MINELAND RECLAMATION AND SOIL ORGANIC CARBON SEQUESTRATION IN OHIO[1]

by

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Abstract. The mining industry has been continuously involved in initiatives to reduce the emission of green house gases in to atmosphere. Control measures have been introduced in all steps starting from the mining of coal to energy production. Reclamation of mined land was and is one of the eco-friendly measures adopted by the industry. Apart from the inherent benefits of reclamation to improve on and offsite environmental quality, its potential to produce biomass and enhance soil organic carbon (SOC) has not been addressed. Reclamative effects of establishing forest and pasture with (graded) and without topsoil (ungraded) application on soil quality and soil carbon sequestration was studied on mine land in Ohio. The SOC pool for 0-30 cm depth for the undisturbed control sites was 56.6 MgC/ha for forest and 66.3 MgC/ha for pasture. In comparison, the SOC pool in the forest and pasture of graded mineland for 0-30 cm depth after 25 years of reclamation was 58.9 MgC/ha and 62.7 MgC/ha respectively. In ungraded mineland, the SOC pool in the 0-30 cm depth after 30 years of reclamation was 51.5 MgC/ha in forest and 58.9 MgC/ha in the pasture.

Additional Key Words: mineland, reclamation, mining, green house gases, soil organic carbon (SOC), sequestration

Introduction

Fossil fuel combustion is a major cause of gaseous emission in the US and Ohio. The net emission of CO_2 in the US resulted in increase from 1037 Tg in 1990 to 1263 Tg in 1996 (EPA, 1998) and from 223 to 248 Tg in Ohio (EPA, 1998). The ultimate goal of green house gas control initiatives is to reduce the concentration of the gases in the atmosphere. Terrestrial soils are the third largest storehouse of carbon after oceans and fossil fuel deposits. Disturbance to soil leads to loss of SOC but the disturbed soils are the ones with the high potential to re-incorporate SOC (Lal, 1998).

Land degradation is caused by several anthropogenic factors including mining. Coal is the source for 24% of the total energy produced in the US and Ohio is the third largest consumer of coal in the US. Surface mining for coal has steadily increased in the US and Ohio to 6534 Tg and 29 Tg respectively (NMA, 1997) and the total land area under active mining is more than 0.7 million hectares. The negative impact of this in relation to the greenhouse effect may be interpreted in many ways. These include C loss due to clearing of vegetative cover and land disturbance and the increased CO_2 emission from coal combustion. The release of C being attributed to mining induced soil disturbance, restoration of soil and ecosystem should lead to C sequestration in soil.

Successful revegetation and subsequent C sequestration potential of surface mine soils requires careful management of not only soil physical and chemical parameters but also revegetative consideration regarding species selection, seedbed preparation, seeding rates and times, and the appropriate use of mulch in order to assure vegetative establishment and restoration of intended land use (Andrews *et al.*, 1998; Barnhisel and Hower, 1997). Success in the reclamation of lignite mine sites, especially when the topsoil has been discarded depends on the rapid formation of a surface horizon that is

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rich in organic matter (Tate et al., 1987). These factors affect the process of C sequestration in mine soils in many ways and the best management practice would incorporate and address most of these variables. In a study conducted by Thomas and Jansen (1985) on eight coal surface mine spoils, the most apparent change in all of the sites was development of an A horizon that was darkened by organic matter. All of the A horizon had developed genetic soil structure. Indorante et al., (1981) compared the organic matter content between undisturbed land and that disturbed by mining, and observed that organic carbon levels were lower for the constructed soils except in the surfaces of the units that had been treated with surface soil.

