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Recommendations for the extraction of forest fuel and compensation fertilising

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Introduction

The forest has a significant role to play in Sweden as a renewable energy resource in a sustainable society.

The recommendations below outline how the National Board of Forestry, Sweden considers the extraction of forest fuels[1] and compensation fertilising[2] should be conducted in order to avoid any undesirable effects on the nutritional balance in the soil, on the biological diversity and the water quality in lakes, watercourses and water tables, and also to avoid any net flow of noxious substances (e.g. heavy metals) into the soil.

The National Board of Forestry is positive towards the use of forest fuels, provided that the recommendations below are followed. The fuels from Swedish forests are renewable, of domestic origin, and contribute minimally to the greenhouse effect and related climatic effects. Extraction, transport and processing of forest fuels create new employment opportunities. Moreover, the utilisation of fuels from Swedish forests reduces dependency on energy supplies from abroad.

[1] This refers to so-called *primary forest fuel*, i.e. the part of forest fuel that comes directly from the forest, such as forest residue (branches and tops that are left after the extraction of stemwood) and a range of fuels from final felling, thinning, cleaning and other timber operations.
[2] Compensation fertilising refers to the introduction of nutrients with the aim of compensating for the removal of mineral nutrients that occurs in connection with the extraction of primary forest fuel. Mineral nutrients refers to all nutrients with the exception of nitrogen.

Preserve the nutritive balance in forestry land

The National Board of Forestry is of the opinion that:

- compensation fertilising should take place when forest fuels have been extracted and most of the needles are left in situ, with some effort being made to spread them out.

  One extraction per rotation, however, can be carried out without compensation fertilising, provided that most of the needles are left and spread out.

  Compensation fertilising ought to be carried out:
  → When extracting from highly acidified forestry land.
  → When extracting from peat land.
  → When extracting the greater part of the needles in connection with regeneration felling.

  The needles may be taken out:
  → Once during the rotation in connection with light thinning or clearing.
  → From areas with a high degree of nitrogen impact, provided that compensation fertilising takes place.

The predominant part of the nutrient content of a tree is retrieved from the needles, branches and tops. Depending on the nutrient, the removal of nutrients with logging residues (i.e. branches and tops) increases by 1.5 – 5 times compared with harvesting only stemwood. Ordinarily, in the extraction of forest fuel, the removal of mineral nutrients cannot be fully compensated by weathering and deposition. Consequently, the supply of mineral nutrients available to plants diminishes. By leaving most of the needles, the extraction of nutrients is limited considerably. In this way, the need for compensation fertilising is also reduced. If the needles are left and compensation fertilising takes place, then the loss of mineral nutrients is prevented.

By spreading out the needles as evenly as possible, the risk of nutrient leakage is reduced as the vegetation is then given a greater opportunity to avail itself of the nutrients that are released from the needles at the same time as the composting effect in piles of slash and needles is counteracted. Today, logging residues are often left in smaller piles, spread over the cutting area to dry and to allow the needles to fall off. A successive improvement in spreading out needles, employing technical means, should be an ambition within the development sector. One alternative to allowing the needles to fall off is to leave behind more sprigs, branches and tops so that their nutrient content corresponds to the amount in the needles. Compensation fertilising should always be carried out when extracting forest fuel in connection with final felling, which comprises removal of all biomass above the stump, including the needles.

One logging residue extraction per rotation can take place without compensation fertilising. To avoid the need for compensation occurring after extraction that is associated with regeneration felling most of the needles should be left and spread more or less evenly. The risk for a rapid change in soil conditions is small even if compensation is not carried out for the occasional extraction. A great deal of nutritious fractions remains during practical handling. There should, however, be an ambition to successively develop and introduce new technology for compensation fertilising.

In highly acidified forest land[3] in south-west Sweden, significant sections of the volume of the nutrients available to plants is lost due to leaching. In order not to make the situation worse, such areas ought to undergo compensation fertilising following the extraction of forest fuel.

In forest ecosystems in peat land, the availability of certain mineral nutrients is limited. A large amount of the nutrients is confined to the trees. If logging residue extraction occurs in peat land, it is therefore especially important to leave the needles behind and also carry out compensation fertilising.

When extraction takes place during thinning out and clearing operations, which may even include the needles, no compensation fertilising is necessary. The reason for this is that the extraction and the distribution of compensation fertiliser involves more transport and thereby an increased risk for damage to the soil and trees. Moreover, the removal of nutrients resulting from a logging residue extraction in thinning out or clearing operations is relatively moderate. It should, however, be an ambition to successively develop technology to enable the careful removal of needles and nutrient compensation.

