ARE MPUMALANGA'S COMMERCIAL FORESTS AT RISK FROM ATMOSPHERIC DEPOSITION?

A RESEARCH SYNTHESIS: 1988 - 1995

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INTRODUCTION

Are the commercial forest plantations on the Eastern Transvaal escarpment att risk of negative impacts from air pollution generated in the Eastern Transvaal Highveld? This question was first asked at a workshop in 1987, which was held to examine the air pollution situation on the Eastern Transvaal Highveld, and its potential environmental implications[1]. The workshop concluded that the climatic conditions of the Highveld were exceedingly adverse for the dispersion of atmospheric pollutants, with the result that relatively high levels of pollutants could occur under certain circumstances. This suggested a high risk of negative impacts in the Highveld and adjacent regions. Commercial forestry was identified as being one of the resources at high risk, as result of their location along the eastern Transvaal escarpment, and the sensitivity of forests to atmospheric pollution impacts.

In response to this, a series of research projects were undertaken by the CSIR (Forestek) over the period 1990 to 1995 to investigate the potential impacts of atmospheric pollution on commercial forests in the Eastern Transvaal (now known as the Mpumalanga escarpment). The results of this research are reviewed in detail in Olbrich 1995[2]. This paper highlights the results of the work that specifically focused on analysing the risks to forests, and presents an overview of current development in impacts research in Mpumalanga, with recommendations for future research.

ASSESSING THE POTENTIAL RISKS TO THE FOREST INDUSTRY

The risk of soil acidification

Forestek carried out a project over 1992 and 1993, funded by, and in cooperation with Eskom, titled 'Assessing the risks posed by air pollution to forestry in the eastern Transvaal, South Africa'[3]. The final component of the report was a risk analysis, based on deposition data collected by Eskom over the duration of the project, a soil sensitivity classification defined on the basis of soil acid neutralising capacity, experimental data on the contribution of cations and anions by filtering of a pine forest canopy, and forest acidification data gathered from an analysis of the work carried out by Du Toit[4] and that of Morris[5]. This risk analysis was updated in 1995, using recent data, and incorporating some of the comments on the earlier study[2]. The objectives of the risk analysis were to highlight the factors of importance to the long term sustainability of the forests, and to gain some understanding to of the potential risk posed by acid deposition to our commercial forest soils.

The approach used to conduct the risk analysis was to produce maps using a geographic information system (GIS), and use GIS modelling to assess the changes in risk with different scenarios. The risk analysis focused on the region encompassed in the 1:250 000 Barberton topographic map, which includes the majority of forestry areas within eastern and south-eastern Mpumalanga.

Risk was expressed in terms of the time taken for a particular soil to exhaust its acid neutralising capacity (ANC) to the point where a critical threshold value was reached. This critical threshold was set at pH 3.8 (measured in a strong salt solution), and is defined as the point beyond which negative impacts on the growth of trees may start to occur.

Risks was calculated as follows:

$$T_t = \frac{ANC_s}{TD} \qquad (1)$$

where: T_t *time to critical threshold (years)*
ANC_s *Acid neutralising capacity of the soil (keq ha)*
TD *Total deposition load per year*

Total deposition load was calculated as:

$$TD = (SD + FA) - (BC + W) \qquad (2)$$

where: SD - *total annual S deposition* ($keq.ha^{-1}$)
FA *Forest acidification per annum* ($keq.ha^{-1}$)
BC *Base cation deposition per annum* ($keq.ha^{-1}$)
W *Annual weathering* ($keq.ha^{-1}.annum^{-1}$)

The ($SD + FA$) term refers to the net **outputs** of acid neutralising capacity from the system, where it is assumed that atmospheric deposition of sulphate (SD) leaches an equivalent amount of base cations from the soil profile. Similarly, forest acidification (FA) refers to the bases that are lost from the system as a result of the harvesting of trees. The ($BC + W$) term refers to the net **inputs** of acid neutralising capacity into the system. Here the only inputs considered are the atmospheric deposition of base cations (BC), and the annual input of base cations to the soil profile as a result of weathering of parent material (W). Outputs of base cations from the system as a result of soil erosion are not considered in this analysis. A detailed description of the methods used to obtain these values is given in [3] and [2].