The most comprehensive and effective strip mining law in Ohio, largely pertaining to reclamation was passed in 1972 (ODNR, 1999). This law requires re-grading of the mine spoil to approximate pre-mining land contour, replacing the topsoil, and establishing a vegetative cover by the mine operator prior to the release of reclamation bond. The federal Surface Mining Control and Reclamation Act (SMCRA) of 1977, which brought this requirement to the federal level, followed the 1972 Ohio law. Pre-1972 reclaimed lands did not have any topsoil applied to the spoils and are considered as "ungraded" (the topsoil was part of the total overburden and treated as part of the spoil) whereas post-1972 reclaimed lands have stored topsoil applied on spoil material and are considered as "graded". Comparison of graded and ungraded mine lands for specific parameter is outlined in Table I.

Table I. Differences between graded and ungraded mineland reclamation strategies

Parameter	Graded	Ungraded
Topsoil	Topsoil stored before mining is applied on the spoils to an average depth of 25-30 cm	No topsoil applied separately on the spoil before 1972 in Ohio
Land use	Mostly forests	Mostly pasture and hayland
Soil structure	Presence of granular to subgranular structure after 10-15 years of reclamation. Coarse fragments at depths >30cm	Even distribution of coarse fragments and signs of soil development after 20 years of reclamation
Compaction	High	Low
Aeration	Very low in the upper layers and therefore anaerobic conditions may prevail in the subsoil below 30 cm depth	As the spoil is evenly distributed, aeration is high and homogenous
Macro-pore	Only in depths >30 cm	Throughout the soil profile
Infiltration rate	Low	High
pH	Mostly neutral to alkaline and sometimes acidic	Mostly acidic
Nutrient availability	Moderate	Low
Biomass productivity	Low in the early years of reclamation but may be high after 15-20 years	Consistently low
SOC	Overall sequestration high	Overall sequestration low

Source: Holl and Cairns (1994), Skousen et al. (1994)

While increasing the cost, an important impact of these laws and acts was successful establishment of the vegetation on the reclaimed mineland. The establishment of vegetation was impacted (during the first 5 to 15 years) by the compaction associated with intensive grading and low soil fertility (Powell, 1988). The potential of Soil Organic Carbon (SOC) sequestration in minelands is dependent on biomass productivity, root development in sub soil and soil aggregation. Increase in soil aggregation is an important factor influencing SOC sequestration in minelands. (Boerner et al., 1998; Haering et al., 1993, Malik and Scullion, 1998).

Quantitative data on the rate and mechanism of C sequestration through reclamation of minelands in Ohio and elsewhere in the US is scanty. Therefore, the objective of this study was to determine the temporal changes in SOC pool in relation to different reclamation treatments.

Afforestation Of Mineland and SOC Sequestration

The natural vegetation of the eastern coalfields of Ohio is predominantly hardwood forest. As early as 1930's most of the reclamation activities in the Appalachian region, including Ohio involved establishing tree cover of mixed hardwood species (Plass and Powell, 1988). Important factors that determine reforestation plans are climate, mineland characteristics, economic and regulatory compliance. The site-specific conditions considered by mine operators include on site moisture conservation, soil amendments, topography, species selection and availability, regulatory compliance and economics. Prior to 1972, the soil related constraints to reclamation were low pH, soil erosion, elemental toxicity (e.g. Al, Mn), and non-availability of N, P and K in the spoil (Barnhisel and Hower, 1997; Hossner, 1997). Since 1972 most of the reclamation involving afforestation were based on monoculture stand. The data in TableII show common tree species grown and the biomass productivity for two reclamative systems. The reclaimed forests are thinned and harvested from time to time for timber, a practice that also affect the biomass productivity. The below ground biomass which contributes to SOC sequestration is another that merits consideration, but the relevant data are not available.

Pasture Establishment and SOC Sequestration

Most of the post-1972 reclamation in Ohio was done by establishing improved pastures. The procedure involved establishing vigorously growing grass species usually in combination with legumes (Ries and Stout, 1988). Traditional or unimproved pastures, which consist of volunteer grasses and legumes, have also been used in many mine lands. The productivity of improved pastures depends on seeding rates, soil properties, fertilizer inputs, runoff and erosion, and grazing pressure (Barnhisel and Hower, 1997). The mining operators often lease the reclaimed mineland to farmers and developers for harvesting the hay. The data in Table II show the biomass productivity and common species used for pasture reclamation in both graded and ungraded systems.

