GRØNN FORSKNING FOR FRAMTIDAS LANDBRUK

Pest risk assessment (PRA)

for Norway on

Ralstonia solanacearum

by

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Pest Risk Assessment (PRA) for Norway on *Ralstonia solanacearum*

1. Endagered area

The pest risk assessment (PRA) area is Norway.

2. Name and taxonomic position of the pathogen

2.1 Name:

Ralstonia solanacearum (Smith) Yabuuchi *et. al.*

2.2 Synonyms:

Bacterium solanacearum (Smith) Chester
Burkholderia solanacearum (Smith) Yabuuchi *et. al.*
Pseudomonas solanacearum (Smith) Smith

2.3 Common names:

Potato brown rot (English)
Pourriture brune de la pomme de terre (French)
Braunfäule, Schleimkrankheit der Kartoffel (German)
Mørk ringråte på potet (Norwegian)

2.4 Taxonomic position:

Bacteria: Gracilicutes

3. Regulatory criteria

Norway: *R. solanacearum* is on the A-list (Quarantine pest, limit of tolerance 0%)
EPPO: A2 list, No. 58
EU: Annex designation: II/A2
R. solanacearum is absent from the PRA area. It has not been intercepted in the area.

4. Methods for detection and identification

Brown rot in potato plants and tubers can be diagnosed on the basis of symptoms, isolation of the pathogen, and subsequent identification of the isolate as *R. solanacearum.*

4.1 Visual inspection in the field:

Symptoms on the foliage are at first wilting of the leaves towards the top of the plant, later external brown discoloration as streaks on the stem, and if stems are cut transversely, white, bacterial slime exudes from the vascular bundles, or it can be expressed by squeezing the stem with pliers. Finally the vines wilt completely and die. External symptoms may be visible on tubers as bacterial ooze that emerges from the eyes and stem-end attachment. Cutting the tubers may reveal a browning and necrosis of the vascular ring and the immediately surroundig tissues. A creamy fluid exudate usually appears spontaneously on the vascular ring of the cut surface a few minutes after cutting.
Plants with foliar symptoms caused by *R. solanacearum* may bear healthy and diseased tubers, while plants that show no signs of the disease may sometimes produce diseased tubers.

4.2 Laboratory techniques:

The bacterium may be detected, also in its latent form, in plant tissue, water and soil by laboratory techniques like immunofluorescence (IF), ELISA, PCR, or by isolation on a selective medium. A positive result should be confirmed with a pathogenicity test on tomato. With the use of these methods potato tuber lots may be screened for infection by taking samples of 200 tubers per 25 t of potatoes (EPPO 1990). The sensitivity of different methods for detection has been evaluated by Elphinstone *et al.*(1996).
Identification of *R. solanacearum*can be achieved by different biochemical tests, fatty acid analysis, RFLP, protein analysis and pathogenicity tests (Seal & Elphinstone 1994).

5. Establishment potential

5.1 Biological information of the pest

5.1.1 The bacterium

R. solanacearum is an aerobic, Gram-negative rod, motile with a polar flagellar tuft. It is non-fluorescent, but some strains produce a brown, diffusible pigment. PHB is accumulated intracellularly. The species is heterogenous and has been divided into four biovars (biotypes) according to acid production from three disaccharides and three sugar alcohols (Hayward 1964). It has also been divided into three races on the basis of pathogenicity (Buddenhagen *et al.* 1962). Within the species 38 RFLP-groups have been distinguished, and they form two genetically distinct major divisions with origins in Australasia and the Americas (Cook & Sequeira 1994).

5.1.2 Hosts

The host range, which includes over 200 plant species, is one of the widest of all the phytopathogenic bacteria. The most susceptible plant family, in terms of numbers of species affected is the *Solanaceae*, but more than fifty other plant families also contain susceptible species. Worldwide, the most important are: tomatoes, *Musa* spp., tobacco (*Nicotiana tabacum*) and potatoes. Many weeds are also hosts of the pathogen and therefore increase the potential of *R. solanacearum* to build up inoculum. The different pathogenic races within the species may show very limited host ranges (Buddenhagen *et al.* 1962):

Race 1 affects tobacco, tomatoes, potatoes, aubergines, diploid bananas and many other (solanaceous) crops and weeds, and has a high growth temperature optimum (35-37 ^{0}C).

Race 2 affects triploid bananas and *Heliconia* spp., and has a high temperature optimum (35-37 ^{0}C).

