SNAP CODE: **110401**
110402
110403
110404

SOURCE ACTIVITY TITLE: **OTHER SOURCES AND SINKS**
Natural Grassland and Other Vegetation
Grassland
Tundra
Other Low Vegetation
Other Vegetation (Mediterranean scrub,)

NOSE CODE: **301.04.01**
301.04.02
301.04.03
301.04.04

NFR CODE: **N/A**

1 ACTIVITIES INCLUDED

This chapter deals with NMVOC emissions from all types of grasslands and other types of vegetation (natural, semi-natural and in some cases cultivated) which do not fit easily into the forest classification. This includes especially the Mediterranean maquis/garrique and other low scrub-type vegetation, heathland, Tundra, etc. Table 1.1 outlines some examples within the SNAP codes.

Most of the grasslands in mid- and northern Europe are agriculturally used for either harvesting hay (meadows) or for grazing (pastures). Natural grasslands can be found in alpine regions above the timberline (alpine Tundra), at lower elevation northwards of the timberline (boreal Tundra), in dry climatic regions with poor soil (Steppe), on saltfloors and on moorland.

Low vegetation (< 5 m height), apart from grassland, is widespread across Europe. For example, in many parts of Europe moorland and heathland cover large areas, with *Erica sp, Ulex sp., Calluna sp., Pteridium sp.,* and similar species being common. In the Mediterranean region maquis, garrique and jaral are characteristic landscapes (see definitions, 3.2).

Many types of vegetation could be covered within this system, and many overlap with other SNAP categories. E.g. reed vegetation, or maritime coastal vegetation (halopsammophytic), could be included here or under SNAP1105 (wetlands). Unfortunately, we have no information on emission rates yet, so this particular problem does not arise. More importantly, methods are given here for calculating VOC emissions from Agricultural crops such as wheat, as the methodology is identical to that for other vegetation. These emissions should be entered under SNAP-level 10-Agriculture, and not SNAP-11 - Other sources and sinks.

Emissions of N_2O are assumed to follow IPCC methodologies and so are not covered here. Emissions of NO_x from the soil are dealt with in a separate chapter covering all types of forests and grasslands. Emissions arising from fires are covered in SNAP 1103 (Forest and other vegetation fires). Emissions of CH_4 should strictly be treated also in the soils section, but in any case are assumed to be zero (the flux is probably to the ground, not to the atmosphere).

Table 1.1: Classification scheme for grassland and other non-forest vegetation in Europe

110401	Natural grassland Pastures, Meadows, Steppe
110402	Tundra alpine Tundra, boreal (treeless) Tundra
110403	Other low vegetation Heathland, Moorland Miscellaneous dwarf shrub vegetation(Garrique etc.)
110404	Other vegetation Maquis
100205	Grasslands (Agricultural) Agricultural grassland of low and medium productivity (< 8 t ha^{-1} yr^{-1} yield), Agricultural grassland with high productivity (> 8 t ha^{-1} yr^{-1} yield)

2 CONTRIBUTIONS TO TOTAL EMISSIONS

According to the CORINAIR-1990 inventory, natural grassland accounts for 0.6% of European NMVOC emission, 0.4% of CH_4 emissions, 2.9% of N_2O emissions and 0.3% of NH_3 emissions. However emission rates for NMVOC need to be substantially revised. Simpson et al., 1998, using the recommended defaults in this chapter estimate that pastures and meadows may contribute nearly 1 Mt to European NMVOC emissions (ca. 4%) and crops also ca. 1 Mt. Uncertainties are still very large and in some other areas emissions might be appreciable, e.g. the NH_3 emission from pastures (due to animal droppings) and meadows (in particular when fertilised with manure).

The area coverage of grasslands in Europe is second highest after forests, however the biomass density of grasslands is often lower than the foliar biomass density of forests.

The emissions from other low vegetation were not covered in CORINAIR-90/94, however their emissions may have been included by some countries under the "forest" SNAP codes.

These activities are not believed to be a significant source of $PM_{2.5}$ (as of December 2006).

3 GENERAL

3.1 Description

Emissions of NMVOC from plants are usually divided into isoprene, monoterpene, and OVOC (other VOC) emissions for inventory purposes. In general isoprene and monoterpene emissions are the most photochemically reactive and hence of most interest for ozone studies. However, for grasslands the major emission probably consists of OVOC, and these may be significant in mass terms.

Only a small number of screening studies have been undertaken until now to survey biogenic VOC emissions from non-forest vegetation.

Hewitt & Street (1992) tested the 21 most abundant grass and herbaceous species in the U.K with a qualitative method. Only purple moor grass (*Molinia caerulea*), bracken (*Pteridium aquilinum*) and common gorse (*Ulex europaeus*) were found to emit isoprene, and only ivy (*Hedera helix*) and cocksfoot grass (*Dactylis glomerata*) found to emit monoterpenes. 28 species of agricultural crops were also screened, of which only blackcurrant (*Ribes nigrum* v. Ben Sark and Ben Lomond) produced any significant emissions. The only major species, in terms of abundance, of which no varieties were tested was winter barley (*Hordeum vulgare*). As pointed out by Hewitt & Street, genetically different varieties of the same species may display different emission characteristics to those found above, but these data strongly suggest that isoprene as well as terpene emissions from crops and grasses are not important in the U.K. This result supports the previous findings that grasses and grass related crops are generally no or low emitters for isoprene and terpenes. (However, other VOC emissions are probably very significant).

A compilation of biogenic VOC emissions from crops and "hay" (meadows for hay production) from US sites is found in Lamb et al. (1993). Except for Tomato and Maize (Corn) all agricultural crops tested as well as "hay" were classified as "low emitters" (emission rate of all VOC determined < 1 µg g^{-1} h^{-1} DW) in the Lamb et al. (1993) study (Table 8.4). However, in their compilation the chemical nature of VOC other than isoprene and terpenes (OVOC) has not been specified, though for several crop species the OVOC emission rate exceeded the emission rates of the "classical" biogenic VOCs isoprene and terpenes. Arey et al. (1991) and Winer et al. (1992) investigated emission rates from a number of agricultural crops and from a perennial grassland plot in the US in more detail (Table 8.1). They specified the "OVOCs" and found (Z)-3-hexenol ("leaf alcohol") and (Z)-3-hexenylacetate ("leaf ester") in many crops as the two most dominant compounds of the group of "OVOCs".