Table II. Biomass productivity and species used in graded and ungraded systems under forest and pasture reclamation strategies

Treatment	Graded	Ungraded
Forest		
Biomass productivity (Mg/ha) (*)	80-100 (25 years)	75-120 (30 years)
Species	Most of the *Pinus* species. *P. flexilis, P. nigra, P. resinosa, P. sylvestris, P. taeda, P. Virginiana* and *Abies saccharum, Fraxinus americana, Juglans nigra. Leriodendron tulipifera*	Mixed hardwood species. *Abies spp.,Artemisia tridentata, Betula spp., Fraximus spp., Junipers spp., Malus spp., Picea spp., Pinus spp., Populus spp., Quercus spp., Robinia spp.,*

Pasture		
Biomass productivity (Mg/ha) (*)	7-8 (25 years)	5-6 (30 years)
Species	*Andropogon gerardi, A. scoparius, Dactylis glomerata, Festuca arundinacea, Panicum virgatum, Phleum pratense, Lotus corniculatus, Medicago sativa,*	*Agrostis alba, Dactylis glomerata, Festuca elatior, Phleum pretense, Poa pretensis, Trifolium pretense, T. repens*

(*) - Years after reclamation

Material and Methods

Site description and Sampling

Measurements of SOC sequestration in reclaimed minelands were done on sites in Morgan, Muskingum and Noble counties of Ohio (Figure I). The reclaimed minelands are owned and operated by Central Ohio Coal Company, a subsidiary of the American Electric Power. The mining process involves clearing the secondary forest established since the first mining in the 1930's. The first mining was relatively less detrimental to soil because the technology used was suitable only for the mining of shallow coal seams. Sites selected for the study were mined completely, and subsequently put under final restorative land use. The natural soils of the region are fine loamy mixed mesic aquultic/ultic/typic Hapludalfs. There is no official classification of unreclaimed and reclaimed minelands though the material is often classified on the basis of pH, texture, stoniness, dominant slope, effectiveness of the reclamation, land use, etc. (Carter *et al.*, 1974).

Soil samples were obtained both for the graded and the ungraded sites in the base year of 1997. Soil sampling was the most difficult for the ungraded areas of both forest and pasture sites due to poor access and difficult location of these sites. A chronosequence consisting of 30, 35, 40, 45 and 50 year old reclaimed sites, corresponding to reclamation since 1967, '62, '57, '52 and '47, respectively, were chosen for ungraded sites. A comparative chronosequence of 0, 5, 10, 15, 20, and 25 year old reclaimed sites corresponding to reclamation since 1997, '92, '87, '82, '77, and '72, respectively, were chosen for the graded sites. The criteria for choosing the sampling sites included similarity of topography and coal mining from similar geologic series thus assuring that there is negligible variation in spoil (overburden).

