as quickly as possible to prevent erosional loss (Bennett et al., 1978). One way to stabilize the newly reclaimed soils is the establishment of forage legumes and grasses which not only contribute erosion protection, but can aid in the soil rebuilding process (Hons et. al., 1979; Bennett et al., 1978). Once established, these forages can be of additional value in the form of pasture and hay for livestock production.

The growth of grasses on sodic spoils in North Dakota was shown to be dramatically increased when as little as 5 cm of topsoil was spread over the sodic spoil (Power et al., 1974). Later experiments showed that maximum yields of alfalfa (Medicago sativa L.) and crested wheatgrass (Agropyron desertorum (Fisch.) Schult) were obtained with 20 cm of topsoil and 71 cm of subsoil over sodic spoil (Power et al., 1981). Results of other experiments with unfavorable spoil have shown that more than 30 cm of topsoil over spoil is required to achieve maximum production of grasses (Sandoval and Gould, 1978; Ries et al., 1978; Merrill et al. 1983b). Barth and Martin (1984) also found that the depth of soil materials necessary for maximum production is dependent upon the nature of the spoil material. Maximum cool-season grass production was achieved at soil depths of 152 cm over acidic spoil, 50 cm over generic spoil (non-toxic, but of different origin than the soil), 70 cm over sodic spoil, and none over soil-like spoil.

Merrill et al. (1985) found that roots of crested wheatgrass were able to penetrate at least 25 cm into sodic spoil when the spoil was covered with only 20 cm of topsoil and 5 cm of subsoil. Root densities taken at 50 cm depth for this treatment were not significantly different from those occurring at the same depth in other treatments with deeper replaced subsoils. However, measured root water uptake was much less from the minespoil than subsoil material, attributed to the low hydraulic conductivity of the spoil material. Corresponding yields on 20 cm topsoil plus 80 cm subsoil were 2 to 3.5 times higher than yields on 20 cm topsoil plus 5 cm of subsoil. In Canada, researchers found that yields of an alfalfa-smooth bromegrass (Bromus inermis Leyss.) mixture were significantly lower on plots with topsoil over spoil than on plots which received subsoil plus topsoil (Oddie and Bailey, 1988).

The depth of soil to be replaced for maximum forage yields will depend on the quality of the soil material available for replacement and the nature of the spoil material. This study was conducted 1) to determine the effects on forage yields of subsoil depth under 30 cm of topsoil when placed over a non-sodic, moderately saline spoil and 2) to determine the effects of deep ripping a newly constructed soil on forage yields.

MATERAIALS AND METHODS

Experimental plots were constructed in the fall of 1985 at P & M Midway Mine in Linn county, Kansas. The pre-mine soil in the study area was mapped as a Parsons silt loam (Fine, mixed, thermic Mollic Albaqualf) with nearby occurrances of Dennis silt loam (Fine, mixed, thermic Aquic Paleudoll) (USDA Soil Conservation Service, 1981). Twelve plots, each measuring 54 m x 54 m, were constructed using scraper pans and bulldozers for all soil transport and placement. Each constructed profile consisted of 30 cm of topsoil with either 0, 30, 60, or 90 cm of subsoil placed over graded minespoil. The subsoil depth treatments were arranged in a randomized complete block design with three replications (Figure 1). On 7 March 1986, one half of each block was ripped with a chisel type subsoiler to a depth of about 51 cm. The overall experimental design was a split-plot with ripping as the whole plot and subsoil depth as sub-plots arranged in strips. Crops were randomly assigned to a 9 m x 54 m strip on each subsoil depth treatment, perpendicular to the direction of ripping, so that each crop contained a ripped and unripped treatment.

Soil Sampling

In May 1986 two soil cores were taken from each treatment using a truck-mounted Giddings press fitted with a 7.5

cm diameter Giddings probe (Manufacturer, Giddings Mach., Ft. Collins, CO). Sampling depth in each plot was limited to the depth of the replaced soil material because the probe was unable to penetrate more than 5.0 cm into the spoil material. A total of 48 cores were removed, half of them for bulk density determinations, and the other half for chemical analysis. For bulk density measurements, sections 7.5 cm in length were removed from each core for depths centered at 3.5, 11, 26, 49, 75, and 105 cm. The soil cores were weighed, dipped in paraffin, and reweighed. For chemical analyses, cores were divided into sections at 0-15, 15-30, 30-60, 60-90, and 90-120 cm and sealed in plastic bags for transport to the laboratory. Additional samples were taken with a hand probe for chemical and textural analysis at depths of 0-7.5 cm and 7.5-15 cm.

Soil Analyses

Soil samples and spoil fines were air-dried and ground to pass a 2 mm sieve. Soil pH was measured with a pH meter in a 1:1 soil/distilled water mixture. Exchangeable cations were determined by extracting 2 g soil material with 20 ml ammonium acetate adjusted to pH 7.0. Samples were shaken for five minutes, extracted, and cations measured with an atomic absorption spectrometer. The Bray P1 method (Bray and Kurtz, 1945) was used as an index for available P. Values for electrical conductivity were determined from saturation extracts using procedures developed by the U.S. Salinity Laboratory Staff (1954). Zn was measured by DTPA extraction (Whitney, 1980). Organic matter was measured using the Walkley-Black procedure described by Nelson and Sommers (1986). Bulk densities were determined using a method described by Blake and Hartage (1986), using paraffin-coated cores instead of clods. Particle-size analysis was performed using the pipet method described by Gee and Bauder (1986).

Prior to seeding fescue on 3 April 1986, plots were disked twice and the seedbed prepared with a roller. Tall fescue (Festuca arundinacea Schreb.), variety KY-31, was drilled at a 1.2 cm depth in 17.5 cm row spacing. Phosphorus fertilizer was banded below and to the side of the seed at 23 kg P ha^{-1}. On 15 April, the plots were topdressed with 84 kg N ha^{-1}. Fescue was not harvested in 1986 to allow for good stand establishment, but plots were clipped in late May for weed control. Fescue received a spring topdress application of 100 kg N ha^{-1} each subsequent year of the study, but no additional P in 1987 or 1988. In 1989, sub-sub plots were established by applying 39 kg P ha^{-1} to one-half of each plot.

Attempts at establishing a stand of alfalfa (Medicago sativa L.) were not successful in April and September of 1986, and April of 1987 even with fungicide treatments. Relatively wet soil conditions favoring damping off and

Phytopthora root rot existed. In September 1987, alflafa was established on plots that had lain idle since oats were harvested in the summer of 1986. Seed of Peak variety was treated with a fungicide, Metalaxyl, [N-(2,6-dimethylphenyl)-N-(methoxyacetyl) alanine methyl ester] and drilled at a rate of 16 kg ha^{-1}, 1.2 cm seeding depth and 17.5 cm row spacing. N and P starter fertilizer was banded below and to the side of the seed at rates of 20 and 23 kg ha^{-1}, respectively.

On 17 July 1987, soil cores were taken from the fescue plots for rooting depth determinations. Three 7.5 cm diameter cores were taken to the depth of the spoil from the ripped and non-ripped half of each subsoil depth treatment for a total of 72 cores. Sections of each core, 7.5 cm in length, were removed at the following depths: 5 to 12.5 cm, immediately above and below the topsoil-subsoil interface, and at depths of 60, 90 and 120 cm where these depths were included in the profile. Spoil samples were obtained where possible. Generally, the deepest sections from each subsoil depth treatment contained the soil-spoil interface. Root counts were made using the core-break method described by Bohm (1979). Each core was broken in half and the number of exposed roots on each face was counted. To aide in counting, a magnifying lens and hand-held counter were used. All exposed roots, regardless of size were counted as one root. Many times the break occurred along a crack in which a mass of roots were revealed. In most cases a satisfactory second break could be made. If not, a best estimate was recorded using knowledge of previous counts at that depth as an aide. A total of 650 faces were counted in the procedure. An average value for each depth in each ripping treatment was calculated from six core faces.

Fescue was harvested on 1 June 1987, 25 May 1988, and 19 May 1989. Cuttings of alfalfa were taken on 25 May and 20 July 1988, and 19 May and 23 June 1989. Areas measuring .83 m x 4.5 m were harvested for both crops using a sickle-bar mower. Fresh weights were recorded in the field, and subsamples were collected, air-dried and used to calculate the moisture percentage and dry matter production. Analysis of variance was performed using SAS (SAS Institute, 1985). When significance was indicated, means were separated using Fisher's least significance difference procedure.

RESULTS AND DISCUSSION

Soil samples were taken at the beginning of the study to establish that soil replacement was relatively uniform and that soil depth treatments were similar in chemical and physical properties. Chemical properties of the original topsoil in two increments (0-15 and 15-30 cm) have been compared among subsoil depth treatments to ascertain if differences existed in the initial replacement topsoil. Available P in the surface 15 cm was significantly lower for the 30 cm subsoil depth treatments (Table 1), although all treatments are low in available Bray-1 extractable P. Significant differences were also detected for electrical conductivity (EC), but all treatments are well below a critical salinity level of 4.0 dS m^{-1} (U.S. Salinity Laboratory Staff, 1954). The pH of the surface soil, ranging from 6.6-6.8 is near optimum for production of most crops. Chemical analyses of the lower 15-30 cm layer of replaced topsoil are found in Table 2. Compared to the other three treatments, the 30 cm subsoil depth treatment means were higher in exchangeable Mg, Na, and exchangeable sodium percentage (ESP), and lower in organic matter. Bray-1 extractable P was lowest in the 30 cm subsoil depth treatments, but the difference was not significant. Although significant differences were found, most were small and would not be expected to differentially impact plant growth.

The replaced subsoil and spoil chemical analysis are given in Table 3. Statistical analyses were not performed on chemical and physical properties of the subsoil because of differences in sample size between subsoil depth treatments. The results for each sample depth are averaged across all treatments with sufficient subsoil depth to obtain a sample. The spoil tended to have a slightly higher pH than the subsoil, and was higher in soluble salts, with an EC of 4.4 dS m^{-1}, slightly saline. Both subsoil and spoil were high in exchangeable cations , and had very low Bray-1 extractable phosphorus. The higher value for organic matter in the spoil is probably due to small amounts of carbon-containing coal fragments in the samples (Jansen et al., 1984). From a soil chemical analysis standpoint, these new soils appear to have no growth limiting levels of nutrients that cannot be alleviated with normal fertilizer management. The spoil material is a little less desirable than the top and subsoil because of its higher level of salinity. However problems such as sodicity or acidity which can create plant growth problems do not exist.

The reconstructed soil physical condition is of concern for its effects on plant root growth and subsequent production. Soil textural analysis (Table 4) showed the topsoil to be a silty clay, and the subsoil and spoil fines to be classified as clays. Bulk density analysis did not indicate any appreciable differences at any depth among the four subsoil depth treatments (Table 5) An exception is at the 45-52.5 cm depth , where the bulk density measured in the 30 cm subsoil treatment was significantly higher than in the 90 cm subsoil treatment. The small difference is probably not of great importance, however, but suggests the subsoil immediately above the spoil was slightly more compacted. The replaced subsoil exhibited platy structure, common in compacted soils (Lamond, 1984) and massive structure, a condition commonly found in soils that have been extensively graded during reconstruction (McSweeney and Jansen, 1984). Overall, the initial bulk densities of the reconstructed soils in this study are within the reported range for similarly textured soils in the area (USDA Soil Conservation Service, 1981), although they are at the high end of the normal range. The spoil bulk densities were extremely high, averaging 1.8 g cm^{-3}., although they are probably inflated because they were not corrected for the presence of coarse shale and limestone fragments. Visual observation of the spoil found it to be very hard and firmly packed. The physical condition of the spoil combined with moderately high salinity will likely make it a poor medium for root growth.

YIELDS

Statistical analyses for yields of fescue and alfalfa are presented in Tables 6 and 7 and should be consulted when necessary in the following discussion. Forage yields of fescue in 1987 showed a significant interaction between subsoil depth and ripping (Figure 2) Yields increased with each additional increment of subsoil depth to 60 cm and then decreased at 90 cm on the ripped treatments, but on the non-ripped treatments the increase in yield tended to level off above 30 cm depth of subsoil. Comparisons within each subsoil depth treatment show an overall trend favoring the ripped treatment, but only at the 60 cm subsoil depth was the effect significant. Yields from the ripped treatment averaged more than 1500 kg ha^{-1} greater than from the unripped treatment for this subsoil depth.

Fescue yields in 1988 were significantly lower on the 30 cm subsoil depth than the other three depth treatments (Figure 3). Maximum yields were obtained with 90 cm subsoil depth, but differences between 0, 60, and 90 cm depths were not significant. Fescue did not significantly respond to ripping, yielding 3481 kg ha^{-1} and 3380 kg ha^{-1} on the unripped and ripped treatments, respectively.

Fescue yields in 1989 were not significantly affected by either subsoil depth or ripping, but there was a trend for lower yields on 30 cm of subsoil as seen in 1988 (Figure 4). There was, however, a significant P x ripping interaction with P increasing fescue yields (Figure 5) slightly on the ripped treatments, whereas P reduced yields on the unripped treatments, a result that is difficult to interpret.

In the summer of 1987 soil cores were removed from the fescue plots for comparison of root penetration among subsoil depth treatments (Table 8). Root counts in the surface 5 to 15 cm showed no significant effects of either subsoil depth or ripping. A second count was made on samples taken from the 30 cm depth of the projected surface-subsoil interface, but because of wide variation in topsoil depth are not presented. Root counts at the 60 cm depth were not significantly affected by either subsoil depth or ripping, but tended to be highest in the 30 cm subsoil depth treatment , probably reflecting root proliferation at the subsoil-spoil interface. Significant differences were observed at the 90 cm depth with more roots counted in the 60 cm subsoil depth treatment. Because this sample depth also corresponds to the subsoil-spoil interface for 60 cm subsoil treatments, root penetration into the spoil is likely hampered by the dense, tightly-packed nature of the graded spoil material. Variability in root counts was extremely high in the subsoil as indicated by C.V.'s of 28.8% and 70.9% for the 60 and 90 cm sample depths, respectively. Because rocks in the spoil only allowed a maximum of 5 to 10 cm of spoil material to be sampled with the probe, the depth of root penetration into the spoil was not determined. In those plots where spoil samples were collected, fescue roots were much more prevalent in the spoil under 30 cm of topsoil without subsoil than any of the other treatments.

Alfalfa yields were low in 1988, the first year of establishment, and were not significantly affected by subsoil depth in either the first or second cuttings (Table 9). There was a significant yield increase to ripping for the second cutting (Figure 6). This suggests a residual effect of the 1986 ripping treatment in a year having lower than normal rainfall.

In 1989, there was a significant (0.10 probability level) interaction between ripping and subsoil depth for the first cutting (Figure 7.). On the ripped treatments, yields increased consistently from 3803 kg ha^{-1} on the 0 cm subsoil plot to 5184 kg ha^{-1} on the 90 cm plot, whereas on the unripped treatments yields decreased sharply with 30 cm of subsoil compared to 0 cm of subsoil, and then increased again at the two deeper subsoil depths. The response to ripping seen in 1988 was not apparent in 1989, probably because moisture was not limiting growth and the root system of alflafa had more fully developed.

Yields from the second cutting (Figure 8) were significantly higher on the 90 cm subsoil depth treatment than on either the 0 or 30 cm subsoil depth treatments with no ripping by subsoil depth interaction. Yields measured on 60 cm of subsoil were not different than those from 0 cm of subsoil, but were significantly higher than those from 30 cm of subsoil. The two shallowest treatments showed no significant differences, although the 30 cm depth tended to produce the poorest yields as previously shown for fescue. The response to ripping again was not significant, with yields of 4307 kg ha^{-1} and 4430 kg ha^{-1} from the unripped and rippped treatments, respectively.

A single subsoil depth has not emerged from this study as the most favorable for forage production on reclaimed lands. The response to subsoil depth was not consistent between years. The fescue data from 1987 favors replacing from 30 to 60 cm of subsoil, while data from 1988 and 1989 indicates that only 30 cm of topsoil without any subsoil will be sufficient for maximum yields. Alfalfa showed no response to subsoil depth the first year after establishment, but significantly favored the 60 and 90 cm treatments the second year (1989) probably because a more developed root system could exploit the greater soil volume. The 30 cm subsoil depth treatments tended to produce the lowest yields of both forages except fescue in 1987. Tissue P concentration of fescue was significantly lower in 1987 on the 30 cm subsoil depth treatments (Table 10), and the same trend was observed, but was not significant, for fescue in 1988, and for both cuttings of alfalfa in 1988 and the second cutting in 1989. There was a significant (0.10 probability level) subsoil depth x ripping interaction of alfalfa tissue P concentration in the first cutting of alfalfa in 1989 (Figure 9). Differences in P concentration between ripped and unripped treatments were observed at the 0 and 30 cm subsoil depths, but they disappeared with 60 or 90 cm of subsoil.