Very little is known of emissions from shrubs and bushes, except that obtained as a result of a limited number of intensive field campaigns held at a few locations in the north-western Mediterranean region, as part of the Biogenic Emissions in the Mediterranean Region (BEMA) project (e.g. Owen et al, 1997) and in the U.K. (e.g. Cao et al., 1997). Additionally a limited amount of screening work has been carried out on these ecosystems (e.g. Hewitt and Street, 1992).

However, the vegetation species found in these ecosystems are often very aromatic and hence may be expected to emit a very wide and complex range of volatile organic compounds. This is especially so for Mediterranean vegetation. By far the majority of efforts to date have been focused on the emissions of isoprene and monoterpenes, so it is difficult to quantify the emissions of these other VOC, including the oxygenated compounds. Additionally, nothing is known of the emission of nitrogen and sulphur compounds from these plants.

There are very few data about VOC emissions from single herbaceous species which may occur in certain areas in relatively large quantities. An example is *allium ursinum* (wild garlic) which grows in mid and northern Europe in beech and other mixed hardwood forests in spring with biomass densities up to 300 g m^{-2}. Although wild garlic emits no isoprene and only a little of terpenes, the emission rate of OVOCs was found to be 2.6 µg g^{-1} h^{-1} DW (Puxbaum & König 1997) and thus it can be classified as "high OVOC - emitter". Similarly Tanner & Zylinska (1994) found relatively high emission rates of oxygenated terpenoids (> 4 µg g^{-1} h^{-1} DW) in undercover vegetation (tarweed) in the San Joaquin Valley. Although these examples are for species under forests - and not in grasslands, they might indicate that there might be grassland biomes which contain herbaceous plants with higher emission rates than those to be recommended in section 8.

König et al. (1995) tested VOC emissions from agricultural plants such as wheat, rye, rape, grape and three types of grassland in East Austria. They used the Arey et al. (1991) approach to include also specified OVOC emissions. In terms of prevalence of one of the groups of emitted VOCs (isoprene, terpenes, OVOC) wheat, rye, oilseed rape, grape and two of the grass plots examined were "OVOC" - emitters. However, for one of the examined grass plots, terpene and OVOC - emissions were of equal importance (grassland A3, Table 8.2). After mowing of one of the grass plots the emissions of terpenes and OVOCs increased roughly by a factor of three. The same group performed a measurement campaign in Northern Germany in 1995. Although the results are not published until now, we include the data for an examined grass plot (grassland G in Table 8.2, Puxbaum et al., in preparation). The data fit well into the results for grasslands from the above mentioned studies from the US and Austria.

3.2 Definitions

OVOC - Other non-methane VOC, excluding isoprene and terpene. Usually used to encompass a wide range of emitted VOC - see section 9.

BMD - Biomass density (g m^{-2} DW) averaged over vegetation period

DW - dry weight of plants(used for emission rates), as opposed to fresh weight.

NPP - Net primary production (g Carbon m^{-2} yr^{-1}) Buildup of biomass carbon during a year

PAR- Photosynthetically active radiation, typically about 45-50% of total global radiation.

Grasslands are areas which are dominated by grassy plants, but usually also containing other herbs. There are mainly two families of grassy plants: *poaceae* ("sweet grasses") and *cyperaceae* ("acidic grasses"), the first of the two occurring most frequently in European grasslands.

Tundra - vast level treeless (almost) Arctic region where subsoil is frozen.

Names and definitions of Mediterranean landscape classes vary from country-to-country and from author-to-author (Di Castri et al., 1981). However the following are in common usage:

Maquis
- also known as matorral denso, espinal (ES), chaparral (UK, USA), macchia alta (IT).
- comprising evergreen shrubs and small trees, typically olive (*Olea oleaster)*, carob (*Ceratonia siliqua*), dwarf *Quercus ilex* and *Erica multiflora*

Garrique
- also know as maturral claro (ES), scrub (UK), macchia bassa (IT)
- comprised of mid-height shrubs, 0.6-2 m high on calcerous soils, typically *Pistachia lentiscus*, *Arbutus unedo*, *Myrtus communis* and *Ulex sp*.

Garrique is sometimes used for vegetation less than 0.6 m high also, in which case **lande** (FR), **tomillar** (ES), **gairriga** (IT), **phyrgana** (GR) are alternative names.

Jaral
- similar sized shrubs on siliceous soils, e.g. *Erica sp*., *Cistus sp*.

3.3 Techniques

Not applicable

3.4 Emissions

This chapter deals with NMVOC - emissions of grassland and other low vegetation including crops. As for forests, NMVOC species are classified into three groups: Isoprene, Terpenes (Mono- and Sesquiterpenes), OVOC (other VOC). The composition of OVOC is discussed in section 9.

3.5 Controls

Principally there seems to be no control to natural emissions by definition, however land-use changes obviously can significantly affect total emissions (e.g. very early changes which date back to the bronze age, when forests were cleared in Europe to gain agricultural land and meadows, or more recent changes due to nitrogen deposition where heather gets converted to grassland).

4 SIMPLER METHODOLOGY

Grasslands and other low vegetation ecosystems consist generally of plant communities (except for crops which are usually monocultures). Often a few species dominate the

community. We introduce a classification scheme for grassland and other low vegetation in Europe (Table 8.2), but emission rate data for grasslands are not available for the different types. Similarly for Mediterranean shrubland landscapes it does not seem possible at present to subdivide into species for inventory purposes, and northern moorlands and heathlands must also be treated together.

