Remediation for Rice Cultivation on Soil Affected by Coal Mining in Jaintia Hills, Meghalaya

By

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Declaration

I, Bondita Goswami, hereby declare that the subject matter of this thesis entitled 'Remediation for Rice Cultivation on Soil Affected by Coal Mining in Jaintia Hills, Meghalaya' is the record of work done by me, that the contents of this thesis did not form basis of the award of any previous degree to me or to the best of my knowledge to anybody else, and that the thesis has not been submitted by me for any research degree in any other university or institute.

This is being submitted to the North-Eastern Hill University, Shillong for the award of the Degree of Doctor of Philosophy in Environmental Science.

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Preface

The work recorded in this thesis is the outcome of the study undertaken during 2004-2008 on 'Remediation for Rice Cultivation on Soil Affected by Coal Mining in Jaintia Hills, Meghalaya'. The Jaintia Hills district is situated in the eastern part of the state of Meghalaya and lies between 25°5′ N to 25°4′ N latitudes; and between 91°51′ E to 92°45′ E longitudes. It covers an area of 3819 km^2 with a total population of 2, 95,692 persons (2001 Census). The area is covered by mostly deciduous to evergreen forests and transitional tropical moist deciduous pine forests.

The thesis explains the effect of coal mining on soil quality and agricultural productivity in Jaintia Hills district of Meghalaya. A pot culture experiment was conducted on coal mine affected rice soil of Jaintia Hills with three rice varieties under different remediation options such as organic enrichment and lime treatment. Data pertaining to following aspects are included in this thesis.

(a) Variation of land utilization pattern in Jaintia Hills from 1987 to 2002

(b) Area, Production and productivity status of agricultural crops in Jaintia Hills district (1987-88 to 2001-2002)

(c) Physico-chemical analysis of soils from coal mining area

(d) Remediation of coal mine affected acidic soil by various treatments

(e) Varietal trial of rice under different remediation options.

The thesis begins with general Introduction followed by Review of Literature, Study Area, Methodology, Results and Discussion, Summary and References.

Information on land utilization and agricultural production have been analysed to know the agricultural impact of coal mining in the area. Physico-chemical analysis of soils collected from various coal mining sites of Jaintia Hills was done to know the extent of land degradation and to reveal underlying causes of such degradation. Based on the results of pot culture experiment, suitable rice variety with proper soil ameliorant has been recommended for cultivation on coal mining sites of Jaintia Hills.

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INTRODUCTION

Chapter 1

Coal is a complex mixture of compounds of carbon, hydrogen, oxygen and some free carbon (Trivedi, 2000). It is found in deep mines under the surface of earth. Coal is important because it can be used as a source of energy as such, or it can be converted into other forms of energy like coal gas and electricity. Coal is also an important source of a large number of organic compounds which are used in manufacturing dyes, drugs, explosives, synthetic fibres and synthetic detergents. Coal mining is one of the core industries that contribute to the economic development of a country.

Coal is second only to oil in meeting world's energy needs and has a critical input in the manufacture of steel. Coal continues to provide 22% of the world's energy and is used to generate about 40% of global electricity. World coal resources were estimated in 2004 at 1,000,912 tonnes of total recoverable coal (U. S. Energy Information Administration, 2004).

Coal occupies the most important place in the energy spectrum of India meeting presently about 60% of the total commercial energy consumption (Sharma, 2003a). Total coal reserves in the country up to a depth of 1200m (as on 1.1.2004) is 245.7 billion tonnes and total annual coal production (2004-05) is 382.137 million tonnes (Ministry of Mines, Govt. of India, 2006). Major coal fields in India are Raniganj, Jharia, East Bokaro and West Bokaro; Panch-Kanham (Tawa valley), Singrauli, Talchar, Chanda-Wardha and Godavari valley. The major states known for coal reserves are Bihar, Jharkhand, Orissa, West Bengal, Madhya Pradesh, Andhra Pradesh, Maharashtra, Assam and Meghalaya (Sharma, 1999).

Meghalaya, a hilly state, is one of the seven states of North Eastern Region of India. It is located between $25^0$2' to $26^0$6' North latitudes and $89^0$48' to $92^0$50' East longitude. The state is greatly blessed in respect of mineral wealth. In this context, good deposits of coal, limestone and clay are found in various parts of the state. Coal is found in all three regions of Meghalaya viz. Jaintia Hills, Khasi Hills and Garo Hills. Though the coal found in Meghalaya is of superior quality in terms of calorific value and ash content yet the drawback is in its high sulphur content. The inferred reserve of coal in the state is estimated to be about 640 million tonnes (Directorate of Economics and Statistics, 2003).