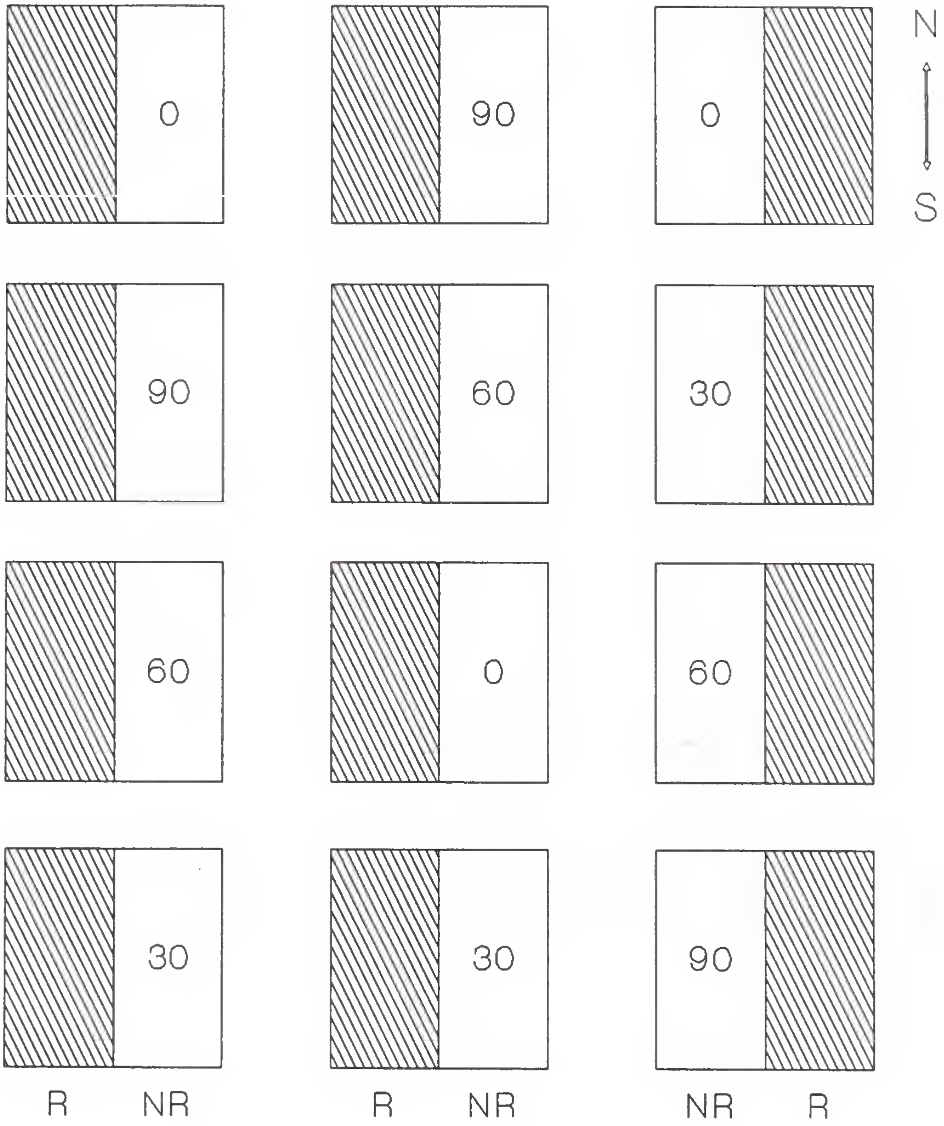
It is interesting that initial soil chemical analyses found significantly lower available P in the topsoils of the 30 cm subsoil treatment. Whether this relationship between tissue P and initial available P affected forage yields is not known. Phosphorus fertilizer was applied at planting to correct any deficiencies present in the reconstructed soils, but P was not applied to fescue or alfalfa in their second years. When P treatments were established in fescue in 1989, tissue P concentration was significantly higher in those samples harvested from plots receiving P (Figure 10), but it was not reflected in yields discussed previously. As with fescue in 1987, the lower tissue P concentration measured in samples from the 30 cm subsoil depth shown in Figure 10 was significant at the 0.10 level of probability.

Because this is a relatively short-term study for reclamation, it is not possible to evaluate the long-term effects of soil replacement depths on productivity. There are, however, clues that might aid in determining the best depth to be replaced. Newly graded spoil and overburden are subject to varying degrees of differential settling or subsidence because the volume occupied by the freshly excavated overburden exceeds that which it occupied in the natural setting (Paone et al., 1978; USDA Forest Service, 1984). Over time, subsidence can lead to ponding, alter drainage patterns, alter surface topography, and effectively decrease the original depth of replaced soil. Also, the 0 cm subsoil plots in this study contain more stones and rocks at the surface, possibly a result of ripping, and some soil erosion losses. All of these factors will tend to decrease the desirability of the land for future production of forages, as well as grain crops. Settling has already occurred on some of the plots in this study, and probably has contributed to the variability within treatments, masking some responses that might otherwise be observed. The greatest negative effect of erosion or settling would be on the shallow soil depths and thus the 0 cm subsoil treatment should be discounted as an option for future reclamation. It has not been shown to yield superior to other depths, and has at times, had significantly lower yields compared to 60 or 90 cm of subsoil. Severe subsidence occurred on one of the three 30 cm subsoil depth treatments (on the unripped treatment), and both alfalfa and fescue yields were lower in that treatment. In addition, plot randomization placed the other two 30 cm treatments in a location that is generally poorly drained on the experimental site because of reclamation of the surrounding area, impeding surface water drainage from the site. Evidence of the wetter condition of these plots was a "swampy" area in the alleyway between the plots that persisted through the winter and spring seasons. Under similar soil conditions on undisturbed soils, Feherenbacher et al. (1969) observed atypically shallow rooting of meadow and wheat attributed to poorly drained, wet subsoils in the spring.

CONCLUSIONS

A single most favorable subsoil depth for reclamation of mined land for forage production at this site could not be identified. However, in some cases, significant yield increases on both the 60 and 90 cm subsoil depths compared to shallower depths were observed. Therefore, at least 60 cm of subsoil plus 30 cm of topsoil should be respread to reclaim these lands to their highest productivity potential for fescue and alfalfa, while at the same time guarding against the possible long-term effects of erosion and settling. Ripping the newly constructed profile in 1986 did not appreciably affect fescue yields, but did aide in increasing alfalfa yields in 1988, a dry year. Ripping did not affect alfalfa yields in 1989, so it appears that the beneficial effect of ripping was in better stand establishment, but the benefit did not carry over into the second year of alfalfa production. If the new soil is ripped under favorable soil moisture conditions, opening up of these dense subsoils would certainly create a more favorable environment for rooting. However, because the effect of ripping in this study was slight and short-lived, and the process of ripping is quite costly, it should not be considered a vital procedure for maximum productivity of forages on the reclaimed mined-land at this site.

Fig. 1. PLOT LAYOUT: P & M MIDWAY MINE
RIPPING AND SUBSOIL DEPTH (cm)



NR = unripped R = ripped

Table 1. Initial chemical properties of the top 15 cm of replaced topsoil, compared among subsoil depth treatments.

Chemical property	Subsoil depth ------cm------ 0	 30	 60	 90	Fisher's LSD (0.10)
pH	6.7	6.6	6.8	6.6	NS[1]
Exch.Ca, cmole kg^{-1}	15.6	14.5	14.2	14.6	NS
Exch.Mg, cmole kg^{-1}	5.33	5.61	5.31	4.97	NS
Exch.K, cmole kg^{-1}	0.44	0.48	0.43	0.41	NS
Exch.Na, cmole kg^{-1}	0.80	0.97	0.87	0.80	NS
ESP, %	3.69	4.68	4.30	3.96	NS
EC, dS m^{-1}	0.46	0.49	0.58	0.39	0.11
Bray-1 P, mg kg^{-1}	6.0	4.83	6.17	6.83	1.09
DTPA Zn, mg kg^{-1}	0.50	0.50	0.60	0.67	NS
Organic matter, g kg^{-1}	16.3	16.7	16.3	17.8	NS

[1] NS = not significant at the 0.10 level of probability.

Table 2. Initial chemical properties of the replaced topsoil in the 15-30 cm depth, compared among subsoil depth treatments.

Chemical property	Subsoil depth ------cm------ 0	 30	 60	 90	Fisher's LSD (0.10)
pH	6.5	6.7	6.7	6.6	NS[1]
Exch.Ca, cmole kg^{-1}	15.6	15.9	17.3	14.3	NS
Exch.Mg, cmole kg^{-1}	5.89	6.52	5.50	4.91	0.64
Exch.K, cmole kg^{-1}	0.49	0.50	0.44	0.42	NS
Exch.Na, cmole kg^{-1}	0.98	1.30	1.04	0.87	0.25
ESP, %	4.45	5.68	4.50	4.45	0.75
EC, dS m^{-1}	0.520	1.20	1.06	0.583	NS
Bray-1 P, mg kg^{-1}	5.0	3.83	5.33	5.77	NS
DTPA Zn, mg kg^{-1}	0.50	0.37	0.60	1.07	NS
Organic matter, g kg^{-1}	16.3	13.7	18.0	17.7	2.3

1 NS = not significant at the 0.10 level of probability.

Table 3. Chemical properties of the replacement subsoil.[1]

Property	Sample Depth[2] cm 30-60	 60-90	 90-120	 spoil
pH	7.3	7.3	7.4	7.7
Exch.cations,cmole kg^{-1}				
Ca	21.0	23.7	24.9	24.0
Mg	7.3	7.3	7.3	4.9
Na	2.3	2.4	2.3	2.3
K	0.6	0.6	0.6	0.6
Total	31.7	34.6	35.6	32.3
ESP, %	7.3	6.9	6.5	7.2
EC,dS m^{-1}	2.4	3.1	3.5	4.4
Bray 1-P,mg kg^{-1}	1.9	2.0	1.5	1.8
DTPA Zn,mg kg^{-1}	0.3	0.3	0.3	1.1
Organic matter,g kg^{-1}	7.0	7.0	7.0	11.0

[1] Samples taken in 1986 prior to beginning yield studies.

[2] Sample results averaged across subsoil treatments with sufficient depth to include that increment.

Table 4. Textural analyses of the topsoil and subsoil of the reconstructed profiles.[1]

	Sample Depth				
	Topsoil	Subsoil			
	----	----	cm	----	----
Size fraction	0-15	30-60	60-90	90-120	spoil
Sand,%	15.9	15.0	15.3	14.8	20.8
Silt,%	42.2	35.2	34.2	33.8	34.6
Clay,%	42.3	50.2	50.7	51.8	45.4
Textural class	sic	c	c	c	c

[1] Averaged across all subsoil depth treatments.

Table 5. Initial average bulk densities[1] of the reconstructed soil profiles.

Sample depth	Subsoil depth treatment, cm 0	30	60	90	Fisher's LSD (0.10)
cm	---------------g cm^{-3}-------------				
0-7.5	1.39	1.39	1.41	1.37	NS[2]
7.5-15	1.46	1.45	1.45	1.49	NS
22.5-30	1.44	1.46	1.44	1.43	NS
45-52.5	--	1.56	1.51	1.48	0.06
71-78.5	--	--	1.52	1.49	NS
101-108.5	--	--	--	1.54	--

[1] Each value is averaged across ripping treatments and three blocks for a total of 12 measurements per reported value.

[2] NS = not significant at the 0.10 level of probability.

Table 6. Mean squares for fescue yields, 1987-89.

Source	df	Year		
		1987	1988	1989
Rep	2	2593756	253098	814078
Rip (R)	1	3068780 *	61206	1044890
Error a	2	273108	209744	1021206
Depth (D)	3	661302 **	1747126 *	6543778
Error b	6	32753	299836	3818626
R x D	3	954039 *	450064	229773
Error c	6	191530	167475	1108503
P rate (P)	1	--	--	1153820
R x P	1	--	--	408333 *
D x P	3	--	--	409116
Error d	10	--	--	510465
R x D x P	3	--	--	1576062
Error e	6	--	--	418457

**,* Significant at 0.01 and 0.05 probability levels, respectively.

Table 7. Mean squares for alfalfa yields, 1988-89.

		1988		1989	
Source	df	1st cut	2nd cut	1st cut	2nd cut
Rep	2	120285	37524	59983	214873
Rip (R)	1	4988	1307600 *	23940	195482
Error a	2	13205	37928	170213	645721
Depth (D)	3	276384	61470	1533208 #	2000092 *
Error b	6	374466	120365	417862	282524
R x D	3	22543	41457	384952 #	398495
Error c	6	45399	81810	102408	302981

*,# Significant at 0.05 and 0.10 probability levels, respectively.