The extraction of forest fuel results in a significant amount of nitrogen being removed. In nitrogen-rich forest land with a high nitrogen load[4], logging residue extractions including needles can be positive. They counteract the accumulation of nitrogen that can lead to an increase in nitrogen leaching, soil acidification and changes in vegetation. Compensation fertilising should be conducted following such extractions provided that the fertiliser and application rate do not lead to nitrification and nitrogen leaching.

The removal of nitrogen through the extraction of forest fuel may, in certain cases, lead to a relatively large decrease in the total available nitrogen supply (above all in northern Sweden), with temporary reductions in growth increment as a consequence. In certain areas, even the provision of ashes may result in temporary growth reductions. Leaving the needles behind can counteract these

[3] Highly acidified forest land refers here to forest land within areas with a relatively high deposition of acidifying substances (primarily in Blekinge, Skåne, Halland, Bohuslän and adjacent parts of Småland, Västergötland, Dalsland and south-western Värmland) provided that it is located within catchment areas for i) acidified lakes or watercourses in which surface water alkalinity is less than 0.05 mequiv/litre (measured during a stable period), or for ii) lakes that have been liimed to counteract acidification and which the county administrative board has judged as being in need of liming. Bog, and other naturally acidified lakes are *not* regarded as being acidified.

[4] Forest land with a high nitrogen impact primarily refers to coastal locations in south-western Sweden where a risk for nitrogen saturation may exist. Even within other areas in Götaland and parts of Svealand, where nitrogen fallout is high and the soil fertile, the extraction of forest fuel that includes the needles may be positive from the perspective of reducing the nitrogen load.

effects. Alternatively, it might be appropriate to apply nitrogen. Guidelines regarding nitrogen application are to be found in the National Board of Forestry's General Recommendations, SKSFS 1991:2. (A revised issue of this publication is planned for 2002.)

Forest fuel extraction in lichen-rich areas in northern Sweden may result in regeneration difficulties and should therefore be avoided.

Preserve biological diversity

The National Board of Forestry is of the opinion that:

- It is important that trees and bushes that have previously been left untouched in consideration of the natural and cultural environments are not damaged.
- Wet forest land and other forests with a high natural values should be exempt from extraction operations if their natural values are affected negatively.
- Extraction should not include species of trees that are less common. This applies to a particular stand as well as in the landscape.
- When extracting forest fuel, a certain proportion of tops should be left behind. It is especially important to leave dead wood as well as tops and large-dimension branches from deciduous trees.

The extraction of forest fuel means a more intensive utilisation of forests and forest land. It is therefore especially important that trees and bushes, both standing and lying, that have been left untouched during previous forestry operations due to ecological and cultural considerations are not damaged. Special attention should be paid to grazing land, the edges of woods near fields and meadows, burnt forest land and deciduous trees bordering lakes and watercourses when extracting forest fuel. One-sided extraction of deciduous trees in mixed forests should be avoided. Regulations regarding the consideration of the interests of nature conservation and cultural environment conservation (paragraph 30 in the Silvicultural Act) also apply to the extraction of forest fuel.

Dead wood, especially large-dimension dead wood from both coniferous and deciduous trees, has a significant bearing on the flora and fauna. Consequently, wood like this should be left when extracting forest fuel. The most significant contribution to biological diversity is wood from pine and deciduous trees, especially large-dimension wood from [5]selected broad-leaf tree species.

During the summer, certain species of rare insect use wood from selected broad-leaf tree species as host trees. The extraction of wood from selected broad-leaf tree species should therefore be carried out immediately after felling or by 15th May if felling took place during the period 1st September to 15th May. If this is not possible, then all twigs, branches and tops from at least every fifth tree, or equivalent, should be left and, preferably, exposed. These measures are most urgent in southeastern Sweden.

[5] In the present context, the term "selected broad-leaf tree species" refers to beech, oak, ash, elm, lime, maple, hornbeam and wild cherry.

