SOIL WATER PERCOLATION AND EROSION ON UNCOMPACTED SURFACE MINE SOIL IN EASTERN KENTUCKY[1]

E.J. Byrd [2], R.K. Kolka, R.C. Warner, and J.M. Ringe

Abstract. Previous research has found that little to no compaction of mine spoils has positive effects on tree growth but no studies have evaluated the effect that uncompacted spoils have on soil percolation and erosion. This paper examined the movement of sediment transported by surface erosion and soil water percolation in uncompacted mine spoils located in eastern Kentucky. In sparsely vegetated, uncompacted mine spoils approximately 32% of the incident precipitation percolates as soil water to a depth of approximately 2.6 m (8.5 ft.), which is comparable to forested conditions in eastern Kentucky. Estimated annual erosion rates for the uncompacted mine spoils were 1750 kg ha^{-1} (0.8 t ac^{-1}), which is above that of forested sites but considerably lower than those on agricultural lands in Kentucky. The relatively low erosion rates are the result rough soil surfaces, depressional storage, and high infiltration and percolation capacities associated with the uncompacted spoils.

---

[1] Poster was presented at the 2002 National Meeting of the American Society of Mining and Reclamation, Lexington, KY, June 9-13, 2002. Published by ASMR, 3134 Montavesta Rd., Lexington, KY, 40502.

[2] E. J. Byrd, Environmental Consultant, Kentucky Business Environmental Assistance Program, University of Kentucky, Lexington, KY 40546.
R.C. Warner, Professor, Department of Biosystems and Agricultural Engineering.
R.K. Kolka, USDA Forest Service - North Central Research Station, 1831 Hwy. 169 E., Grand Rapids, MN 55744
J.M. Ringe, Associate Professor, Department of Forestry, University of Kentucky, Lexington, KY 40546.

Proceedings America Society of Mining and Reclamation, 2002 pp 1049-1059
DOI: 10.21000/JASMR02011049

https://doi.org/10.21000/JASMR02011049

Introduction

With the passage of the Surface Mining Control and Reclamation Act of 1977 (SMCRA, 1977), states were regulated in the manner by which they reclaimed disturbed mine land. Typically, reclamation includes grading the overburden or residual material with heavy equipment leading to soil compaction. Because of the excessive compaction levels and the need to prevent erosion, a mixture of grasses and legumes were used to establish a fast-growing ground cover where forests once existed (SMCRA, 1977). The method was quick, relatively inexpensive, and led to a simplified way for mining inspectors to interpret the law. Unfortunately, the SCMRA reclamation approach skirts the issue that the mining company must "restore the land affected to a condition capable of supporting uses which it was capable of supporting prior to any mining…" (SMCRA, 1977; Sec 515(b)(2)). In simple terms, current mining reclamation practices have reduced high value timberland to a lesser-valued pastureland (Burger, 1999).

Although the Act provided detailed guidelines on how to reclaim the land, the interpretation of the Act fell short of its goals. Over the past 20 years, research has provided data on how to better interpret the articles of SMCRA. Studies have shown that trees grow better in uncompacted soils (Graves et al., 2000; Andrews et al., 1998; Burger and Torbert, 1992), and none to little compaction of spoil piles do not contribute significantly to nonpoint source pollution when covered with grasses, legumes, or trees (Andrews et al., 1998).

When soils are compacted, bulk density increases which reduces the aeration zone required for root development of hardwood trees (Hopkins and Patrick, 1969). Bulk density readings of 1.33g cm^{-3} for agricultural fields were seen as optimal by Singh and Gupta (1971), while bulk density readings of 1.7 g cm^{-3} or greater collected from compacted mine sites resulted in very slow to no growth in trees (Thomas, 1999; Andrews et al., 1998; Graves, 1995; Bussler et al., 1984).

As a result of heavily compacted soils, porosity is reduced allowing for little infiltration and percolation, and an increased potential for surface runoff. Kemp (1990) characterized how the effect of loose dumped mining spoils created macropores and channels that either contained infiltrated water in perched tables or directed the flow through the different layers of mining spoil. In both scenarios, the promotion of soil macropores can minimize surface runoff, maximize infiltration and percolation and leads to little erosion.

In forested watersheds surface runoff is minimal because of interception by vegetation and forest floor, the roughness of the forest floor, and the extensive networks of macropores and micropores found in forest soils (Pritchett and Fisher, 1987). In mine spoils however, surface runoff varies depending upon the compaction level of the soil. Excessive contouring of the spoil leads to soil compaction and the crushing and grinding action of heavy equipment reduces the soil pore sizes available for water retention and gaseous exchange and reduces the soils ability to allow infiltration (Binger, 1988; Patterson, 1976). The resultant surface runoff is laden with sediment that ultimately moves downslope impacting low-lying areas and streams. Minimal grading to no grading (semi-compaction to no-compaction) can increase infiltration rates and decrease subsequent surface runoff (Burger and Torbert, 1992).