Race 3 affects mainly potatoes and tomatoes without a high virulence on other solanaceous crops, has a lower temperature optimum (27 ^{0}C). Other natural occuring hosts are the weeds *S. dulcamara* and *S. nigrum*, in Australia *S. cinereum*, and the composite weed *Melampodium perfoliatum* in Costa Rica. By artificial inoculation the weeds *Eupatorium cannabinum,Cerastium glomeratum, Portulaca oleracea, Ranunculus scleratus* and *Tussilago farfara*, several of which commonly inhabit edges of waterways, have been shown to be potential hosts (Elphinstone 1996). There are also reports of natural occurence of race 3 in *Pelargonium hortorum* (Janse 1996).

Within the EPPO-region it is race 3 (equivalent to biovar 2, Hayward 1983) which is present and has potential for spread (EPPO 1997a).

5.1.3 Interaction pathogen / host

R. solanacearum enter into plants by way of injured roots, stem wounds or through stomata. Within the plant, the bacteria move in the vascular bundles, a process which is accelerated by higher temperature. Speed of movement is also dependent on the plant part colonized. Blocking of the vessels by bacteria is the major cause of wilting (EPPO 1997a).

The disease is most severe at 24-35 ^{0}C. It is seldom found in temperate climates where the mean temperature for any winter month falls below 10 ^{0}C. There are distinct temperature requirements for optimum disease development and reproduction for the different races (biovars) (Swanepol 1990). High soil moisture and periods of wet weather or rainy seasons are associated with high disease severity. Soil moisture is also one of the major factors affecting reproduction and survival of the pathogen (Nesmith & Jenkins 1985).

5.1.4 Dissemination and dispersal

The natural spread of *R. solanacearum* is usually limited and slow. Root-to-root spread of the bacterium has been recorded (Kelman & Sequeira 1965), but there is little evidence of long-distance spread from field to field. However, race 2 is known to be transmitted by insects and has a high potential for natural spread. Race 3 has been shown to be spread over long distances with surface water when infected *S. dulcamara* grows with its roots floating in water. The bacterium may be subsequently spread to other hosts, like potato, when contaminated surface water is used for irrigation. A likely source of infection of *S. dulcamara* in the first place is sewage effluent from potato processing industry and households using infected ware potatoes (Olsson 1976, Stead *et al.* 1996).

R. solanacearumt can be carried over very long distances in symptomless, infected vegetative propagating material. Examples of well-documented cases of long-range dispersal are the use of infected ginger rhizomes as planting material within China, Indonesia and Malaysia (Lum 1973), tomato transplants in U.S.A. and Canada, and latently infected potato tubers being spread locally and internationally (Hayward 1991, Olsson 1976, Turco & Saccardi 1997).

Substantial evidence of spread by infected true seed has so far not been given. Neither is there evidence that *R. solanacearum* survives as an epiphyte on leaf and other plant surfaces, as with some pathovars of *P. syringae* (Kelman *et al.*1994).

5.1.5 Survival

R. solanacearum may survive in soil, but probably only in relatively short periods on its own (Sequeira 1994). Survival is strongly influenced by a number of interacting physical, chemical and biological factors. It is known that *R. solanacearum* persist longest when it is protected from desiccation and antagonism by other microorganisms, and in sheltered environments such as alternative crop and weed hosts, self-sown volunteer potatoes, host debris or in deeper soil layers sown to at least 75 cm (Graham *et al.* 1979). It may also survive in the rhizosphere of non-hosts (Sequeira 1994). The range and variety of weed hosts is very extensive, but their significance also varies greatly in different environments and cropping systems (Kelman 1953). Some are symptomless carriers (Hayward 1991). Soil type is an important factor affecting survival (Moffet *et al.* 1983), and different soils may be conducive or supressive to pathogen survival and subsequent disease development (Nesmith & Jenkins 1985). Soil moisture affects pathogen persistence (Moffet *et al* 1983). It tends to be longest in moist, well-drained soil, but is inhibited by desiccation or flooding (Hayward 1991). Different strains and races of the pathogen vary in their ability to survive in soil. Race 1 may persist in the same soil for many years, while race 2 and 3 disappear rapidly after a disease outbreak when weed hosts are eliminated (Sequeira 1994). Survival of race 3 in soil in cool climates seems to be restricted to one or two years after harvest of potato crops infected by brown rot. The bacterium may also persist in groundkeepers for the same length of time. Long term survival in perennial weed hosts like *Solanum dulcamara* has however been an important means of persistence and subsequent spread in several countries in Northern Europe (Olsson 1976, Elphinstone 1996).