We therefore recommend the use of ecosystem-wide rates for dealing with these types of vegetation. However, we give emission rates for individual species where known. These may be used to devise more appropriate ecosystem rates for particular regions, or to conduct a species-specific approach if desired.

For all types of vegetation, an appropriate system describing the emissions flux on an hourly basis is that of Guenther et al. (1996):

$$\text{Flux } (\mu g\ m^{-2}\ yr^{-1}) = \int \varepsilon \,.\, D \,.\, \gamma \ dt \qquad (1)$$

where ε is the average emission potential ($\mu g\ g^{-1}\ h^{-1}$) for any particular species, "D" is the foliar biomass density (g dry weight foliage m^{-2}), and γ is a unitless environmental correction factor representing the effects of short-term (e.g. hourly) temperature and solar radiation changes on emissions. For isoprene emissions, and light-activated terpene emissions (so far only quantified for two forest species, *Picea abies* and *Quercu ilex*), γ is a function of light and temperature, and is denoted γ-iso. Terpene and OVOC emissions from most vegetation types are simply dependant on temperature, in which case γ is temperature-only dependant, and denoted γ-mt.

The simplified methodology consists of modifying equation (1) to be a seasonal rather than an hourly calculation.

$$F = \varepsilon \,.\, D \,.\, \Gamma \qquad (2)$$

Where Γ represents the integrated value of γ over the growing season of the vegetation concerned.

The total emission from an area is then obtained in a detailed methodology by calculating F every hour for each vegetation category and group of VOC compounds and multiplying by the appropriate areas.

Using meteorological data from the EMEP MSC-W models the integrated values, Γ-iso and Γ-mts, have been calculated for both 6 monthly (May-October) and 12 monthly growing seasons, as averages over each country. These have been calculated from hourly γ values, and thus have units of hours. The Γ values are tabulated in Table 4.1. With this simplified methodology we could estimate for example the OVOC emissions from 1 km^2 of grassland as simply:

$$\text{Emission} = \text{Area} \times \varepsilon \,.\, D \,.\, \Gamma\text{-mts}$$
$$= 1000\,000\ m^2 \times 1.5\ \mu g\ g^{-1}\ h^{-1} \times 500\ g\ m^{-2} \times \Gamma\text{-mts h}$$

For Austria, for example, Table 4.1 gives Γ-mts (=Γ-ovoc) for 6-months as 588, therefore we have:

Emission = 1000 000 m^2 x 1.5 μg g^{-1} h^{-1} x 500 g m^{-2} x 588 h = 441 kg km^{-2}

Table 4.1: Country average values of integrated environmental correction factors, Γ-iso and Γ-mts for 6 and 12 month growing seasons (unit = hours).

	Γ-mts (= Γ-ovoc)		**Γ-iso**	
	6-month	12-month	6-month	12-month
Albania	745	976	563	719
Austria	588	734	452	540
Belarus	753	895	581	684
Belgium	739	969	580	712
Bosnia Herzegovina	709	893	561	686
Bulgaria	824	1029	620	755
Croatia	883	1121	667	815
Czech_Republic	712	885	533	633
Denmark	518	704	373	485
Estonia	565	669	422	491
Finland	458	523	339	379
France	840	1107	669	829
Germany	698	890	525	632
Greece	1076	1440	816	1057
Hungary	966	1188	730	874
Ireland	467	713	337	478
Italy	904	1208	711	902
Latvia	636	757	486	572
Lithuania	675	813	516	613
Luxembourg	786	1003	620	745
Macedonia,F.Y.R.	631	783	492	597
Moldova, Rep. of	858	1040	649	771
Netherlands	676	901	513	643
Norway	327	397	240	284
Poland	736	912	558	669
Portugal	1015	1388	853	1093
Romania	783	964	587	706
Russia, Fed.	808	917	637	717
Slovakia	797	977	607	724
Slovenia	745	940	562	682
Spain	982	1301	806	1004
Sweden	423	508	315	368
Switzerland	465	580	368	432
Turkey	976	1263	783	983
United_Kingdom	493	720	358	492
Ukraine	856	1023	656	771
Yugoslavia	752	937	557	674

5 DETAILED STATE OF THE ART METHODOLOGY

For a more detailed calculation the environmental correction factors (γ-iso, γ-mts) may be calculated explicitly on a monthly or an hourly basis if relevant meteorological data are available. The procedure is identical to that presented for forest emissions in 1101, 1102, and is not repeated here.

6 RELEVANT ACTIVITY STATISTICS

The relevant statistics are vegetation cover, foliar biomass density, and possibly monthly and/or hourly temperature and radiation parameters if the detailed methodology is to be pursued.

Vegetation coverage in terms of the vegetation types discussed in section 8 are required, together with foliar biomass estimates (D), and estimates of growing seasons. Grasslands are found in land use statistics generally under grassland, pastures and possibly meadows. Care should also be taken not to double count species/vegetation types.

We have not found a comprehensive discussion of biomass densities. However, there is information about the annual net primary production (Ruimy et al., 1994, Lieth and Whittaker, 1975). Data for natural grasslands are compiled in Table 6.1.

Table 6.1: Compilation of Annual Net Primary Production for Grasslands (g C m^{-2} yr^{-1}) according to Ruimy et al. (1994) and Lieth and Whittaker (1975) and estimate for default biomass density values. BMD = Biomass density.

	"REF" Ruimy et al.	"MEAN" Lieth&W	default BMD g m^{-2} DW
Tundra	100	50	100
Savanna	530	400	500
Temperate grasslands	470	300	450

Notes: The default biomass densities (BMD) are derived in the following way: The net primary production is the build up of new biomass in the vegetation period in g C m^{-2} yr^{-1}. The conversion factor from C (Carbon) to biomass DW is 2.2 (Ruimy et al., 1994). It is assumed that 50 g m^{-2} biomass is remaining from the past year. The new (at the end of the vegetation period) and old biomass value is averaged over the vegetation period.