If we are to utilize reclamation techniques that reestablish forest communities in surface mined areas of eastern Kentucky, we need to consider the substrate conditions that will lead to soil physical properties that are compatible with tree establishment and growth. We also need to understand how those substrate conditions effect the generation of nonpoint source pollution, especially sediment production. The objective of this paper is to develop a quantitative understanding of the interactions of soil water percolation and erosion in uncompacted mine soils.

Site Description

The study site (Figure 1), known as the Starfire Mine, is located in eastern Perry County and western Knott County in southeastern Kentucky (37°24’N, 83°8’W). It is currently under the ownership of Enviropower and is managed by the Addington Mining Company. In April 1998, two uncompacted mine spoil research sites were installed, one for the analysis of soil water percolation (0.53 ha (1.3 ac)), and the other for erosion (0.27 ha (0.66 ac)). The mine spoil, consisting of intermixed sandstone with shale deposits, was dumped in place over compacted overburden from previous mining operations. Seven tree species including white oak (*Quercus alba*), red oak (*Q. rubra*), Royal paulownia (*Paulownia tomentosa*), green ash (*Fraxinus pennsylvanica*), white pine (*Pinus strobus*), yellow poplar (*Liriodendron tulipifera*), and black walnut (*Juglans nigra*) were planted at each site as part of a companion study (Graves, 1995).

Materials and Methods

For the soil water percolation study, 38 5m x 5m (16.4 ft x 16.4 ft) subcatchment basins were constructed and arranged in four rows. The site was graded at approximately 2% from the SW corner to the NE corner. A 5m (16.4 ft) buffer zone was created around each basin to provide for a distinct collection area. Each individual basin consisted of a field-constructed lysimeter pan fitted with a geomembrane liner and covered with 30.5mm (12 in) of construction grade sand for puncture protection. Loose dumped spoil was placed over the entire test site to approximately 2.6 m (8.5 ft) in depth. The mine spoil ranged in size from clay-size particles to boulders 4 meters (13 ft.) in diameter. The geomembrane was connected to 12.7 mm (0.5 in) diameter irrigation tubing and multiple tubes were installed within 15.2 cm (6 in) PVC pipe that was covered with ~1 meter of selected mine spoil to protect it from the crushing action of the dumped material. The irrigation tubing ran adjacent to the lysimeter pans that carried the percolated water into individual tipping buckets that were nested at the east end of the experimental site. Each tipping bucket was precalibrated to collect and record the volume of water mechanically, by counting 600 mls (20 oz.) per tip. Metal shields were installed over the buckets to protect the counters, prevent any direct rainfall from entering the buckets, and to minimize the amount of evaporation from the buckets.

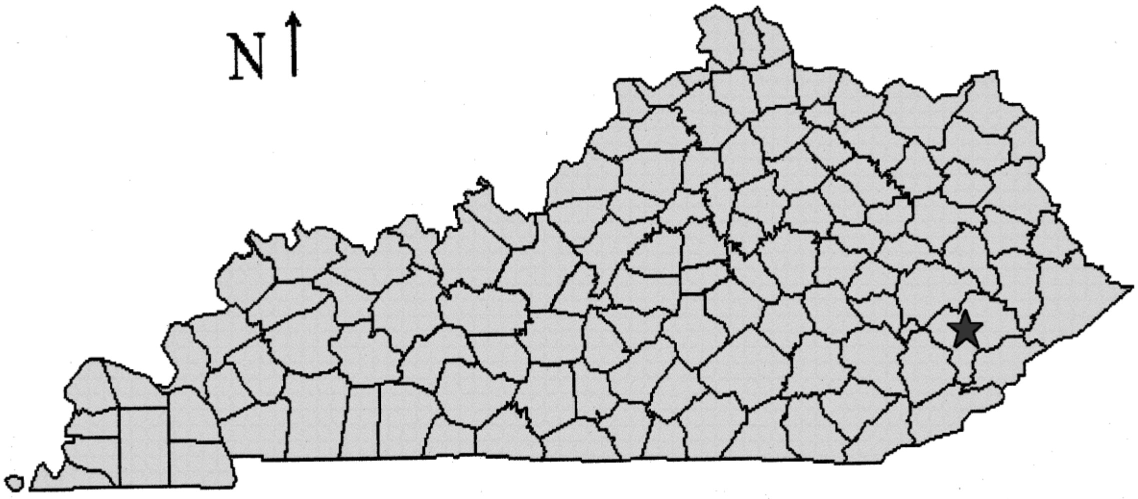

Figure 1. State of Kentucky map indicating the study site located at the Starfire Mine in Perry County and Knott County, Kentucky.