R. solanacearum may survive in tap water for 25 days at room temperature (Olsson 1976), in ditch water at 4 ^{0}C for 33 days (Janse 1996). In sterile distilled water water the bacterium may survive for many years and even multiply (Wakimoto *et al.* 1982). However, data concerning the survival of the bacterium on its own in water under natural conditions are not available.

5.1.6 Adaptability

R. solanacearum race 3 is homogenous and in contrast to the other races very well defined genetically and epidemiologically (Gillings & Fahy 1994) The bacterium has a growth optimum (27 ^{0}C), well adapted to more temparate and cooler climates than the other races. It is presumed to originate in South America and has been dissiminated to other parts of the world in seed tubers (Hayward 1991). No report has so far been presented after the recent introduction of race 3 in Northern Europe regarding any change in host range, epidemiolgy or damage potential.

5.2 Geographical distribution of the pest

5.2.1 Present occurence in the PRA area

R. solanacearum has never been detected or intercepted in Norway.

5.2.2 World distribution

As reported by EPPO (1997a, 1997b) *R. solanacearum* is widespread in tropical, subtropical and temperate areas around the world. Race 3 is adapted to cooler climates in the highlands of the tropics, the Mediterranean area, and more recently in several Northern European countries. In the EPPO region race 3 has been reported from many countries. Some of these reports are old and unconfirmed, and may also be of more dubious value because of lack of proper identification of the bacterium and in particular of race 3. There are also several reports of isolated incidents which have been eradicated. In the EPPO region the bacterium is under eradication whereever it has occurred.

5.2.3 Area of origin

The highland of the Andes in South America seems to be the most likely place of origin of race 3. In Europe there are early reports of potato brown rot in Italy in 1904 and 1922, Egypt in 1925, Spain 1928, Portugal 1945, and later from several other European countries. Most of these findings are claimed to be eradicated (Janse 1996).

5.3 Host plants of the pest

5.3.1 Host plants reported in areas where the pest occurs

The major natural host of race 3 is potato. In addition, tomato is also an important host, especially when planted after infected potato. Other natural hosts reported are *Solanum dulcamara, S. nigrum, S. cinereum, S. melanogena, Pelargonium hortorum, Zinnia elegans, Tropaeolum majus, Melampodium perfoliatum* and *Capsicum annum* (Janse 1996). By inoculation under controlled conditions a number of other hosts has been described, but no evidence has so far been found that they are infected in their natural habitat.

5.3.2 Host plants growing in the PRA area

Potato is one of the major crops in Norway. The number of farms growing potatoes at an area of more than 5 daa was in 1995 ca. 16 000, with a total area of 180 000 daa, producing 395 000 tonnes of potatoes at a value of 530 mill NOK. (Anon. 1996) A considerable potato production is in addition taking place at a great number of small farms (less than 5 daa) and in private gardens. *Tomato is commercially grown only in greenhouses, at around 395 daa, producing 10 900 tonnes of* tomatoes in 1995 (Anon. 1996).

Solanum dulcamara and *S. nigrum* are both common weeds in Norway, but they are not growing further north than the county of Nordland (Lid 1985). *Pelargonium hortorum* is an important plant for the greenhouse industry in Norway. It is a very popular and common plant in private and public parks and gardens.

6. Potential of the pest for establishment in the PRA area

6.1 Climate in the PRA potato growing areas.

Potato is grown in every county in Norway, but production of economic importance takes only place in the following counties: Østfold, Akershus, Hedmark, Oppland, Buskerud, Vestfold, Telemark, Aust-Agder, Rogaland, Møre og Romsdal, Sør- and Nord-Trøndelag, and Nordland. Tables 1-13 (pp 15-21) give the normal values for mean monthly temperature and precipitation during the years 1961-1990 in these counties. Data were provided by the Norwegian Meteorological institute (DNMI) in Oslo. The tables also include observations on soil temperature 10 cm below ground made by weather stations placed in close vicinity to, or at the DNMI stations. The latter data were provided by the Agricultural Meteorological Service at the Norwegian Crop Research Institute.