Nutrient compensation

The National Board of Forestry is of the opinion that:

- Compensation fertilising should, primarily, be carried out through the provision of ashes. However, other products that contain mineral nutrients can also be used. Ashes and mineral products may also be combined.
- Most of the ashes used in products to be spread about in the forest should originate from the combustion of forest fuel. However, mixing in a certain amount of ashes from other fuels is not a problem. It is the quality of the ashes that determines its suitability.
- The ashes should to be stabilised and slow to dissolve.
- In compensation fertilising, the dose per hectare and rotation should be based on the loss of liming effect and the total removal of base cations (i.e. Ca^{2+}, Mg^{2+}, K^{+}) in branches, tops and needles during the rotation. The extraction of stemwood should be taken into consideration when judging the level of compensation.
- In order to avoid short-term negative effects, a maximum of 3 tonnes of DM (dry matter) in ashes should be returned per hectare and 10-year period if the total compensation requirement is greater than 3 tonnes DM per hectare.
- In compensation fertilising, the total input of heavy metals and other undesirable substances per rotation should not be greater than the amount removed with the total biomass.
- During the extraction of forest fuel it may be necessary to compensate for removed nitrogen and thereby counteract a reduction in growth increment. Guidelines for nitrogen input can be found in SKSFS 1991:2. (A revised issue of this publication is planned for 2002.)
- In compensation fertilising, nitrogen leaching and loss of input nutrients ought to be prevented by the choice of the work method, product and the point of time for the measures to be taken.

Guidelines with regard to the rate of application of ashes, appropriate nutrient composition, the highest permitted input of heavy metals, as well as the degree of stabilisation of the ashes are given in “Recommended application rates of ashes and desired quality in compensation fertilising”, Appendix 1.

The National Radiation Protection Institute (SSI) has, in its “Policy for biofuel”, Reg. No. 822/504/99, drawn up guidelines for the highest permitted caesium content in ashes that are to be returned to forestry land. At the moment, the SSI is preparing regulations regarding the handling of biofuel ashes that contain Cs^{137}.

Heavy metals may disturb the biological processes in the soil and affect the quality of surface and ground water. The content of heavy metals in ashes must not be so high that biological processes in the soil are impaired or the input of ashes exceeds the total removal of heavy metals per rotation, see Appendix 1.

Compensation should take place to compensate for the diminishing effect of lime as well as the complete removal of base cations (Ca^{2+}, Mg^{2+}, K^{+}), caused by the increased removal of biomass during the rotation. Compensation for the removal of individual nutrients may lead to unacceptably high supply of ashes with regard to environmental effects and availability of ashes. Desired quality and recommended doses of ashes are presented in Appendix 1. However, the need for compensation in peat soil should be calculated based on the removal of phosphorus and potassium. Ashes included in compensation fertilisers should, with regard to the rotation, originate mainly from combustion of forest fuels.

It may be necessary to store ashes in intermediate storage facilities or storage places pending being spread in the forest. Ashes or products made out of ashes should be stored in such a way as to prevent leaching as much as possible. Potassium is the nutrient most susceptible to leaching. The storage place should be dry and be situated relatively high in the terrain. Permanent intermediate storage facilities ought to have hardened surfaces and/or roofs. From the perspective of Swedish law, ashes are considered to be refuse. A permit is normally required for the transport, handling, processing, intermediate storage and stockpiling of refuse or, alternatively, there is an obligation to report such operations to the authorities. Further details on test levels, etc. can be found in the National Environment Protection Agency – General Recommendations 99:1.

Poorly stabilised ashes may be injurious to flora and fauna and also increase nutrient leaching. Only stabilised (chemical/physical) ashes and those that dissolve slowly should therefore be used. Negative environmental effects grow with increasing application rates of ashes. However, the negative environmental effects of application rates of up to 3 tonnes (DM) per hectare are judged to be very small.

Compensation fertilising must not take place during periods of snow-cover, ground frost or severe run-off if there is a risk that nutrients will subsequently end up in a watercourse. Consequently, they will be of no benefit to the soil or to the flora. Compensation fertilising should be conducted so that: 1) the fertiliser is spread evenly in the stand, 2) mechanical damage to the soil is limited and 3) damage to trees is limited.

Due to the risk of leaching on recently clear-felled areas, compensation fertilising ought not to take place prior to the re-establishment of ground vegetation. In practice, spreading should be avoided over a period that extends from five years before to approximately five years after regeneration felling with ashes that are not particularly stabile or dissolve slowly. If products containing ashes are developed that do not give rise to any particular leaching during the felling phase, then they can be spread in connection with regeneration felling.

Limit damage caused by vehicles and prevent damage caused by insects

The National Board of Forestry is of the opinion that:

- It is important that the technique and point in time for forest fuel extraction and compensation fertilising are chosen so that the risk of damage to the ground and to remaining trees is limited.
- Large-dimension, fresh coniferous wood should be handled separately when extracting forest fuel.
- Stacks with forest fuel should not be stored immediately adjacent to the edge of a stand comprising the same species of tree as that stored in the stacks.