Fig. 2. FESCUE RESPONSE TO SUBSOIL DEPTH AND RIPPING, 1987

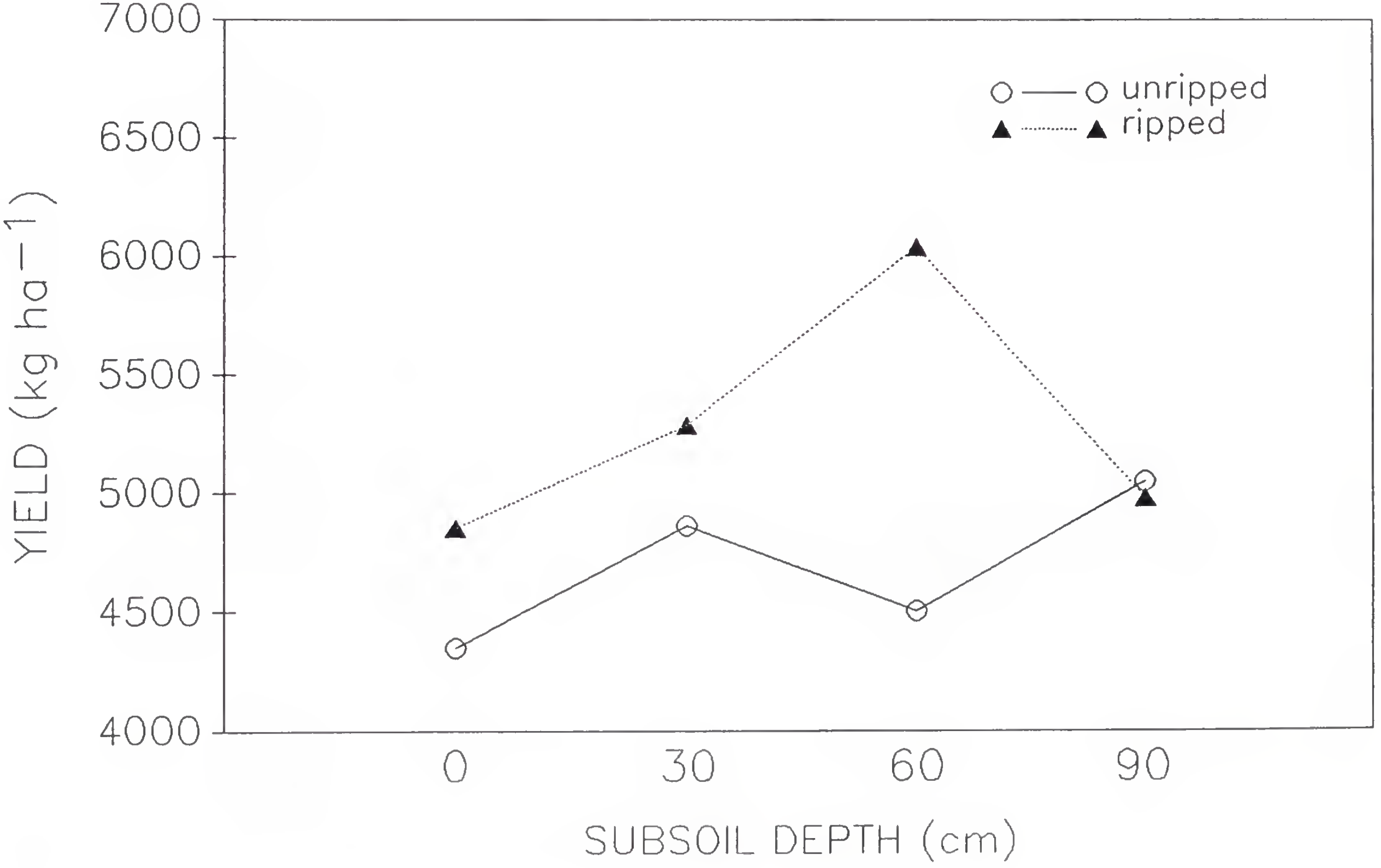


Fig. 3. FESCUE RESPONSE TO SUBSOIL DEPTH, 1988

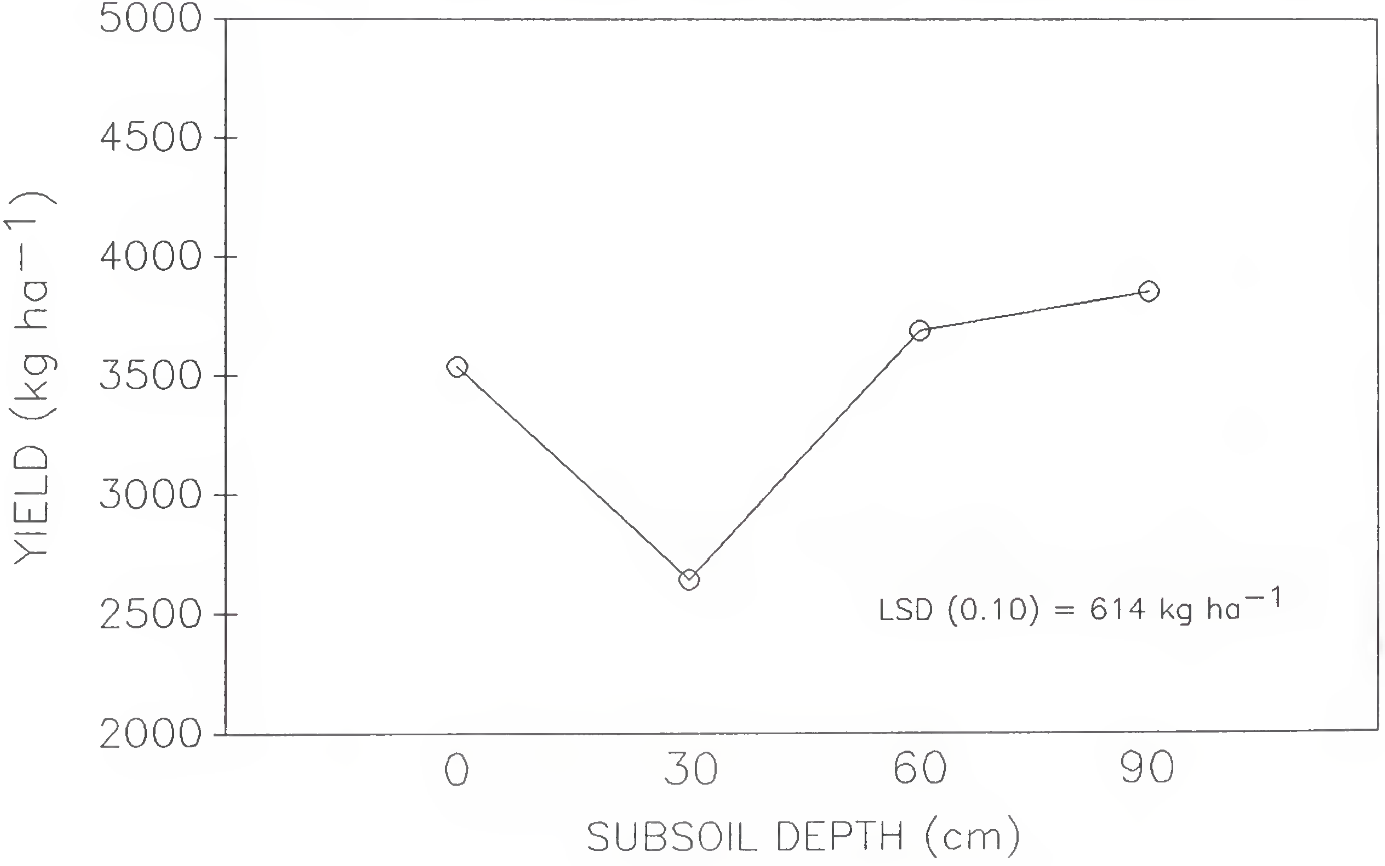


Fig. 4. FESCUE RESPONSE TO SUBSOIL DEPTH, 1989

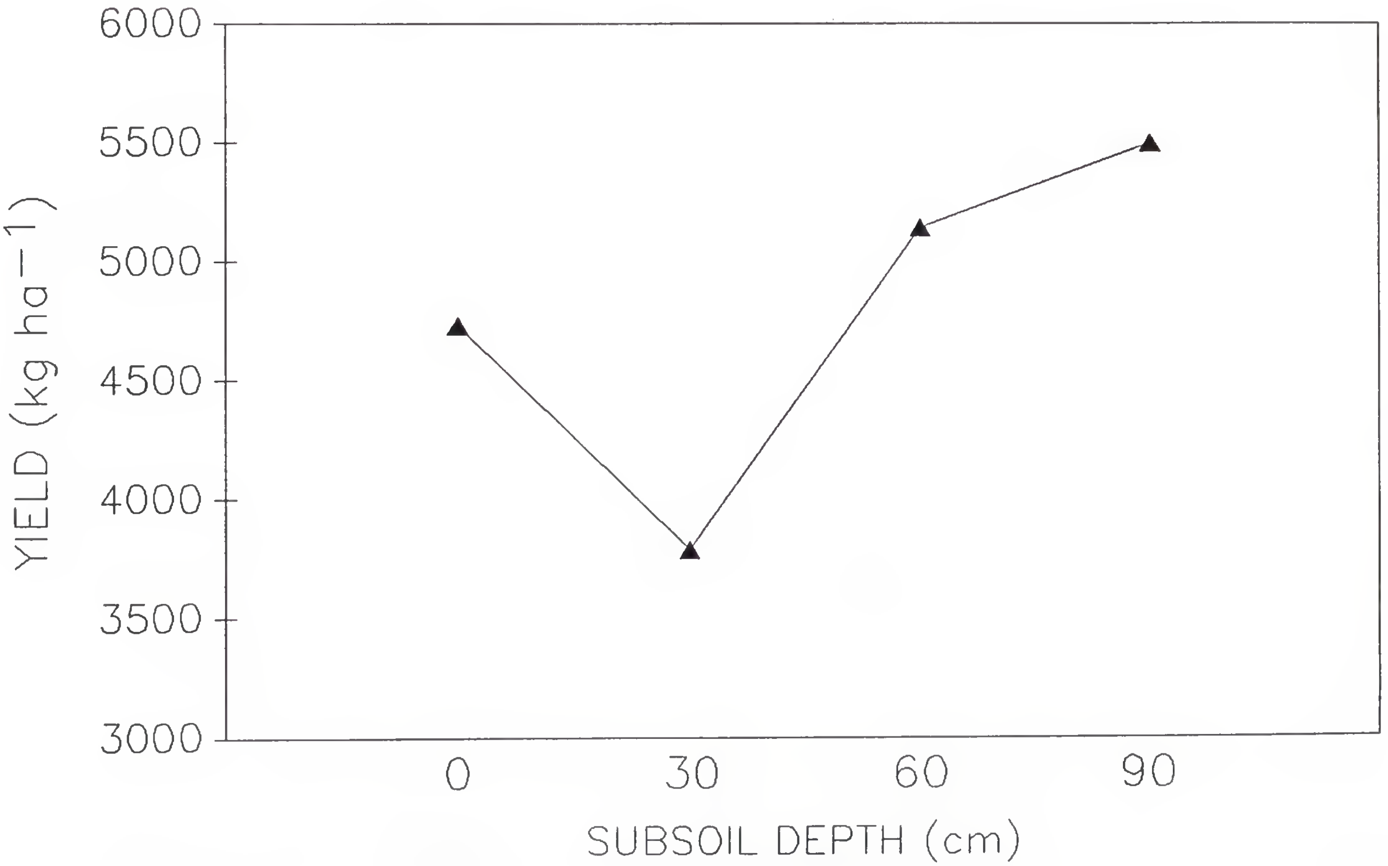


Fig. 5. FESCUE RESPONSE TO RIPPING AND P, 1989

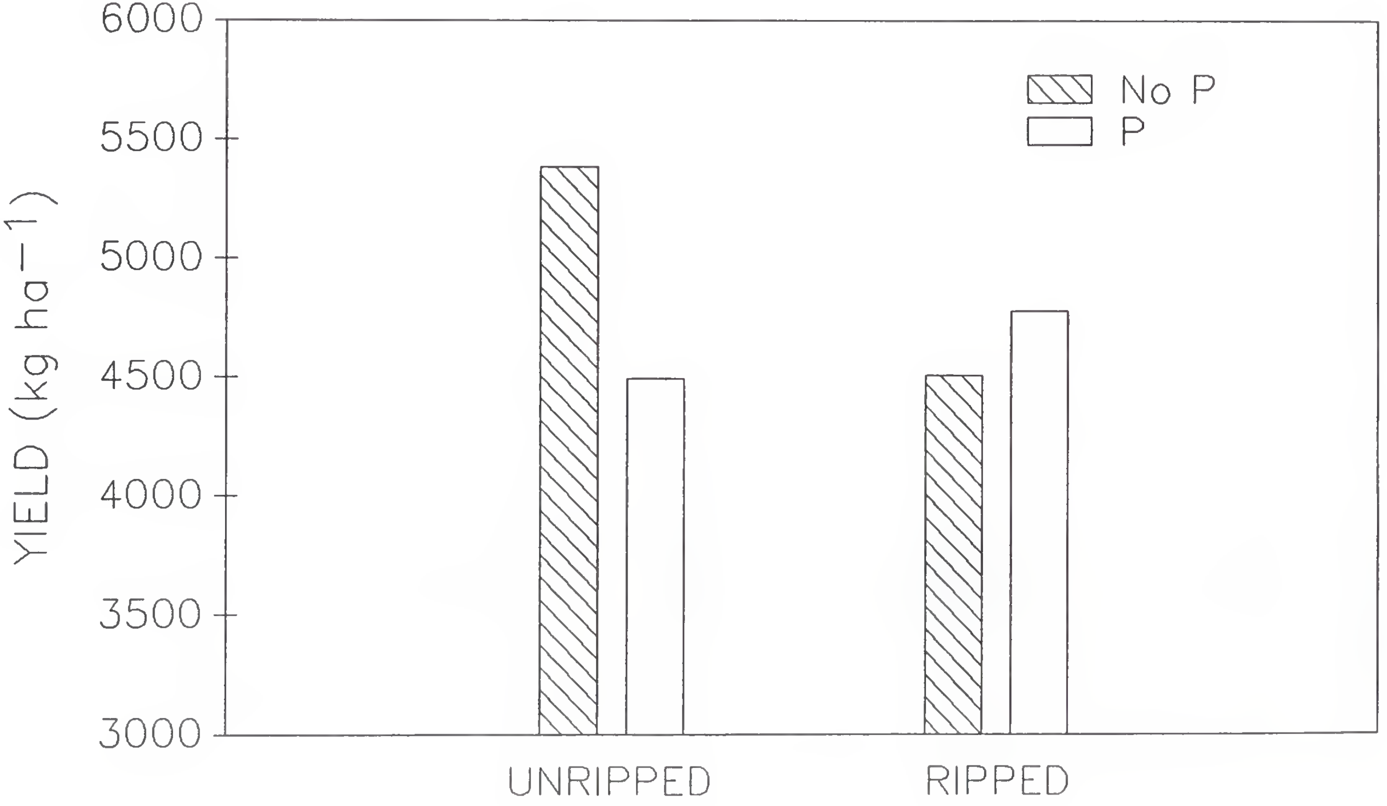


Table 8. Effect of replaced subsoil depth on depth of fescue root penetration, 1987.

Subsoil depth	Sample depth 5-15 cm	60 cm	90 cm
cm	-------no. roots------		
0	58	--	--
30	66	11	--
60	56	8	4
90	65	7	2
Significance	NS[1]	NS	**
C.V.,%	15	29	71

** Significant at the 0.01 level of probability.

[1] NS = not significant at the 0.10 level of probability.

Table 9. Effect of subsoil depth on yields of alfalfa, 1988.

Subsoil depth	Yield 1st cut	 2nd cut
cm	------kg ha^{-1}	-----
0	2146	2500
30	1860	2117
60	1892	2223
90	2310	2359
Significance	NS[1]	NS

[1] NS=not significant at the 0.10 level of probability.

