COMMERCIAL IN CONFIDENCE

Assessment of suitable application rates for the recycling of Ahlstrom black liquor to agricultural soils

Prepared for:

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1. BACKGROUND

The Ahlstrom black liquor is produced as a by-product of cellulose fibre extraction from Abaca (Musa textilis). The cellulose is extracted with caustic soda and sodium sulphite at high temperature, high pH and high pressure. The lignin in the plant material is dissolved leaving behind the cellulose fibres. The lignin combines with the sulphite to form water-soluble sodium lignosulphonate which makes up the bulk of the liquor together with any surplus sulphite and sulphate. The remaining sulphite would be converted to either the lignosulphonate or sulphate.

Ahlstrom recycle the liquor to agricultural land and the Environment Agency have recently questioned technical aspects of this activity and responded with the following comments:-

"With regards to your comments on sulphur, I am aware of the issue with regards to the reduction in atmospheric deposition and therefore the requirement for sulphates to be added through "fertilisers" and the mineralization of organic sulphur. In most typical agricultural soils (i.e. neutral soils) the sulphate behaves like nitrate, i.e. it is not bound and is easily leached.

RB209 (much as with the recommendations for nitrogen) provides guidance on the optimum sulphur addition to meet a particular crops need. Application rates above those recommended will present a risk of the excess leaching from the soil. If this excess sulphur enter surface waters it may affect the water's pH and be reduced to potentially toxic sulphides by the same anaerobic bacteria that will reduce nitrates to ammonia. Because the potential for excess sulphur to leach from a soil is similar to that for nitrogen the current advice provided on avoiding nitrate leaching is likely to be equally applicable, e.g. minimise leaching by following recommended rates and timings for fertilisers (see the Defra Code of Good Agricultural Practice for the Protection of Water).

I have calculated that you are applying 557 kg/ha of sulphur trioxide (which is what RB209 quotes) when spreading at 26 tonnes per hectare. The level recommended for silage is 25-40kg/ha when sulphur deficiency is noted prior to each cut."

4Recycling's technical specialists have been asked to provide a detailed technical evaluation of the actual facts and chemistry of the interactions which occur when Ahlstrom black liquor is spread onto agricultural land.

2. INSTRUCTIONS

In response to the queries posed above by the Environment Agency, this report provides an analysis of the validity of the EA claims and provides researched technical details showing:

- The actual risk of leaching and water pollution and a review of literature to back up these facts.
- Data relating to the "polluting" potential of surface applied sulphate and sulphide, including the chemical reactions which compounds of this type undergo when mixed with organic and mineral matter in soil.
- Rate of leaching of S compounds added to soil compared with nitrate, Na and K.
- Characterisation of the S compounds in the black liquor, from current analysis or new analysis to show the speciation of S compounds.
- Whether or not current application rates are indeed safe and sustainable.

3. LITERATURE SEARCH

A literature search with specific reference to the application of Alhstrom type liquors, "Kraft black liquor" and sodium lignosulphonates to agricultural land yielded few experimental papers or reports of direct relevance.

One reference by Canmig Xiao (PhD thesis, Washington State University 2005) was more concerned with the fate of sodium from these liquors when applied to land and was proposing the substitution of sodium hydroxide with potassium hydroxide. His thesis did not study or consider the fate of the sulphur component of the liquor.

Discussions with Soil Scientists, both within the university community and external consultancies, provided little information on the Ahlstrom type liquors, or the soil chemistry of sodium sulphonates, and only a small amount of information on sulphate leaching that could be verified by experimental data.

It was striking how little information could be obtained on S leaching in soil or any EU or UK policy initiatives to restrict the movement of any S compounds from land to surface or ground waters. No comparison or linkage with nitrate leaching was evident.

Consequently, the report has been based on existing data from various reports commissioned by Alhstrom, analytical data from operational activities or appraised from current literature.

4. ANALYSIS OF THE AHLSTROM BLACK LIQUOR

Below is a summary of the most recent chemical analysis of the black liquor over the past 3 years.