Meghalaya falls under the provisions of the sixth schedule of the Indian Constitution, and so, the land is solely owned by the people. The state and central governments have little control on the land. The prevailing land holding system allows the land owners to excavate coal without any restriction. Thus there are thousands of private coal mine owners who excavate coal for generating income for themselves. The excavation of coal by the private operators is done by a very unscientific method of mining known as ‘rat-hole’ method. This process of coal exploitation has severely affected the environment and ecological conditions of the area (Das Gupta *et al*., 2002).

Although coal mining is done in all three regions of the state, Jaintia Hills contribute maximum in terms of production. From the year 1991-2002 the district alone contributed about 27,230.62 thousand tonnes which is 74.27% of the total coal production of the state (Dkhar and Rai, 2005).

Coal mining is one of the most important economic activities in Jaintia Hills District, Meghalaya. Coal mining in the area is unscientific, unsystematic and primitive in nature. Sutnga, Lakadong, Musiang-Lamare, Khliehriat, Ioksi, Ladrymbai, Rymbai, Byrwai, Chyrmang, Bapung, Jarain, Shkentalang, Lumshnong, Sakynphor etc. are the main coal mining areas of the District (Dkhar and Rai, 2005). Out of all coal mining areas Bapung is reported to have highest estimated coal reserves (34 million tonnes) (Rai, 1996).

The coal bearing areas of the district present a panorama of flat topped low hills, devoid of vegetation and plateau of rolling grasslands inter sparsed by river valleys. The main characteristics of the coal found in Jaintia Hills are its low ash content, high volatile matter, high calorific value and comparatively high sulfur content. The coal is mostly sub-bituminous in character. The physical properties of the coal of Jaintia Hills District are hard, lumpy bright and jointed except for the coal in Jarain which is both soft and hard in nature. Composition of the coal revealed by chemical analysis indicates moisture content between 0.4-9.2%, ash content between 1.3-24.7%, and sulphur content between 2.7-5.0%. The calorific value ranges from 5,694 to 8230 kilo calories/kg (Directorate of Mineral Resources, 1985).

Extraction of coal in Jaintia Hills District is carried out by primitive surface mining method commonly known as 'rat-hole' mining. In this method the land is, first cleared by cutting and removing the ground vegetation and then pit ranging from 5 to 100 m^2 is dug into the ground to reach the coal seam. Thereafter, tunnels are made into the seam sideways for extraction of coal, which is brought into the pit by using a conical basket or a wheel barrow. The coal is taken out of the pit manually and dumped on nearby un-mined area, from where it is carried to the larger dumping places near highways for its trade and transportation. Though this method may be the most economical and suitable to the local populace who own the mines, it is proving to be environmentally degrading. Deforestation, soil erosion, surface run-off, caving in of the ground and pollution of land, air and water are some of the prominent environmental problems associated with coal mining in the area (Das Gupta *et al.*, 2002; Swer and Singh, 2004a). In addition, depletion of water resources, destruction of agricultural land, adverse impact on human and disruption of socio-economic fabric in the area have also been noticed in recent past (Singh, 2005).

Mining activities directly or indirectly contribute to the environmental problem in many ways. Mining causes air pollution (Chaulya *et al.*, 2002). The main air pollutant associated with opencast coal mining has been found to be dust which is commonly referred to as suspended particulate matter (SPM). A part of SPM is Respirable Particulate Matter (RPM) whose size is less than 10 micron. Some amount of gaseous pollutants such as sulphur dioxide, nitrogen oxide and carbon dioxide are also emitted due to mining activities. Both nitrogen oxide and sulphur dioxide contribute to acid rain and carbon dioxide is the chief global warming gas (Sharma, 2003a).

A common process that is associated with coal mining is discharge of Acid Mine Drainage (AMD) (Taylor and Waters, 2003). The Acid Mine Drainage is formed when certain sulfide minerals such as pyrite and marcasite (FeS_2), present in coal mining regions are exposed to water and oxygen (De Nicola and Stapleton, 2002; Tiwary, 2001). In this oxidation reaction solid pyrite (FeS_2), oxygen (O_2)

and water (H_2O) are reactants, and sulfuric acid (H_2SO_4), solid ferric hydroxide (Fe $(OH)_3$), sulphate (SO_4^{2-}) and hydrogen ions (H^+) are products (Johnson and Bradshaw, 1978). The products together with water form a colored acidic discharge which is referred to as AMD.

