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THE INFLUENCE OF LOGGING AND ANIMAL GRAZING ON THE LITTER LAYER AND WATER INFILTRATION RATE OF SOILS IN PLANTATION FORESTS

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ABELI, W. S. & SAWE, C. T. 1999. **The influence of logging and animal grazing on the litter layer and water infiltration rate of soils in plantation forests.** Investigations to show the extent of soil disturbance caused by logging and animal grazing were carried out in one of the forest plantations in Tanzania. Water infiltration capacity and ground litter thickness were used as a measure to determine the extent of soil disturbance. Data on infiltration rate and litter depth on stands under different management practices were collected, analysed and compared with data from the nearby undisturbed natural forests. The study found that logging and animal grazing reduced water infiltration rate in the soil and deposition of ground litter. Depending on the management practice or the condition of the stand, the rate of water infiltration was reduced from 36 to 96% when compared to water infiltration rate experienced in the nearby natural forest. While in undisturbed natural forest the mean litter depth was 11.1 cm, on clearfelled and grazed stands, the litter depth was only 0.9 cm. The effects of low water infiltration rates and low litter deposition are discussed and measures aimed at increasing water infiltration rate and litter deposition are suggested.

Key words: Logging - animal grazing - soil disturbance - water infiltration rate - soil erosion -soil compaction and litter depth

ABELI, W. S. & SAWE, C. T. 1999. **Pengaruh pembalakan dan ragutan haiwan terhadap lapisan sarap dan kadar penyerapan air bagi tanah di hutan ladang.** Pemeriksaan dijalankan untuk menunjukkan tahap kerosakan tanah yang disebabkan oleh pembalakan dan ragutan haiwan di salah sebuah ladang hutan di Tanzania. Keupayaan penyerapan air dan ketebalan sarap tanah digunakan sebagai pengukur untuk menentukan tahap kerosakan tanah. Data mengenai kadar penyerapan dan kedalaman sarap di atas dirian dengan amalan pengurusan yang berbeza diambil, dianalisis dan dibandingkan dengan data dari hutan asli tidak rosak yang berhampiran. Kajian mendapati pembalakan dan ragutan haiwan mengurangkan kadar penyerapan air dalam tanah dan penimbunan sarap tanah. Bergantung kepada amalan pengurusan atau keadaan dirian tersebut, kadar penyerapan air dikurangkan daripada 36 kepada 96% dibandingkan dengan penyerapan air yang dialami oleh hutan asli yang berhampiran. Sementara itu, dalam hutan asli tidak diganggu, kedalaman sarap purata ialah 11.1 cm, di dirian yang telah ditebang bersih dan di dirian ragutan, kedalaman sarap hanyalah 0.9 cm. Kesan kadar penyerapan air yang rendah dan penimbunan sarap yang rendah telah dibincangkan manakala cara-cara untuk meningkatkan kadar penyerapan air dan penimbunan sarap juga disyorkan.

Introduction

Soil erosion is the physical removal of soil particles from the earth surface by either water or wind. Although erosion hazards have been reported over more than 700 years ago, to date soil erosion is still a serious threat to man's existence despite several scientific investigations carried out (Hudson 1984).

In the tropics soil erosion is much more pronounced than in temperate regions due to heavy rainfall, high rates of oxidation and decomposition of litter, browsing animals, uncontrolled shifting cultivation and bush fires which tend to reduce soil cover and encourage soil erosion (Hudson 1984).

Many soil erosion and other environmental studies have shown that logging operations modify the ecological balance of a forest ecosystem. For example, logging has been found to cause soil compaction and reduce litter deposition, and this greatly reduces water infiltration rate (Rochadi *et al.* 1981, Ole Meiludie & Njau 1989, Warkotsch 1989, Malmer & Grip 1990, Baharuddin *et al.* 1995). Again, the same studies have found that soil disturbance, which includes soil compaction and removal of soil cover, encourages surface water runoff and restricts both water and nutrient movements in the soil.

Of late there has been a growing concern over the degradation and destruction of tropical forests. One factor which has been cited as the main cause is inappropriate forest management practices (Montalembert 1991). Political, economic and social pressures have led to most of the natural forests to be cleared and give way to agricultural activities. To a large extent, this has caused soil erosion, floods and drying of streams (Kalaghe *et al.* 1988), while in some places this has significantly changed the physical properties of the soils and reduced once dense and virgin tropical forests to open bushlands or grasslands (Malmer & Grip 1990).