		23.07.07	25.07.06	23.11.05	Mean
Dry matter	%	9.41	8.89	10.6	**9.63**
pH		8.6	8.94	7.93	**8.49**
Conductivity (1:6 ratio)	µS/cm	7720	6550	7480	**7250**
Total Nitrogen	% w/w	0.016	0.03	0.035	**0.027**
Nitrate Nitrogen	mg/kg	<0.1	<0.1		**0.00**
Ammonium Nitrogen	mg/kg	<0.1	13.4		**6.70**
Total					
Phosphorus (P)	mg/kg	42.4	8.33	15.1	**21.9**
Potassium (K)	mg/kg	2298	3165	2315	**2593**
Magnesium (Mg)	mg/kg	0.102	7.51	<0.01	**2.54**
Sulphur (S)	mg/kg	8573	3393	7738	**6568**
Sodium (Na)	mg/kg	16578		16411	**16495**
Calcium (Ca)	mg/kg	4.49	7.94		**6.22**
Water soluble					
Phosphorus (P)	mg/kg	40.6	6.8		**23.7**
Potassium (K)	mg/kg	2179	3065		**2622**
Magnesium (Mg)	mg/kg	0.8	6.9		**3.85**
Sulphur (S)	mg/kg	8426	3303		**5865**
Calcium	mg/kg	4.32	4.57		**4.45**
Total					
Copper	mg/kg	0.077	0.352	0.683	**0.37**
Zinc	mg/kg	0.016	0.759	7.51	**2.76**
Lead (Pb)	mg/kg	<0.01	0.027	0.207	**0.08**
Cadmium (Cd)	mg/kg	<0.01	<0.01	<0.01	**0.00**
Mercury (Hg)	mg/kg	<0.05	<0.05	<0.05	**0.00**
Nickel (Ni)	mg/kg	0.017	0.16	0.34	**0.17**
Chromium (Cr)	mg/kg	0.132	0.131	0.056	**0.11**
Lime Equivalent as CaO	% w/w	0.7	0.5		**0.6**

The analysis of the liquor shows it to contain significant quantities of potassium, sulphur, and sodium. The analysis also shows the liquor to be relatively consistent for dry matter, pH, electrical conductivity, sodium and calcium. The sulphur and sodium are derived from the extraction reagents, with the remaining nutrients derived from the dissolved plant matter.

The mean water soluble concentrations are higher than the mean total concentrations for some of the elements. This is due to the few sample numbers analysed and the variability of extraction techniques within the analytical methods.

Approximately 90% of the sulphur and calcium are soluble in water. However, this does not necessarily mean that these elements will be immediately available for plant uptake or leaching due to the fact that they are closely bound to the lignin.

The potentially toxic elements are all very low and will have an insignificant impact on the environment and/or plant uptake.

5. RATES OF APPLICATION AND FERTILISER VALUE

The fertiliser value has been calculated based on the mean values above and at an application rate of:

Application rate 30.0 t/ha

TOTALS	result	units	Nutrient value (kg/tonne)	Amount applied (kg/ha)
Nitrogen (N)	0.27	g/kg	0.3	8
Ammonium-N	6.7	mg/kg	0.01	0
Phosphorus (P)	21.9	mg/kg	0.02	1
Phosphate (P2O5)			0.05	1
Potassium (K)	2593	mg/kg	2.59	78
Potash (K2O)			3.11	93
Magnesium (Mg)	2.54	mg/kg	0.00	0
Magnesium (MgO)			0.00	0
Sulphur (S)	6568	mg/kg	6.6	197
Sulphur (SO_3)			16.4	493
Sodium (Na)	16495	mg/kg	16.5	495
WATER SOLUBLE				
Phosphorus (P)	23.7	mg/kg	0.02	1
Phosphate (P2O5)			0.05	2
Potassium (K)	2622	mg/kg	2.62	79
Potash (K2O)			3.15	94
Magnesium (Mg)	3.85	mg/kg	0.00	0
Magnesium (MgO)			0.01	0
Sulphur (S)	5865	mg/kg	5.9	176
Sulphur (SO_3)			14.7	440

The major constituents of the liquor are sodium, sulphur and potassium. The amount of the nutrient applied from an application of 30 m^3/ ha is 93 kg/ha of potash, 197 kg/ha of S (493 kg/ha SO_3) and 495 kg/ha of sodium.