Each of the parameters described above was manipulated in different ways, to determine the net result on the T_t. Table 1 summarizes the different levels of each variable used in the risk analysis.

Risk was classified into 5 possible classes:

Time to threshold	Risk class	Description
0 ≥ Tt ≥ 25	1	Very high risk
26 ≥ Tt ≥ 50	2	High risk
51 ≥ Tt ≥ 100	3	Moderate risk
101 > Tt	4	Low risk
Tt < 0	5	No risk

It is possible for Equation [2] to give rise to negative values, if the addition of base cations to the system (BC + W) exceeds the inputs of acidity (SD + FA). In these cases, the land system in question was classified at being at no risk. It must be stressed that, although the final risk maps generated were classified in terms of T_t, this only represents an **index** of relative risk. Considering the assumptions and generalisations made to arrive at the final risk analysis, the 'years to threshold' can at best only give a very rough approximation of the actual time frame in which negative impacts on soils may occur.

Table 1 A summary of the model variables used to determine the time to threshold of a particular land system, and the different values used for each variable in the risk analysis.

Model variable	Code	Levels examined
Acid neutralising capacity of the soil	*ANC_s*	1. For entire soil solum
Total Sulphate deposition	*SD*	1. Actual deposition (SD) 2. Half actual deposition (SD/2) 3. Double actual deposition (2SD)
Forest acidification rate	*FA*	1. Pine + 0.67 keq.ha^{-1}.annum^{-1} 2. Eucalypt = 1.24 keq.ha^{-1} .annum-1
Base cation deposition	*BC*	1. No forest effect 2. Forest effect.
Weathering rate rate of soil	*W*	1. 0.16 keq.ha^{-1}.annum^{-1} 2. 0.39 keq.ha^{-1}.annum^{-1} 3. 0.86 keq.ha^{-1}.annum^{-1}

Table 2 summarises the results of the risk analysis. The a major implications of these results are:

- Under the current estimated deposition load, there is a proportion of forestry soils at risk of acidification within a relatively short time-frame (50 years). This varies from a minimum of 0.5% of total area under forest within the region of interest, to a maximum of 25% depending on the species in question, and the actual weathering rate of the parent material. Spatially, the areas at greatest risk are located to the south west of Nelspruit, which have a combination of sensitive soils, and high deposition loads. The forestry areas around Sabie tend to be at lower risk, due to the lower sulphate deposition loads.
- Areas under E. grandis are at higher risk than those under P. patula. This is due to the higher rate of acidification that takes under a eucalyptus tree crop.
- The enhanced capture of base cations by the forest canopy plays an important role in buffering the potential acidification of the soil.
- The weathering rate of the parent material plays a critical role in determining the likelihood of acidification.

Table 2 The influence of the different scenarios on the percentage area of forest soils within the study areas allocated to the five risk classes defined for assessing the sensitivity of forestry soils to acid deposition. The terms SD, FA, BC, and W are defined in Table 1.

SD	FA	BC	W	Percentage area of forest soil per risk class				
				Very high risk	High	Moderate	Low risk	No risk
SD	PINE	FOREST	0.16	2	11.4	10.7	64.6	11.3
			0.39	0.8	2.3	11.4	41.6	43.9
			0.86	0	0.5	2.3	21.1	76.1
SD	EUC	FOREST	0.16	5.3	18.8	10.8	65.1	0
			0.39	4.4	16.3	5.9	73.4	0
			0.86	1.2	9.4	4	50.3	35.1
SD	PINE	NO FOREST	0.16	5.1	16.2	14	64.7	0
			0.39	2	12.5	10.6	74.8	0
			0.86	0.8	2.3	10.5	42.5	43.9
SD/2	PINE	FOREST	0.16	0	2	4.7	58.2	35.1
			0.86	0	0	0	0	100
2SD	PINE	FOREST	0.16	14.3	9.9	7	68.8	0
			0.86	3	10.4	9.4	33.3	43.9

The risk of soil fertility declines

In a paper examining the major factors influencing the sustainability of the commercial forest industry, Olbrich *et al.*[6] conducted a simple nutrient input-output analysis, using a typical granitic soil on the Eastern Transvaal escarpment. This analysis is repeated here, but is extended to include other estimates of base cation deposition, and the potential leaching effects of acidic deposition. The modified analysis is presented in Table 3.