6.2 Climate in areas in Europe where *R. solanacearum* race 3 has occured.

Table 14 (p 21) gives the normal values for mean monthly temperature and precipitation during the years 1961 – 1990 in Birmingham, England, De Bilt, the Netherlands and Stockholm, Sweden. Data were provided by the Norwegian Meteorological Institute (DNMI) in Oslo. Brown rot in England has been reported from Oxfordshire region, (Stead *et al.* 1996), which is close to Birmingham. In the Netherlands there was an outbreak in Leveroj, near the border to Belgium in 1992 (Janse 1992), later outbreaks elsewhere, but the localities have not been given. De Bilt, which is close to Utrecht, most likely has climatic conditions which could be regarded as representative for many areas where potatoes are grown in the Netherlands. The infestation reported in 1976 in Sweden was in the southern part of the country, but unfortunately climatic data from this area was not available. However, in connection with investigations concerning the outbreak, successful field infection experiments with *R. solanacearum* were carried out at Solna, which is close to Stockholm (Olsson 1976). This area is at a latitude of 59 ^{0} N, while the natural outbreak of the disease was at 55 ^{0} N, most likely an area which usually has somewhat higher temperatures.

6.3 Comparison of the climate in the PRA-area and in areas where *R. solanacearum* has occured

As can be seen in Tables 1-14, the differences in mean temperature and in precipitation in the growing season between Norway and three European countries where brown rot has occured is at least for the southern part of Norway minor, and most likely not a hindrance for an establishment of the disease. In infection experiments with potato and *R. solanacearum* biovar 2 (race 3) in growth chambers with a dark/light temperature of 14/16 ^{0} C, Swanepoel (1990) obtained a mean percentage of wilting of 18.3, and the disease was transmitted to 34.4% of the plants grown from these tubers. At 18/20 ^{0} C and higher temperatures, the percentage was 100, and no tubers could be harvested. Olsson (1976b) has given soil temperatures at Solna, Stockholm for a three-year-period when infection experiments with *R. solanacearum* where carried out. The temperature was below 0 ^{0} C for about two months during the winter 1974-1975, and somewhat lower the following winter. The bacterium was found to survive in *S. dulcamara* under these conditions. Soil temperatures at several of the localities given in Tables 1-14 are at the same level, in Rogaland (Table 9) some years considerably higher.

7. Control of the pest

7.1 Control measures

Chemical control of *R. solanacearum* cannot be achieved. Soil fumigation has little or no effect (Murakoshi & Takahasi 1984), neither has the use of antibiotics (Farag *et al.* 1982).

Biological control with the use of antagonistic rhizobacteria and avirulent mutants of *R. solanacearum* has had some success, but it is still at an experimental stage, and much more work is needed before commercial application can be achieved (Hayward 1991).

Selection and development of resistant potato cultivars have been successful, but the race and strain diversity of the pathogen make it difficult to utilize these in different countries (EPPO 1997a). Immunity has not been achieved, and resistant cultivars may harbour latent infections (Hayward 1991).

Various cropping systems have reduced the incidence of brown rot, in particular long-term crop rotation up to 5-7 years years without susceptible crops have been recommended. Application of fertilizers to change soil pH may also reduce disease incidence, as well certain soil amendments (Hayward 1991).

The most important control strategies for brown rot are the use of healthy seed potaoes, early detection and eradication of disease outbreaks by exclusion of contaminated fields for potato production for a number of years, disinfection of machines and other equipment used in the potato production, long term crop rotation, control of weed hosts and volunteer plants, and to avoid the use of surface water for irrigation (EPPO 1997a).

7.2 Records of eradication

Around the world there are many reports of attempted eradication campaigns for *R. solanacearum* race 3. In Europe, the campaign in Sweden after the infestation in the mid-1970s has proved succesful. Quarantine measures were taken on farms with infected fields, i.e. absence of potato crops for 3 years, no irrigation, and disinfection of farming equipment. *S. dulcamara* was removed, partly by mechanical means, partly by chemicals from the infested waterways. Tests carried out in the region of samples of water and of *S. dulcamara* repeatedly during the years up to 1995 have failed to detect *R. solanacearum*, and the Swedish authorities now consider Sweden free from *R. solanacearum* (EPPO 1997b). Eradication campaigns following the same lines have been performed in Belgium, England, France, Germany, Italy, the Netherlands and Portugal after the disease outbreaks in these countries in 1989, 1992, 1995 and 1996. Success has been reported concerning the affected farms, but in Belgium, England and the Netherlands the bacterium still survives in *S. dulcamara* in waterways connected with these farms, (EPPO 1997b). In England, tomatoes growing in glasshouses in the same district as the 1992-outbreak in potatoes, have in 1997 been infected by *R. solanacearum* after being watered by contaminated irrigation water, (EPPO 1997c).

