HOW GREAT A RISK DOES ACID RAIN POSE TO COMMERCIAL FOREST SOILS IN THE EASTERN TRANSVAAL?

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INTRODUCTION

Commercial forests in the Eastern Transvaal have been highlighted as one of the resources at potential risk from air pollution generated on the Eastern Transvaal Highveld. A cooperative project between Eskom and Forestek was conducted over the period July 1992 to October 1993 to determine the magnitude of the risk in terms of the contribution of acid deposition to the acidification of commercial forest soils in the Eastern Transvaal.

To establish the magnitude of this risk, a number of different questions were addressed:

1. What is the spatial variation in deposition rates over the region of concern?
2. What is the relative sensitivity of the soils in the region to acid deposition?
3. What role does the Pinus patula canopy play in modifying acid deposition?
4. How important are the leaching effects of acid deposition to long term soil fertility relative to the effects of tree growth and intensive harvesting?
5. What is the importance of the Highveld's contribution to acid deposition impacts on forest soils relative to a) local emission sources, and b) natural impacts of tree growth and harvesting?

This paper will review the methods used to address each of these key questions, and summarize the results to date. The field work and wet deposition monitoring component of the project has been completed, and the chemical analysis of all wet samples collected will be completed shortly. The detailed analysis and modelling phase for this project is currently in progress.

SPATIAL VARIATION IN WET DEPOSITION (QUESTION 1)

Information on the spatial and temporal variation in wet deposition of the major cations and anions in rainfall is needed to assess the potential impacts of wet deposition. Comparisons of the spatial patterns of wet deposition with the distribution of sensitive soils will identify points of overlap between high annual deposition, and highly sensitive soils. Similarly, the temporal variation in wet deposition will affect the risk to a commercial plantation. For example, highly acid rainfall events may have potentially greater impacts in early summer, when the trees are producing young, rapidly expanding foliage.

Eskom's existing rainfall monitoring network, described in[1], was supplemented by three additional wet deposition monitoring sites, which were established in June 1992. The three additional sites were located at Palmer, near Dullstroom; at Long Tom State Forest, on Long Tom Pass, and at Cairn, between Ngodwana and Nelspruit. These sites were established to complement Eskom's existing monitoring network by providing more detailed information on rainfall chemistry within the Escarpment and Lowveld regions. Rainfall samples were collected over the period June 1992 until April 1993, and subjected to full chemical analysis at the Eskom laboratories. This data is currently being analysed by Eskom, to enable maps to be produced defining the spatial variation of SO_4^{2}, H^+, and NO_3^- deposition.

SOIL SENSITIVITY (QUESTION 2)

The focus of this study is on the potential effects of acid deposition on the soil. This can affect the productivity of commercial forests by increased leaching of base cations from the soil, thus decreasing long term soil fertility; and by decreasing the soil solution pH, which results in increased solubility of toxic heavy metals, which can inhibit root growth, nutrient uptake, and rhizosphere organisms.

The risk of damage to soils may be increased by the practice of forestry itself, as trees naturally acidify the soil through uptake of base cations. The planting of rapid-growing tree species, exporting of base cations from a site through tree harvesting, and the short rotations practised in commerical forestry may all contribute to enhancing the natural rate of acidification by trees. For these reasons, it was decided to first concentrate on the risks posed by acidic deposition to commercial forests, rather than the other potentially injurious pollutants, sulphur dioxide (SO_2) and ozone (O_3). Also, the level of rainfall acidity in Sabie[2], (five year mean=pH4.2) is comparable to areas in the United States[3], where the chronic deposition of acidic or acidifying compounds has significantly altered soil chemical properties in certain areas.

The focus of this key question is to determine the amount of tolerance the major forestry soil types have to acidification, summarized in terms of a map defining the relative sensitivity of the forestry soils to acid deposition. Forest soil sensitivity is best described in terms of acid neutralizing capacity (ANC), which defines the amount of H^+ deposition the soils can absorb before their pH drops below a critical value. Another factor which will determine the sensitivity of a soil to acid deposition is its capacity to fix sulphate. If sulphate is fixed by the soil, it is no longer available to leach base cations out of the soil, so the rate of acidification is slowed.