As a way of reclaiming denuded lands and supplementing the supply of timber and other wood products, afforestation programmes through establishment of fast-growing softwood plantations forests have been implemented in most tropical countries. In Tanzania there are 19 forest plantation forests covering an area of about 98 300 ha, which besides providing timber and other forest products, serve also as water catchment forests (Kowero 1990, Mgeni & Kajembe 1996).

Although plantation forests play important roles in society in terms of economic, social and environmental ameliorations, in general they are not as stable as the natural forests in terms of biotic regulations and biogeochemistry. This means therefore more studies on plantation forests need to be undertaken in order to know their behaviour under different management practices.

At present most of the plantation forests in Tanzania are at the mature stage and logging is the main activity going on. Although logging in plantation forests normally removes the tree stems only, it exposes the soil surface resulting in loss of top soil nutrients and severe fluctuations in surface temperatures (Borhan *et al.* 1987).

Some studies on the impact of logging on soil disturbances and soil erosion have been conducted in Tanzania (Maganga & Chamshama 1984, Ole Meiludie & Njau 1989). These studies were concentrated mainly on the impact of logging on the soils and to date there is no information available on the impact of animal grazing in plantation forests in combination with logging activities on soil disturbances. This study, conducted in one of the forest plantations in Tanzania, quantifies and analyses the extent of soil disturbance caused by logging and animal grazing on soil water infiltration capacity and litter deposition. Soil erosion potential is also discussed.

Materials and method

The study area

The study was conducted at the Meru Forest Plantations Project near Arusha, northern part of Tanzania. The project is located on the slopes of Mt. Meru at an altitude of between 1650 and 2400 m above sea-level and borders the natural forest on the upper part and densely populated farmlands on the lower side (Lundgren 1978). The terrain slopes are gentle on the lower parts (5-10%) and moderately steep (10–20%) on the upper side of the forest and on the river banks which are normally covered with natural vegetation.

The plantations experience four climatic seasons, i.e. long rains, cool dry season, short rains and hot dry season. Long rains fall in March–May and short rains in November–December. June–October is cool and dry while January and February are hot and dry months. The mean annual rainfall for this area is about 1000 mm and ranges from 650 mm in the northwestern dry part to 1965 mm in the southeastern part (Lundgren 1978). Temperatures decrease with increasing altitude and range from 7 to 29 °C during extreme cool and hot months respectively.

According to Lundgren (1978), the main vegetation types of Mt. Meru are montane rain forests extending up to about 2300 m and above that a bamboo zone up to 2700 m. Dominant trees in the montane rain forest are *Podocarpus gracilior, P. milanjianus, Ficus* spp., *Olea welwitschii, Ekebergia rueppeliana, Entandrophragma stolzii, Lachnophylis platyphylla* and *Croton megalocarpus*. On the drier upper slopes, the dominant species is *Juniperus procera* while in the wetter valleys, *Hagenia abyssinica* often associated with *Nixia congesta* is common.

Soils of Mt. Meru are of volcanic deep ash deposits of very recent origin. According to the FAO/UNESCO classification system, they are andosols while in the soil map of Tanzania, they are mapped as eutrophic brown soils. Texturally, these soils are dominated by fine particles of sand, silt and clay, i.e. 20% course sand, 50% fine sand, 20% silt and 10% clay. Porosity is high and bulk density very low, normally below 0.9 g cm^{-3}. Although the soils are freely drained and have good moisture retention ability, the top soils dry out easily when exposed and become very susceptible to both wind and water erosion during dry and wet seasons respectively (Lundgren 1978).

Meru forest with a total area of about 5100 ha is planted mainly with *Pinus patula, Cupressus lusitanica* and *Eucalyptus* spp. The first two species cover about 70% of the total area while *Eucalyptus* spp. constitute the major portion of the rest (Tarimo 1996). Although the project started in 1924, large scale planting was undertaken in the 1960s and early 1970s. Intensive logging started in the late 1970s and due to increasing log demands, mechanised logging methods have been adopted and more forest roads constructed in order to increase the volume of logs harvested and hauled annually from this forest.