The original analysis (option **A**) indicates that, under the assumed levels of weathering, deposition, erosion, leaching, and harvest export, the system's supply of Mg^{2+} will only last 45 years, K^+, 103 years , and Ca^{2+}, 256 years. Clearly, this analysis suggests that nutritional problems will be expected within the short to medium term, possibly as soon as the following rotation.

The results of the **B** analysis give a different picture, in that the system's supply of Mg^{2+} and Ca^{2+} are calculated to last longer, for 119 and 626 years respectively. However, the supply of K^+ is predicted to last only 52 years. Again, nutritional problems appear possible within the short to medium term, although in this case the limiting nutrient will be K^+ rather than Mg^{2+}.

Table 3 An approximate, but representative, nutrient input-output analysis for a granitic soil afforested with Pinus patula in the Eastern Transvaal, giving the time by which the system available stock of potassium (K^+), calcium (Ca^{2+}), and magnesium (Mg^{2+}) will be depleted. The analysis is presented without (**A**) and with (**B**) the effects of acidic deposition. See the text for a detailed explanation. Units are kg.ha^{-1}.yr^{-1}.

Item	K+	Ca2=	Mg2+
Primary weathering[1]	1.9	1.8	0.3
Atmospheric deposition[2a] - **A**	4.08	7.13	0.19
Atmospheric deposition[2b] - **B**	3.27	14.3	1.68
Soil erosion[3]	-0.2	-0.8	-0.04
Leaching[4a] - **A**	-2.3	-5.3	-3.18
Leaching[4b] - **B**	-5.7	-9.3	-1.1
Harvest: softwood[5]	-7.5	-7.4	-3.0
Balance (kg.ha^{-1}.yr^{-1}) - **A**	-4.22	-5.37	-5.77
Balance (kg.ha^{-1}.yr^{-1}) - **B**	-8.43	-2.2	-2.2
System available stock[6] (kg.ha^{-1})	436	1377	261
Time (years) - A	103	256	45
Time (years) - B	52	626	119

Notes for Table 3

1. Data from granitic landscape, Zimbabwe[7].

2a. Bulk deposition values for Sabie Forest Research Centre[8].

2b. Represents the mean total deposition recorded at three *P. patula* sites on the Eastern Transvaal escarpment using throughfall as an indicator of dry deposition[3].

3. Assuming a loss of 10 mm of soil per 20 year rotation. Almost all of this soil is lost during clear-felling. Topsoil data from Sabie FRC[9].

4a. Catchment data from Witklip, near Nelspruit, 1982 - 1987, 48% afforested.

4b. Represents the average total deposition of sulphate recorded at three *P. patula* sites on the Eastern Transvaal escarpment using throughfall as an indicator of dry deposition[3]. This value, 33.6 kg.ha^{-1}.yr^{-1}, was partitioned according to the respective availability of the three cations, viz: K: Ca: Mg = 1.7: 5.3: 1, assuming that each equivalent of sulphate leaches an equivalent of cation, and all sulphate is leached through the soil profile.

5. The data presented here represents the average of three *P. patula* compartments measured at clearfelling age[10]. Comparable data for Eucalyptus grandis can be calculated using data from Herbert[11]: 8.3 N, 0.3 P, 12.1 K, 14.0 Ca and 2.8 Mg.

6. 'Available' is defined here as available to plants over a time of less than a century, which is assumed to be all of the extractable cations. The value given here were calculated suing the soil analytical data for a typical granite soil presented in the thesis by Schutz[12].