5.1 Potash

At this rate of application the liquor provides sufficient **potash** to meet most crop demands. Potash fulfils many vital functions in a wide variety of processes in plants, animals and man. It is typically taken-in in greater quantities than required and surpluses are naturally excreted. This process occurs in animals & humans via the kidneys and urine and in plants by the return of potash in senescent tissue at the end of each season - leaves from trees, cereal stubble and roots, etc. Potash is, therefore, naturally recycled widely and in large quantities. Soil reserves are an essential requirement for adequate nutrient supply of potash to plants which commonly contain more potassium than any other nutrient including nitrogen.

5.2 Sulphur

The amount of **sulphur** supplied is greater than crop demand, however, not all of the nutrients will be available for uptake as it is tightly bound to the lignin. This aspect will be discussed later in this report under “plant uptake”. Sulphur is an important plant nutrient and needed by plants in similar quantities to phosphorus. Historically, the crop’s requirement for sulphur has been met from atmospheric deposition and fertilisers that have contained sulphur as a by-product. However, sulphur deposition from the atmosphere has fallen rapidly in recent years and deposition in 1999 was about 15% of that in 1980. Sulphur deposition will continue to fall in the future.

5.3 Sodium

The amount of **sodium** applied is slightly more than that applied as agricultural salt to sugar beet crops e.g. 375 kg/ha (200 kg/ha Na_2O). The application will have no adverse effect on soil structure even on soils of low structural stability (RB209 Section 4, Pg 96). In addition, sodium is an essential element for grass herbage growth. Sodium fertilisers will not normally give extra grass yield but they will increase the Na content of grass which will improve the palatability of herbage and can reduce the chance of grass staggers. Sodium is also associated with a greater % of live herbage, higher D values and sugar content of grass. Research from Bangor University indicates that these effects increase milk output and % butterfat and may also have a small benefit on somatic cell count. Grass palatability and milk output increase at herbage sodium levels up to 0.5% in the dry matter.

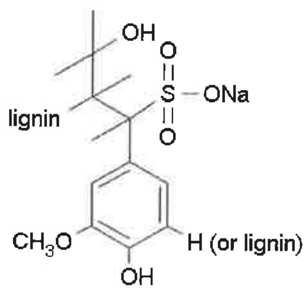
5.4 Potentially Toxic Elements

			Concentration	Amount applied	
TOTALS	result	units	(g/tonne)	(kg/ha)	Limit (kg/ha/yr)
Zinc	2.76	mg/kg	2.76	0.08	15.00
Copper	0.37	mg/kg	0.37	0.01	7.50
Nickel	0.17	mg/kg	0.17	0.01	3.00
Lead	0.08	mg/kg	0.08	0.00	15.00
Cadmium	0.00	mg/kg	0.00	0.00	0.15
Chromium	0.11	mg/kg	0.11	0.00	15.00
Mercury	0.00	mg/kg	0.00	0.00	0.10

The amounts of potentially toxic elements applied are insignificant to the amounts permitted under the "Sludge Use in Agriculture Regulations" (1989).

6. FORMS OF SULPHUR PRESENT IN THE BLACK LIQUOR

It is wrong to assume that because the analysis shows that the majority of sulphur is present in a water soluble form, that it must be present as sulphate or possibly sulphite. The extraction process uses sodium hydroxide and sodium sulphite to digest the plant material with the eventual formation of the complex molecule lignosulphonate. These are stable compounds and have been used as soil conditioners as they promote soil aggregation. The majority of the lignosulphonate will exist in the sodium form due to the amount of sodium sulphite added during the extraction process, but other base metals e.g. potassium and calcium derived from the plant material will also be present. The chemical structure of sodium lignosulphonate is shown below.