8. Transport of the pest

8.1 Pattern of international trade in potatoes

Potato tubers is one of the major commodities in international agricultural trade. The number of exporting and importing countries is very high. Norway only occassionally export potatoes. Ware potatoes are imported in varying amounts from year to year, usually in the spring, and the amount depends on the size of the national crop the last year. In 1997 imports were around 21 000 tonnes (Anon 1996). The potatoes are only imported from countries considered free from brown rot, and mainly from Denmark, Sweden, Finland, Germany, Cyprus and Canada. Seed potatoes are only allowed imported in very small quantities for research purposes, and they have to be grown one year in quarantine and are subjected to extensive pathogen testing before being released.

8.2 Records of interception of the pest on host plants in international trade

R. solanacearum has never been intercepted into Norway. In international trade it is regularly intercepted in both seed and ware potatoes imported into different countries (EPPO 1997b).

8.3 Records of the movement of the pest between countries other than on host plants

There are no records so far of *R. solanacearum* being moved between countries by other means than on host plants. However, the infestation of waterways in Belgium and the Netherlands may be of concern for potential spread of the bacterium in waterways running between these countries, and to other countries connected with these waterways.

9. Economic impact of the pest

9.1 Type of damage

R. solanacearum causes wilting of plants, with extensive rotting of tubers. Rotted tubers will be rejected for quality reasons, latent infected tubers, i.e. tubers infected by the bacterium, but not showing visula disease symptoms, will be rejected as seed potatoes because their potential to transfer disease to future generations of potatoes.

9.2 Recorded economic impact on major host plants

R. solanacearum is in particular a limiting factor in tropical agriculture, where losses up to 75% of the potato crop have occured in several countries (Cook & Sequeira 1994, Oerke *et al.* 1994). Extensive losses have also been reported from Mediterranian countries. No records of the economic impact of the disease outbreaks in countries like Belgium, England and the Netherlands could be found. Apart from the considerable cost of infected ware and seed potato lots being rejected , the cost of eradication programmes and disease surveys in connection with the disease outbreaks must have been very great. In addition, most likely the export of seed and ware potatoes has been considerably reduced.

10. Conclusion

If *R. solanacearum* was introduced into Norway, the climatic conditions and other factors of importance for the development of the disease will not prevent its establishment and survival in groundkeepers and common weeds. Because of the cool climate, the rotting of tubers would probably be of minor importance. But all infected potato lots and related lots would have to be destroyed in order to control the disease, as well as strict measures for hygiene and crop rotation would have to be put in action, to a considerable cost for the affected grower, and the official authorities. The high number of small farms and private gardens where potatoes are grown will make it difficult and expensive to enforce the necessary statutory orders to control the disease. Potential export markets would be lost, and reduced supply of home grown potatoes would make the country more dependent on import from other countries. Brown rot has the potential to become a devastating disease for potato growers in Norway. Many of them have small farms, and have to rely on potato in their crop rotation schemes. The social impact of a disease outbreak could therefore become considerable. *R. solanacearum* race 3 also has the potential to be established in greenhouses growing tomatoes. Particularly in some districts in Norway this is a very important production, and the economic impact of a disease outbreak would be substantial.

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Tables

Table 1. Tomb, Østfold county. Climatological normals for the period 1961-1990 for mean air temperature (°C) and amount of precipitation (mm); soil temperature (°C) 10 cm below ground for the period 1991-1995.

	Climatological normals		Soil temperature				
Month	Temp.	Precip.	1991	1992	1993	1994	1995
January	-4.8	59	-0.3	0.4	0.3	0.1	1.2
February	-4.6	44	-2.6	-0.4	-0.1	0.1	0.8
March	-0.8	54	0.2	2.0	0.3	0.0	1.6
April	4.2	42	5.4	4.1	4.1	4.7	4.8
May	10.3	57	9.5	9.4	12.0	9.3	8.5
June	14.7	66	12.4	15.3	13.6	10.8	14.4
July	16.1	72	15.9	16.2	14.6	16.4	15.8
August	15.0	74	16.7	14.6	13.3	16.0	17.1
September	10.6	92	12.4	11.7	9.1	11.9	13.2
October	6.0	83	7.6	6.0	6.0	7.1	10.7
November	0.6	90	3.5	2.6	2.3	4.2	
December	-3.0	64	1.3	1.7	0.3	2.6	

Table 2. Ås, Akershus county. Climatological normals for the period 1961-1990 for mean air temperature (°C) and amount of precipitation (mm); soil temperature (°C) 10 cm below ground for the period 1991-1995.