If the figures in Table 3 are observed, it can be seen that the main difference between the **A** and the **B** analysis is the estimated atmospheric deposition of base cations, particularly for Ca^{2+} and Mg^{2+}. The values given by Van Wyk[8] (analysis **A**) were based on bulk deposition samplers, which under-estimate total deposition[13]. The values taken from[3] were based on measurements of throughfall, and so attempt to include the capture of dry deposition by the forest canopy. These are more likely to be an over-estimate of atmospheric deposition, due to the leaching of ions from the canopy itself. In terms of the leaching figures given in analysis **B**, a worst case scenario is assumed, in that it is taken that all the sulphate will leach a corresponding amount of base cations. This therefore excludes the possibility of biological fixation of sulphate, or the absorption of sulphate by the soil. The sulphate absorption capacity of the soil is a large unknown, and could potentially be high[14]. A high sulphate retention ability in the soils would result in the sulphate being fixed by the soil, and hence not available to leach out base cations. However, the effect of this would just be to delay the negative impacts until the soil's sulphate fixing was exhausted.

This analysis differs from that of the previous section, in that, in this case, risk is viewed in terms of the duration of available nutrients in the system. In the previous section, the analysis looks at the time required to exhaust the acid neutralising capacity of the soil. However, the results are similar in the sense that firstly, there is an indication that some negative effects may occur within a relatively short time frame. Also, the significance of accurate estimates of cation inputs to the system (viz. weathering, atmospheric deposition) is emphasized, in terms of predicting the likelihood that the ecosystem in question will suffer negative impacts.

Risk of ozone-induced productivity declines

Colleen Carlson conducted a detailed analysis in 1994 to assess the risk posed by the gaseous pollutant ozone to commercial forests in the Eastern Transvaal[15]. She analysed ozone data provided by Eskom form two of their monitoring sites: Palmer (altitude = 2000 m), which is located close to Dullstroom, and Rivulets (altitude = 800 m), which is close to Nelspruit. The potential risk of ozone toxicity to commercial forests was assessed with reference to three indices:

- the 7 hour mean threshold level of 25 ppb (0900 - 1600), as defined by the UNECE[16].
- the one hour mean threshold of 75 ppb[16]
- the critical level for ozone, as defined for the United Kingdom. This critical is defined as 10 000 ppb.h above a threshold of 40 ppb[17]. This is calculated as the concen-

tration difference between the threshold (40ppb) and the measured concentration, summed for each hourly measurement during the day in which the ambient concentration was greater than the critical level.

The major results of the analysis of the O_3 monitoring data were as follows:

- Seasonal variation in ozone concentrations was evident, with a distinct peak in spring.
- The 7-hour mean threshold of 25 ppb was exceeded on between 163 and 250 days per year, over the period 1990 to 1993 at the Palmer site. The figures for Rivulets were 92 days over the period July - December 1992, and 24 days over the period January to June 1993.
- An hourly mean of 80 ppb was exceeded on between 2 and 8 days per year att the Palmer site over the period 1990 to 1993, for an average of 2 hours. At the Rivulets site, this threshold was only exceeded on 1 day, for 1 hour only.
- The critical level of 10 000 ppb.h above the threshold of 40 ppb was frequently exceeded at the Palmer site, with a total average annual cumulative dose of 26 772 ppb.h. The critical level was not exceeded at the Rivulets site.

Based on her analysis of the monitoring data, Carlson makes the following recommendations:

- Peak concentrations of O_3 tend to occur in spring, which coincides with bud burst of plants growing in the area. The potential implications of this need to be investigated further.
- Experiments need to be conducted under local conditions before an accurate assessment of the impact of O_3 on plant productivity can be made.
- The regular exceedance of the 10 000 ppb.h critical level indicates that here is definite need for further studies to determine the exact impact that current levels of O_3 are having on the growth of the commercial forest species growing in the area.