Fig. 6. EFFECT OF RIPPING ON YIELDS OF ALFALFA, 1988

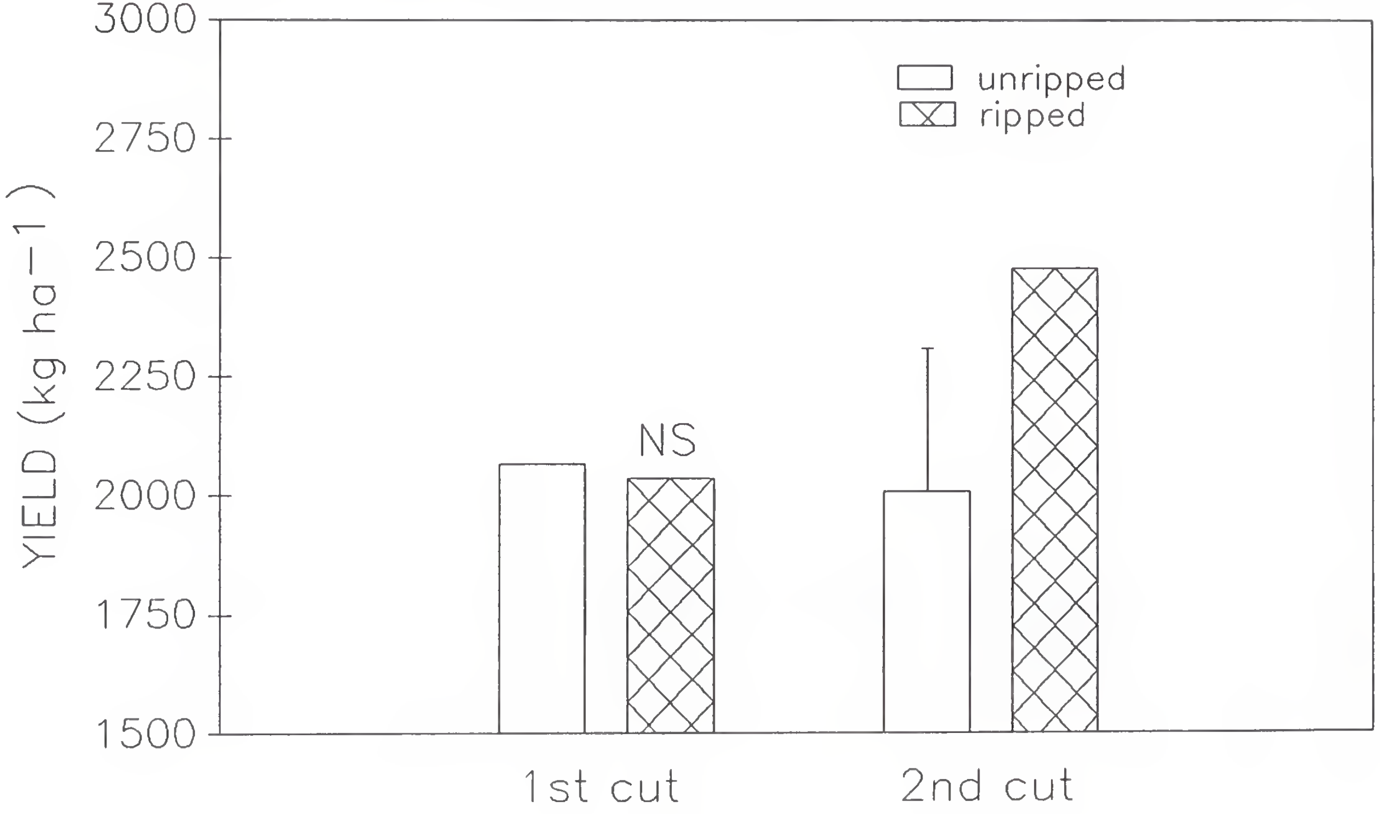


Fig. 7. EFFECTS OF RIPPING AND SUBSOIL DEPTH ON YIELDS OF ALFALFA, 1st CUTTING, 1989

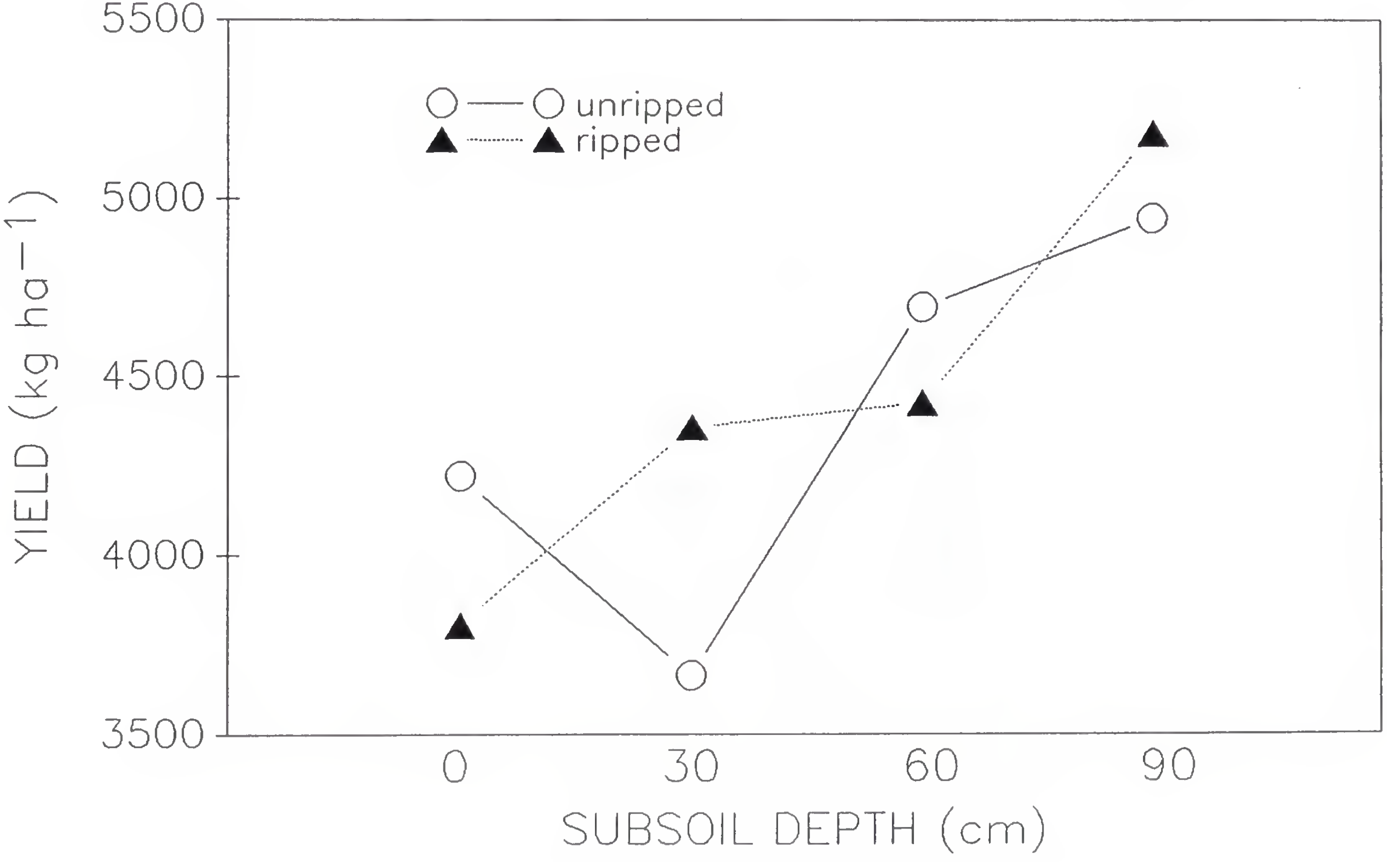


Fig. 8. EFFECT OF SUBSOIL DEPTH ON YIELD OF ALFALFA, 2nd CUTTING, 1989

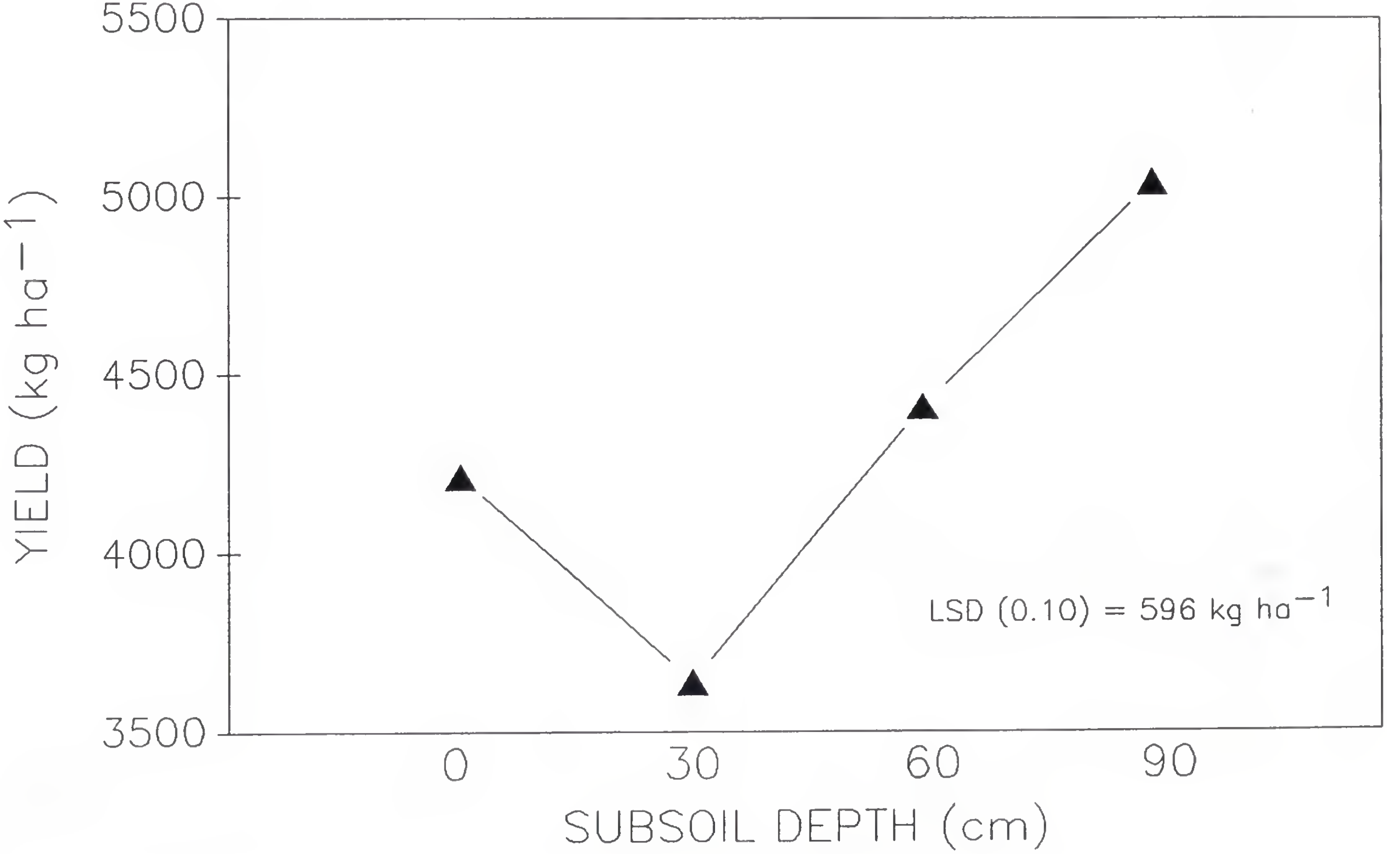


Table 10. Effect of replaced subsoil depth on tissue P content of fescue, 1987-88, and alfalfa, 1988-89.

Subsoil depth	Fescue 1987	Fescue 1988	Alfalfa 1988-1	Alfalfa 1988-2	Alfalfa 1989-2
	----------	----------	%	----------	----------
0	0.138	0.150	0.116	0.244	0.226
30	0.103	0.134	0.115	0.233	0.196
60	0.128	0.133	0.140	0.246	0.224
90	0.136	0.143	0.132	0.251	0.223
LSD (.010)	0.019	NS	NS	NS	NS

1 and 2 denote first and second cuttings, respectively.
NS = not significant at the 0.10 level of probability.

Fig. 9. EFFECTS OF RIPPING AND SUBSOIL DEPTH ON ALFALFA TISSUE P CONCENTRATION, 1st CUTTING, 1989

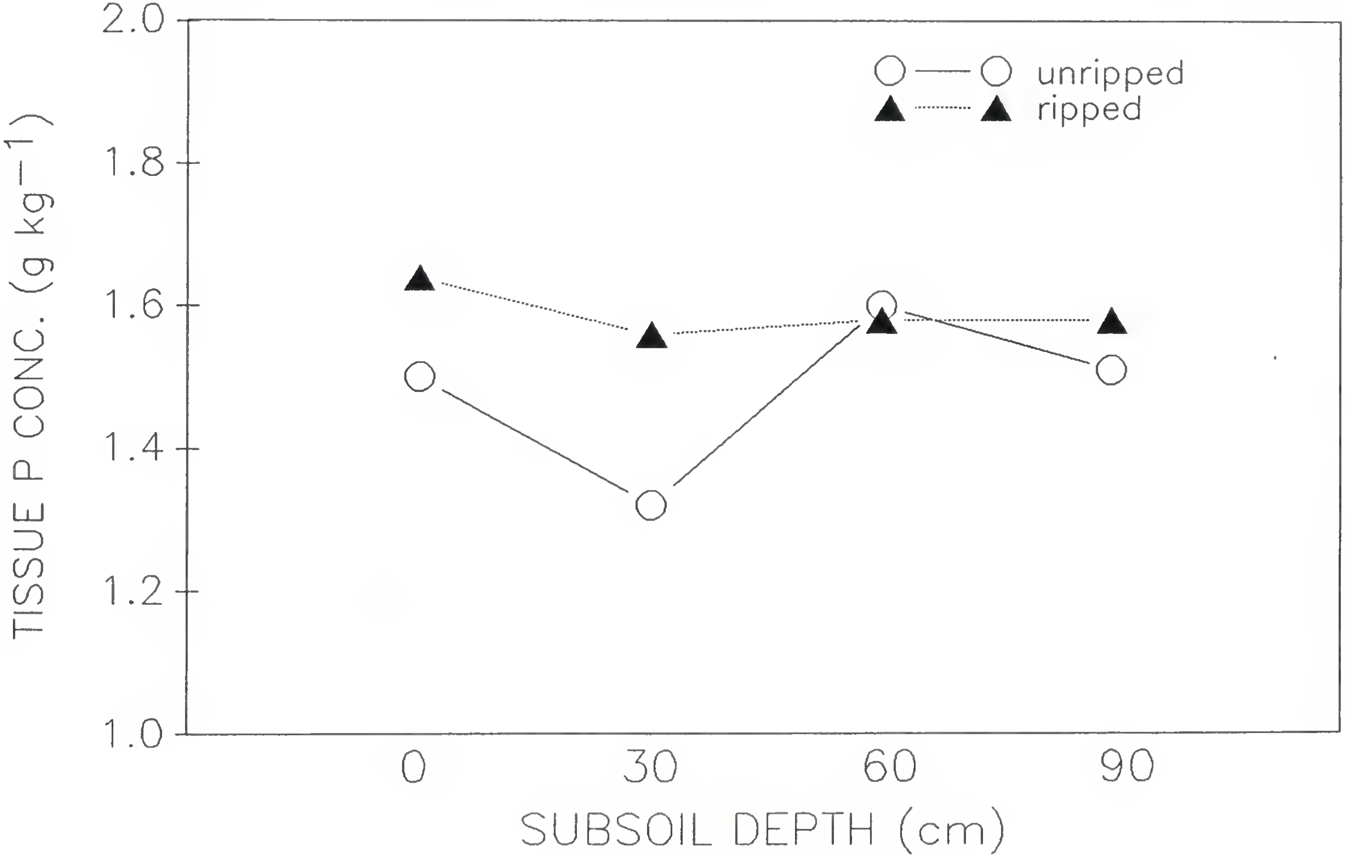
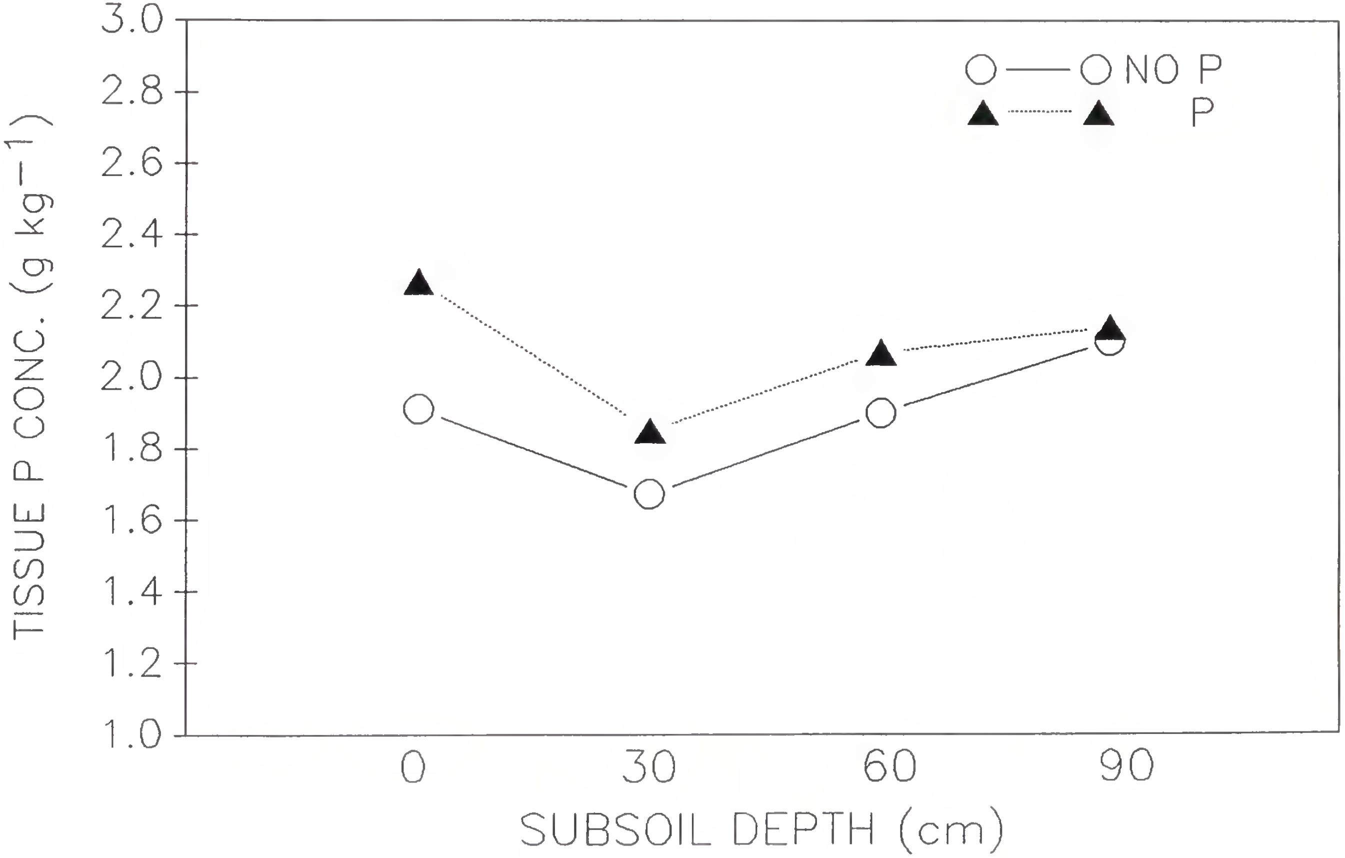


Fig. 10. EFFECTS OF SUBSOIL DEPTH AND P ON FESCUE TISSUE P CONCENTRATION, 1989



II. RESPONSE OF ROWCROPS AND SMALL GRAINS TO REPLACED SUBSOIL DEPTH AND RIPPING ON RECONSTRUCTED SURFACE-MINED LAND IN SOUTHEAST KANSAS

ABSTRACT

Research was conducted to evaluate the effects of replaced soil depth and deep ripping on the production of row crops (grain sorghum, Sorghum bicolor (L.) Moench; soybean, Glycine max Merrill) and small grains (oat, Avena sativa L.; wheat, Triticum aestivum L.) on reclaimed surface-mined land in southeast Kansas. Experimental plots were constructed with 30 cm of topsoil plus either 0, 30, 60, or 90 cm of subsoil placed over graded spoil, and one-half of each plot was ripped to a depth of 51 cm. Prior to the third year of the study, a second ripping treatment was added to the row crops by ripping one-half of each plot 38 cm deep perpendicular to the first ripping. Subsoil replacement did not significantly affect yields of oats, soybeans, or grain sorghum in the first year following soil construction. Ripping significantly increased yields of both oats and soybeans that year, but not grain sorghum. In the second year, neither ripping nor subsoil replacement significantly affected yields of soybeans, grain sorghum following soybeans (SB-GS), or continuous grain sorghum (GS-GS). Third-year yields of both grain sorghum rotations were significantly lowest on 30 cm of topsoil over spoil and tended to reach a maximum on 30 cm of topsoil plus 60 cm of subsoil. Yields of soybeans and wheat were not influenced by subsoil replacement. Sorghum yields of GS-GS increased

in response to both the first and second ripping treatments, but the response to the latter was much greater when the two were combined than when applied to previously unripped treatments. Sorghum yields of SB-GS were not significantly increased by the first ripping and were significantly decreased by the second. A response by soybeans to the second ripping was seen only on plots that had been previously unripped. When the two rippings were combined, yields were not appreciably increased over those from the first ripping alone. In the fourth year, yields of wheat from the 30 cm topsoil plus 30 cm subsoil treatments were significantly lower than other treatments. No differences in yield was observed between the ripped and unripped treatments. Ripping newly constructed profiles was of benefit to first-year crop production and appears to have had more influence on yields in the third year than the second ripping. With adequate rainfall, subsoil replacement does not appear to be a critical factor in crop production at this site. However, in years of severe moisture stress, more than 30 cm of topsoil over spoil may be necessary to achieve maximum crop production.