Determination of acid neutralizing capacities of forest soils.

The acid neutralizing capacity (ANC) of soils has to be measured with reference to a particular degree of acidification, and this is usually represented by a pre-selected soil pH value[4]. For the purposes of this study, a critical pH of 3.8 (measured in a strong salt solution) was chosen. This value has been dubbed the 'ulceration threshold' to signify an acidified state where the liberation of aluminium cations into the soil solution can be expected to reach levels that are toxic to the majority of comnmercial crops. ANC is influenced by a number of factors, such as soil depth, soil pH, clay percentage, clay type, organic matter content, base saturation, and parent material (geology)[5].

Our initial approach was to attempt to model the soil ANC, as a function of a soil's chemical characteristics. As the chemical characteristics of a large number of forest soils have been defined, it would then be possible to extrapolate to soil ANC over a large area. However, a satisfactory model could not be obtained.

The final approach was therefore to survey the range of soils found in the region, by measuring the ANC of selected soil samples. A total of 64 model profile soil samples of the Barberton land type map[6] were selected. This dataset included a wide variety of soils, from margallitic soils to highly weathered dystrophic soils, with a corresponding wide range in ANC values. Soil analysis data of this dataset was made available by the Institute for Soil, Climate and Water (ISCW), Pretoria, and the ANC of soils in this dataset was determined by ISCW, using the method developed by Du Toit and Fey[7]. To complement this dataset, a number of additional soil samples were selected from forestry areas in the Eastern Transvaal, to cover the range in soil types corresponding to specific land systems defined by Louw[8]. Once the soil analyses are completed, the measured ANC values will be grouped into classes, and mapped.

Soil sulphate fixing capability.

Many studies have shown that sulphate retention in soils is inhibited by the presence of organic acids[9,10,11]. Since the focus of this study is to determine the ANC of topsoils of afforested areas that are typically rich in organic matter, it is unlikely that sulphate retention would make a significant contribution to soil ANC. However, in order to determine the possible range in sulphate fixing capactiy of forest soils, a small subsample of forest topsoils will be subjected to serial titration using sulphuric acid. The buffer curves of the subsample obtained by titration with H_2SO_4 will be compared to buffer curves obtained from the same set of samples that have been obtained by titration with HCI. In this way, anindication of the potential sulphate fixing capability of the forest soils will be given. This information will be used to modify the soil sensitivity classes defined on the basis of soil ANC alone.

Results

Table 1 illustrates the range in ANC classes for different Forestry Land Systems encompassed in the Barberton 1:250 000 land type map.

Table 1. Mean, minimum and maximum soil ANC values measured on soils characteristic of different forestry land systems. Bolded values indicate areas which are planted to commercial forest.

Forestry Land System	obs	Soil ANC ($cmol_c/l$)# Mean	Max	Min	Suitability for forestry
Lebombo	1	10.6	10.6	10.6	Unsuitable
Komatipoort	10	20*	7.2	34*	Unsuitable
Lowveld	7	9.3	3.8	18*	Unsuitable
Nelspruit	3	6.9	4.6	10.0	Unsuitable
White River	**5**	**5.6**	**4.9**	**6.4**	**Marginal-suitable**
Escarpment foothills	**9**	**4.9**	**4.1**	**6.6**	**Optimal**
Malmane	**4**	**5.5**	**3.5**	**7.2**	**Suitable-optimal**
Timeball Hill	**2**	**4.2**	**4.2**	**4.2**	**Marginal-optimal**
Transvaal Drakensberg	**2**	**4.3**	**3.0**	**5.6**	**Marginal-suitable**
Ngodwana	4	8.1	6.3	10.1	Unsuitable-marginal
Lydenburg	4	11.3	6.9	20*	Unsuitable-marginal
Machadodorp	3	11.5	3.6	20*	Unsuitable-marginal
Belfast	**3**	**4.8**	**4.0**	**5.3**	**Unsuitable-suitable**
Witbank	2	6.0	5.8	6.2	Unsuitable
Grobersdal	1	5.4	5.4	5.4	Unsuitable
Badplass	1	9.9	9.9	9.9	Unsuitable-marginal

\# 1 ha of soil, 20 cm deep, and with an ANC of 1 $cmol_c/1$, has the acid neutralizing properties equivalent to 1 ton of $CaCO_3$.