The extraction of forest fuel and compensation fertilising requires increased transport in the forests while, at the same time, the ground-protecting effect of the slash is lost. This increases the risk of damage to the soil and to growing trees caused by vehicles and to trees that have been left standing or lying for reasons of environmental consideration. Special care should be taken in areas with poor carrying capacity.

The spreading of ashes in stands may result in blasting damage to trees closest to access tracks when spreading from the ground, especially during the period when the sap rises. It is therefore vital that both spreading techniques and the products used are designed so that such damage does not occur.

If large-dimension, fresh, coniferous wood is left unbarked in the forest during the spring and early summer, it will easily become nest material for insect pests. Such wood should therefore be handled separately. Regulations concerning the limitation of insect pests (§ 29 of the Silvicultural Act) apply in connection with the extraction of forest fuel.

If logging residues from coniferous trees are stored immediately next to the stand, this may result in attacks of pests on living, adjacent trees. Stacks of slash should be positioned at least 50 metres from the edge of the forest. This only applies if the species of tree is the same in the edge of the stand as the one stored in the piles.

Documentation, regulations and contacts with authorities

Documentation

The National Board of Forestry is of the opinion that:

- The extraction of forest fuel and completed compensation fertilising should be documented.

Many years may pass between the extraction of forest fuel and compensation fertilising. Completed measures should therefore be documented. Documentation is best done in a forest management plan or similar document. It should contain details of the extraction/extracted species of tree, time of extraction, if the needles were removed or left behind, and also details of probable compensation fertilising (time, amount and chemical composition).

Regulations and contacts with authorities

In the Silvicultural Act, extraction of forest fuel and compensation fertilising is regulated in Regulations and General Recommendations to § 30 (Consideration to Nature), § 14 (Notification of Forest Fuel Extraction) and with regard to storage § 29 (Forest Protection). The consideration that must be shown to the environment in all activities is presented in Chapter 2 of the Environmental Code. Activities or measures that may significantly alter the natural environment shall, in accordance with Chapter 12, § 6 of the Environmental Code (1998:808), be reported for consultation.

In those cases in which it is considered that forest fuel extraction or compensation fertilising will significantly alter the natural environment, applications for consultation are to be submitted to the National Board of Forestry. The person reporting the extraction of forest fuel, in accordance with § 14 of the Silvicultural Act, is also considered as having completed an application for consultation in this respect. If there is a risk of surface water or ground water pollution, compensation fertilising is also included in the regulations regarding activities harmful to the environment in the Environmental Code, Ch. 9.

Further guidelines regarding the handling of ashes can be found in, for instance, the Environmental Code, Ch. 15 and the Public Cleansing Ordinance (1998:902). There are guidelines in these sections that concern the storage of ash in intermediate storage facilities or storage places, which could be appropriate pending its spreading in forests. Ashes are considered to be refuse under Swedish law. A permit is normally required for the transport, handling, processing, intermediate storage and stockpiling of refuse or, alternatively, there is an obligation to report such operations to the authorities. Further details on test levels, etc. can be found in the National Environment Protection Agency – General Recommendations 99:1[6].

[6] Reading suggestions regarding activities harmful to the environment. General Recommendations 99:1. The National Environment Protection Agency, 1998. For later amendments, see www.environ.se ”Lagar och rättesnören” (i.e. *Laws and Guiding Principles)*.

Appendix 1.

Recommended application rates and desired quality of ashes in compensation fertilising

Ash dosage

Compensation should take place following the extraction of branches and tops (i.e. logging residues). Compensation can be done for stemwood extraction, as a separate measure or in connection with compensation for extraction of logging residues. Stemwood compensation is especially important in the highly acidified areas of southern Sweden. The guiding values for the suitable dose in nutrient compensation are, for practical reasons, somewhat standard.

The application rate of ashes can be decided by one of two methods; a simpler (standardised method) or a more detailed (nutritional balance method).

Standardised method

This method is employed when details of previous logging residue extractions are lacking or if compensation is to take place for stemwood during the current rotation. Ashes used must fulfil quality requirements in accordance with Table 5 and also SSI guidelines for caesium. The peak values for heavy metals given in Tables 6 and 7 do not need to be taken into consideration when the standardised method is employed. Compensation normally occurs once per rotation.