Lignosulphonates are stable molecules, with a molecular weight between 10,000-100,000, depending on their degree of the polymerization.

Lignosulphonates are also soluble in water, which is surprising considering their molecular weight. The C-S covalent bond and the S=O bonds will be broken by microbiological activity and not as a result of chemical reaction.

The Environment Agency appears to be concerned about sulphates leaching into surface or ground water resulting in the production of "potentially toxic" sulphides from the application of the Ahlstrom liquor. The release of sulphides from sulphates is a highly specialised process. It is carried out by specific sulphate reducing micro-organisms (Desulphovibrio bacteria) as a result of anaerobic respiration, and will not occur in normal aerated agricultural soils. It can not be reduced by the same micro-organisms as those which reduce nitrate to ammonia as has been implied by the Environment Agency.

Conditions in soil or water need to be intensely anaerobic in order for sulphate reduction to occur. The following table shows the sequence of oxidation-reduction potentials for inorganic reductions that poise a soil as it becomes more anaerobic.

System	Redox potential at 25 °C (mV)	
	pH 5	pH 7
$O_2 + 4H^+ + 4e^- = 2H_2O$	930	820
$NO_3^- + 2H^+ + 2e^- = NO_2 + H_2O$	530	420
$MnO_2 + 4H^+ + 2e^- = Mn^{2+} + 2H_2O$	640	410
$Fe(OH)_3 + 3H^+ + e^- = Fe^{2+} + 3H_2O$	170	-180
$SO_4 2- + 10H^+ + 8e^- = H_2S + 4H_2O$	-70	-220

In normal aerated agricultural soils the redox potential is poised above +400 mV, depending on soil conditions. Soil respiration systems will be based on oxygen, nitrate, manganese and iron depending on the soil conditions. However, for sulphate reduction to occur, the soil must be extremely waterlogged (bog conditions) and sulphate reducing micro organisms to be present. Consequently, sulphate reducing conditions are highly unlikely to occur under normal soil conditions for crop production.

7. SULPHUR IN SOILS

Sulphur occurs in the soil in both inorganic and organic forms, with the organic bound S comprising of over 90% of the sulphur. The majority of the inorganic sulphur will be present as sulphates of varying solubilities.

Soil analysis form fields where the Ahlstrom black liquor is to be applied show total sulphur contents ranging from 0.02% to 0.08 % S. This equates to a total sulphur content ranging from 500 to 2000 kg/ha S, assuming that a hectare of soil in the top 20 cm weighs approximately 2,500 tonnes.

8. INFILTRATION TRIALS

Soil infiltration tests were carried out by Dr R Davies, Soil Environment Services. The infiltration rate was assessed with a double ring infiltrometer on two soil textures using both water and Ahlstrom 410 liquor. The Philips equation was used to calculate infiltration after 1 hour and the average for water was 85 mm/hr and for Ahlstrom liquor 56 mm/hr. This was carried out during relatively dry conditions and therefore could be expected to be half this rate during wetter conditions.

Based on these infiltration data, an application rate of 29.76 tonnes per ha will, therefore, result in percolation of the black liquor to no more than 2.9 mm depth if spread uniformly on the soil when soil conditions were suitable (not during rain or when the soil is at field capacity). If the liquor is applied at moisture contents less than field capacity, the liquor will infiltrate at the above rates but will not pass through the profile due to the relatively small quantities applied and will add very little to the soil moisture content. The soil mass available to absorb the liquor would be expected to retain all of the nutrients and liquor constituents.

This means that the surface soil layer enriched with the black liquor will need to be flushed with a very large quantity of excess winter rainfall (annual rainfall minus evapo-transpiration) to push the material through the soil profile like a piston, assuming the constituents are freely mobile.