	Climatological normals		Soil temperature				
Month	Temp.	Precip.	1991	1992	1993	1994	1995
January	-4.8	49	0.2	-0.4	-0.2	0.0	0.4
February	-4.8	35	-1.0	-0.9	-0.3	0.2	0.3
March	-0.7	48	-0.1	0.2	-0.2	0.1	0.3
April	4.1	39	4.4	4.1	2.8	4.0	3.1
May	10.3	60	9.0	11.0	11.4	9.7	8.7
June	14.8	68	13.0	17.1	14.4	13.3	15.0
July	16.1	81	17.7	-	15.9	18.2	16.9
August	14.9	83	16.6	15.2	14.4	16.5	17.5
September	10.6	90	12.1	12.4	10.2	11.6	12.4
October	6.2	100	7.3	6.1	5.8	6.1	9.7
November	0.4	79	2.6	1.7	2.0	2.7	
December	-3.4	53	0.6	0.9	0.3	0.7	

Table 3. Kise, Hedmark county. Climatological normals for the period 1961-1990 for mean air temperature (°C) and amount of precipitation (mm); soil temperature (°C) 10 cm below ground for the period 1993-1995.

	Climatological normals		Soil temperature		
Month	Temp.	Precip.	1993	1994	1995
January	-7.4	36	-2.2	-1.2	-1.2
February	-8.1	29	-	-1.1	-1.8
March	-3.1	27	-1.4	-0.9	-1.3
April	2.2	34	3.0	1.6	1.5
May	8.5	44	10.3	8.4	7.7
June	13.6	59	13.4	12.0	13.4
July	15.2	66	15.6	17.9	15.2
August	14.0	76	13.6	15.1	15.4
September	9.6	64	8.8	9.8	10.4
October	5.1	63	4.3	4.3	6.5
November	-0.8	50	0.5	2.0	
December	-5.3	37	-	-0.9	

Table 4. Apelsvoll, Oppland county. Climatological normals for the period 1961-1990 for mean air temperature (°C) and amount of precipitation (mm); soil temperature (°C) 10 cm below ground for the period 1991-1995.

	Climatological normals		Soil temperature				
Month	Temp.	Precip.	1991	1992	1993	1994	1995
January	-7.4	37	-0.3	-0.2	-1.3	0.4	-0.3
February	-7.0	26	-0.5	-0.6	-1.7	-0.1	-0.1
March	-2.5	29	-0.2	-0.1	-0.7	0.0	-0.1
April	2.3	32	3.1	1.8	1.3	1.2	0.2
May	9.0	44	9.7	11.5	10.9	9.2	8.0
June	13.7	60	13.8	18.0	14.3	12.8	13.7
July	14.8	77	18.3	16.9	15.9	18.3	16.1
August	13.5	72	16.8	14.4	-	15.6	16.6
September	9.1	66	11.1	10.7	9.6	10.4	11.1
October	4.6	64	6.2	5.1	4.8	4.6	7.4
November	-1.3	53	1.9	2.0	1.3	2.3	
December	-5.3	40	0.2	-0.1	0.8	0.0	

Table 5. Lier, Buskerud county. Climatological normals for the period 1961-1990 for mean air temperature (°C) and amount of precipitation (mm); soil temperature (°C) 10 cm below ground for the period 1991-1995.

	Climatological normals		Soil temperature				
Month	Temp.	Precip.	1991	1992	1993	1994	1995
January	-5.5	70		-1.3	-0.3	0.1	0.2
February	-5.0	52		-1.3	-0.4	0.5	0.1
March	-0.4	60		1.0	-0.3	0.5	0.1
April	4.8	50		4.8	3.9	3.6	2.5
May	11.0	70		13.1	11.2	8.9	7.7
June	15.7	70		19.2	12.8	11.9	13.2
July	17.1	85		17.8	14.3	16.4	15.0
August	15.7	105		15.1	13.4	15.4	15.6
September	11.3	108		11.7	9.6	11.2	11.9
October	6.6	115	4.8	5.6	5.8	6.0	9.1
November	0.6	95	1.2	1.4	2.3	3.4	2.6
December	-3.5	70	-0.6	0.6	0.5	0.8	0.3

Table 6. Ramnes, Vestfold county. Climatological normals for the period 1961-1990 for mean air temperature (°C) and amount of precipitation (mm); soil temperature (°C) 10 cm below ground for the period 1991-1995.