Introduction

Surface mining in southeast Kansas disturbs historically productive agricultural soils. In compliance with federal and state regulations, current reclamation programs strive to restore these mined lands to a condition that will equal or exceed the productivity of non-mined lands in the surrounding area. A common practice for reclaiming surface mined lands to premining condition is replacement of the surface soil layer over the graded cast overburden.

The processes of soil removal, transport, and respreading can drastically alter the physical, chemical, and microbial properties of a soil (Doll et al., 1984). If soil materials must be stockpiled, unfavorable changes can occur in soil fungal populations, mycorrhizae infection potential, and the loss of other microorganisms (Rives et al., 1980; Schuman and Power, 1981), which may result in lower nutrient cycling rates and reduced nutrient availability (Stark and Redente, 1987). Stockpiled materials may also suffer a loss of organic matter, increased soil density (USDA Forest Service, 1984), and degradation of favorable soil structure. In spite of the destructive impact of mining on soils, the A and B horizons are generally the most desirable materials for use in soil reconstruction (Jansen, 1981). Topsoil, in particular, serves as a substrate for the reestablishment of desirable soil properties (Doll et al.) because it generally has higher organic matter and nutrient content (Power, et al., 1979), and more favorable chemical and physical properties which encourage a rapid replenishment of soil microbial populations (Jansen, 1981).

The depth of soil materials that must be replaced depends on the chemical and physical condition of the underlying spoil (Doll et al., 1984), as well as the soil materials themselves. Spoils with unfavorable chemical properties such as sodicity or acidity should be excluded from the new root zone. In many areas, however, there is not enough available topsoil (A horizon) to construct a profile of adequate thickness. Salvaged subsoil can be used to increase the depth of the new soil, serving as an effective buffer from unfavorable spoils, and/or increasing the water holding capacity of the root zone (Halvorson and Doll, 1985). Researchers in North Dakota (Power et al., 1981) concluded that 20 cm topsoil plus 70 cm subsoil over sodic spoil was sufficient to achieve maximum yields of most crops under the conditions encountered at that site. In southwest Canada, barley (Hordeum vulgare L.) yields were significantly increased by replacing topsoil plus subsoil over sodic spoil compared to topsoil only over spoil. Highest yields were achieved on treatments with 55 to 95 cm of subsoil plus 15 cm of topsoil over spoil (Oddie and Bailey, 1988). On non-sodic spoils, Schroeder and Halvorson (1988) found differences in soil depth requirements depending on the texture of both the soil and spoil because of their effects on the water holding capacity of the reconstructed root zone.

In the more humid regions of the Midwest, Jansen et al. (1984) saw maximum corn (Zea mays L.) and soybean (Glycine max (L.) Merr.) yields when 80 cm of good quality soil was replaced over favorable spoil. In Kentucky, maximum yields of wheat (Triticum aestivum L.) were obtained on at least 50 cm of replaced soil, and highest grain sorghum (Sorghum bicolor (L.) Moench) yields occurred on soils consisting of between 40 and 80 cm of subsoil plus 20 cm of topsoil placed over limed acid spoil (Barnhisel et al., 1987; Barnhisel et al., 1988). Soil thickness in excess of that required for maximum productivity has not been shown to be beneficial, and in some cases has caused yield reductions. These yield reductions have been attributed to compaction from the traffic required to construct the deeper soils (Jansen et al., 1984), and reductions in the moisture holding capacity of the root zone with increased thickness of coarser textured soils over finer textured spoils (Halvorson and Doll, 1985).

One of the most troublesome aspects of reclamation is the creation of soils exhibiting a compact physical condition, attributed to the extensive use of rubber-tired scrapers during grading and shaping operations (McSweeney et al., 1987; Dunker and Jansen, 1987). As a result, root development is generally less in reconstructed soils than in undisturbed soils (Fehrenbacher et al., 1982) which could lead to increased plant susceptibility to temperature and moisture stress (Jansen et al., 1984).

Deep ripping (subsoiling) may be one way to ameliorate the compacted condition of reclaimed minesoils. On agricultural soils containing natural or tillage-induced hardpans, deep ripping has been shown to improve root proliferation into the subsoil, resulting in increased yields, especially in years of below normal precipitation (Vepraskas et al., 1987; Ide et al., 1984); Oussible and Crookston, 1987). In many reconstructed soils, however, the entire profile is compacted. Consequently, roots are able only to exploit the soil above the tillage depth, unlike natural soils containing hardpans in which roots can normally exploit the subsoil once the hardpan has been penetrated (van Es et al., 1988). On a reconstructed soil, ripping to the soil-spoil interface resulted in taller and more vigorous plant growth than on unripped treatments (Huntington et al., 1980). Barnhisel et al. (1988) saw a slight increase in wheat yields as a result of ripping, attributed to the lowering of the bulk density within the narrow zone affected by the ripper shank. van Es et al. (1988), on the other hand, concluded that microtopographic variations on newly constructed soils strongly affected corn yields to such a degree that any effects due to ripping were concealed. It appears that ripping reclaimed soils as a means to increase productivity is of questionable value, and requires further investigation.

Current reclamation laws (U.S. Congress, 1977) require that prime agricultural soils be restored by replacing at least 120 cm of soil over graded minespoil unless it can be shown that the desired post-mining level of productivity can be achieved with alternative procedures. This study was initiated to evaluate row crop and small grain response to different depths of reconstructed soils, measured by yield, and to ascertain if ripping the reconstructed soil will improve crop yields.

MATERIALS AND METHODS

Plot Design and Construction

Experimental plots were constructed in the fall of 1985 at P & M Midway mine located in Linn county, southeast Kansas. The climate in this region is continental, having a total annual rainfall of about 980 mm, of which about 70 percent normally falls April through September. The pre-mine soil in the study area was mapped as a Parsons silt loam (Fine, mixed, thermic Mollic Albaqualf) with nearby occurrences of Dennis silt loam (Fine, mixed, thermic Acquic Paleudoll) (USDA, Soil Conservation Service, 1981).

Topsoil and subsoil materials used to construct the research plots were taken from existing stockpiles consisting of segregated A and B horizons as separated during the mining operation. The cast overburden (spoil) consisted of mostly shale and limestone fragments encased in a clayey matrix. Prior to soil replacement, rubber-tire scrapers were used to grade the spoil material to a nearly level contour.

Plots measuring 54 m x 54 m each were constructed using scrapers to transport soil materials to the research site. Subsoil was placed over the spoil at depths of 0, 30, 60, or 90 cm. After grading the subsoil, 30 cm of topsoil was spread over all plots. The finished plots were again graded and shaped with scrapers and tracked bulldozers. Treatments were arranged in a randomized complete block design with three replications In the spring of 1986, one-half of each plot was ripped to approximately 51 cm depth using an agricultural subsoiler. Crops were randomly assigned to 9 m by 54 m strips on each subsoil depth treatment laid out perpendicular to the subsoiling so that each crop contained a ripped and a non-ripped soil treatment. Two strips on each plot were seeded to soybeans the first crop year to establish a grain sorghum-soybean rotation (SB-GS) for comparison to continuous grain sorghum (GS-GS). An additional ripping treatment was added in the fall of 1987 on those plots assigned to grain sorghum and soybean by ripping one-half of each plot to a depth of about 38 cm, perpendicular to the direction of the initial ripping.

The experiment was designed as a split-plot with three replications (blocks) with ripping as the whole plot. Subsoil depth was arranged as a strip across each block (Chap 1., Figure 1). Crops and second ripping were arranged as split, and split-split-plots, respectively, within each subsoil depth treatment (Figure 1). Included in the study were row crops: grain sorghum (Sorghum bicolor (L.), Moench), hybrid 'Paymaster DR1125', and soybean (Glycine max (L.), Merr), variety 'Pershing', and small grains: oats (Avena sativa, L.), variety 'Bates', and hard red winter wheat (Triticum aestivum, L.), variety 'Arkan'.

Pre-plant tillage for all crops was done with an offset disk, and seedbeds were prepared with a roller-harrow.

Small Grains

Since plot construction was not completed in time to plant wheat in the fall of 1985, oats were planted instead on 29 March 1986 at a seeding rate of 100 kg ha^{-1}. Fertilizer P was applied to oats at planting as triple superphosphate (0-20-0) banded below and to the side of seed at 36 kg P ha^{-1}. Plots were topdressed with urea ammonium nitrate (28-0-0) liquid fertilizer on 15 April 1986 at a rate of 69 kg N ha^{-1}. Wheat again was not planted in the fall of 1986 because of wet soil conditions, but successful plantings were achieved on 9 September 1987, and 11 October 1988 at seeding rates of 85 and 80 kg ha^{-1}, respectively. Diammonium phosphate (18-20-0) was banded below and to the side of seed at the rate of 112 kg ha^{-1} of material both years. Plots were topdressed with urea ammonium nitrate on 6 April 1988 and 1 April 1989 at rates of 43 and 56 kg N ha^{-1}, respectively. Chemical weed control in the small grains was used only for the 1987-planted wheat. Chlorsulfuron, 2-chloro-N-[(4-methoxy-6-methyl-1,3,5-triazin-2-yl)aminocarbonyl] benzenesulfonamide, was applied in the spring of 1988 at a rate of 10.6 g ha^{-1}.

Soybeans

Soybeans were planted on 20 June 1986, 9 June 1987, and 18 June 1988 at seeding rates of 430,000 seeds ha^{-1} in a 76.2 cm row spacing. Diammonium phosphate (18-20-0) was applied as starter fertilizer, banded below and to the side of the seed at rates of 112 kg ha^{-1} each year. Weeds in the soybeans were controlled using a mixture of metribuzin, 4-amino-6- (1,1-dimethylethyl) -3- (methylthio)-1,2,4-triazin-5(4H)-one, and alachlor, 2-chloro-2′,6′-diethyl-N-(methoxymethyl)acetanilide, applied pre-emerge at rates of 0.42 + 2.20 kg ha^{-1} each year.

Grain Sorghum

Ammonium nitrate (34-0-0), at a rate of 106 kg N ha^{-1}, was broadcast and incorporated on grain sorghum plots on 31 March 1986. On 20 June 1986 plots were planted at a seeding rate of 173,000 seeds ha^{-1} in 72.6 cm row spacing. Diammonium phosphate was banded below and to the side of the seed at a rate of 100 kg ha^{-1}.

In 1987, treatments were established consisting of normal, and one-half of normal N rates in both GS-GS and SB-GS rotations. On 1 June 1987, urea (46-0-0) was broadcast and incorporated on one-half of each plot at rates of either 105 or 53 kg N ha^{-1}. On 9 June 1987 plots were planted in

76.2 cm rows at a rate of 222,000 seeds ha^{-1}. Diammonium phosphate was banded below and to the side of the seed at a rate of 112 kg N ha^{-1}.

On 17 May 1988, urea ammonium nitrate was broadcast and incorporated at rates of 112 and 56 kg N ha^{-1} for the GS-GS and SB-GS rotations, respectively. Plots were planted on 18 June 1988 at a seeding rate of 173,000 seeds ha^{-1} in 76.2 cm row spacing. Diammonium phosphate was banded below and to the side of seed at a rate of 112 kg ha^{-1}.

Weeds in grain sorghum were controlled using a mixture of metolachlor, 2-chloro-N-(2-ethyl-6-methylphenyl)-N-(2-methoxy-1-methylethyl) acetamide, and atrazine, 2-chloro-4-ethylamino6-isopropylamino-s-triazine, applied pre-emerge at rates of 2.8 + 2.2, 1.9 + 1.5, and 2.3 + 1.9 kg ha^{-1} in 1986, 1987, and 1988, respectively.

Data Collection and Analysis

Infiltration

An infiltration study was performed in August of 1986 using a double-ring infiltrometer (Bertrand, 1965) on plots designated for alfalfa but not yet planted. Infiltrometer rings were constructed of 14 gauge steel, the inner ring measuring 35 cm in diameter, and the larger outside ring measuring 60 cm in diameter. Two measurements were taken from the ripped and unripped treatments of all subsoil depth plots for a total of 48 sampling sites. Water was ponded over the infiltrometer and the rate of inflow was measured in the inner ring, using a hook gauge and a triangular engineer's scale, until steadty state infiltration was reached. Infiltration measurements were then take every 30 minutes for two hours and used to calculate cumulative infiltration.

Yield Data

Yields were taken from the interior rows of all plots. Grain sorghum and soybean samples were harvested by hand on 7 Nov. 1986, 21 Oct. 1987, and 17 Oct. 1988. Harvested areas in 1986 and 1988 were 6.75 m^2 and 4.50 m^2, respectively, for both crops. In 1987, soybean area harvested was 7.20 m^2 and grain sorghum area harvested was 3.6 m^2. Oats and wheat were harvested with a self-propelled plot binder on 26 June 1986 for oats, and 16 June 1988 and 23 June 1989 for wheat. Oat area harvested was 4.7 m^2 and wheat area harvested was 3.2 m^2 both years. Harvested samples of all crops were threshed at the site with a portable thresher. Yields were adjusted for variations in grain moisture to 14, 12, 12.5, and 13.0 percent moisture for grain sorghum, soybeans, oats, and wheat, respectively.

Statistical analysis was performed using the SAS analysis of variance procedure using SAS computer program (SAS

Institute, 1985) to detect significant differences between treatments. Statistical significance of results are reported up to the 0.10 level of probability.

RESULTS AND DISCUSSION

1986

Statistical analyses for yields are presented in tables 1-3 for 1986, 1987, and 1988, respectively, for reference in the following discussion. The chemical and physical properties of the reconstructed soils were found to be within ranges satisfactory for the production of crops used in this study as discussed in chapter one of this thesis. A major concern with a mined-land reconstructed soil is the ability to supply moisture to growing plants (Merrill, et al., 1985). Climatic conditions in 1986 were such that a moisture deficit did not occur for any subsoil depth treatment (Figure 2). Rainfall from March through May was above normal, but not excessive for favorable growth of oats. However, beginning in June, and extending through October, rainfall was far in excess of normal. Extended periods of water-logging and ponding occurred. No yield response to subsoil depth was observed for grain sorghum, soybeans, or oats in 1986 (Table 4), undoubtedly in part because of the abundant moisture.

Soybean and oat yields were significantly higher on ripped than unripped plots (Table 5). Early season oat growth was visibly much more vigorous on ripped compared to unripped treatments. Oat yield increases from ripping are attributed to the opening of the dense subsoil, enabling greater root penetration and increased utilization of subsoil moisture and nutrients. Because soybean is especially sensitive to poorly aerated soil conditions such as would be found in excessively wet soils (Coop. Ext. Serv., Kans. St. Univ., 1987, C-449), the beneficial effect of the ripping was not unexpected. Improved drainage of the upper portion of the profiles is supported by the effect on infiltration data shown in Figure 3. At the same time, the ripping possibly allowed root exploitation of a greater soil volume than on unripped treatments. Grain sorghum yields followed a trend similar to oats and soybeans, but were not significant at the 0.10 level of probability (Table 5).