Data collection and analysis

To study the extent of soil disturbances caused by logging and animal grazing, three stands of *C. lusitanica* and two stands of *E. maideni* under different management practices were randomly selected and studied. Stands studied were categorised as follows:

- Stands clearfelled one year ago and yet to be replanted with trees (RC)
- Stands clearfelled at least two years ago and left to regenerate naturally (CL)
- Stands at their second rotation with some agricultural crops (SR)
- Stands still under the first rotation with no ground disturbances (FR)
- Stands recently clearfelled, logged and grazed intensively (CG)

The study was carried out in February/March 1994 when the soils were in fairly wet condition. In each stand, data on the stand age, stand mean slope, stands area and the extent of soil disturbances were collected. Stands studied lay on the middle part of the forest and as such their terrain physical characteristics were almost the same. The stands studied were subjectively picked in order to include all the above five defined stand categories. With the exception of CG stands, data in all stands were collected in about 25–30 sample plots which were randomly distributed within the stands. In CG, sample plots were systematically established every 10 m along the tractor or animal tracks. In each sample plot, both water infiltration rate and litter depth measurements on disturbed and adjacent undisturbed sites were taken. The site was considered undisturbed if the soil or ground cover and litter deposition was intact and disturbed if the ground was bare with no ground cover or litter deposition. Undisturbed sample sites were selected within 2 m from the disturbed sample sites. As a control, data were also collected from the nearby undisturbed natural forests (NF). Compared to other clearfelled stands where most of the logging slash had been removed, in RC, the stand still had a lot of logging slash on the ground.

Water infiltration rate (WIR) was determined by pouring 250 ml of water into a locally made core (4.4 cm diameter, 16 cm height) driven 2. 5 cm below the ground surface. Time taken for this water to infiltrate into the soil was recorded using a stop watch (Rochadi *et al.* 1981, Ole Meiludie & Njau 1989). To determine water infiltration rate, the following equation was used (Ole Meiludie & Njau 1989):

$$\text{WIR(cm min}^{-1}) = \frac{\text{volume of water in the core (cm}^3)}{\text{infiltration time (min)} \times \text{core area (cm}^2)} \quad (1)$$

Percentage decrease in the rate of water infiltration rate was determined as follows:

$$\text{\% decrease in WIR} = \frac{\text{WIR(undisturbed) - WIR(disturbed)} \times 100}{\text{WIR(undisturbed)}} \quad (2)$$

The mean litter depths for disturbed and undisturbed areas were determined by making a vertical cut in the soil (Ole Meiludie & Njau 1989) 5–10 cm from the same spots where water infiltration rate measurements were taken. Differences in water infiltration rates and the percentage decrease in the litter depth between disturbed and undisturbed adjacent sites, and between the natural forests and the undisturbed sites of stands under different management practices were statistically analysed and compared using Student's *t*-test. In addition, regression equations were developed to see if there were any correlation or association between water infiltration rate and the litter depth.

Although terrain slope, soil type and soil texture have been found to influence water infiltration rate (Ole Meiludie & Njau 1989), in this study these factors were not considered when analysing the data as the stands studied had almost the same soil types and experienced the same climatic conditions and topographic features.

Results and discussion

Table 1 shows the mean water infiltration rates, percentage decreases in WIR in stands under different management practices and other stand features.

Table 1. Mean water infiltration rates (WIR, cm min^{-1}), stand age and mean slope of sampled and studied stands

Forest/stand type	NF	RC	CL	SR	FR	CG
Age (y)	>100	1	2	2.5	23	< 1
Slope (%)	11	8	10	8	9	9
Area (ha)	>118	15.8	25.5	37.7	29.1	12.8
Mean WIR (undisturbed)	2.85	4.74*	1.34*	1.83*	0.81*	0.36*
% decrease in WIR	-	+ 66	- 53	- 36	- 71	- 87
Standard error of the mean	0.908	0.821	0.393	0.524	0.27	0.15

*Significantly different from NF at p< 0.01, Student's *t*-test.

Table 1 shows that WIR in the natural forest (NF) is significantly higher (p< 0.01) than WIR in all stands under different management practices with the exception of the stand clearfelled one year before (RC). In RC stand, WIR was higher due to undecomposed litter and logging slash on the ground which easily let through water into the soil. When WIR in NF was compared with WIR in logged and grazed stands (CG), WIR in the NF was found to be seven times faster due to the least soil disturbances in the natural forests. These results agree with the findings of Rochadi *et al.* (1981) who found WIR of disturbed soils to be seven times slower than undisturbed soils of dipterocarp forests in Indonesia. The results are also in conformity with those found in Malaysia (Baharuddin *et al.* 1995), where the rate of surface runoff was low in undisturbed forest areas due to low soil bulk density, high porosity, high organic matter and high infiltration rate.