For Alpine grasslands the following defaults are recommended:

	D (g m^{-2} DW)
Alpine pastures above timberline:	50
Mid productivity alpine grassland (1-3 cuts)	200

For heathlands and moorlands very little data is available. We recommend a default based upon the biomass density of Gorse, which is widespread in the UK, assuming 50% coverage:

	D (g m^{-2} DW)
Heathland /moorland	175

For Mediterranean scrublands, the following are recommended:

Maquis	400
Garrique/low-scrubland	200
Monte-hueco*	100

* mixed pastures and trees, mainly Holm and Cork oaks.

For Karelian (Russian) spruce forests (marshy-grassy-types) the following data are available. The ground-biomass densities of Russian forests are probably larger though than those of many managed forests in other parts of Europe:

	D (g m^{-2} DW)
Forest grass-biomass	90
Forest ferns	14
lichen+mosses	100-300
shrub, including berries	10-30

For a more detailed evaluation of D, local information is required. Some insight about the biomass of meadows can be obtained from harvest yields of hay. In Austria the yield of hay is of the order of 6-10 t ha^{-1} and more, which is equivalent to 600-1000 g m^{-2} harvested dry biomass. The frequency of harvests per year is 1-6, depending of altitude and fertilisation. If we assume that after harvest a biomass density of 50 g m^{-2} remains, and there is a linear growth rate between harvests, the annual average biomass density is estimated to 200-300 g m^{-2}. This number is for medium productive grassland in the alpine region and is lower than Lamb et al's (1987) estimate for meadows for hay production in the US of 540 g m^{-2}. However, in highly productive grasslands in flat terrain in Europe the biomass density might be as high as the Lamb et al. 1987 estimate.

For agricultural grassland an estimation of the vegetation period averaged biomass density can be obtained by the following formula:

$$BMD = [Y * 100/2 * n] + 50$$

Where BMD is biomass density (g m^{-2} DW), Y is yield of biomass DW per vegetation period (t ha^{-1}), n is the number of cuts per year, and 50 is the biomass remaining after cutting

7 POINT SOURCE CRITERIA

No point sources

8 EMISSION FACTORS, QUALITY CODES AND REFERENCES

NMVOC

For grassland areas the emission potentials (ε, equation 1) should be given as standardised values at 30 °C and for full sunlight=1000 µmole photons m^{-2} s^{-1} PAR. A summary of default ecosystem-type emission factors which seem appropriate especially for European species is given in Table 8.1 below

Table 8.1 Ecosystem-default emission potentials (ε) for isoprene (iso), terpenes (mts) and OVOC, and biomass densities. ε (µg g^{-1} DW h^{-1}) is given for 30°C and 1000µmol PAR.

Ecosystem	D (g m^{-2} DW)	ε-iso	ε-mts	ε-ovoc	Main reference
Grass	400*	0	0.1	1.5	K
Maquis	400	8	0.65	1.5	O,G95
Garrique	200	8	0.65	1.5	O, G95
Monte-hueco	100	1	10**	1.5	***
Moorland/heathland	350	8	0.65	1.5	C

Notes: * but see section 6 for Alpine grasslands; ** Calculate with γ-iso. All other terpenes with γ-mts; *** Assumes ca. 50% *Q.ilex*, 50% *Q.suber*; K=König et al., 1985, C=Cao et al., 1997, G95=Guenther et al., 1995, O=Owen et al. 1997

It is important to note that the 1.5 µg g^{-1} h^{-1} rate for OVOC given here is a default (from Guenther et al., 1995) with a wide uncertainty range. Almost all measurements have used methods for the determination of VOCs, which are not capable of finding and quantifying polar compounds with less than four carbon atoms (e.g. methanol, formaldehyde, etc.). For this reason the OVOC results in these tables also list separately OVOC ≥ C_4 and OVOC<C_4 if known. Recently it was shown that plants may emit methanol (MacDonald & Fall 1993), low molecular weight aldehydes (Kotzias et al. 1997) and low molecular weight organic acids (Bode et al. 1997) in relevant quantities. For grasslands and crops no data are available however to quantify this further.

The following tables give species-specific emission potentials and some more detail about the OVOC split.

Table 8.2: Species-specific emission potentials in µg g^{-1} h^{-1} dry weight of plants for grassland (SNAP 110401) normalised to 30°C, PAR levels not specified

	Biomass density g m^{-2}	**ε-iso**	**ε-mts**	**ε-ovoc**	**OVOC split (>C_4,<C_4)**	**Refs**
USA:						
"hay"	540	0.07	0.175	1.5	(0.11*,n.a.)	L
Grassland#		n.d.	0.015	1.5	(0.06,n.a.)	A/W
Europe:						
Grassland A1		0.001/C§	0.02	1.5	(0.015,n.a.)	K
Grassland A2	300	0.002/S§	0.015	1.5	(0.06,n.a.)	K
Grassland A3	420	0.003/S§	0.07	1.5	(0.08,n.a.)	K
Grassland A3m (after mowing)	420	0.002/S§	0.20	1.5	(0.27,n.a.)	K
Grassland G	230	n.d./xx§	0.03	1.5	(0.15,n.a.)	P/
Recommended default for grassland	**400****	**0**	**0.1**	**1.5**		

Notes: n.d. not detected; n.a. not analyzed; S§ measured under sunny conditions; C§ measured under cloudy conditions; *OVOC not specified; ** see also section 6. ; # perennial natural grassland; A1) grassland under oak forest; A2) grassland with no flowers, 35 cm height; A3) grassland with some flowers, 25 cm height; A3m) grassland 3 mowed; G grassland in northern Germany.
Refs: L: Lamb et al. 1987, 1993, A/W: Arey et al. 1991, Winer et al. 1992, K: König et al. 1995, S: Street et al. 1997, P: Puxbaum and König 1997, P/: Puxbaum et al. in preparation, Tanner and Zylinska 1994.