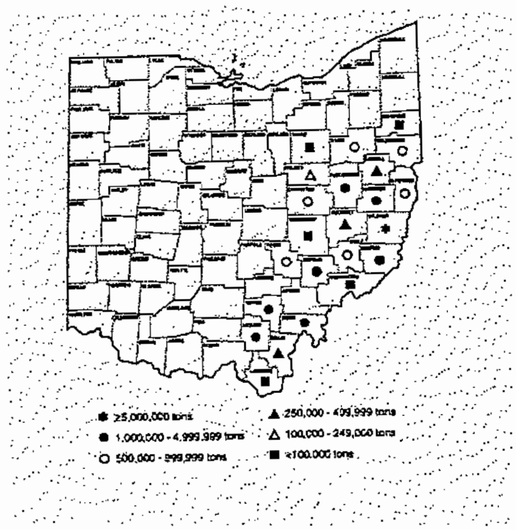

Figure I. Map of Ohio showing the coal producing counties and study site

Soil analysis

Soil samples were obtained for 0-30 cm depth by digging soil profiles using a backhoe. A total of three sub samples were obtained for each depth and composited. The soil bulk density was determined by the core method (Blake and Hartge, 1986), and corrected for gravel content assuming the particle density of 2.65 Mg/m^3. The whole soil samples were ground to pass through 0.5 mm sieve. An average sample amount of 0.4-0.5 g was used to analyze SOC content using the Walkley and Black method (Nelson and Sommers, 1986). Prior to the analysis, the method was calibrated using standard soil samples of known SOC content. Aggregates larger than 2 mm were excluded from analyses as the sample contained only small amounts of soil, but had large proportion of gravel and organic litter/debris. The SOC content for 0-30 cm depth was calculated using the following equation:

$$MgC/ha = \%C \times \text{Corrected } \rho b \; (Mg/m^3) \times 0.30 \text{ m} \times 10^4 \text{ m}^2/ha$$

Results and Discussion

Description of the Reclaimed Sites

Afforestation, with graded and ungraded method, exhibited better soil structure than pasture primarily due to the physical action of the roots and its impact on the development of the mineland profile. However, it was also apparent that graded system in both forest and pasture methods developed better soil profile than the ungraded system (Table III). This may be due to the application and presence of topsoil and its ability to recuperate after reclamation.

Soil Organic Carbon Pool

Total biomass productivity of the forests after 25 to 30 years of reclamation may be more than that of the pastures, yet the potential of pastures to sequester SOC maybe high. The potential of the graded system to sequester SOC was higher than that of the ungraded system. The SOC pool of undisturbed forest and pasture to 30 cm depth was 56.6 MgC/ha and 66.3 MgC/ha, respectively, and is assumed to be in equilibrium.

The SOC pool for 0-30 cm depth in the graded system increased from an initial level of 21.8 MgC/ha to 58.9 MgC/ha for the forest, and from 26.1 MgC/ha to 62.7 MgC/ha for the pasture system. Temporal changes in SOC pool under forest and pasture shown in Figure II indicate that SOC pool in 25 year old graded reclaimed forest exceeded that of the undisturbed forest by 2.25 MgC/ha. The SOC pool of the graded reclaimed pasture has still not attained the steady state level of the undisturbed pasture, and is less by 3.6 MgC/ha even after 25 years of afforestation.

The SOC pool for 0-30cm depth in the ungraded system increased from 51.5 MgC/ha in the 30th year to 54.9 MgC/ha at the 50th year for the forest and from 58.9 MgC/ha to 61.5 MgC/ha for the pasture (Figure III). Both ungraded forest and pasture systems had not attained the SOC pool of the undisturbed forest and pasture. The difference in SOC pool is 1.7 MgC/ha for the undisturbed forest and ungraded reclaimed forest and 4.8 MgC/ha for undisturbed pasture and ungraded reclaimed pasture of 50 years.