* Soil ANC values above 15 $cmol_c/1$ were rounded off to the nearest 1 $cmol_c/1$ as the accuracy of the technique in this ANC range has not been verified.

Table 1 illustrates that there is a large variation in ANC between different land systems. However, all the Land Systems suitable for commerical forestry have soils with low acid neutralizing capacities. This implies that forest soils in general will have lower buffering capacities than other soils, although variations in sensitivity will exist between different types of forest soils.

CANOPY-DEPOSITION INTERACTIONS (QUESTION 3)

To assess the potential effects of acid deposition on soils under commercial forest plantations, we need to understand the role the tree canopy plays in modifying the rainfall chemistry before it reaches the soil surface. For example, the tree canopy can act as a sink for certain ions, so that the concentration in throughfall is reduced relative to the incoming rainfall. Similarly, the canopy can act as a source of certain ions, so that throughfall concentrations are enhanced. In addition, the tree canopy acts as a filter for dry depositions, so that analysis of the throughfall will allow some estimate of dry deposition to be obtained[12]. A comparison of solute fluxes through canopies in relation to fluxes on open plots will, therefore, provide the canopy source or sink capability for each ion, an estimate of total deposition, and a characterization of the final chemistry of wet deposition before it reaches the soil[13].

Three sites were selected in the Escarpment region, to cover a range in altitude and potential site fertility. At each site the trees had reached canopy closure. Collectors were placed under the tree canopy, to sample throughfall, and in the open, to sample the rainfall. To accurately determine wet deposition, an Aerochem-metrics wet-dry sampler was located close to the experimental sites. Sampling of throughfall (under-canopy) and rainfall at the three sites was terminated at the end of April 1993. The throughfall samples, and the open plot samples were bulked to give a single under-canopy, and single open-plot sample at each site per rainfall event. The pH of each under-canopy and open sample was determined in the laboratory within 24 hours of the event, with a separate sample frozen for chemical analysis. Chemical analyses were carried out by the Eskom laboratories.

Results

Figure 1 contrasts mean concentrations of cations and anions in throughfall samples (under-canopy) and open samples at two of the sites.

The site at Longtom is at an altitude of 1700m, with 10 year-old trees, and low site fertility. The site at Frankfort is at an altitude of 900m, with four-year-old trees, and high site fertility. The higher site fertility at Frankfort may explain the higher mean concentrations of certain of the ions measured. Generally, concentrations of ions in throughfall were enhanced relative to open samples, indicating that the canopy acts as a source, rather than a sink, of ions. Data analysis is in progress to assess the relative contributions of dry deposition and canopy leaching, and to determine the likely factors explained the observed trends.

ASSESSING THE RELATIVE IMPORTANCE OF DIFFERENT COMPONENTS TO THE PREDICTED RISK TO FOREST SOILS (QUESTIONS 4 AND 5)

The central objective of this study is to establish whether acid deposition poses a risk to commercial forest soils. If there is a risk, we need to establish the relative importance of this risk