	Climatological normals		Soil temperature				
Month	Temp.	Precip.	1991	1992	1993	1994	1995
January	-4.5	85	0.0	0.0	0.8	0.0	0.4
February	-4.5	60	-0.2	-0.3	-0.2	0.0	0.4
March	-0.3	68	0.1	0.5	-0.2	-	0.1
April	4.0	55	5.2	4.0	3.1	-	2.2
May	10.2	75	10.4	11.7	12.3	10.6	8.7
June	14.5	67	13.4	17.8	15.2	14.1	15.2
July	15.5	87	17.7	-	16.3	18.5	17.3
August	14.4	106	16.5	15.0	14.6	16.7	17.8
September	10.3	116	11.9	11.7	10.2	11.8	12.8
October	6.2	132	7.0	6.0	6.1	6.4	9.6
November	1.0	122	2.5	1.7	1.9	3.5	
December	-3.0	87	0.5	0.7	0.4	0.8	

Table 7. Bø, Telemark county. Climatological normals for the period 1961-1990 for mean air temperature (°C) and amount of precipitation (mm); soil temperature (°C) 10 cm below ground for the period 1991-1995.

	Climatological normals		Soil temperature				
Month	Temp.	Precip.	1991	1992	1993	1994	1995
January	-6.5	50	-	-	-	-	-0.3
February	-5.5	35	-	-	-	-	-0.2
March	-0.5	45	-	0.0	-	0.5	-0.1
April	4.3	40	-	3.4	4.9	3.5	1.9
May	10.4	65	-	12.0	11.9	9.8	8.1
June	14.8	65	-	18.2	15.1	13.2	14.7
July	16.0	75	-	-	16.1	16.8	16.4
August	14.5	95	-	15.2	14.2	15.7	16.8
September	9.8	95	-	12.1	10.2	10.4	11.3
October	5.5	95	5.1	4.9	7.2	4.7	8.0
November	-0.2	75	1.1	0.5	-	2.3	
December	-4.5	55	-0.8	0.2	-	0.1	

Table 8. Landvik, Aust-Agder county. Climatological normals for the period 1961-1990 for mean air temperature (°C) and amount of precipitation (mm); soil temperature (°C) 10 cm below ground for the period 1991-1995.

	Climatological normals		Soil temperature				
Month	Temp.	Precip.	1991	1992	1993	1994	1995
January	-1.6	113	0.2	0.6	0.5	0.7	0.1
February	-1.9	73	-0.7	-	0.3	0.4	0.0
March	1.0	85	1.0	3.4	2.1	0.7	1.1
April	5.1	58	6.2	5.4	5.7	5.9	5.4
May	10.4	82	12.0	12.0	12.3	10.8	9.5
June	14.7	71	14.0	17.9	15.7	14.2	15.2
July	16.2	92	19.1	17.4	15.7	18.1	17.3
August	15.4	113	17.8	15.4	14.4	16.8	17.9
September	11.8	136	13.4	12.9	11.0	12.1	13.0
October	7.9	162	7.8	6.6	6.8	7.4	9.9
November	3.2	143	3.7	2.6	3.0	3.9	
December	0.2	102	0.9	1.8	0.9	1.6	

Table 9. Særheim, Rogaland county. Climatological normals for the period 1961-1990 for mean air temperature (°C) and amount of precipitation (mm); soil temperature (°C) 10 cm below ground for the period 1991-1995.

	Climatological normals		Soil temperature				
Month	Temp.	Precip.	1991	1992	1993	1994	1995
January	0.5	105	1.9	3.3	2.2	0.8	2.2
February	0.4	75	-0.5	3.3	2.7	0.1	2.5
March	2.4	80	3.6	4.0	2.7	1.3	2.5
April	5.1	60	6.4	6.1	6.5	5.9	5.7
May	9.5	70	9.6	12.1	12.3	10.5	9.0
June	12.5	75	12.0	16.4	13.8	12.2	13.7
July	13.9	95	16.8	15.8	13.8	16.4	15.5
August	14.1	125	14.4	14.0	15.2	15.5	
September	11.5	160	12.2	12.4	10.8	12.1	12.7
October	8.6	160	8.2	6.6	7.3	7.7	10.1
November	4.4	150	4.7	3.9	2.8	6.3	
December	2.0	125	3.5	2.8	1.0	4.3	

Table 10. Surnadal, Møre og Romsdal county. Climatological normals for the period 1961-1990 for mean air temperature (°C) and amount of precipitation (mm); soil temperature (°C) 10 cm below ground for the period 1993-1995.