Acid Mine Drainage is the greatest environmental problem of the mining sector. It is highly acidic with high concentrations of dissolved metals such as Fe, Al, Zn, Mn, Cu and Pb (DeNicola and Stapleton, 2002). This acidic water with elevated metal concentrations invariably runs off mine lands in overland flow or percolates its way through the substratum to enter streams (Dieffenbach, 1974). The AMD on contamination turns local rivers and streams acidic. The affected water bodies become unfit for consumption and disrupt the aquatic life (Swer and Singh, 2003). Aquatic organisms do not tolerate AMD physiologically (Henry *et al.*, 1999; Cole *et al.*, 2001). AMD contamination eliminates the more sensitive species from the aquatic ecosystem (Weed and Rutschky, 1971). Grey (1998) found an 87% decline in river species below a mining complex in Ireland.

Acid Mine Drainage has marked impacts on soil environment, too (Das Gupta *et al.*, 2002; Long peng *et al.*, 2004). Soil is a basic natural resource that should not only be preserved but where ever possible also improved (Pascual *et al.*, 2000). Acid Mine Drainage deteriorates soil's physico-chemical properties and thereby adversely affects crop growth and yield (Foy *et al.*, 1979; Bonta *et al.*, 1992; Smeth and De-Smeth, 1992). Major impacts of Acid Mine Drainage on soil include soil acidity (Visser *et al.*, 1979; Chandra and Kehri, 1994; Das Gupta *et al.*, 2002) and soil contamination with heavy metals (Filipek and Pawlowski, 1990; Long peng *et al.*, 2004). Irrigation of agricultural fields with AMD contaminated water also causes various problems, which altogether decrease agricultural productivity (Moran *et al.*, 1989; Tiwary and Dhar, 1994; Swer and Singh, 2004b).

Soil acidity has negative impact on fertility, biological activity and plant productivity. The direct effect of acidity on plants is the high concentrations of hydrogen ions, which inactivate most enzyme systems, restrict respiration, and root uptake of salts and water (Tan, 1980). Soil pH influences nutrient availability. Aluminium toxicity is the most important associated problem of acidic soils, when pH drops below 5.0. The aluminium sensitive crops may get damaged when aluminium saturation of Cation Exchange Capacity exceeds 10%. Aluminium toxicity usually damages the root system first. Aluminium affected roots tend to be shortened and swollen, having a stubby appearance (Patiram *et al.*, 1991). In addition to aluminium toxicity to plants growing on acidic soils, there may be deficiency of nitrogen, phosphorous, calcium, magnesium, molybdenum and boron and toxicity of iron and manganese, which overall imbalance the nutrient status in the soil and plant (Panda, 1987). Phosphorus deficiency takes place in acidic soil due to leaching and lack of binding power of the soil (Das Gupta *et al.*, 2002). Phosphorus can also react strongly with Iron and Aluminium components of acidic soils thereby becoming unavailable for plant uptake (Prasad and Biswas, 1998). Rice and wheat are highly responsive to nitrogen (Biswas and Mukherjee, 1999). Solubilization and transport of phosphorus to the water environment from soil and manure caused by Acid Mine Drainage is a critical environmental issue associated with agricultural productivity (Adler and Sibrell, 2003).

The uptake of nutrients by plants is strongly dependent upon soil microorganisms. Certain bacteria which live in root nodules of leguminous plants help plants in obtaining Nitrogen by converting atmospheric Nitrogen into a form of N that plants can use (Venkataraman, 1988). The effectiveness of these bacteria which enter legume roots and fix nitrogen (nodulation) is highest at pH 6.5 to 7.0 and declines rapidly when pH levels falls under 6.0 (Biswas and Mukharjee, 1999). Decomposition of organic matter also contributes to aggregation (clumping) of soil particles which provide good soil tilth, aeration and drainage (Bhardwaj, 1998). Although these organisms function best at soil pH levels of 8.0, their effectiveness drop rapidly when pH level drops below 6.0 (Biswas and Mukharjee, 1999). Strongly acidic soils (pH<3.5) also favour the development of plant pathogenic fungi i.e. *Pythium* spp. which commonly cause damping-off of seedlings and necrosis of feeder roots of established plants (Stovold, 1974).