1987

Unseasonably wet weather in the fall of 1986 prevented the seeding of winter wheat, so only grain sorghum and soybean data are presented for 1987. Growing season rainfall in 1987 was again above average except for a 23 day period beginning in mid July (Figure 2). The effects of subsoil depth on yields of soybeans and grain sorghum are presented in Table 6. A moisture deficit in late July-early August delayed maturity and reduced final soybean plant height, but rainfall received during pod set and seed development was sufficient to produce moderate yields. Soybean yields tended to increase with subsoil depth up to

60 cm, however, differences were not significant at the 0.10 level of probability.

Grain sorghum was affected more by the July rainfall deficit than soybeans because severe moisture deficit coincided with the boot stage of development, adversely affecting head exertion and pollination. Of those heads that succesfully pollinated, many were damaged by sorghum midge (Contarinia sorghicola) and corn earworm (Noctuidae, Peridroma saucia), to such an extent that there were no unaffected areas for yield estimates. Maximum yields were measured on 90 cm and 60 cm of subsoil for GS-GS, and SB-GS, respectively. In both crop rotations, lowest yields were measured on the 30 cm subsoil treatment. While the observed differences were large and tended to favor the deeper subsoil depths, the extreme variability caused by the poor pollination and insect infestation resulted in these differences being non-significant.

No significant differences were observed between the ripped and unripped treatments in either the grain sorghum or soybeans (Table 7).

Continuous grain sorghum yields were significantly lower at the 0.05 level of probability when one-half rate of N was applied compared to full N rate (Table 8). Yields of SB-GS on the other hand, were not significantly affected by N rate. GS-GS yields at 105 kg ha^{-1} N, were equivalent to SB-GS yields at 53 kg ha^{-1} N. This is in agreement with the findings of other researchers (Gakale and Clegg, 1987; Janssen et al., 1985; Raney et al., 1985) that soybeans contributed N to a grain sorghum crop grown the following season, reducing the amount of N necessary to achieve maximum grain production.

1988-89

The effects of subsoil depth on yields of grain sorghum, soybeans, and wheat in 1988, and wheat in 1989 are presented in Table 9. Climatic conditions in the 1988 growing season were the most stressful of the three years of the study with severe summer drought (Figure 2). Because rainfall in the months prior to planting of soybeans and grain sorghum was below normal, soil conditions at planting were relatively dry. From May 24 through June 14, no rainfall was recorded, and planting was delayed until June 18, following a minor rainfall event on the 16th. Throughout the first 45 days of growth, rainfall averaged about 30 mm per week, sufficient for adequate growth of both crops. The most severe moisture deficit occurred from mid-August through mid-September. The moisture deficit, accompanied by high temperatures, coincided with half-bloom in grain sorghum, and pod set in soybeans, and persisted throughout most of the seed development period. In terms of yield reduction, pod-fill is the period during which soybean is the most susceptible to a moisture deficit (Sionet and Kramer, 1977; Doss et al., 1974)). Consequently, soybean yields, in general, were poor, attributable to the severity and timing of the drought in 1988. Yield differences between subsoil depth treatments were small, and not significant, but yields tended to increase with subsoil depth from 784 kg ha^{-1} to 970 kg ha^{-1} for the 0 cm and 90 cm subsoil depth, respectively.

Grain sorghum was also subjected to a moisture deficit at a critical period of development shortly after boot stage and extending through bloom into grain-fill. Plants growing on 30 cm topsoil without subsoil were visually more stressed in comparison to treatments with subsoil. Yields of GS-GS and SB-GS were very similar. Yields of both GS-GS and SB-GS were significantly lower on the 0 cm subsoil treatment than on 30, 60, or 90 cm treatments. Maximum yields were measured on the 60 cm subsoil depth treatment, but they were not significantly different from 30 or 90 cm of subsoil. Yields from the 0 cm subsoil treatment averaged 67 and 68 percent of those from the 60 cm subsoil treatment for GS-GS and SB-GS, respectively. These results indicate that 30 cm of topsoil placed over spoil (0 cm subsoil) did not supply sufficient moisture for maximum grain sorghum production. Similar yield reductions on an undisturbed soil were reported by Lewis et al. (1974) when grain sorghum was subjected to moisture stress during flowering and grain-fill. Spoil material at this site, therefore, is not a suitable medium for use as the upper portion of the profile for grain sorghum production in years of moisture stress.

Most of the growth of the 1988 wheat occurred prior to the onset of the drought, but below normal rainfall during heading and grain-fill may have had an impact on yields. Wheat yields in 1988 tended to be highest on the 90 cm subsoil treatments, but subsoil depth did not significantly affect yields at the 0.10 level of probability. Wheat yields in 1989 were considerably below those normally expected for the area. Most of the poor yield is attributed to winter growth prompted by an unseasonably warm period in January, which ended when temperatures rapidly dropped to well below freezing. The resulting wheat stand was extremely thin. Yields from the 30 cm subsoil depth treatment were significantly lower than any of the other three subsoil depths and 40 percent lower than yields on 60 cm of subsoil. Maximum yields were obtained from the 60 cm subsoil depth, but these were not significantly different from the 0 cm or 90 cm depth treatments.

Yields of wheat in 1988 and 1989 were not significantly affected by the original ripping treatment established in 1986. Yields in 1988 were 2043 and 2080 kg ha^{-1} for the unripped and ripped treatments, respectively. In 1989, yields were 1243 and 1304 kg ha^{-1} for the same comparison.

Grain sorghum and soybean plots in 1988 contained a second ripping treatment established in the fall of 1987. Because the second ripping treatment (R2) was stripped across the first (R1), comparisons of the effects of the second ripping must be made within the same level of the first. The same is true when looking at the effects of the first ripping treatment.

The response of soybeans to ripping was a significant interaction between R1 and R2. Yields of soybean from the individual ripping treatments are shown in Figure 4. When the second ripping (R2) was applied to previously unripped treatments (NR), yields were increased an average of 127 kg ha^{-1}. However, when the second ripping was combined with the first ripping (R1+R2), yields were not appreciably increased over those from the first ripping alone (R1). The fact that yields were influenced by ripping and not by subsoil depth might indicate that the effective soil depth of all plots was limited to the depth of the ripping. This is supported by the data from 1986 where soybean yields under conditions of excess moisture were also increased by ripping but not by subsoil replacement. It appears that ripping can increase soybean yields when exposed to either excess moisture, or moisture defecit.

The effects of ripping on grain sorghum yields were different for the two rotations (Figure 5). A significant interaction between the first and second ripping treatments occurred in GS-GS. The response to the second ripping was much greater when combined with the first than when the second ripping was applied to a previously unripped profile. This suggests a residual effect of the first ripping on continuous grain sorghum yields which was expressed only during a severe moisture defecit. By comparison, yields of SB-GS were reduced by the second ripping, but were much higher than GS-GS on treatments that had never been ripped. Because there was no interaction between the two ripping treatments, yields of SB-GS are combined in Figure 6 to show the overall effect of the first and second ripping. The first ripping did not significantly affect yields, while the second ripping significantly reduced yields. The reason for the different responses of GS-GS and SB-GS to the ripping treatments is not clear, but is probably related to a 'rotation effect' of the grain sorghum and soybeans. In Kansas, typical N contributions from soybeans to a succeeding grain sorghum crop range from 34 to 67 kg ha^{-1} (KSU Coop. Ext. Serv., 1987, C-687). Since SB-GS received a lower rate of N than GS-GS in 1988 (76 versus 130 kg ha^{-1}), the N credit, or N rotation effect (Pierce and Rice, 1988) of the previous year's soybeans would be expected to supply the difference (54 kg ha^{-1}). On plots that were initially unripped and did not receive the second ripping, however, mean SB-GS yields exceeded those of GS-GS by more than 500 kg ha^{-1} as was shown in Figure 5. This suggests that there were additional benefits to the rotation with soybeans, possibly soil loosening or soil structural improvement (Browning et al., 1942), that were effectively removed by the second ripping performed in the fall of 1987.

The results of this study show that the response to ripping or depth of replaced subsoil (given that 30 cm of topsoil will always be replaced) will depend on 1) climatic conditions, particularly the severity and timing of moisture defecits, 2) the type of crop grown, and 3) crop rotations. In 1988, wheat had the advantage of maturing before the summer drought and neither ripping nor subsoil depth significantly increased yields. Grain sorghum, on the other hand, suffered from moisture defecit at the most critical stage of development and placement of at least 30 cm of subsoil under topsoil apparently increased soil moisture in the root zone and significantly increased yields. The effect of ripping on grain sorghum yields depended on the rotation. GS-GS yields responded to both the first and second ripping and were highest when the two were combined. SB-GS yields were significantly reduced by the second ripping, and yields from the unripped treatment were not appreciably different compared to those from the first ripping treatment. This suggests that the rotation effect of soybeans with grain sorghum might effectively substitute for ripping. Finally, soybeans responded favorably to ripping during periods of both excess moisture in 1986 and moisture deficit in 1988, but did not respond to subsoil depth in either year. In 1987, a year of relatively normal rainfall, soybean yields were not affected by either variable.

CONCLUSIONS

An underlying goal of mineland reclamation is the reconstruction of a soil that will be able to support the intended post-mining land use(s). On the soils of interest in this study, the production of agricultural crops commonly produced in the area is of interest. The reconstructed soils should, therefore, be able to support crop growth and optimum production, not only in years of favorable climatic conditions but in years of extremes. Any reclamation practice that cannot sustain adequate crop production must be discounted as an option in selecting a reclamation method. On this basis, the 0 cm subsoil plus 30 cm topsoil treatment must be discounted as an option when planning future reclamation in this area, even though rainfall in most years may not be limiting, and therefore depth of subsoil would not be a critical factor. Using the same rationale, one must also conclude that the 30 cm subsoil plus 30 cm topsoil treatment is suspect when the negative response of wheat to this treatment in 1988 is considered. It is unclear whether this response was in fact related solely to the actual profile depth or to conditions that might have been created during soil replacement. If the former is true, then the 30/30 should be discounted. However, plot randomization placed two of three 30/30 treatments in a poorly drained area of the research site. Because wheat yields in 1988 were not statistically different between 0, 60, and 90 cm of subsoil, it is probable that factors other than subsoil depth were the cause of the observed negative response on the 30 cm subsoil treatments.

Because yields of all crops studied were not significantly increased with replaced subsoil depths above 30 cm, it appears that, under the conditions at this site, maximum yields of most crops can be obtained when 30 cm of subsoil plus 30 cm of topsoil are replaced over leveled spoil.

Ripping of the newly constructed profiles also proved to be of value, and should be maintained as a part of the reclamation process at this time. Ripping increased water infiltration, stand establishment and yield of oats and soybeans in 1986. It also was shown to have a residual effect on continuous grain sorghum and soybean yields after two years which helped lessen the effects of severe moisture stress. Repeated ripping for the production of row-crops as done in this study is not recommended unless the chosen crop is continuous grain sorghum. No significant increase in yield of either soybeans, or grain sorghum following soybeans was obtained over the original ripping treatment alone.

Fig. 1. EXAMPLE OF CROP PLACEMENT ON A SUBSOIL DEPTH SUBPLOT

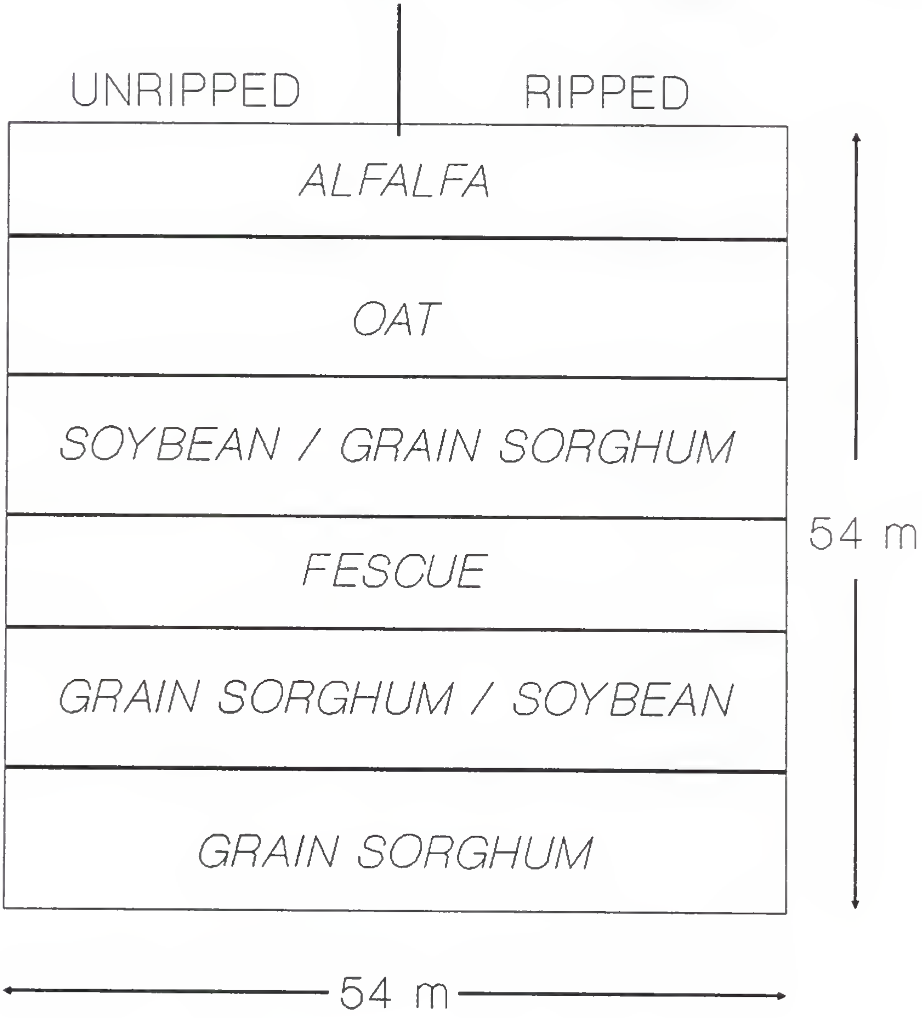


Table 1. Mean squares for crop yields, 1986.

Source	df	Crop		
		GS	SB	Oat
Total	23			
Rep	2	85307	86187	162895
Rip (R)	1	418018	1432771 **	3634038 *
Error a	2	162532	8052	173924
Depth (D)	3	79336	11192	207483
Error b	6	359975	57899	129102
R x D	3	291790	5303	83777
Error c	6	178200	55016	44737

**,* Significant at 0.01 and 0.05 probability levels, respectively.

Table 2. Mean squares for crop yields, 1987.