Over the first 12 months of the study, it was noticed that a portion of the 38 tipping buckets produced less flow than anticipated. The results were interpreted as a potential problem since the test site was relatively flat (2%) and should have resulted in comparable flows. Delivery lines were assessed for blockage by pouring 7.5 liters (2.0 gallons) of water into each purge line located upstream of the lysimeter pan. The field tests showed that two subcatchments were not functioning correctly and they were removed from the data set. The remaining 36 subcatchments (1728 observations) were analyzed. Carefully recorded field notes, taken over the three years, indicated mechanical failures (56 observations) at different times during the collection period. Failures included rusted counters, broken tipping mechanisms, overgrown vegetation and sediment deposits that prohibited the proper functioning of the tipping buckets. Because of these malfunctions, these points were removed from the data set. The remaining flow readings (1672 observations) were analyzed on the 36 subcatcments by using a box plot statistic. Flow readings that exceeded 3x the Inner Quartile Range were eliminated from the data set as outliers (44 observations). Linear regression comparing flow to precipitation volume was applied to the final data set (1628 observations) for each subcatchment. Those subcatchments that did not have a significant relationship (F significance >0.05) between flow and precipitation were assumed to be malfunctioning and were eliminated from further analysis. The final data set consisted of 25 subcatchments and was used to produce an outflow analysis for the three years of study.

For the erosion study, spoil was simply loose dumped and erosion pans were installed. A prototype erosion pan was built to assess the method. The prototype was constructed from 1.6mm (0.063 in) gage aluminum and measured 0.6m (2 ft) wide by 0.9 m (3 ft) in length with a three-sided rim 2.54cm (1.0 in) in height. The pan was embedded 5.0 cm (2.0 in) into the foot of the confluence between two adjacent hillslopes and leveled slightly downwards to allow for overflow of runoff while trapping the transported sediment. Following two preliminary erosion collections (May and June, 2000), the pan was functioning as desired. As a result of the success of the prototype, five additional pans were built and installed. A slight modification to the new pans was made by shortening the length to 0.6m (2 ft). It was noted from the prototype that length was not a function of performance as a large portion of the pan was not being used to capture sediment. Monthly sediment collection commenced in July 2000 and continued through the end of December 2000. A total of 30 sediment samples were collected from the soil pans during the six-month period. Sediment samples were not collected during the month of

November because of flooded pans. Samples collected from each soil pan were measured for total mass after being oven dried at 105°C. Each soil pan collection zone was surveyed at the conclusion of the study period to avoid disturbing the soil surface during the sample collections. Radius, slope, and theta (azimuth difference between radius sides) were individually measured and used to determine the surface area corresponding to each collection pan that contributed sediment via surface runoff.

Bulk density was measured to assess the compaction level at both the soil water percolation and erosion sites. Bulk densities were obtained by using the foam method developed by Muller and Hamilton (1992) whereby approximately 500 mg of soil (~ 10 cm depth) was excavated from the desired location and retained for mass. Expanding urethane foam was injected into the excavated hole and allowed to solidify for 24 hours. After 24 hours, the foam casting of the excavated hole was removed and immersed in water to determine volume. Seven bulk density measurements were randomly selected from the 38 available subcatchments located on the infiltration site. For the erosion site, there were no predetermined subplots established. The site was divided into 36 subplots approximately equal to the infiltration subplots sizes. Six bulk density samples were randomly collected from the 36 subplots.

Results

Bulk Density

The mean bulk density of the soil water percolation site was 1.28 g cm^{-3} as compared with 1.39 g cm^{-3} for the erosion site. No significant differences existed among sites ($p>0.05$). Our bulk densities fell near to and within the range of Thomas's (1999) study (1.32 – 1.49 g cm^{-3}), also conducted on the Starfire Mine on nearby loose dumped sites. Compacted soils on site range in bulk density from 2.01 to 2.69 g cm^{-3} (Thomas, 1999).

Soil Water Percolation

Over the soil water percolation site, a mean of 32.2% of incident precipitation resulted in outflow over the three-year study with a range of 26.6 to 36.9% for individual subcatchments. The mean value is similar to eastern Kentucky forested watersheds where 35% of incident precipitation results in streamflow with the remaining 65% either evaporated or transpired back to the atmosphere (Dyer, 1983). Regression analysis indicated that approximately 64% (rvalues) of the variation in percolated volume could be explained by precipitation volume including several individual subcatchments where over 80% of the variation was explained.