AMD also affects crop productivity by deteriorating the quality of irrigation water. Low pH, high conductivity, high concentration of sulphates, iron and toxic metals, low Dissolved Oxygen (DO) and high Biochemical Oxygen Demand (BOD) are some of the features of AMD contaminated surface water that indicate extensive degradation of water quality (Swer and Singh, 2003). Under such circumstances, the yield of crops is very poor.

Coal mining activities significantly contribute to heavy metal pollution of the soil and metal accumulation especially with Co, Cu, Zn, Ni, and Pb (Long Peng *et al.*, 2004). Movement of heavy metals down the profile is more near AMD discharge site, leading to higher pollution problem than at the points of increasing distances (Campos *et al.*, 2003).

Another reason that mine spoils are generally nutritionally and microbiologically poor is that mining activity results in the loss of topsoil, which is an integral exchange and storage site for nutrients (Visser *et al.*, 1979). Besides, mining is one of the major contributors of soil erosion due to loosening of soil and increasing vulnerability of loosened soil to water and wind erosion (Wiles, 1987).

Mining operation undoubtedly has brought wealth and employment opportunities in Jaintia Hills District (JHD), Meghalaya but simultaneously has led to extensive environmental degradation. Large-scale denudation of forest cover, scarcity of water, pollution of air, water and soil and degradation of agricultural land are some of the conspicuous environmental implications of coal mining in the area. Entire road sides in and around mining areas are used for piling of coal which is a major source of air, water and soil pollution. Off road movement of trucks and other vehicles in the area causes further damage to the ecology of the area. Hence, a large area of land is spoiled and denuded of vegetal cover not only by mining but also by dumping and storage of coal and associated vehicular movement. Further, entire coal mining area of the Jaintia Hills District has become full of mine pits and caves. These open, unfilled pits are the places where surface water percolates and disappears. As a result smaller streams and rivers of the area, which served as life lines of the people, are either completely disappearing from the face of the earth or becoming seasonal. Consequently, the area is facing acute shortage of clean drinking and irrigation water. Besides, a vast area has become physically disfigured due to haphazard dumping of overburden and mined coal, and caving in of the ground and subsidence of land (Swer and Singh, 2003). The water bodies of the area are the greatest victims of coal mining. The water bodies are badly affected by contamination of Acid Mine Drainage originating from mines and spoils, leaching of heavy metals, organic enrichment and silting by coal and sand particles. The polluted water has contaminated the agricultural fields and reduced the agricultural productivity drastically (Swer and Singh, 2004b).

Various heavy metals such as Se, Pb, Fe, Ni, Mn, Co and Zn have been detected in mine water of coal-bearing strata of Jarain coal field of JHD (Nath, 2004).

Agriculture is an age-old practice in Jaintia Hills. Majority of the population has to depend on agriculture as the source of livelihood. There is a wide range of farming systems in Jaintia Hills of Meghalaya, of which rice based farming system is dominant. A variety of crops including rice is grown in the area. Though rice is a staple food of the district, yet its production is not sufficient to meet the requirement in the region (Directorate of Economics and Statistics, Meghalaya, 2003). Unfortunately, during recent years the area is experiencing overall decline in agricultural productivity due to multiple environmental problems caused by coal mining including remarkable qualitative and quantitative reduction of agricultural fields.

Coal mining has severely affected the physico-chemical and biological properties of soil of the district, thus making it less suitable for growth and development of plants. Lower soil moisture content, overwhelming percentage of sand, inadequate nitrogen, phosphorous and potassium make the soil less suitable for growth and development of crops (Das Gupta *et al.*, 2002; Swer and Singh, 2003). As a result farmers are forced to abandon the agricultural activity and to engage in some other professions. However, in the absence of comprehensive data on the extent and severity of impact of coal mining on land degradation and agricultural productivity, it is obviously not possible to estimate the actual loss in terms of productivity and economic costs. However, a variety of indications is available that suggest the adverse impact of coal mining on agriculture in the area. Das Gupta *et al.,* (2002) reported that the low moisture content (6%) of coal mine spoil of Bapung area of Janitia Hills District, Meghalaya has been considered an important factor limiting the plant growth. Jaintia Hills District of Meghalaya has the largest proportion of wasteland (30.72%) of the total geographical area of the state due to extensive 'rat-hole' mining of coal (Sharma, 2003b). The results of impact assessment of coal mining on land use/land cover using IRS-1A satellite data for Jaintia Hills District, Meghalaya showed that during the last 12 years (1983-95) coal mining area has increased by 1.2% and agricultural land has decreased by 1.5%. Deposition of coal particles, soil erosion and water-logging through seepage water are major causes of agricultural land degradation in the coal mining area (Semwal *et al.*, 2004).