In terms of potential risk to commercial forest productivity, this analysis indicates that some impact of ozone on tree growth or functioning may be expected. This is particularly for those plantations established at higher altitudes on the edge of the escarpment. Whether this will have a significant impact on final yields remains an open question. The reasons for the high O_3 concentrations must also be considered. It is possible that these arise from a combination of natural factors (high radiation levels, natural emissions from vegetation), biomass burning, as well as local and regional pollution. The fact that ozone is a secondary air pollutant makes it extremely difficult to conclusively identify the principal cause.

CURRENT DEVELOPMENT IN IMPACTS RESEARCH

The ADRAS initiative

The Atmospheric Deposition Risk Advisory System (ADRAS) was conceptualised by the CSIR as an initiative which aims to provide a backbone of which national air pollution research efforts can be based. The integrating tool of ADRAS is the critical approach. This has been developed in Europe, largely through the United Nations Economic Commission for Europe (UN-ECE), which is using critical loads to refine sulphur and nitrogen emission protocols in Europe[18]. The critical load/level is defined as the maximum quantity (or level) of a given pollutant that a receptor can tolerate without suffering any adverse effects.

The critical load approach involves three steps. The first is to map the actual levels of deposition of a given pollutant. The second step is to plot the critical load to the receptor of interest (vegetation, water, soils) for that pollutant. The third step is to contrast the two maps, and identify the area where actual loads exceed critical loads — the so called 'exceedance' maps. The construction and comparison of the maps is done using a geographic information system (GIS). This process is described in more detail in Olbrich *et al.*[19]

The development of ADRAS has revolved around a pilot study of the Mpumalanga province. Actual wet deposition loads of sulphate were mapped for the province, based on sixteen monitoring sites from Eskom's rainfall monitoring network. A map defining soil sensitivity to acid deposition was created based on geology, soil type, and land use. In addition, a provision critical load map was constructed for the surface waters, based on sampling and chemical analysis of streams in the province. By contrasting the actual loads of sulphate with the critical load and sensitivity maps, areas of potential high risk of negative impacts were identified[20].

Further development of ADRAS is focusing on improving actual load estimates by incorporating dry deposition, and the results of the Kiepersol network. Also to improve our understanding of ecosystem sensitivity to acid deposition, particularly in afforested areas.

Soil chemical assessment of industrial impacts on the South African environment

Eskom is currently funding research directed by Professor Martin Fey (Geological Sciences dept, University of Cape Town) to examine the impacts of various industrial activities on the chemistry of soils in the highveld and lowveld regions. At present, the work is focused on two major activities. The first, started in 1994, is an assessment of the effects of exotic tree plantations on the chemistry of upland soils and associated surface waters, which is being carried out by Tom Nowicki. The second, started in 1995, is an assessment of the impacts of acidifying air pollutants on Eastern Highveld soils and pan environments, which is being carried out by Heather Dodds, and Mieke van Tienhoven. Martin Fey is currently organising a workshop, scheduled for August 1996, titled: 'impacts of air pollution on the quality of soil and water: a South African assessment'. One of the aims of this workshop is to evaluate the suitability of the critical loads approach for the South African situation. Three overseas expects will be attending the workshop, as well as a number of local scientists. The major conclusions of this workshop will be given during the oral presentation of this paper.

RECOMMENDATIONS

Based on the research conducted over the past six years in relation to the impacts of atmospheric deposition on commercial forests, the following are recommended:

- the first priority is to research the potential impacts of acidic deposition on the long term sustainability of commercial forest ecosystems.
- Critical loads of nitrogen and sulphate should be determined for forest ecosystems, through intensive studies on potentially sensitive catchments to quantify nitrogen, sulphate and cation budgets. The most important aspects of this work are to accurately quantify deposition inputs to the catchment, particularly for base cations, understand the interactions below the soil surface, understand the sensitivity of different forest species, and to determine the potential effects on the long term fertility of the soil, and the quality of water draining the catchments.
- The potential effects of ozone on forest productivity should be regarded as second priority. If funds allow, small scale pilot studies should be conducted to gain more accurate measurements of ozone levels occurring in plantations, and to assess if there is any evidence of ozone damage to plantation species. However, an intensive research effort is not recommended at this stage.

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