Table 1. Recommended application rates when the standardised method is employed

Species of tree	Tonnes of ashes DM/hectare and rotation (poor soil – fertile soil)
Spruce	1 – 2
Pine	0.7 – 1.5
Birch/other deciduous trees	1 – 2

The upper part of the interval is regarded as fertile soil/southern Sweden and the lower part as soil/northern Sweden. For mixed stands, the application rate can be decided upon by weighting the values based on the distribution of tree species.

Nutritional balance method

In compensation for the extraction of logging residue, the ash dosage that is to be introduced into the stands is decided, primarily, by the species of tree, the extent of the logging residue extraction, which parts of the trees are removed and the chemical composition of the ashes.

Normally, the return of the ashes is done on one occasion per rotation; however, the dosage may be divided into several treatment operations.

Tables 2-4 can serve as a guide when estimating the size of the application rate for compensation during one rotation in different stands and in different extractions. The application rate can be decided upon by weighting the values based on the distribution of tree species.

The table values assume that the ashes spread fulfil the quality requirements given in Table 5 and SSI guidelines regarding caesium. The total input of heavy metals during the rotation should not exceed the maximum values given in Tables 6 and 7.

The data given in Tables 2-4 is calculated using the programme, *"Snurran 1.0"*, which was developed by SkogForsk (Forest Research Institute of Sweden). The values given are based upon the content of 4 % potassium, 15 % calcium and 3 % magnesium. The values are not claimed to be exact for extractions from particular stands. The dosage may be adjusted if the contents are substantially higher. In peat land on the other hand, the compensation requirements should be governed by the extraction of phosphorus and potassium, but the guidelines below can also be followed for such areas. In order to avoid short-term negative effects, the total amount of dry matter (DM) in ashes returned per hectare over a 10-year period ought not to exceed 3 tonnes.

When introducing nutrient-enriched ashes, the portion should be adapted so that the equivalent amount of base cations[7] and effects of calcium will be the same as when using pure ashes. The amount of easily dissolvable salts should be limited.

[7] The equivalent sum total of base cations = amount of calcium introduced / 20.0 (equivalent value for Ca) + amount of magnesium introduced / 12.2 (equivalent value for Mg) + amount of potassium introduced / 39.1 (equivalent value for K). If the amount introduced is given in kilograms then the equivalent sum total of the particular sort is given in kilogram equivalents, if the weight is expressed in tonnes then tonne equivalents are given, etc.

Table 2. Spruce stand – the standard values in nutrient compensation, tonnes of dry matter (DM) in ashes per hectare and rotation

Extraction		**Habitat index**, compensation dosage, tonnes of DM in ashes/hectare and rotation		
		G18	G26	G34
All stemwood during rotation		1.5	2.0	2.5
Final felling	Logging residue without the greater part being needles *	0.7	0.8	0.9
	Logging residue with the greater part being needles **	1.1	1.3	1.4
Cleaning -thinning	Delayed cleaning***	0.4	0.5	0.6
	All thinning: logging residue without the greater part being needles ****	0.3	0.6	0.8
	All thinning: logging residue with the greater part being needles *****	0.6	1.0	1.3

* In the extraction of logging residue without the greater part being needles in the final felling, the application rate of ashes is based on 75 % of the logging residue and 25 % of the needles being removed.
** In the extraction of logging residue with the greater part being needles in the final felling, the application rate of ashes is based on 75 % of the logging residue and 75 % of the needles being removed.
*** In the compensation for the extraction of logging residue and stemwood in delayed cleaning, it is assumed that 75 % of the logging residue, 75 % of the needles and all stemwood are removed. The extraction is estimated to be between 25 m^3tvb (i.e. total volume over bark) and 50 m^3tvb per hectare. The arithmetic mean diameter is estimated to be between 6 cm and 10 cm.
**** In the extraction of logging residue without the greater part being needles in all thinning that is normally conducted during one rotation, it is assumed that 75 % of the logging residue and 25 % of the needles are removed.
***** In the extraction of logging residue with the greater part being needles in all thinning that is normally conducted during one rotation, it is assumed that 75 % of the logging residue and 75 % of the needles are removed.