Table 8.3: Species-specific emission potentials in µg g^{-1} DW h^{-1} for shrubs and low vegetation, standardised to 30 °C and 1000 µmol m^{-2} s^{-1} PAR.

NOTE: Many tree species can be shrub like - their emission potentials may be found for these in the chapter covering forests (SNAP1101,etc.)

Common name (**example**)	-	ε-iso.	ε-mts	ε-ovoc$	References	
					Iso	Terp.
Wild garlic	Allium_ursinum	0	0	3	P	P
-	Anthyllis	0.1	0.2	1.5	O	O
Strawberry tree-	Arbutus	0.1	0.2	1.5	B3,O	O
-	Arundo	60	0.2	1.5	O,H90,B3	B3
	Artemisia	0	0.2	1.5	P/	P/
Dwarf_boxwood	Buxus	10	0.2	1.5	O,B3	B3
Carob	Ceratonia	0.1	0.65	1.5	O	O
	Chrysanthenum	0.1	0.65	1.5	O	O
Rockrose	Cistus	0.1	0.2	1.5	O	O
Broom	Cytisus	20	0.2	1.5	S:Sf;B3	B3,-O
Tree_heath	Erica	5	0.2	1.5	S:Sf:O	B3,O
	Helichrysum	0.1	3	1.5	O	O
Tarweed	Holocarpha	0	3	3	TZ	TZ
Juniper	Juniperus	0.1	0.65	1.5	S:Sf;B3	B3,O
Lavender	Lavendula	0.1	0.65	1.5	S	O
Common_myrtle	Myrtus	34	0.2	1.5	S:Sf;B3	O
	Phillyrea	0.1	0.65	1.5	O	O
	Rhamus	20	0	1.5	O,B3	B3
Rosemary	Rosmarinus	0	1.5	1.5	S:Sf	Ha
Sage	Salvia	0.1	1.5	1.5	B3	B3
Broom	Spartium	5	0.2	1.5	S:Sf;O	B3,O
Bil/blueberry	Vaccinium	0.1	0	1.5	B3	B3
Gorse	Ulex	8	0.65	1.5	S:B,i6;C;B3	B
Grape	Vitis	0.1	0.1	1.5	B3	A,-K

Notes: $We have used a default ε-OVOC of 1.5 µg g^{-1} h^{-1} for all compounds except Wild garlic, which includes 1.6 µg g^{-1} h^{-1} oxygenated compounds, 1.0 µg g^{-1} h^{-1} h carbon from sulphurous organics, and tarweed for which TZ give higher rates. References as for Table 8.1, plus B3=Guenther et al. 1998, O=Owen et al.,1997, Sf=Seufert et al., 1997.

Table 8.3: Emission rates in µg h^{-1} g^{-1} dry weight of plants for crops, normalised to 30°C, PAR levels not specified

	Biomass density g m^{-2}	**ε-iso**	**ε-mts**	**ε-ovoc**	**Measured OVOC split (>C_4,<C_4)**	**Authors**
Wheat (*Triticum*)**:**						
USA	740	0.002	0.008	1.5	(0.03*,n.a.)	L
USA	n.a.	0	0	1.5	(0.05,0.5*)	A/W
Europe (after bloom)	800	0/S§	0	1.5	(0.016,n.a.)	K
Rye *(Secale)***:**						
USA	2430	0.003	0.008	1.5	(0.005*,n.a.)	L
Europe	400	0/S§	0.10	1.5	(0.25,n.a.)	K
Barley *()***:**						
USA	1290	0.006	0.015	1.5	(0.009,n.a.)	L
Oats *(Avena)***:**						
USA	750	0.01	0.026	1.5	(0.0015*,n.a.)	L
Recommended default for grass related crops	**800**	**0.002**	**0.1**	**1.5**		
Other crops:						
"High emitters":						
Maize/Corn US	1610	0	0.22	1.5	(0.88*,n.a.)	L
Maize/Corn Europe	n.a.	0	0	1.5	6.4 1.0	S R
Tomato (S.)	n.a.	0	13.2	1.5	(0.4,n.a.)	A/W
Tomato (C.)	n.a.	0	21.8	1.5	(1.2,n.a.)	A/W
Miscellaneous						
Alfalfa	3250	0.005	0.2	1.5	(0.6,n.a.)	L, A/W
Safflower	n.a.	0	0.3	1.5	(0.7,n.a.)	A/W
Sorghum	3180	0.002	0.03	1.5	(1.0,n.a.)	L, A/W
Rice	1050	0.10	0.24	1.5	(0.15*,n.a.)	L
Tobacco	490	0	0.12	1.5	(0.48*,n.a.)	L
Soybeans	740	0.03	0	1.5.	(n.a.,n.a)	L
Sunflower	n.a.	0.05	0.7	1.5	(0.3,n.a.)	SCH
Oilseed Rape	400	0/S§	0.12	1.5	(0.23,n.a.)	K
Grape:						
USA (T.S.)	n.a.	0	0	1.5	(1.4,n.a.)	A/W
USA (F.C.)	n.a.	0	0.07	1.5	(1.3,n.a.)	A/W
Europe (Ch.)	410/l.o.	0.002/S§	0.002	1.5	(0.05,n.a.)	K
Misc. crops default	**1335**	**0.09**	**0.13**	**1.5**	**(0.6,0.9)*** **	

Notes: 0 not detected. n.a. not analyzed. S§ measured under sunny conditions.
*OVOC not specified; *** the OVOC <4C emission rate is a guess based on very little data l.o. leaves only.
Refs: L: Lamb et al. 1987, 1993, A/W: Arey et al. 1991, Winer et al. 1992, K: König et al. 1995, S: Street et al. 1997, R: Rudolph et al. (in press).