Source	df	Crop GS-GS	 SB-GS	 Soybean
Rep	2	208219	731455	56827
Rip (R)	1	71843	679966	111248
Error a	2	562891	173036	26792
Depth (D)	3	2871998	1409968	104387
Error b	6	1338250	477820	116006
R x D	3	258750	188309	13853
Error c	6	198607	218628	20089
N rate (N)	1	2714630 *	1439015	---
D x N	3	195381	33868	---
Error d	8	345673	470137	---
R x N	1	78813	393675	---
R x D x N	3	426172	455941	---
Error e	8	263766	267105	---

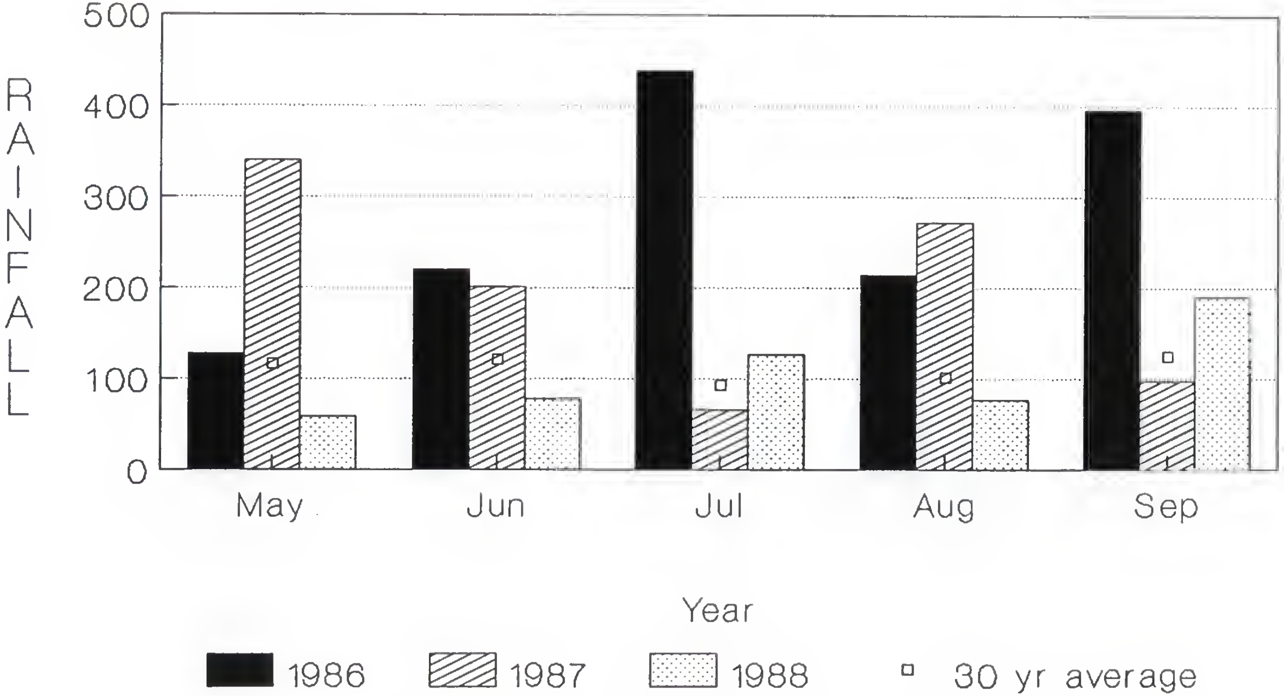
* Significant at the 0.05 level of probability.

Table 3. Mean squares for crop yields, 1988-89.

Source	df	Crop				
		GS-GS	SB-GS	Soybean	Wheat	Wheat
Rep	2	351410	161438	27936	257463	348570
1st Rip (R1)	1	4029264 *	949500	210808	7921	22448
Error a	2	54341	774933	63685	55431	52893
Depth (D)	3	6641184 *	7249268 *	86895	200518	360064 #
Error b	6	1046888	974538	106747	74919	109891
R1 x D	3	82385	156689	26433	115873	38041
Error c	6	518973	486595	27136	50937	48472
2nd rip (R2)	1	1139292 *	2082917 *	93545 *	---	---
D x R2	3	80808	242448	17674	---	---
Error d	8	114261	268870	16220	---	---
R1 x R2	1	682826 #	180934	18684 *	---	---
R1 x D x R2	3	495397	115581	2007	---	---
Error e	8	189395	386650	3423	---	---

*,# Significant at the 0.05 and 0.10 levels of probability, respectively.

Fig. 2. GROWING SEASON MONTHLY RAINFALL FOR THREE YEARS (mm)



Measured at P & M Midway Mine office,
1.6 km north of experimental site

Table 4. Crop yields from four subsoil depths of reconstructed surface-mined soils[1], 1986.

Subsoil depth	Grain sorghum	Soybean	Oat
cm		-------------kg ha^{-1}------------	
0	3515	1746	2046
30	3523	1678	2072
60	3393	1765	2451
90	3280	1687	2225
LSD (.10)	NS[2]	NS	NS

1 All soil profiles contain 30 cm topsoil over the subsoil depth treatment.

2 Not significant at 0.10 level of probability.

Table 5. Effect of deep ripping of a reconstructed surface-mined soil on crop yields, 1986.

Ripping	Grain sorghum	Soybean	Oat
	-------------kg ha^{-1}	------------	
Unripped	3296	1475	1809
Ripped	3560	1963	2587
Significance	NS[1]	**	*

*,** Significant at the 0.05 and 0.01 levels of probability, respectively.

[1] Not significant at 0.10 level of probability.

Fig. 3. EFFECT OF DEEP RIPPING ON INFILTRATION INTO THE RECONSTRUCTED SOIL PROFILES, 1986

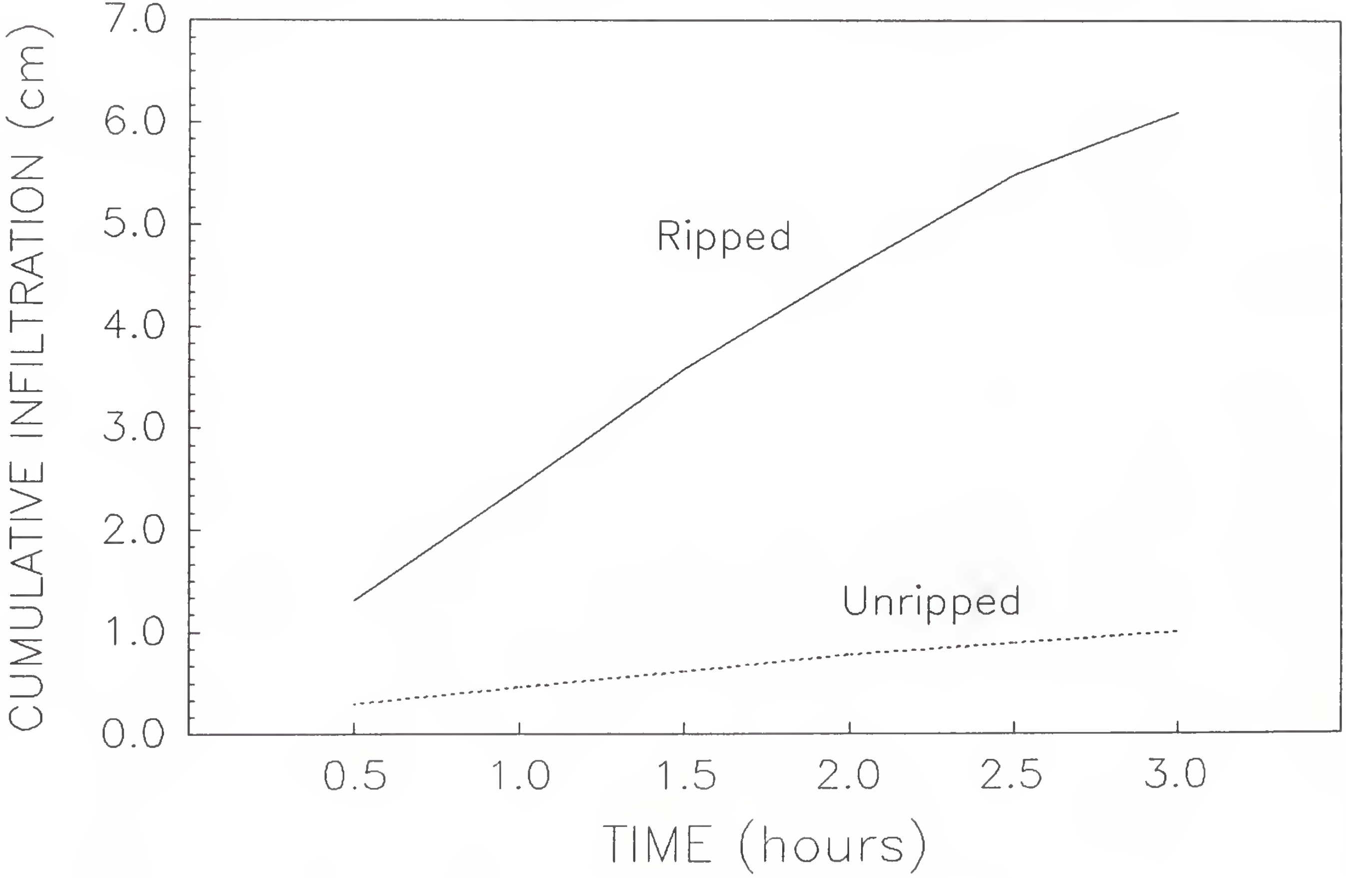


Table 6. Crop yields from four subsoil depths of reconstructed surface-mined soils[1], 1987.

Subsoil depth	GS-GS	SB-GS	Soybean
cm		------kg ha^{-1}------	
0	2294	2517	1600
30	1887	2488	1768
60	2346	3124	1916
90	3064	3065	1706
LSD (.10)	NS[2]	NS	NS

[1] All soil profiles contain 30 cm topsoil over the subsoil depth treatment.

[2] Not significant at 0.10 level of probability.

Table 7. Effect of deep ripping a reconstructed surface-mined soil on crop yields the second year after ripping, 1987.

Ripping	GS-GS	SB-GS	Soybean
	-------------kg ha^{-1}------------		
Unripped	2436	2679	1680
Ripped	2360	2917	1816
Significance	NS[2]	NS	NS

[1] Not significant at 0.10 level of probability.

Table 8. Effect of N rate on yields of continuous grain sorghum and grain sorghum following soybean, 1987.

N rate	GS-GS	SB-GS
kg ha^{-1}	------kg ha^{-1}-----	
53	2160	2625
105	2636	2971
Significance	*	NS[1]

* Significant at the 0.05 level of problity.

1 Not significant at the 0.10 level of probability.

Table 9. Crop yields from four subsoil depths of reconstructed surface-mined soils[1], 1988-89.

Subsoil depth	1988 GS-GS	1988 SB-GS	1988 Soybean	1988 Wheat	1989 Wheat
cm			$kg\ ha^{-1}$		
0	3631	3617	787	1899	1300
30	4860	4999	897	2021	926
60	5327	5366	965	2003	1494
90	5013	5047	969	2324	1374
LSD (.10)	812	783	NS	NS	372

---

[1] All soil profiles contain 30 cm topsoil over the subsoil depth treatment.

[2] Not significant at 0.10 level of probability.