Erosion and Sediment Production

The data from six individual soil erosion pan contributing areas ranged in size from 16.7 to 30.7 m^2 (180 to 330 ft^2) with an average area of 23.7 m^2 (255 ft^2) and slope of 45 degrees (Table 1). The total sediment transported as a result of erosion ranged from 390 to 2100 kg ha^{-1} (0.17 to 0.94 t ac^{-1}) with a mean of 928 kg ha^{-1} (0.42 t ac^{-1}). The mean amount of sediment transported per collection period was significantly related to precipitation volume (Figure 2). If we substitute the mean annual precipitation (120 cm or 47 in.) for eastern Kentucky into the regression, we estimate that 1750 kg ha^{-1} (0.8 t ac^{-1}) would erode annually from loose dumped spoils that have recently been planted into trees.

Table 1. Area parameters and total erosion rate for individual pans over the sampling period (~6 months).

Pan	Slope (Degrees)	Radius (Meters)	Theta (Degrees)	Surface Area (ft^2)	Surface Area (m^2)	Erosion Rate (t ac^{-1})	Erosion Rate (kg ha^{-1})
1	38.8	19.3	80	260.9	24.2	0.94	2098
2	38.4	21.4	79	315.7	29.3	0.20	443
3	45.3	19.5	56	185.8	17.3	0.22	490
4	45.8	20.2	93	330.2	30.7	0.17	390
5	50.8	15.1	90	180.0	16.7	0.54	1204
6	53.3	18.2	90	259.3	24.1	0.42	940
Mean	45.4	19.0	81	255.3	23.7	0.42	928

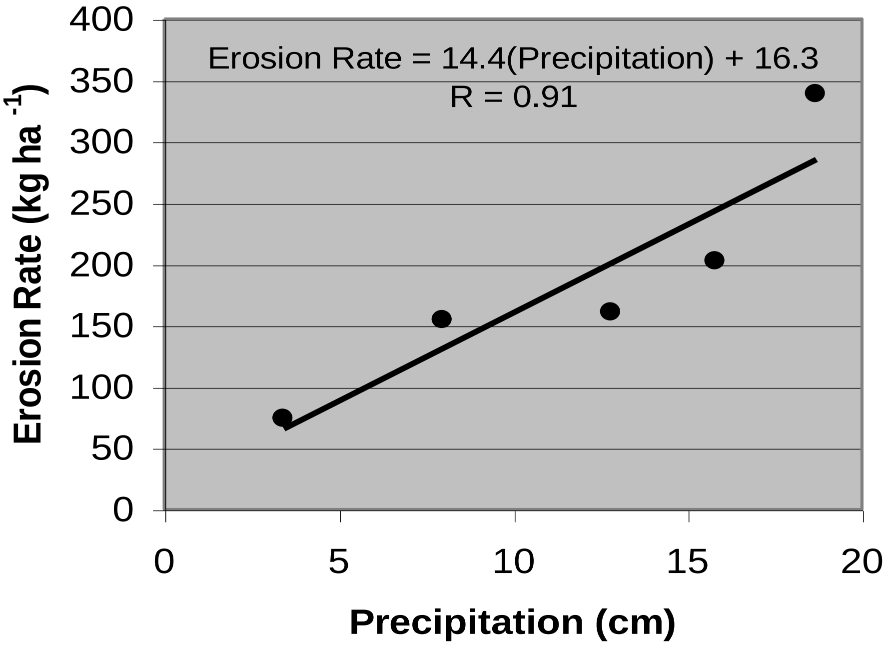

Figure 2. Relationship between precipitation and mean erosion rate.

Discussion

The relatively low bulk densities of the loose dumped spoil indicate considerable porosity near the soil surface and potentially throughout the entire spoil profile. Considering the relatively low bulk densities, the roughness of the site and the considerable depression storage present, we would expect relatively high infiltration, high percolation rates and little surface runoff and erosion. The subsurface runoff resulting from our soil water percolation study confirmed that comparable soil water outputs occur on uncompacted mine soils as in forested watersheds in eastern Kentucky. In both environments, evapotranspiration processes consume the bulk of infiltrated water. In forest systems the greater proportion is utilized through transpiration processes whereas, because of the age of trees and sparse ground cover on the mine spoil site, we suspect that the bulk of infiltrated water is evaporated back to the atmosphere. The lack of insulation from tree canopies may contribute to higher evaporation rates on mine lands because of higher near-surface air temperatures and the lack of protection from wind. We would expect the balance of evaporation and transpiration to change as the trees mature.