As mining operations alter ecosystem structure and function, there is an urgent need for ecorestoration of mine affected area. Use of Acid mine drainage ameliorant, conservation of topsoil, revegetation of mine spoils, channeling of acidic seepage for checking Acid Mine drainage contamination of water bodies and agriculture fields coupled with scientific management of mining operation are some of the measures which can be helpful in ameliorating the problems of coal mining (Swer and Singh, 2003). Use of alkaline material such as lime in scientific manner may reduce the acidity of water and save agricultural field and water bodies of neighbouring areas to some extent. Lime treated Acid Mine Drainage can also be used for irrigation of agricultural crops (Javanovic *et al.*, 1998).

Caruccio (1968) found while evaluating the factors affecting AMD that soil cover plays an important role in preventing AMD. Study revealed that soil cover is extremely important in developing alkalinity as high carbon-di-oxide levels found in soil air contribute towards increasing neutralization capacity. Thus, conservation of topsoil is very important in the process of ecorestoration and to sustain agricultural productivity in mine affected soil. Removal of topsoil prior to mining and its replacement as the final cover following coal mining is a beneficial method for assuring quick establishment of vegetation and ecorestoration (Dancer, 1982). Establishing vegetation on coal mined land is another important step in overall reclamation process. Vegetation aids in stabilizing the soil surface from erosion and controlling siltation of water bodies. Growth characteristics of some plants help to bind the soil particles thus making the loose mine spoil more stable and less prone to soil erosion (Lyngdoh *et al.*, 1992). On disturbed mine land with exposed acidic spoil/overburden, the plant species which volunteer and become established are species which are capable of surviving under acidic conditions. Bermuda grass (*Cynadon dactylon*) has been recommended as a suitable species for acid mine rehabilitation (Taylor *et al.*, 1989).

Although, technologies have been developed for rehabilitation of mine spoil by developing silvi-pastural system (Sharma *et al.,* 1997), very few studies have been done for restoration of agricultural land severely affected by AMD. In a study, superior strains of *Eragrostis* spp. were selected for adaptation in acid mine soils (Foy *et al.*, 1979). Utilization of lime treated AMD for irrigation of agricultural crops have also been tried and yielded some promising results (Du Plessis, 1983). It has been indicated that level of existing deterioration of soil decides the lime requirement for AMD treatment. However, no study has been done in local conditions of Jaintia Hills considering the prevailing environmental conditions, extent of soil degradation and crop varieties grown in the area.

As basic socio-economy of the area is highly dependent on agriculture, it is extremely important to find out proper management practices to minimize the risk of such environmental damages on agriculture. This requires soil profile modifications and planting suitable crop varieties, as we know that there is wide variation in inherent acid tolerance of various crop species and their varieties. The inter-varietal differences can be exploited for selection of crop variety under a given root zone acidity. Therefore, study of physico-chemical properties of mine affected soils and its detailed monitoring under various remediation options are essential for improving soil quality and restoration of agriculture. In order to restore the agriculture, a proper choice of crop varieties is therefore very important considering the soil conditions. The choice of tolerant varieties is essential for better production and economic returns from acid mine degraded soils of this region.

Thus, considering the seriousness of the problem, present study has been done to assess the effects of coal mining on soil quality and its impact on agriculture in Jaintia Hills district of Meghalaya. We have also evaluated various rice varieties for growing in AMD contaminated soils under different remediation options such as organic enrichment and lime treatment. Based on the study suitable rice varieties have been recommended for cultivation in AMD affected soil of Jaintia Hills district. The results include information on the impact of coal mining on quality of soil and agricultural productivity in Jaintia Hills; underlying causes of land degradation in the area; tolerant rice varieties for cultivation on degraded soils under different remediation options. Measures for restoration of cultivation of rice in soil degraded by coal mining have also been suggested.