Table 2 shows that when WIR values of undisturbed sites are compared with those of disturbed sites (within the same stand), the differences were statistically significant (p< 0.01) in all stands. For instance, in NF, WIR in undisturbed sites was 24 times greater than in soils nearby tramped by animals. In RC stands the difference was four times while in CG the difference was twice. WIR was higher in all undisturbed sites in all stands because on bare and disturbed sites, soils easily become compacted resulting in a decrease in macropore spaces and water movements in the soils (Rochardi *et al.* 1981, Ole Meiludie & Njau 1989).

Table 2. WIR (cm min^{-1}) in disturbed and undisturbed soils in stands under different management practices

Forest/ stand type	WIR (cm min^{-1})			
	Undisturbed	Log disturbed	Wheel disturbed	Animal disturbed
NF	2.85	-	-	0.12* [*96%*] (0.881)
RC	4.74	1.48* [*69%*] (0.59)	1.30* [*73%*] (0.62)	-
CL	1.34	0.38* [*72%*] 0.60)	0.49* [*63%*] (0.619)	-
FR	0.81	-	-	0.31* [*62%*] (0.252)
CG	0.36	0.23* [*36%*] (*0.20*)	0.22* [*39%*] 0.22	-

* Significantly different at p < 0.01, paired *t*-test;
[ ] percentage decrease in WIR between undisturbed and disturbed soils;
( ) estimated standard error of the mean.

When results obtained in this study were compared with the findings of Ole Meiludie and Njau (1989) on the same forest, WIR values in this study were higher due to less soil disturbances experienced in these stands. Stands studied by Ole Meiludie and Njau (1989) had high soil compaction caused by tractor wheels and dragged logs. As observed in CG stands, the more the soil was disturbed , the lower was the water infiltration capacity, and the less the disturbances (NF), the higher was the water infiltration capacity.

The amount of litter deposited or the thickness of ground litter varied depending on the extent of soil disturbances caused by logging and animal tramplings on forest stands. As indicated in Table 3, there is a decrease in litter depth as the intensity of soil disturbance increases. For example, in undisturbed natural forests (NF), the litter depth was about 12 times thicker than in disturbed logged and grazed stands (CG) and about twice thicker than in stands still under the first rotation (FR).

Table 3. The mean litter depth and the percentage decrease in litter depth in relation to NF

Stand type	NFR	RC	FR	SR	CG
Mean litter depth (cm)	11.1	6.8	5.6	4.0	0.9
% decrease in relation to NF	-	39	50	64	92

When the relationship between water infiltration rate and litter depth was analysed using correlation analysis it was found that there was a very high correlation ($p < 0.01$) between WIR and litter depth as demonstrated in the following three forest stands:

$$\text{CL: WIR} = 0.40 + 0.24L \quad n = 30,\ \text{s.e.} = 0.002,\ r^2 = 0.61;\ p < 0.01 \quad (3)$$
$$\text{SR: WIR} = 0.66 + 0.04L \quad n = 30,\ \text{s.e.} = 0.005,\ r^2 = 0.73;\ p < 0.01 \quad (4)$$
$$\text{NF: WIR} = 1.62 + 0.26L \quad n = 25,\ \text{s.e.} = 0.001,\ r^2 = 0.81;\ p < 0.01 \quad (5)$$

where

s.e. = standard error of coefficient, r^2 = coefficient of determination
n = number of observations, $p < 0.01$ = significant at 1% probability level

Of the three stands, litter depth in SR seemed not to have much effect on water infiltration rate due to frequent ploughings which had been going on in this stand. The more the ground is ploughed, the more the soil becomes loose and consequently the higher the water infiltration rate.

Usually ground litter (especially when decomposed) modify soil structure by making it more porous. The higher the soil porosity, the higher the rate of water infiltration which tends to reduce surface water runoff. Thus by minimising soil disturbances in the forest through applying proper logging plans and methods and restricting animal grazing, it will encourage vegetation undergrowth and litter deposition. This will lead to high water infiltration rate and consequently reduction in soil erosion potential.

Conclusion

The study shows that activities like logging and animal grazing result in soil disturbances which reduce litter thickness and water infiltration capacity. The study found that there is a positive correlation between the litter depth and water infiltration capacity. The thicker the ground litter, the higher is the water infiltration capacity and the thinner the litter layer, the lower is the water infiltration capacity.

If timber, other forest products, water and environmental protection are to be realised on a sustainable basis, proper design and spacing of skid trails and the use of proper logging methods to minimise soil disturbances have to be emphasised. Also, in order to encourage vegetation undergrowth, litter deposition and water infiltration rate, animal grazing in plantation forests should be restricted.

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