Also, because there is very little surface cover because of the immature trees, some erosion is occurring onsite, although much lower than would occur, for example, on a typical agricultural field in Kentucky that experiences anywhere from 4000-8000 kg ha^{-1} (4-8 t ac^{-1}) annually (NRCS, 1997).

Conclusion

The results of our study indicate that uncompacted spoil on surface mine lands allow for considerable infiltration and soil water percolation. High rates of infiltration and soil water percolation leads to little surface runoff and erosion. Considering that these sites were relatively devoid of vegetation at the time of the study, the results are very encouraging. As the planted seedlings develop and begin to bind soil with roots, provide canopy cover that will reduce raindrop impact and begin to produce litter that will add to soil surface roughness, we would expect percolation to continue to increase and even less erosion. From these results, it is apparent that uncompacted spoils are not significant sources of nonpoint source pollution and should be considered as an alternative to highly compacted and smoothly contoured reclamation practices currently used today, especially when reestablishing trees.

Literature Cited

Andrews, Jeffrey A., J.E. Johnson, J.L. Torbert, J. A. Burger, and D.L. Kelting. 1998. Minesoil and site properties associated with early height growth of eastern white pine. J. Environ. Qual. 27:192-199. http://dx.doi.org/10.2134/jeq1998.00472425002700010027x.

Binger, Ronald Lee. 1988. A simulation of compaction as a function of soil and machinery characteristics. Thesis. University of Kentucky.

Burger, J. A. 1999. Academic research perspective on experiences, trends, constraints, and needs related to reforestation of mined lands. In: K.C. Vories and D. Trougmorton, eds. Proceedings 1999, Enhancement of reforestation at surface coal mines: Technical interactive forum. OSM, Washington, D.C.

Burger, J. A. and J.L. Torbert. 1992. Restoring forests on surface-mined lands. Virginia Coop Ext. Ser., Virginia Polytechnic Institute and St. Univ. Pub. 460-123. 16 pp.

Bussler, B.H., W.R. Byrnes, P.E. Pope, and W.R. Chaney. 1984. Properties of minesoil reclaimed for forest land use. Soil Sci. Soc. Am. J. 48:178-184. http://dx.doi.org/10.2136/sssaj1984.03615995004800010033x.

Dyer, Kenneth L. 1983. Effects on water quality of coal mining in the basis of the North Fork Kentucky River, eastern Kentucky. USGS. Water- Resources Investigations Report. 81-215.

Graves, D. 1995. An inter-disciplinary approach to establish and evaluate experimental reclamation of surface mine spoil with high value tree species. Robinson Forest Initiative High Value Reclamation Project. University of Kentucky.

Graves, D. H., J. M. Ringe, M. H. Pelkki, R. J. Sweigard, and R. Warner. 2000. High value tree reclamation research. Pages 413-421 in Singhal and Mehrotra, (eds.) *Environmental Issues and Management in Energy and Mineral Production*. Balkema, Rotterdam, The Netherlands.

Hopkins, R.M. and W.H. Patrick, Jr. 1969. Combined effect of oxygen content and soil compaction on root penetration. Soil Sci. 108:408-413. http://dx.doi.org/10.1097/00010694-196912000-00005.

Kemp, John Edward. 1990. Hydrogeological Characterization of Surface Mine Spoil, Star Fire Mine, Eastern Kentucky. Thesis.

Mueller, R.N. and M.E. Hamilton. 1992. A simple, effective method for determining the bulk density of stony soils. Communications Soil Science and Plant Anal. 23(3&4), 313-319. http://dx.doi.org/10.1080/00103629209368590.

Natural Resources Conservation Service. 1997. Average annual soil erosion by water on cropland and CRP land. USDA-NRCS-RID Publication. (www.nhq.nrcs.usda.gov/land/meta/m5058.html)

Patterson, James C. 1976. Soil compaction and its effects upon urban vegetation of better trees for metropolitan landscapes, symposium proceedings., US Forest Service Gen. Tech. Report NE-22. p91-102.

Pritchett, William L. and R.F. Fisher. 1987. Properties and Management of Forest Soils. John Wiley and Sons, Inc. Pub.

Singh, Y.P. and R.N. Gupta. 1971. Fertilizer response to physical effects of soil compaction (wheat). J. Indian Soc. Sci. 19(4): 345-352.

Surface Mining Control and Reclamation Act of 1977. Public Law 95-87 Aug. 3, 1977. 30 USC 1201 Note. GPD.

Thomas, William R. 1999. Reclamation of Surface Mined Lands in Eastern Kentucky Using Native High Value Trees Species. Thesis. University of Kentucky.