Table 3. Pine stand - the standard values in nutrient compensation, tonnes of DM in ashes/hectare and rotation

Extraction		**Habitat index**, compensation dosage, tonnes of DM in ashes/hectare and rotation	
		T18	T26
All stemwood during rotation		0.8	1.2
Final felling	Logging residue without the greater part being needles *	0.2	0.3
	Logging residue with the greater part being needles **	0.3	0.4
Cleaning -thinning	Delayed cleaning***	0.2	0.3
	All thinning: logging residue without the greater part being needles ****	0.1	0.2
	All thinning: logging residue with the greater part being needles *****	0.2	0.3

*, **, ***, **** and *****, see Table 2.

Table 4. Birch stand/other deciduous trees - the standard values in nutrient compensation, tonnes of DM in ashes/hectare and rotation

Extraction		**Soil fertility**, compensation dosage, tonnes of DM in ashes/hectare and rotation	
		B18	B26
All stemwood during rotation		1.4	2.1
Final felling	Logging residue without leaves[0]	0.4	0.5
Cleaning -thinning	Delayed cleaning[00]	0.3	0.6
	All thinning: logging residue without leaves[0]	0.2	0.3

[0] In the extraction of logging residue without leaves in the final felling or all thinning that is normally conducted during one rotation, the application rate of ashes is based on 75 % of the logging residue being removed.
[00] In the compensation for the extraction of logging residue and stemwood in delayed cleaning, it is assumed that 75 % of logging residue and all the stemwood is removed. The extraction is estimated to be between 25 m^3tvb and 50 m^3tvb per hectare. The arithmetic mean diameter is estimated to be between 6 cm and 10 cm.

Desired quality of ashes

Starting points

The quality requirements given below proceed from the following:

- Regulations and General Recommendations (SKSFS 1993:2) of § 30 of the Silvicultural Act.
- The joint policy publication ”Biofuel Ash in Rotations” of the National Board of Forestry and the Swedish National Environment Protection Agency. 1994.
- The documentation report ”Quality requirements for ashes that are to be returned to forest land” of the National Board of Forestry and the Swedish National Environment Protection Agency.

Origin of the ashes

Most of the ashes that are to be spread in the forest probably originate from the combustion of forest fuel. However, a certain admixture of ashes from other fuels would not result in problems. The quality of the ashes is what determines its suitability for being spread on forest land. The guidelines provided do not refer to any other residual products than ashes.

Treatment prior to spreading

Ashes to be spread in the forest must be treated so that:

- Acute damage to the soil and vegetation, such as mechanical damage to trees, is avoided.
- Even spreading is made possible.
- The ashes dissolve gradually.

The ashes are hardened by adding water and also by mechanical processing to produce particles of suitable size and hardness. Ashes can be treated by rolling to form granules or by compacting into pellets. Another possible technique is self-hardening with subsequent crushing and screening. The addition of plant nutrients and a bonding agent may also occur.

Standard values for chemical composition

Recommendations with respect to the chemical composition products made out of ashes are summarised in Table 5. The maximum content of micronutrients and heavy metals is set so that the maximum heavy metal input *for spruce forests* in southern Sweden is not exceeded when the application rate of ashes is in the order of 3 tonnes of dry matter/hectare.

The values given in the table refer to primary contents of the ashes that are spread in the forest, i.e. after any addition of plant nutrients and bonding agents, but without water. If the ashes contain a lot of inert material or a bonding agent, the contents in the ashes will be lower and can then be given per unit of weight of active ingredient. The chosen application should then be based on the active ingredient.

The main principle is that all substances are to fulfil the standard values. Minor deviations for individual elements are, however, acceptable. If the minimum contents given are not reached, then the possibility of introducing such nutrients to the ashes should be considered.

Table 5. Recommended minimum and maximum contents of elements in ashes intended for spreading in forest land. The value for the total polyaromatic hydrocarbons (iPAH) is preliminary.

Elements	Standard values	
	Lowest	Highest
Macronutrients, g/kg DM		
Calcium	125	
Magnesium	20	
Potassium	30	
Phosphorus	10	
Trace elements, mg/kg DM		
Boron		500
Copper		400
Zinc	1 000	7 000
Arsenic		30
Lead		300
Cadmium		30
Chromium		100
Mercury		3
Nickel		70
Vanadium		70
Organic environmental toxins, mg/kg DM		
Total PAH		2

Maximum heavy metal input with ashes

If the introduction of ashes entails a considerable increase in heavy metal content in forest land then negative ecological effects may result in both the short and long term. The risk of unwanted and acute effects in the soil is negligible if the ashes have been stabilised so as to give a slow rate of dissolving. In order for unwanted long-term effects to be avoided, the input of heavy metals must be limited and the maximum values given below should not be exceeded.