9 SPECIES PROFILES

As with forest NMVOC emissions, biogenic emissions from grasslands consist of a wide variety of species, including isoprene, monoterpenes, (alpha-pinene, beta-pinene, limonene, etc.), and 'other' VOC. The 'other' VOC (OVOC) species consist of a large number of oxygenated compounds (alcohols, aldehydes, etc.), and have proven difficult to quantify in atmospheric samples. Progress in quantification of OVOC from European vegetation has been made recently (König et al. 1995, Puxbaum 1997), although many more measurement data will be required before reliable attempts to inventory specific OVOC can be made.

Section 8 has already presented separate emission rates for isoprene, terpenes, and $<C_4$, $>C_4$ OVOC. However, within each of these groups a wide range of species are emitted, as indicated by Table 9.1.

Table 9.1. Main emitted single VOC species (Rank 1-3) emitted from grassland plots and various crops (compiled from König et al. 1995 and Puxbaum et al. in preparation). Note that $<C_4$ organic compounds have not been determined in these studies.

Plot	Rank 1	Rank 2	Rank 3
Grassland A1	a-Pinene	Leaf ester	Hexanal
Grassland A2	Leaf ester	Leaf alcohol	Limonene
Grassland A3	Leaf ester	1,8-Cineol	a-Pinene
Grassland G	Pentanal	Leaf ester	Limonene
Wheat	Leaf ester	Hexanal	2-Pentanone
Rye	1-Hexanol	Leaf alcohol	2-Methyl-1-propanol
Rape	Leaf ester	Limonene	Sabinene
Grape (Chardonnay)	Butanone	Leaf ester	Hexanal

Leaf ester: (Z)-3-hexen-1-ol-acetate, Leaf alcohol: (Z)-3-hexen-1-ol

10 UNCERTAINTY ESTIMATES

With so few data it is very difficult to quantify the uncertainties. Quality codes for all grassland vegetation should probably be "E".

11 WEAKEST ASPECTS/PRIORITY AREAS FOR IMPROVEMENT IN CURRENT METHODOLOGY

Very few measurements are available of VOC emissions from natural grasslands. Emissions of "other" VOC" $< C_4$ in particular (see e.g. aldehyde and ketone emissions from corn as determined by Street et al. 1997) are possibly significant but virtually unquantified for grasslands. In the same way emissions of "other" VOC" $< C_4$ for crops are unknown.

More data are needed about NMVOC emissions for major grassland and shrub-type biomes in Europe, in particular also from Northern, Eastern, and Southern Europe. E.g. there is hardly any information about heather , Tundra, grasslands in the mountainous regions in Northern Europe with ferns and other scrub, alpine pastures, Steppe, etc.

12 SPATIAL DISAGGREGATION CRITERIA FOR AREA SOURCES

Given by vegetation coverage and climate.

13 TEMPORAL DISAGGREGATION CRITERIA

Given by equation (1) if required. It has to be kept in mind, that grassland vegetation in Europe is generally perennial, although in some cases snow-covered. However no data about emissions in the cold season are known.

A detailed treatment could also take into account the changes in biomass density over the growing season. Methods are given in Guenther et al., 1995, for many vegetation types which allows for the gradual changes in biomass dependant on NPP. A more extreme temporal variation is caused by cutting on agricultural or semi-natural areas: an example an alpine meadow at lower elevation with 3 cuts in a season is shown in Figure 13.1.

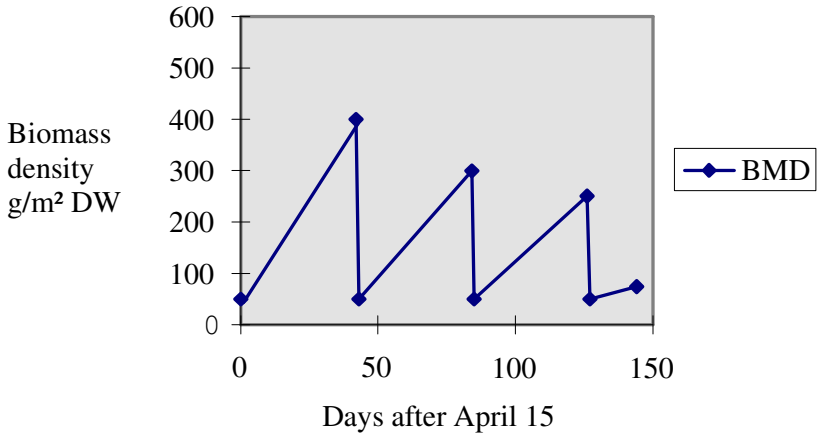

Figure 13.1: Biomass development on a 3-cut alpine meadow

14 ADDITIONAL COMMENTS

For modelling purposes the terpenes and OVOC emissions have to be speciated in some way. As the major emission is OVOC, one could use methanol for the $<C_4$ OVOC and hexenylacetate for $>C_4$ OVOC.

15 SUPPLEMENTARY DOCUMENTS

A land surface characterisation for global mapping purposes is described by DeFries et al. (1995). An interesting feature in this approach is the discrimination between C3 and C4 plants.

The American Biogenic Emission Inventory System (BEIS) has an extensive list of emission potentials. The latest version is documented by Guenther et al. (1998).

16 VERIFICATION PROCEDURES

If satellite data have been used in the land-use mapping process it is essential that these are independently verified by on-the-ground surveys. Large errors are possible in the identification of vegetation types and biomass from remote sensing methods.

In general all of the emission potentials are built upon very few data. More measurements are required of at least the major sources, and several different measurement techniques need to be applied in order to eliminate the artefacts (enhanced emissions) easily generated by disturbances to the vegetation.

17 REFERENCES

Arey, J., Winer, A.M., Atkinson, R., Aschmann, S.M., Long, W.D., and Morrison, C.L., 1991, The emission of (Z)-3-hexen-1-ol, (Z)-3-hexenylacetate and other oxygenated hydrocarbons from agricultural plant species. Atmos. Environ. 25A, 1063-1075.

Bode, K. Helas, G., Kesselmeier, J., 1997, Biogenic contribution to atmospheric organic acids. In: Helas, G., Slanina, J., and Steinbrecher R. (eds.) Biogenic volatile organic carbon compounds in the atmosphere, pp.79-99, SPB Academic Publishing, Amsterdam.