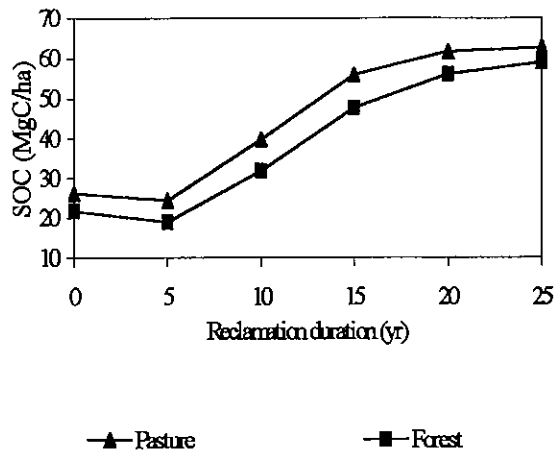

Figure II. Temporal changes in SOC content in the graded system

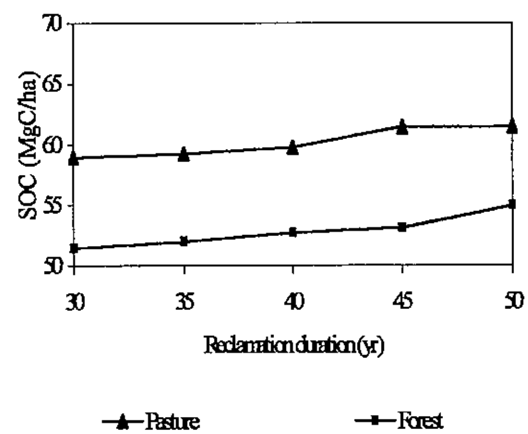

Figure III. Temporal changes in SOC content in the ungraded system

Comparison of the SOC pool for the graded and the ungraded systems shows that the long term potential to sequester SOC is more in the graded than in the ungraded system. This is shown by the fact that SOC pool of the graded system in 25 years exceeds that of the ungraded system in 50 years. This difference in SOC sequestration may be attributed to the application of topsoil and fertilizer use in the graded system and the inherent lack of structure and nutrients in the spoil of the ungraded system. In the initial

Table III. Comparison of graded and ungraded system after 25 and 30 years of reclamation respectively

Ecosystem	Graded	Ungraded
Forest	Dark, many fine, very fine and medium roots with granular structure between 0 to 8 cm, some roots extend up to 20 cm, few coarse to thick roots extend beyond 30 cm, increased porosity, and hydraulic conductivity and less compaction, boundary with the spoil at 30 cm less apparent. Few rocks with more of weathered material with blocky to subangular structure in the spoil material.	A very distinct formation of dark horizon between 0 to 15 cm depth and good accumulation of litter on the surface. The roots extend in all directions, with strong evidence of soil development and weathering. The spoil is more homogenous. Roots penetrate to a depth of 1 m and sometimes grow laterally. A coarse sandy texture with high porosity. Soil pockets found deep in the profile contaminated with coal, shale and other spoil material.
Pasture	0 to 3 cm depth have granular structure and dark horizonation, possibly the formation of distinct A horizon, many roots between 0 to10 cm, medium roots with somewhat dense distribution between 10 to 30 cm depth. The spoil material is slightly weathered and the spoil horizon is distinct below 30 cm. The roots are few beyond 30cm depth and grow laterally along the coarse material.	The root system is prolific in the 0 to 20cm depth with a very distinct dark horizonation in the upper 0 to 5 cm depth. The profile is homogenous in the top 30 cm but has distinct coarse structure below. The roots do not penetrate beyond 60 cm depth and are limited by the coarse fragments.

years of reclamation (5-15 years), the SOC sequestration rate was the highest for the graded pasture reclamation because of its potential to produce higher biomass and its ability to incorporate SOC through deep rooting. Application of the topsoil may pose a problem in the initial years of reclamation due to compaction but with time it has better resilience than the spoil.

Conclusions

The data presented show that topsoil application influences SOC sequestration rate and the potential to sequester carbon in aggrading ecosystems is high. While comparing the potential of the forest and pasture, SOC sequestration potential is more for pasture than the forest in both graded and ungraded system. The SOC pool in pasture was more by 3.8 MgC/ha in the graded system after 25 years and by 6.6 MgC/ha in the ungraded system after 50 years of reclamation. While comparing graded versus the ungraded system, the potential of graded forest system to sequester SOC was more by 4.0 MgC/ha and that of ungraded pasture was more by 1.2 MgC/ha compared with the ungraded system. The graded system attained a higher SOC pool than the ungraded system and in a shorter period of time. While comparing the SOC pools between undisturbed and graded system, the difference was only 1.3 MgC/ha. Additional research is needed to determine why the sequestration rate is higher in the graded than ungraded system.