9. PLANT GROWTH TRIALS (BIOASSAY)

Plant growth trials utilising the Ahlstrom liquor carried out in 2000 has shown a number of interesting results both in terms of nutrient uptake and the effect on the soil. The black liquor used in the bioassay contained between 3-6 times the quantity of sodium and sulphur respectively as is now contained within the black liquor recycled to land (mean data shown in this report). Although not directly comparable, the data can be used to demonstrate nutrient uptake and residual soil nutrient effects of the application of the black liquor to soil.

9.1 Nutrient uptake

Table 1 shows the effect on nutrient uptake in grass as a result of increasing the rate of application of the Ahlstrom liquor from 0 to 50 m^3/ha. The largest effect was the reduction in the potassium and the increase in sodium concentrations. The Ahlstrom liquor supplied the equivalent of 354 kg/ha of sodium at the 6 m^3/ha application of liquor. Sodium uptake was increased from 0.1 % to 0.31 % at the 6 m^3 rate and up to 1.07% at the 50 m^3 rate. The increase in sodium uptake suppressed the uptake of the other cations. This effect was not observed in the uptake of sulphur, despite an application of 222 kg/ha of sulphur (555 kg/ha SO_3) at the 6 m^3 application rate. The sulphur content only increased from 0.24% to 0.26% at the 25 m^3/ha treatment despite the application of the equivalent of 925 kg/ha of sulphur (2,300 kg/ha SO_3). This demonstrates that the majority of the sulphur can not be present in a plant available form, e.g. sulphate, and is therefore, not likely to be leachable.

Table 1 - Nutrient content of grass (%).

Treatment (m^3/ha)	DM (%)	N (%)	P (%)	K (%)	Mg (%)	Na (%)	S (%)	Cu (mg/kg)
0	14.4	2.90	0.38	4.28	0.14	0.10	0.24	6.87
6	14.8	2.63	0.37	3.96	0.12	0.31	0.22	6.43
12	15.9	2.70	0.34	3.48	0.12	0.54	0.22	6.21
25	16.3	2.48	0.30	3.06	0.11	0.73	0.26	5.65
50	16.9	2.45	0.33	2.56	0.09	1.07	0.27	6.32
SE	0.512	0.134	0.014	0.104	0.007	0.025	0.009	0.350
Sig	5%	NS	5%	0.1%	1%	0.1%	5%	NS

Similar results were observed in oilseed rape (Table 2) and the results presented below. There was a similar reduction in the potassium content, and increase in the sodium content. The differences in the nitrogen, phosphorus and sulphur contents as a result of applying the Ahlstrom liquor were not significant.

Table 2 - Nutrient content of oilseed rape (%)

Treatment (m^3/ha)	DM (%)	N (%)	P (%)	K (%)	Mg (%)	Na (%)	S (%)
0	11.2	2.27	0.39	4.37	0.26	0.08	0.87
6	11.2	2.25	0.38	4.15	0.24	0.34	0.85
12	12.1	2.05	0.36	3.57	0.23	0.47	0.79
25	11.7	2.11	0.36	3.47	0.21	0.75	0.79
50	11.7	2.19	0.40	3.09	0.20	1.12	0.91
SE	0.416	0.061	0.013	0.166	0.008	0.049	0.031
Sig	NS	NS	NS	0.1%	1%	0.1%	NS

The normal application rate of **30 m^3/ha**, is based on the mean fertiliser value of the Ahlstrom liquor in this report and it will apply the equivalent amount of sodium and sulphur as the 6m^3/ha treatments used in the plant growth trials.

9.2 Soil analysis

At the end of the plant growth test carried out in 2000, the soils were analysed and the results presented in Table 3.