Cao, X.-L., Boissard, C., Juan, A.J., Hewitt, C.N., and Gallagher, M., 1997, Biogenic emissions of volatile organic compounds from gorse (*Ulex europaeus*): Diurnal emission fluxes at Kelling Heath, England, J. Geophys. Res., 102, No. D15, 18903-18917.

De Fries R.S. and 14 co-authors , 1995, Mapping the land surface for global atmosphere-biosphere models: Towards continuous distributions of vegetation's functional properties, J. Geophys. Res. 100, 20,867-20,882.

Geron, C.D. , Pierce, T.E. , and Guenther, A.B. , 1995, Reassessment of biogenic volatile organic compound emissions in the Atlanta area, Atmos. Environ., 29, No. 13, 1569-1578.

Guenther, A.B. , Zimmerman, P.R. , Harley, P.C. , Monson, R.K. , and Fall, R. , 1993, Isoprene and monoterpene rate variability: model evaluations and sensitivity analyses, J. Geophys. Res., 98, No. D7, 12609-12617.

Guenther, A. , Zimmerman, P. , and Wildermuth, M. , 1994, Natural volatile organic compound emission rate estimates for U.S. woodland landscapes, Atmos. Environ., 28, 1197-1210.

Guenther, A. , Hewitt, C.N. , Erickson, D. , Fall, R. , Geron, C. , Graedel, T. , Harley, P. , Klinger, L. , Lerdau, M. , McKay, W.A. , Pierce, T. , Scholes, R. , Steinbrecher, R. , Tallamraju, R. , Taylor, J. , and Zimmerman, P. , 1995, A global model of natural volatile organic compound emissions, J. Geophys. Res., 100, No. D5, 8873-8892.

Guenther, A. (1997): Seasonal and spatial variations in the natural volatile organic compound emissions. Ecological Applications 7(1) 34-45.

Guenther, A., J. Greenberg, D. Helmig, L. Klinger, L. Vierling, P. Zimmerman, and C. Geron (1996) Leaf, branch, stand and landscape scale measurements of volatile organic compound fluxes from U.S. woodlands. Tree Physiology, 16, 17-24.

Guenther, A., C. Geron, T. Pierce, B. Lamb, P. Harley, and R. Fall, 1998 (in preparation) Natural emissions of volatile organic compounds, carbon monoxide, and oxides of nitrogen from North America.

Guenther, A.B. , Monson, R.K. , and Fall, R. , 1991, Isoprene and monoterpene rate variability: observations with Eucalyptus and emission rate algorithm development, J. Geophys. Res., 96, No. D6, 10799- 10808.

Hewitt, C.N., R. K. Monson, and R. Fall (1990): Isoprene emission from the grass Arundo donax L. are not linked to photorespiration. Plant Science, 66, 130-144.

Hewitt, C.N. and Street, R.A. , 1992, A qualitative assessment of the emissions of non-methane hydrocarbon compounds from the biosphere to the atmosphere in the U.K.:present knowledge and uncertainties, Atmos. Environ., 26A, No. 17, 3069-3077.

König, G. , Brunda, M. , Puxbaum, H. , Hewitt, C.N. , Duckham, S.C. , and Rudolph, J., 1995, Relative contribution of oxygenated hydrocarbons to the total biogenic VOC emissions of selected mid-European agricultural and natural plant species, Atmos. Environ., 29, No. 8, 861-874.

Lamb, B., Guenther A., Gay, D., and Westberg, H., 1987, A national inventory of biogenic hydrocarbon emissions, Atmos. Environ. 21, 1695-1705.

Lamb, B., Gay, D., Westberg, H., and Pierce, T., 1993, A biogenic hydrocarbon emission inventory for the U.S.A. using a simple forest canopy model, Atmos. Environ. 27A, 1673-1690.

Lieth, H., and Whittaker, R.H., 1975, Primary production of the major vegetation units of the world. In: Primary productivity of the biosphere, Eds. Lieth, H., and Whittaker, R.H., Springer-Verlag, New York, pp. 204-215.

MacDonald R.C., and Fall. R., 1993, Detection of substantial emissions of methanol from plants to the atmosphere. Atmos. Environ. 27A, 1709-1713

Ortiz, A. and Dory, M.A.G. , 1990, The estimation of non methane VOC emissions from nature in Spain for CORINAIR inventory, In Pacyna, J. and Joerss, K.E. , editors, EMEP Workshop on emission inventory techniques, Regensburg, Germany, 3-6 July, 1990. Norwegian Institute for Air Research, Kjeller, Norway, EMEP/CCC-Report 7/90.

Owen, S., Boissard, C., Street, R.A., Duckham, C., Csiky, O., Hewitt, C.N., 1997, The BEMA project: screening of 18 Mediterranean plant species for volatile organic compound emissions, Atmos Environ., 31, No.S1, 101-118.

Pierce, T.E. and Waldruff, P.S. , 1991, PC-BEIS: a personal computer version of the biogenic emissions inventory system, J. Air Waste Manage. Assoc., 41, No. 7, 937-941.

Pierce, T.E. , 1991, User's guide to the personal computer version of the biogenic emissions inventory system (PC-BEIS), Atmospheric research and exposure assessment laboratory, U.S.E.P.A., Research Triangle Park, NC. Report EPA/600/8-90/084.

Puxbaum, H. , 1997, Biogenic emissions of alcohols, ester, ether and higher aldehydes. In: Helas, G., Slanina, J., and Steinbrecher R. (eds.) Biogenic volatile organic carbon compounds in the atmosphere, pp.79-99, SPB Academic Publishing, Amsterdam.

Puxbaum, H. , and König G., 1997, Observation of Dipropenyldisulfide and other organic sulfur compounds in the atmosphere of a beech forest with *Allium ursinum* ground cover. Atmos. Environ. 31, 291-294.