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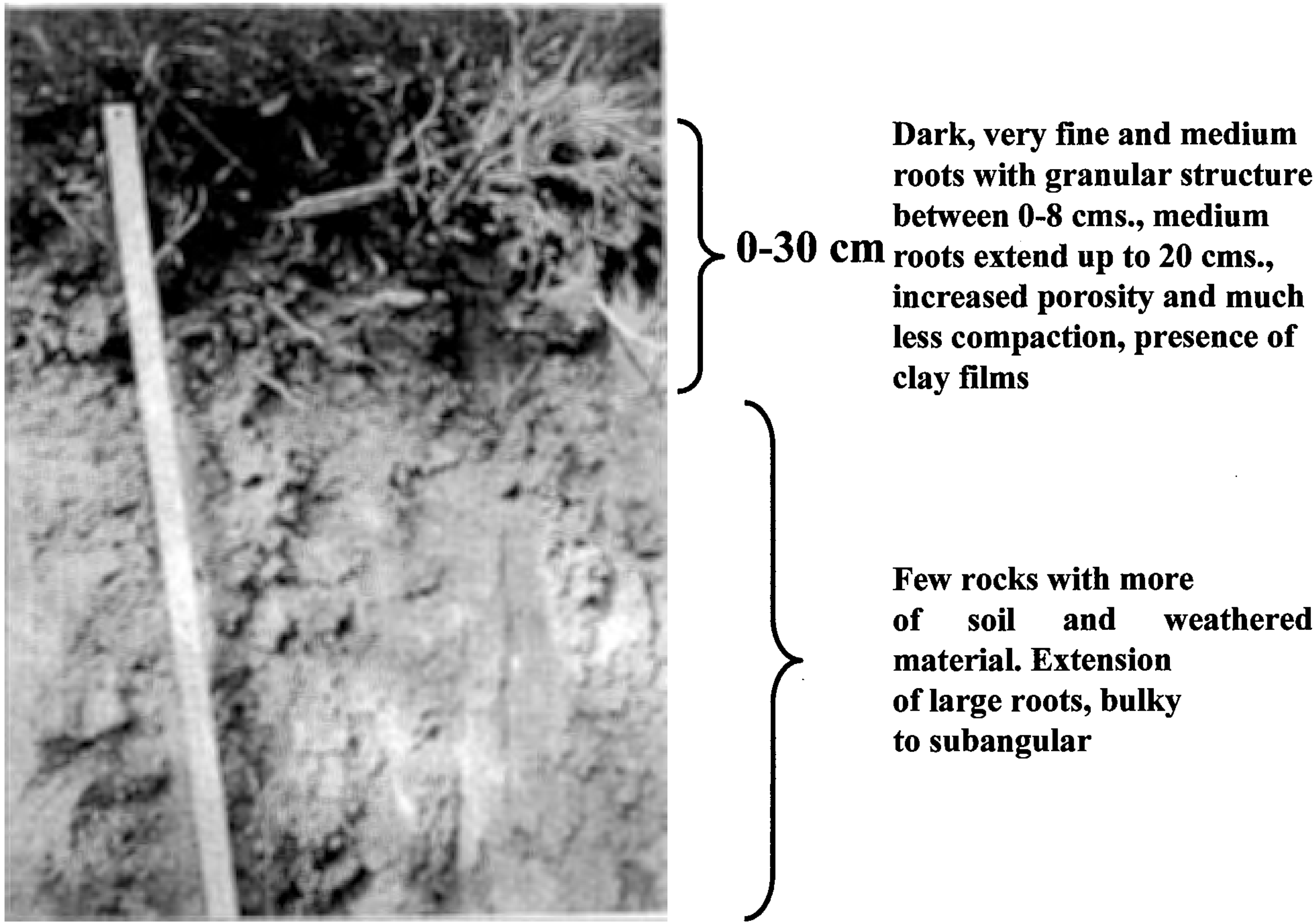

Figure 2. Profile of forest reclaimed site

0-30 cm

Granular structure, dark horizonation (possibly the A horizon), many roots between 0-10cms., slightly porous, decreased compaction

Slightly weathered overburden, no conspicuous presence of organic matter, compacted

Figure 3. Profile of reclaimed pasture site