Table 3 - Soil analysis - Grass

Treatment (m^3/ha)	pH	Extractable (mg/l) P	Extractable (mg/l) K	Extractable (mg/l) Mg	Ext Na mg/l	Total S mg/kg	Ext SO_4-S mg/kg	Cond µS/cm 20°C	Ext Cu (mg/l)
0	6.9	36	243	107	19	333	31	2063	5.4
6	6.9	37	224	113	29	349	22	2043	4.9
12	7.0	45	245	136	56	380	57	2100	5.5
25	7.0	40	210	126	133	422	60	2100	5.1
50	7.1	36	234	109	164	446	51	2185	4.9
SE	**0.056**	**3.85**	**27.88**	**4.914**	**31.221**	**24.38**	**17.507**	**31.992**	**0.171**
Sig	**5%**	**NS**	**NS**	**1%**	**5%**	**5%**	**NS**	**NS**	**NS**

The addition of the Ahlstrom black liquor had no significant effect on the available phosphorus, potassium and magnesium content. There was a small significant increase in soil pH which would offset concerns of potential soil acidification resulting from the application of the Ahlstrom liquor.

There was a significant increase in the sodium content but this increase was small at the 6m^3 /ha rate and would have little impact on the soil. This rate of application would apply the same sodium loading as a 30 m^3/ha application of the current black liquor based on the mean value in this report.

There was a significant increase in the total sulphur content but this increase was not significant at the 6m^3/ha application rate. There was no significant increase in the plant available sulphate (SO_4-S) even at the 50m^3/ha rate which supplied 1,650 kg of water soluble–S (4,000 kg SO_3-S). These data further confirms that although the sulphur is in water soluble form, it is not being measured by standard soil tests to identify sulphur that is readily available for plant uptake or leaching.

10. LEACHING OF SULPHATE

The leaching of sulphate was of primary concern by the Environment Agency. These concerns are unproven as the risk of pollution resulting from sulphate leaching is relatively small. This is because the sulphur is present in the form of lignosulphonates which will be organically bound to the soil. The lignosulphonates although soluble in water, are not extracted by standard soil analysis methods that measure the forms of sulphur that are readily leached or available for plant uptake.

The following analysis is based on **all the sulphur being soluble and available for leaching** and was modelled in order to satisfy the Environment Agency that sulphate leaching is unlikely to occur. The amount of S leached is calculated from the current application rate of 30 m^3/ha using nitrate-nitrogen leaching as baseline (assuming S leaching losses are equivalent to nitrate). The amount of nitrate-nitrogen can be calculated using the ADAS Manner programme for a range of soil types and the 3 excess winter rainfall classes described in MAFF bulletin 209. The programme has been set so that all the nitrogen is available for leaching, and that the material is applied to the surface and incorporated within 2 hours of application. The programme calculates that only 6 kg/ha of nitrate-nitrogen is lost through volatilisation, with the remainder available for leaching.

The following excess winter rainfall scenarios have been used to represent the 3 rainfall classes:

Rainfall Class	Excess winter rainfall range	Excess rainfall used in calculation
Low (500-600 mm)	50-150 mm	100 mm
Moderate (600-700 mm)	150-250 mm	200 mm
High (700 + mm)	250 + mm	300 mm

The following table calculates the amount of nitrate-nitrogen leached from an application of 176 kg/ha of available N. This is the same rate of application of water soluble sulphate–S applied in the Ahlstrom liquor applied at 30 m^3/ha. The soil textures are the same for both the topsoil and subsoil.

Amount of NO_3-N leached from an application of 176 kg/ha available N

Excess rainfall	Sandy loam	Silt loam	Clay loam	Clay
100 mm	0	0	0	0
200 mm	71	5	13	31
300 mm	162	76	89	118

The leaching of sulphate–sulphur is generally accepted as approximately 66% that of nitrate-nitrogen. The amount of sulphate-sulphur that is available for leaching can be calculated and presented in the following table. The data has not taken into account:

- any sulphur taken up by the crop which would be in the order of 24 kg/ha S (60 kg/ha SO_3), based on a 2 cut silage system removing 12 kg/ha S (30 kg/ha SO_3 per cut), or
- any sulphur immobilised by the soil.