Fig. 4. EFFECTS OF INDIVIDUAL RIPPING TREATMENTS ON YIELD OF SOYBEANS, 1988

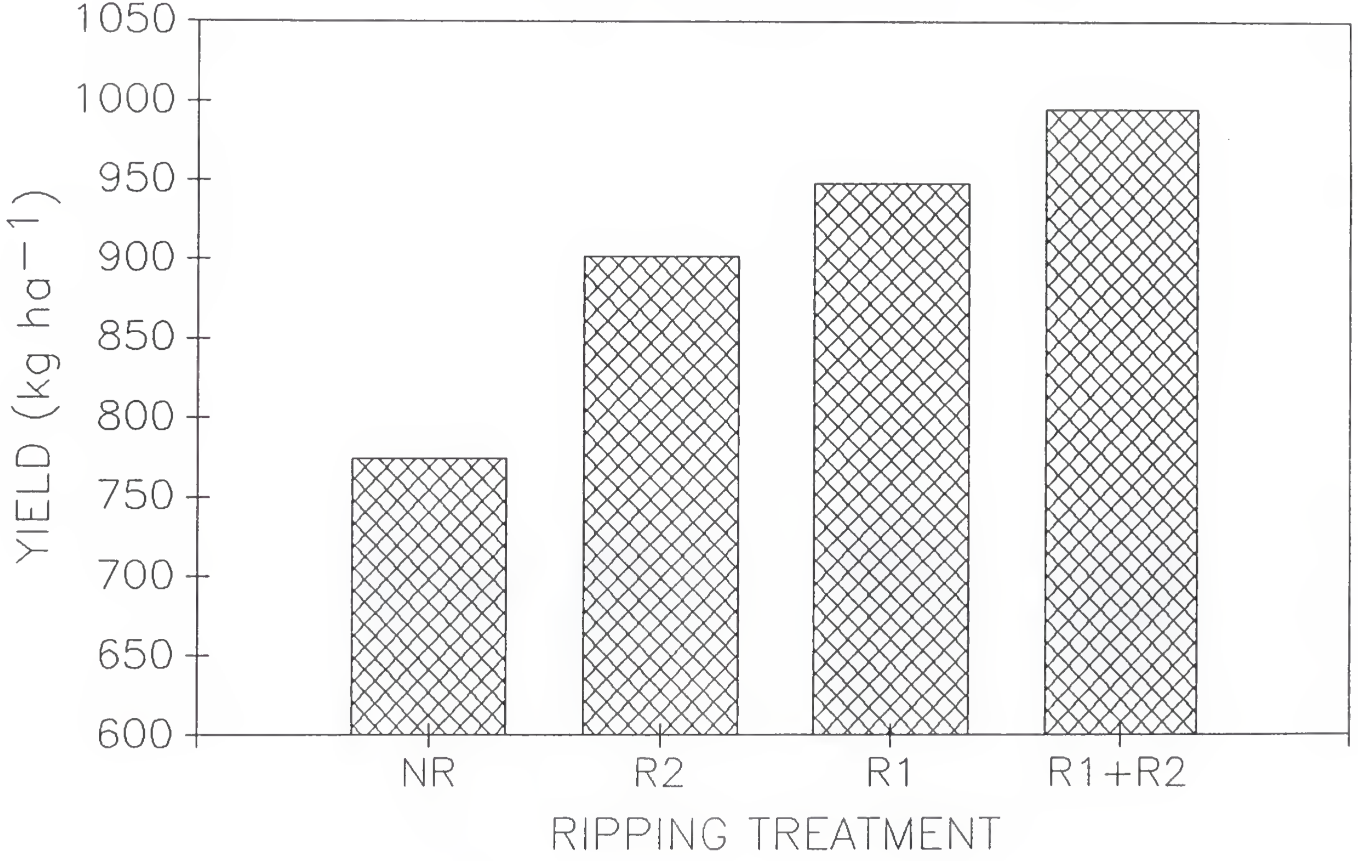


Fig. 5. EFFECTS OF INDIVIDUAL RIPPING TREATMENTS ON YIELDS OF GRAIN SORGHUM UNDER TWO CROPPING SYSTEMS, 1988

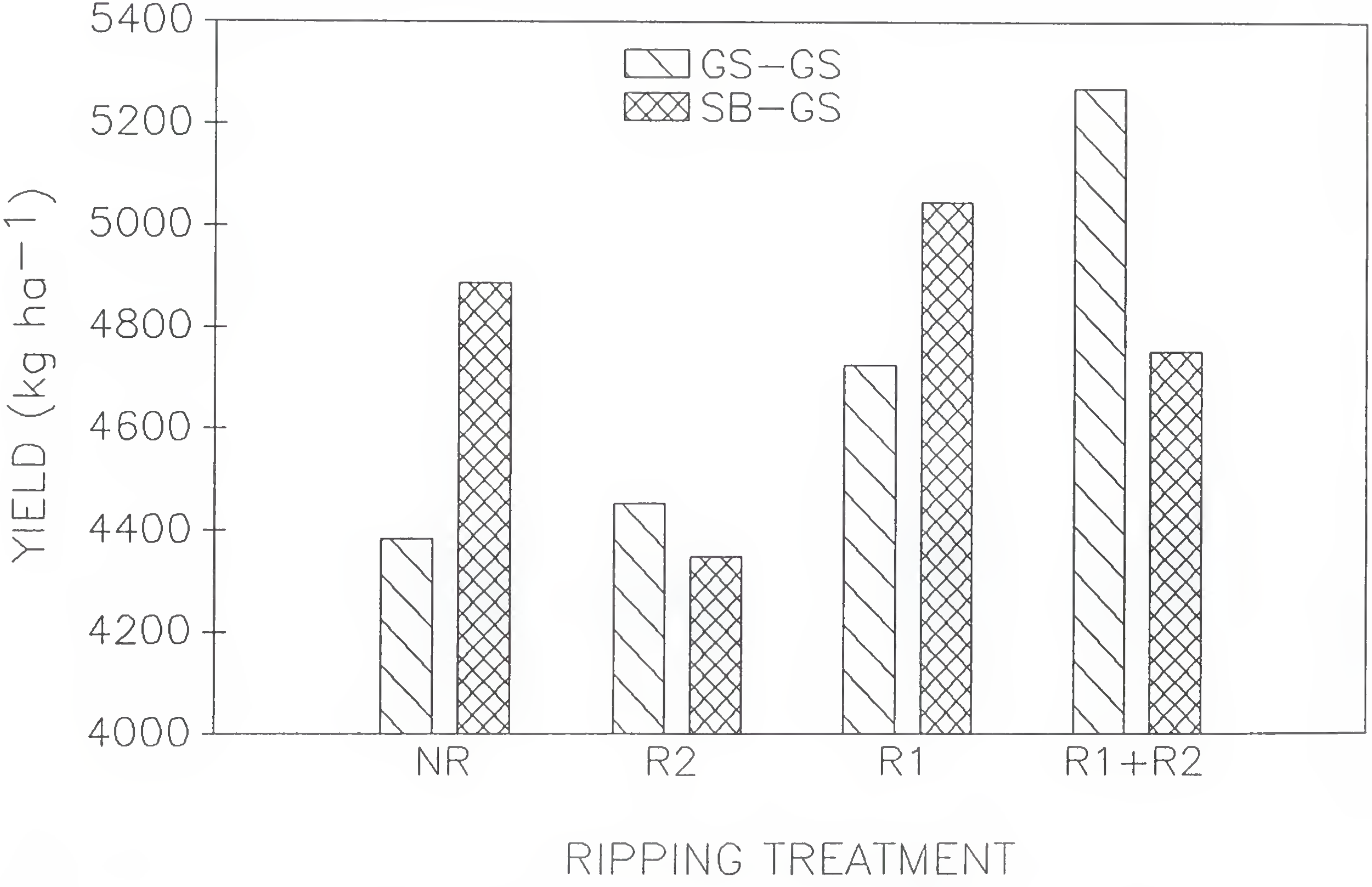
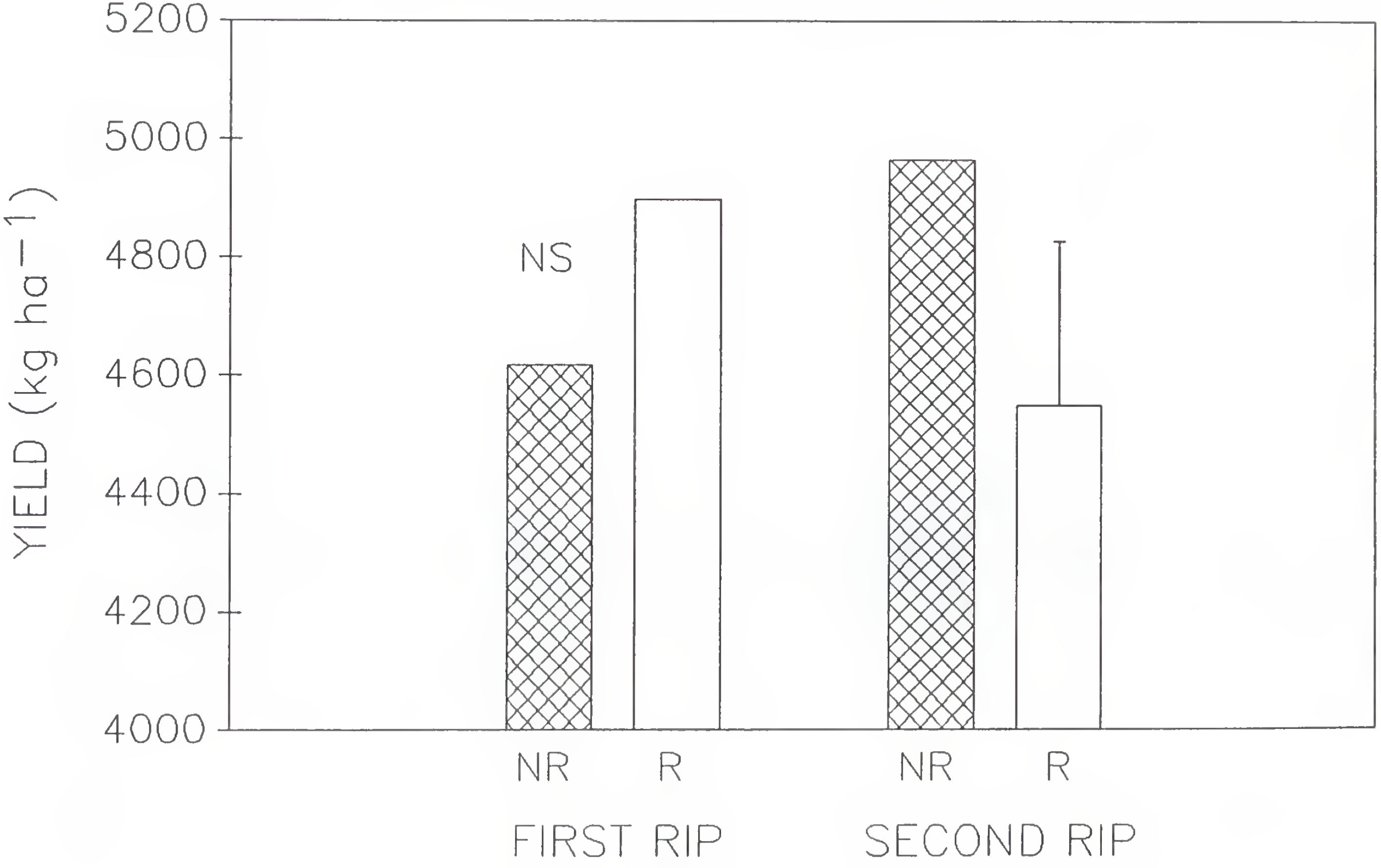


Fig. 6. EFFECTS OF THE FIRST AND SECOND RIPPING ON YIELDS OF GRAIN SORGHUM FOLLOWING SOYBEANS, 1988



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APPENDIX

Appendix Table 1. Forage yields from P & M Midway Mine research plots, 1987-1989

Rep	Rip[1]	Subsoil depth (cm)	Fescue				Alfalfa			
			1987	1988	1989		1988		1989	
					P	No P	1st cut	2nd cut	1st cut	2nd cut
			kg ha^{-1}							
1	1	90	4717	3633	3687	4768	2790	2316	5186	5893
2	1	90	3848	2669	5698	5222	1499	2023	4116	4623
3	1	90	4438	3026	4382	4209	2089	2432	4584	4534
1	1	60	5048	3363	3299	3613	1783	2162	3900	4071
2	1	60	4509	3859	7733	5199	1312	1962	4144	3771
3	1	60	4609	3306	4425	3318	1921	2328	3816	5094
1	1	30	6098	2737	4249	3556	1277	2175	4341	4587
2	1	30	4513	2297	2587	3341	2046	2391	4026	3867
3	1	30	5570	2311	3853	2340	1548	2049	3310	3875
1	1	0	4844	2869	4062	3898	1705	1647	3213	4010
2	1	0	4004	2896	2746	3632	1943	2654	2708	3610
3	1	0	4493	3248	4485	5180	1912	2395	4266	5058
1	2	90	4400	3965	4469	4822	2411	2193	4432	5450
2	2	90	3744	3374	5766	6178	1486	1816	4460	5175
3	2	90	3501	3962	5222	4477	2096	1855	4347	4560
1	2	60	4896	3622	4277	6639	1849	1872	4158	4936
2	2	60	3865	2880	4541	5249	1529	1966	4457	4569
3	2	60	4220	2720	2311	4514	1737	1620	3960	4021
1	2	30	4212	1946	3513	4234	1249	1399	3407	3280
2	2	30	3984	2114	3336	3437	1794	1794	3300	2937
3	2	30	3857	2758	2791	3332	2046	1530	3110	3288
1	2	0	5020	2832	4122	5244	1875	1693	3489	3806
2	2	0	3916	2977	2742	4234	2060	1715	3677	4902
3	2	0	4590	4145	5028	5329	2001	2079	4138	3903

[1] 1 = ripped, 2 = unripped

Appendix Table 2. Yields of oats, soybeans and grain sorghum, 1986.

Rep	Subsoil depth	Ripping[1]	Oats	Soybeans	Grain Sorghum
	cm		----------kg ha^{-1}----------		
1	0	1	1889	1875	3374
1	0	2	1534	1707	3763
1	30	1	1953	2426	3738
1	30	2	1631	1620	3857
1	60	1	2799	2130	4177
1	60	2	2104	1371	3211
1	90	1	2487	1902	3205
1	90	2	2054	1606	3023
2	0	1	2731	2097	4472
2	0	2	2089	1539	3550
2	30	1	2502	1499	2747
2	30	2	1695	1304	3330
2	60	1	2684	2150	3719
2	60	2	1706	1620	2408
2	90	1	2588	2150	3813
2	90	2	1577	1270	3117
3	0	1	2365	1989	3318
3	0	2	1667	1270	2615
3	30	1	2993	1720	3719
3	30	2	1656	1499	3744
3	60	1	3509	1808	3468
3	60	2	1903	1512	3374
3	90	1	2548	1814	2967
3	90	2	2093	1378	3556

[1] = ripped, 2 = unripped

Appendix Table 3. Grain sorghum and soybean yields, 1987.

Rep	Subsoil depth	Rip[1]	N rate[2]	SB-GS[3]	GS-GS[4]	Soybeans[5]
	cm			----------	kg ha^{-1}	---------
1	0	1	1	2383	2302	1492
2	0	1	1	3406	2107	1929
3	0	1	1	3776	2584	1740
1	30	1	1	1938	2183	1861
2	30	1	1	2879	2296	1505
3	30	1	1	3337	1298	1956
1	60	1	1	2822	2352	1868
2	60	1	1	4002	3374	2130
3	60	1	1	2960	2452	1935
1	90	1	1	3556	3243	2117
2	90	1	1	4309	3870	1747
3	90	1	1	2804	2615	1512
1	0	1	0	2252	1386	--
2	0	1	0	1066	1894	--
3	0	1	0	3387	3236	--
1	30	1	0	2503	2371	--
2	30	1	0	2935	1430	--
3	30	1	0	2471	1731	--
1	60	1	0	2785	627	--
2	60	1	0	3004	2735	--
3	60	1	0	2766	1142	--
1	90	1	0	2891	3130	--
2	90	1	0	2459	3920	--
3	90	1	0	3324	2339	--
1	0	0	1	1474	2766	1505
2	0	0	1	2653	2201	1747
3	0	0	1	2145	3569	1189
1	30	0	1	2973	2227	1626
2	30	0	1	2270	2114	1747
3	30	0	1	2321	2176	1915
1	60	0	1	3500	2302	1929
2	60	0	1	3161	2534	1935
3	60	0	1	3619	3393	1700
1	90	0	1	3011	3098	2050
2	90	0	1	2641	3299	1552
3	90	0	1	3374	2898	1263

Appendix Table 3. (cont.)

1	0	0	0	2007	847	--
2	0	0	0	1794	1681	--
3	0	0	0	3857	2960	--
1	30	0	0	1926	2785	--
2	30	0	0	2076	1599	--
3	30	0	0	2227	433	--
1	60	0	0	2772	2647	--
2	60	0	0	3324	2854	--
3	60	0	0	2772	1737	--
1	90	0	0	2804	2785	--
2	90	0	0	2346	2540	--
3	90	0	0	3255	3029	--

1 1 = ripped, 0 = unripped
2 1 = 105 kg ha^{-1}, 0 = 53 kg ha^{-1}
3,4 Grain sorghum following soybeans and continuous grain sorghum, respectively.
5 Column 4 (N rate) does not apply to soybeans.

Appendix Table 4. Grain sorghum and soybean yields for 1988.

Rep	Subsoil depth	R1[1]	R2[2]	GS-GS[3]	SB-GS[4]	Soybeans
	cm			----------kg ha^{-1}--------		
1	90	1	1	5225	5758	1210
2	90	1	1	5877	4503	887
3	90	1	1	4861	4215	1203
1	60	1	1	5632	5983	1109
2	60	1	1	4936	5544	1129
3	60	1	1	6504	5074	1001
1	30	1	1	5513	4585	1203
2	30	1	1	5808	4133	968
3	30	1	1	4861	5457	948
1	0	1	1	3625	3613	585
2	0	1	1	4535	4635	719
3	0	1	1	5871	3512	981
1	90	1	0	5281	5199	1089
2	90	1	0	5482	5902	1048
3	90	1	0	4993	5319	934
1	60	1	0	5469	4999	1068
2	60	1	0	4629	5714	968
3	60	1	0	5921	5933	813
1	30	1	0	5319	4855	1223
2	30	1	0	5501	4829	853
3	30	1	0	4014	6178	874
1	0	1	0	2440	1869	464
2	0	1	0	4127	5043	860
3	0	1	0	3512	4698	1163
1	90	0	1	4566	5889	800
2	90	0	1	4798	4378	968
3	90	0	1	5595	3939	1189
1	60	0	1	5156	4503	766
2	60	0	1	4579	4967	1230
3	60	0	1	5632	4993	974
1	30	0	1	4259	4673	1015
2	30	0	1	4986	5080	833
3	30	0	1	4484	3926	672
1	0	0	1	3048	2778	665
2	0	0	1	2904	3525	773
3	0	0	1	3425	3512	941

Appendix Table 4. (cont.)

1	90	0	0	4096	5714	544
2	90	0	0	4742	4911	941
3	90	0	0	4641	4836	820
1	60	0	0	5406	5751	638
2	60	0	0	5231	5858	1068
3	60	0	0	4829	5074	813
1	30	0	0	4372	5745	813
2	30	0	0	5300	5494	598
3	30	0	0	3901	5030	766
1	0	0	0	3249	3255	538
2	0	0	0	2678	3456	820
3	0	0	0	4152	3512	934

1,2 R1 = first ripping, R2 = second ripping

3,4 Continuous grain sorghum and grain sorghum following soybeans, respectively.

Appendix Table 5. Yields of wheat, 1988-89.

Rep	Subsoil depth	Ripping[1]	1989	1988
	cm		----kg ha^{-1}-----	
1	90	1	1512	2439
2	90	1	1566	2177
3	90	1	1364	2258
1	60	1	1398	2345
2	60	1	1767	1922
3	60	1	1472	2406
1	30	1	1633	1828
2	30	1	585	2110
3	30	1	699	2050
1	0	1	1277	1673
2	0	1	1169	1740
3	0	1	1210	2009
1	90	2	1667	2446
2	90	2	1035	2137
3	90	2	1102	2486
1	60	2	1559	2003
2	60	2	1579	1640
3	60	2	1189	1700
1	30	2	1284	1687
2	30	2	766	1888
3	30	2	591	2560
1	0	2	1781	2097
2	0	2	907	1431
3	0	2	1458	2446

[1] 1 = ripped, 2 = unripped

SOIL REPLACEMENT DEPTH AND DEEP RIPPING TO RECLAIM SURFACE-MINED LAND

by

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B.S., Kansas State University, 1985

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Soil replacement is an important part of restoring productivity to surface-mined lands. The amount of soil that must be replaced is dependent on many soil, plant, and climatic parameters. Therefore, conditions at individual sites must be considered when planning for reclamation. Research was conducted to evaluate effects of replaced soil depth and deep ripping on production of rowcrops, grain sorghum and soybeans (Sorghum bicolor (L.) Moench; Glycine Max Merrill), small grains, oats and wheat (Avena sativa L.; Triticum aestivum L.), and forages, fescue and alfalfa (Festuca arundinacea Schreb.; Medicago sativa L.) on reclaimed mined-lands in southeast Kansas. Experimental plots consisted of 30 cm of topsoil plus either 0, 30, 60, or 90 cm of subsoil placed over graded minespoil. One-half of each newly constructed profile was ripped 51 cm deep. A second ripping treatment was added to the rowcrops the third year by ripping one-half of each plot 38 cm deep perpendicular to the first ripping. Subsoil depth did not significantly affect yields of oats, soybeans, or grain sorghum the first year, but ripping increased yields of oats and soybeans. No significant response to subsoil depth or ripping was observed in the second year, except for an interaction between both variables for fescue. In the third year, yields of both continuous grain sorghum and grain sorghum following soybeans were significantly lowest when only 30 cm of topsoil was placed over spoil, and tended to

be highest on 30 cm of topsoil plus 60 cm of subsoil. Yields of continuous grain sorghum increased in response to both the first and second ripping treatments. Yields of grain sorghum following soybeans, however, were not affected by the first ripping, and were significantly reduced by the second. Yields of soybeans were increased by ripping previously unripped plots, but when combined with the first ripping, were not appreciably increased over those from the first ripping alone. Yields of wheat and fescue from the 30 cm subsoil plus 30 cm of topsoil treatments were significantly lower than the other profile depths, and neither was affected by ripping. Yields of a second cutting of alfalfa were not affected by subsoil depth but were increased by ripping. In the fourth year, alfalfa yields were significantly highest on 90 cm of subsoil plus 30 cm of topsoil. Yields of wheat on 30 cm of subsoil plus 30 cm of topsoil were significantly less than other subsoil depths, while fescue was not significantly affected by subsoil depth or ripping. With adequate precipitation subsoil depth appears to have no significant effect on crop production. However, in years of low rainfall, more subsoil might be required to achieve maximum yields, although this was only observed for grain sorghum in this study. Ripping shortly after soil reconstruction was of benefit to the first year's crop production, and appears to have had a greater influence on yields in the third year than the second, shallower ripping.