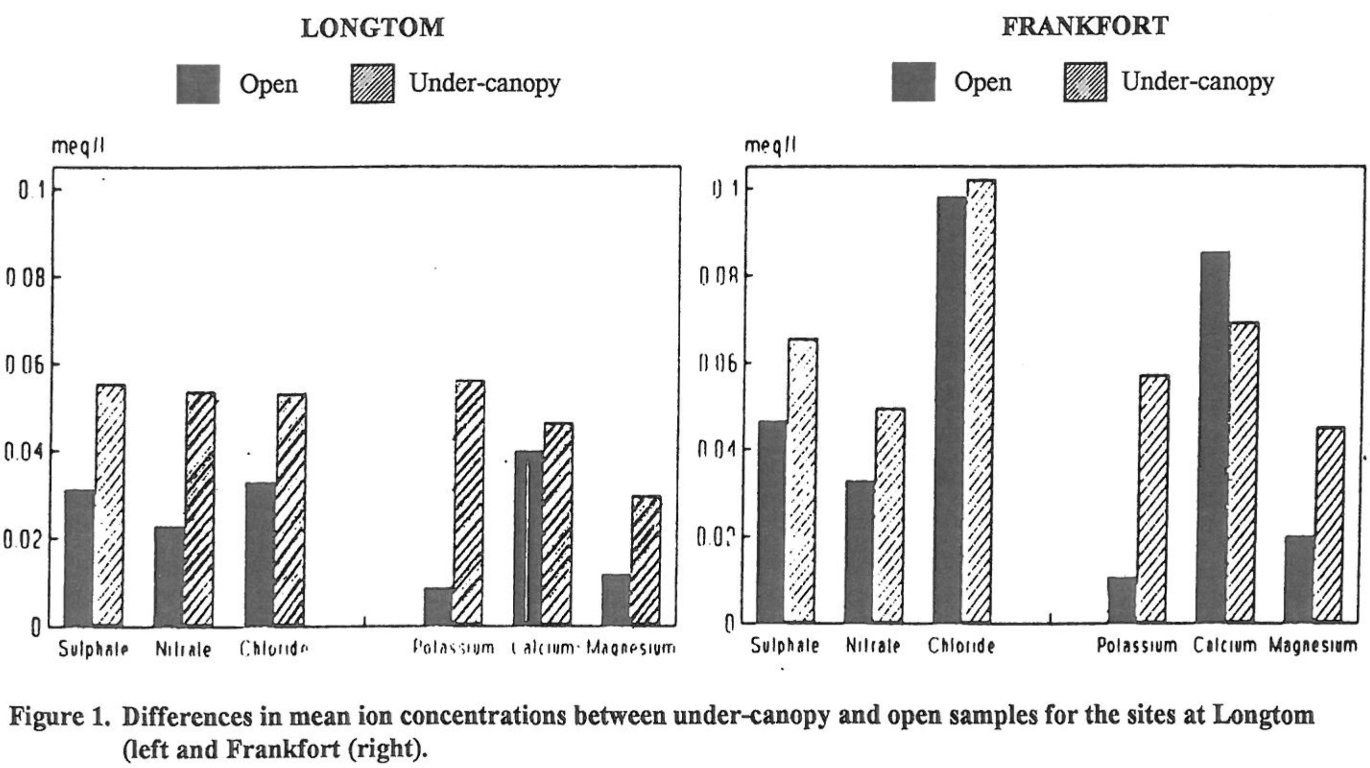

Figure 1. Differences in mean ion concentrations between under-canopy and open samples for the sites at Longtom (left and Frankfort (right).

to other factors that can affect commercial forest soils, and to establish how the risk can change by exercising different management options. An understanding of the relative importance of different factors will be gained by manipulating certain factors, and assessing their impact of the time estimated for different soils to reach the ulceration threshold. The first component that needs to be quantified is the effect of forestry practices themselves on the long term sustainability of commercial forest soils. Du Toit[7] has quantified the acidifying potential of the major commercial forest species on forest soils. Using this information, analyses will be carried out comparing soil acidification under different acid deposition scenarios (i.e. none, current, double current) and different silvicultural regimes (i.e. varying species, and rotation length).

Acidity originating from within the escarpment and Lowveld regions will be primarily the result of biomass burning, viz. controlled burns, wildfires, burning of waste, and burning of wood for fuel, with some contributions from local industries. Acidity transported from the Highveld regions will include emissions from coal-burning power stations, and various other industries. Analysis of the Eskom wet deposition monitoring network data will allow an estimate to be made of the relative contribution of biomass burning versus industrial emissions to the acidity measured in rainfall. This information can then be incorporated into the risk analysis, to determine the relative importance of each to the predicted impact on forest soils.

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