The guiding principle is that the quantity of heavy metals returned during a rotation must not exceed the quantity removed during the same period. A certain degree of standardisation and practical adaptation has been carried out in compiling the values given below. They are based on extraction in timber-rich stands and also with regard being taken to any local variation in biomass content. They are thus to be considered as maximum values that are not normally reached.

The highest acceptable input of heavy metals with ashes during a forest generation is given in Table 6 and Table 7. The differences between spruce and pine depend partly on the biomass being lower in the pine stand than in the spruce stand and partly on the contents differing between the species of tree.

Supporting documentation for providing maximum values for deciduous trees is not available and, instead, the maximum values for spruce can be used.

Table 6. Maximum values, i.e. maximum input of heavy metals with ashes or other compensation fertilisers to forest land with SPRUCE (or deciduous trees) during a forest generation

Heavy metal	**Southern Sweden***	**Central Sweden****	**Northern Sweden*****
	grams/hectare		
Arsenic	90	90	90
Cadmium	100	50	25
Chromium	300	200	150
Copper	1 200	600	500
Mercury	10	10	10
Nickel	200	200	200
Lead	1000	500	250
Zinc	20 000	15 000	10 000
Vanadium	200	100	100

* = south of 60 degrees of latitude
** = between 60 and 64 degrees of latitude
*** = north of 64 degrees of latitude

Table 7. Maximum values, i.e. maximum input of heavy metals with ashes or other compensation fertilisers to forest land with PINE during a forest generation

Heavy metal	**Southern Sweden***	**Central Sweden****	**Northern Sweden*****
	grams/hectare		
Arsenic	30	30	30
Cadmium	100	50	25
Chromium	300	200	200
Copper	800	800	500
Mercury	5	5	5
Nickel	200	200	200
Lead	400	200	100
Zinc	10 000	7 000	5 000
Vanadium	100	50	50

* = south of 60 degrees of latitude
** = between 60 and 64 degrees of latitude
*** = north of 64 degrees of latitude

Caesium

The National Radiation Protection Institute (SSI) has, in its "Policy for biofuel" (Reg. No. 822/504/99), specified, inter alia, that biofuel ashes that have a ^{137}Cs content of 5 kBq/kg or more should be put in depositories and not spread in the forest. At the moment, the SSI is preparing regulations regarding the handling of biofuel ashes that contain ^{137}Cs.

Stability of the ashes

Only stabilised (chemically or physically) ashes and ashes that take a long time to dissolve are to be used. Stabilised ashes considered to be ashes that are granulated, in pellet form or self-hardened/crushed ashes. The target is that the ashes or products made out of ashes shall dissolve over a period of 5 to 25 years in the field. Moreover, the initial speed of dissolution should be so slow that no acute, unwanted effects occur after spreading.

At present, reliable methods to characterise ashes with regard to the speed of dissolution in the field are not available. One way of estimating the stability of products made out of ashes is to measure the conductivity in water extracts in accordance with the reactivity analysis method described below. This gives a total measurement of the dissolution of salts from the ashes and indicates the risk of acute damage to vegetation, especially mosses and lichens. If the guiding values, given in Table 8, are exceeded for a product made out of ashes, the effects on ground vegetation should be examined more stringently before the product is spread on a greater scale.

Table 8. Preliminary target values in assessing products made out of ashes

Dosage	**Conductivity**
1 tonne/hectare	14 mS/cm
2 tonnes/hectare	12 mS/cm
3 tonnes/hectare	10 mS/cm

Another way of judging the characteristics of a product in the field is to use a method for leaching wood ashes (Larsson and Westling, 1999[8]).

This method demonstrates a conceivable process in the field with regard to the acid-neutralising ability of ashes and the release of nutrients. The method may be useful when comparing various products and working out routines for the production of compensation fertilisers. The method is based on the repeated leaching of ashes in a laboratory environment and indirectly describes the long-term leaching process under natural conditions. The leachate corresponds to several decades of precipitation in the field.

[8] Larsson, P.-E. and Westling, O. 1999. Leaching of wood ashes – a laboratory study. Report B 1325, 1999. IVL.

Quality control and chemical analytical methods

Sampling

The finished product is to be sampled but samples should also be taken of the ashes before processing. Sampling should be carried out in accordance with the guidelines given in the Nordtest Method NT ENVIR 004 for the sampling of solid waste particles, or SS 18 71 13 for biofuel and peat. Generally, sampling for analysis should take place for amounts of 250 - 500 tonnes of ashes or products made out of ashes, or at least once during the period (i.e. autumn to spring) when forest fuel is burnt. In larger combustion plants and plants that use pure forest fuel, sampling can be carried out less frequently than in plants using a greater variety of fuels and with different operational conditions.