Rudolph, J., Plass-Dülmer, C., Benning, L., Brandenburger, U., Brauers, T., Dorn, H.-P., Hausmann, M., Hofzumahaus, A., Holland, F., Parusel, E., Ramacher, B., Wahner, A., Wedel, A., Duckham, C., Hewitt, N., König, G., and Puxbaum, H., 1998, The POPCORN campaign 1994, an intensive field study of biogenic and man made volatile organic compounds in the atmosphere: an overview. *J. Atmos. Chem.* in press

Ruimy, A.., Saugier, B., and Dedieu, G., 1994, Methodology for the estimation of terrestrial net primary production from remotely sensed data. J. Geophys. Res. 99, 5263-5283.

Seufert, G., J. Bartzis, T. Bomboi, P. Ciccioli, S. Cieslik, R. Dlugi, P. Foster, N. Hewitt, J. Kesselmeier, D. Kotzias R. Lenz, F. Manes, R. Perez-Pastor, R. Steinbrecher, L. Torres, R. Valentini, and B. Versino (1997): The BEMA-project: and overview of the Castelporziano experiments. Atmos. Environ, 31, S1, 5-18.

Simpson, D. , Guenther, A. , Hewitt, C.N. , and Steinbrecher, R. , 1995, Biogenic emissions in Europe 1. Estimates and uncertainties, J. Geophys. Res., 100, No. D11, 22875-22890.

Simpson, D., Winiwarter, W., Börjesson, G., Cinderby, S., Ferreiro, A., Guenther, A., Hewitt,C.N., Janson, R., Khalil, M.A.K., Owen, S., Pierce, T.E., Puxbaum, H., Shearer, M., Steinbrecher, R., Tarrason, L., and Öquist, M.G., Inventorying emissions from Nature in Europe, submitted.

Steinbrecher, R. , 1994, Emission of VOCs from selected European ecosystems: the state-of-the-art, In Borrell , P., editor, Transport and Transformation of Pollutants in the Troposphere, Proceedings EUROTRAC symposium 1994, pages 448-455. SPB Acad. Publish. bv., the Hague, Netherlands.

Street, R.A. , 1995, Emissions of non-methane hydrocarbons from three forest ecosystems, PhD thesis, Lancaster Univ., Lancaster, England.

Street, R.A., Duckham S.,C., Boissard, and Hewitt, C.N., 1997, Emissions of VOCs from stressed and unstressed vegetation, In: Slanina, S. (ed.) Biosphere-Atmosphere Exchange of Pollutants and Trace Substances, Vol.4, Series Transport and Chemical Transformation of Pollutants in the Troposphere, Springer, Berlin.

Tanner R.L., and Zylinska B., 1994, Determination of the biogenic emission rates of species contributing to VOC in the San Joaquin Valley of California. Atmos. Environ. 28, 1113-1120

Tingey, D.T. , Manning, M. , Ratsch, H.C. , Burns, W.F. , Grothaus, L.C. , and Field, R.W. , 1978a, Monoterpene emission rates from slash pine, Final Report EPA CERL-045. Environmental Protection Agency, Research Triangle Park, North Carolina.

Tingey, D.T. , Ratsch, H.C. , Manning, M. , Grothaus, L.C. , Burns, W.F. , and Peterson, 1978b, Isoprene emissions rates from live oak, Final Report EPA CERL-040. Environmental Protection Agency, Research Triangle Park, North Carolina.

UN-ECE, 1992, The environment in Europe and North America: annotated statistics 1992.

Veldt, C. , 1988, Inventorying natural VOC emissions for the CORINAIR project, Apeldoorn, The Netherlands, MT-TNO Report 88-275; Also published in Coriniar Technical Annexes Volume 2, Default emission factor handbook, European Commission EUR 12586/2, pp101-128.

Veldt, C. , 1989, Leaf biomass data for the estimation of biogenic VOC emissions, Apeldoorn, The Netherlands, MT-TNO Report 89-306.

Veldt, C. , 1991, The use of biogenic VOC measurements in emission inventories, Apeldoorn, The Netherlands, MT-TNO Report 91-323.

Winer, A.M., Arey, J., Atkinson, R., Aschmann, S.M., Long, W.D., Morrison, C.L., and Olszyk, D., 1992, Emission rates of organics from vegetation in California´s central valley. Atmos. Environ. 26A, 2647-2659

Zimmerman, P. , 1979, Testing of hydrocarbon emissions of vegetation, leaf litter and aquatic surfaces and development of a methodology for compiling biogenic emission inventories, EPA 450/4-79-004.

18 BIBLIOGRAPHY

Guenther, A.B. , Zimmerman, P.R. , Harley, P.C. , Monson, R.K. , and Fall, R. , 1993, Isoprene and monoterpene rate variability: model evaluations and sensitivity analyses, J. Geophys. Res., 98, No. D7, 12609-12617.

Guenther, A. , Zimmerman, P. , and Wildermuth, M. , 1994, Natural volatile organic compound emission rate estimates for U.S. woodland landscapes, Atmos. Environ., 28, 1197-1210.

Guenther, A. , Hewitt, C.N. , Erickson, D. , Fall, R. , Geron, C. , Graedel, T. , Harley, P. , Klinger, L. , Lerdau, M. , McKay, W.A. , Pierce, T. , Scholes, R. , Steinbrecher, R. , Tallamraju, R. , Taylor, J. , and Zimmerman, P. , 1995, A global model of natural volatile organic compound emissions, J. Geophys. Res., 100, No. D5, 8873-8892.

Hewitt, C. N., R.A. Street and P.A. Scholefield (1998), Isoprene and Monoterpene-Emitting Species Survey 1998: http://www.es.lancs.ac.uk/es/people/pg/pas/download.html

Veldt, C. , 1989, Leaf biomass data for the estimation of biogenic VOC emissions, Apeldoorn, The Netherlands, MT-TNO Report 89-306.

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