Amount of SO_4-S (mg/l) leached from an application of 176 kg/ha water soluble S

Excess rainfall	Sandy loam	Silt loam	Clay loam	Clay
100 mm	0	0	0	0
200 mm	47	3.3	8.0	20.4
300 mm	107	50	59	78

The data in the above table is for the worst case scenario where 100 % of the applied sulphur is available for leaching. The following table calculates the concentration of sulphate in the drainage water based on the amount of SO_4-S leached for the 4 different soil textures and three excess winter rainfall classes.

Amount of SO_4-S (mg/l) in drainage water from an application of 176 kg/ha water soluble S

Excess rainfall	Sandy loam	Silt loam	Clay loam	Clay
100 mm	0	0	0	0
200 mm	23.5	1.7	4.0	10.2
300 mm	35.7	16.7	19.7	26.0

The calculations above from MANNER show that small concentrations of SO_4-S **(worst case scenario 35.7 mg/l SO_4-S)** would be present in the drainage waters and would not pose a significant risk to the environment. The majority of soils used for spreading the black liquor will be clay loam or sandy clay loam in texture with leaching rates similar to the clay loam texture e.g. 19.7 mg/l SO_4-S. To put this into context, the World Health Organisation, US Environmental Protection Agency and the The Water Supply (Water Quality) Regulations 2000 all show a figure of 250 mg/l sulphate as a guide upper limit for drinking water. The limit is not set not because this is a potentially harmful limit but because it could affect the taste of the water.

All of the analysis above has assumed that:

- S can leach at the same rate as nitrate which it can not.
- All of the S applied to land in the form of the black liquor is soluble and there is no resistance to leaching when there must be.
- The lignosulphate does not bind with the soils organic matter when it must.
- There is no crop uptake and there must be in practice.

The present environmental legislation does not include any specific limitations to sulphur application or its impact on the environment or provide policy advice or action programmes to control sulphur additions to surface or ground waters. The only indirect reference to sulphur application is stated in the RB 209 “Fertiliser Recommendations” which state that applications should be linked to crop requirement.

The environmental impact of spreading the liquor in a catchment would be very small for 2 reasons:

- firstly due to the huge dilution effect of the addition of the black liquor over a very large area of land
- secondly due to the remote possibility of spreading similar wastes containing a high sulphur content within a catchment.

11. CONCLUSIONS

11.1 A literature search with specific reference to the application of Alhstrom type liquors, "Kraft black liquor" and sodium lignosulphonates to agricultural land yielded few experimental papers or reports of direct relevance. Consequently, the report has been based on existing data from various reports commissioned by Alhstrom, or appraised from current literature.

11.2 The analysis of the liquor shows it to contain significant quantities of potassium, sulphur, and sodium. The total amount of the nutrients applied from an application of 30 m^3/ha is 93 kg/ha of potash, 197 kg/ha of S (493 kg/ha SO_3) and 495 kg/ha of sodium.

11.3 The majority of sulphur present is water soluble in the form of a complex molecule lignosulphonate. These are stable compounds and have been used as soil conditioners to promote soil aggregation.

11.4 The leaching of sulphate was of primary concern by the Environment Agency. These concerns are unproven as the risk of pollution resulting from sulphate leaching is relatively small. This is because the sulphur is present in the form of stable lignosulphonate molecules which will be organically bound to the soil.

11.5 The sulphate leaching was modelled in order to satisfy the Environment Agency's concerns. The model was based on worst case scenario in that all of the sulphur was in a soluble form and available for leaching. The calculations show that based on this precautionary analysis that only small concentrations of SO_4-S could be present in the drainage waters and would not pose a significant risk to the environment.

11.6 Based on the analysis of pollution risk from leaching of sulphur compounds in this report, the current application rate of up to **30 m^3/ha** will have little or no adverse impact on the soil and pose a negligible risk to the environment. The beneficial effects of the application of Ahlstrom black liquor on crop growth have been proven in earlier experimental work, from the provision of Professionally Qualified Advice and from operational experience.