Sampling should be carried out by using at least 15 sub-samples, each of which comprising 1 litre so that they represent the finished product as closely as possible. The sub-samples are to be carefully mixed to form a general sample. The number of sub-samples and their size will depend upon the homogeneity of the ashes. Additional sub-samples may be required if the ashes are evidently not homogeneous.

Sub-samples should preferably be taken from a conveyor belt or as the material is falling into a pile or hopper, etc. When taking samples from piles, the sub-samples must be obtained from various heights and depths in the piles.

Reference samples, from every general sample taken from the finished product, should be saved for at least three years together with its analytical value. It must be noted that hardening during the time in storage may impair the reactivity of the reference samples.

Chemical analyses

Accredited laboratories should conduct chemical analyses. The following analytical methods are recommended:

Total contents of macronutrients and trace elements

The target values for contents of macronutrients and trace elements given in Table 5 refer to total contents.

The following standard methods are recommended:

A. Digestion in lithium methaborate; analysis ICP-AES (ASTM 3682).

B. Digestion in HNO_3 + HCl + HF; analysis ICP-AAS, ICP-QMS (ASTM 3683)

The analyses can be used for practically all metals and P. Boron cannot be analysed using Method A. Volatile substances are analysed after decomposition in sealed containers.

Total contents comprise both easily dissolvable as well as slowly soluble fractions. The methods may, therefore, overestimate the value of the ashes as a source of potassium if it contains a lot of sintered material or inert material. Moreover, the accessibility of certain heavy metals is lower than the total analyses indicate.

Content of extractable macronutrients and trace elements

At present, research and development is underway into methods of characterising ashes with regard to availability of plant nutrient and toxic metals. As an approximate measure of the elements that may be released during a forest generation, an analysis of the fraction that is soluble in nitric acid is recommended. This method can be employed as a complement to total analyses, especially for ground ashes or other ashes suspected of containing inert material.

The method entails extraction in hot, concentrated (65 %) nitric acid on a plate or in sealed teflon containers in microwave ovens and following ICP-AAS (Haraldsson 2000[9]). It can be used for analyses of Ca, Mg, K, B, P, Cu, Zn, Mo, Co, Pb, Cd, As, Cr, Ni, and V. Extraction in sealed containers is required for the analysis of Hg.

Total polyaromatic hydrocarbons (PAH)

Analysis using HPLC or GC-MS after extraction in acetone/hexane or the equivalent. The total PAH is counted as the sum of 16 compounds (EPA 16).

Reactivity

Measurement of conductivity in water extracts

50 grams of ashes is mixed with 200 ml of deionised water (weight ratio 1:4) and shaken for one hour. After sedimentation in a sealed vessel for 15 – 30 hours, the conductivity and pH are measured in the clear solution.

Leaching of wood ashes

The leaching of ashes using a leaching liquid comprising deionised water adjusted to pH 4.0 (mixture ratio 1:2000): the leaching liquid is decanted after 24 hours and new liquid is added. The decanted liquid is analysed. This procedure of replacing liquids is continued for 30 days (Larsson and Westling, 1999[10]).

[9] Haraldsson 2000. See the National Board of Forestry web page (www.svo.se)
[10] Larsson, P.-E. and Westling, O. 1999. Leaching of wood ashes – a laboratory study. Report B 1325, 1999. IVL.

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Forests have a significant role in Swedish energy supplies. The predominant part of the energy from forests originates from stemwood but the extraction of branches and tops for energy purposes has also become common in many places. There is a considerable increase in the removal of nutrients when not only stemwood but also branches and tops are harvested. It is essential that these activities do not imply a threat to biodiversity in the forest, that the nutrient conditions in forest soil are maintained and that conditions in subsoil water, lakes, watercourses or seas are not impaired.

In this publication, the National Board of Forestry presents its view on how the extraction of branches and tops and the return of ashes should be conducted in order to conform to present forest policy regarding sustainable production and the preservation of biodiversity.

In the long term, an increase in the removal of nutrients requires that compensation for the lost elements must be carried out. This is important but has not yet begun to be implemented on any particular scale. One section of this text deals with compensation fertilising, in which guidelines are given regarding the quality of ashes, application rates and quality control.