	Climatological normals		Soil temperature			
Month	Temp.	Precip.	1992	1993	1994	1995
January	-2.5	116		-0.8	-1.0	-0.6
February	-1.5	95		-0.3	-0.9	-0.6
March	1.0	99		-0.3	-0.7	-0.5
April	3.7	83		0.8	-0.5	-0.5
May	9.0	64		10.7	7.7	6.8
June	12.0	86		12.7	11.1	13.3
July	13.5	117		16.0	16.5	13.9
August	13.2	120		14.3	15.2	14.2
September	9.4	173		9.1	10.1	10.5
October	6.2	157	1.9	4.0	3.2	6.3
November	1.7	131	-1.4	-1.0	0.1	
December	-1.0	154	-1.4	-1.5	-0.5	

Table 11. Rissa, Sør-Trøndelag county. Climatological normals for the period 1961-1990 for mean air temperature (°C) and amount of precipitation (mm); soil temperature (°C) 10 cm below ground for the period 1992-1995.

	Climatological normals		Soil temperature			
Month	Temp.	Precip.	1992	1993	1994	1995
January	-4.5	162		-0.5	-0.5	-0.3
February	-3.5	132		0.5	-0.4	-0.3
March	-1.0	123		0.3	-0.4	-0.2
April	2.5	115		5.7	3.7	1.6
May	8.0	78		10.7	8.5	7.6
June	11.5	89		11.9	10.6	12.5
July	13.0	110		14.4	15.6	12.7
August	13.0	110		13.0	14.7	12.5
September	9.0	204		9.0	10.5	10.2
October	6.0	199	2.3	4.5	4.1	6.8
November	1.0	162	-0.5	0.0	1.8	
December	-2.5	201	-0.7	-0.7	0.6	

Table 12. Frosta, Nord-Trøndelag county. Climatological normals for the period 1961-1990 for mean air temperature (°C) and amount of precipitation (mm); soil temperature (°C) 10 cm below ground for the period 1991-1995.

	Climatological normals		Soil temperature				
Month	Temp.	Precip.	1991	1992	1993	1994	1995
January	-1.5	74	-0.3	1.6	-	0.0	-0.1
February	-1.5	64	-1.7	1.1	1.2	-0.2	0.1
March	1.0	58	0.3	2.4	1.0	-0.1	0.1
April	4.0	50	5.5	-	4.2	3.6	2.6
May	8.5	45	8.7	-	9.0	9.3	8.4
June	12.0	60	13.7	14.6	9.9	11.7	13.5
July	13.5	80	17.4	15.0	12.7	16.4	14.3
August	13.0	73	16.2	12.6	12.2	15.0	13.7
September	9.0	105	9.5	10.2	8.8	10.0	10.3
October	6.0	100	5.6	3.9	5.2	4.8	6.6
November	2.0	75	2.4	1.0	0.9	2.2	
December	0.0	86	1.4	0.8	0.0	1.0	

Table 13. Sortland, Nordland county. Climatological normals for the period 1961-1990 for mean air temperature (°C) and amount of precipitation (mm); soil temperature (°C) 10 cm below ground for the period 1992-1995.

	Climatological normals		Soil temperature			
Month	Temp.	Precip.	1992	1993	1994	1995
January	-2.0	130		-0.1	-0.3	0.2
February	-2.0	120		-0.1	-0.3	-0.1
March	-1.0	95		0.1	-0.2	-0.1
April	1.9	85	-0.1	0.2	-0.2	0.0
May	6.3	65	6.6	5.7	2.4	1.2
June	10.0	65	13.1	8.8	8.8	9.7
July	12.0	75	12.8	13.4	12.0	11.5
August	12.0	85	12.1	13.1	12.8	11.6
September	8.4	130	8.9	7.6	8.0	8.8
October	4.5	190	3.7	2.5	3.8	4.5
November	0.8	150	0.4	1.3	0.6	
December	-1.4	145	-0.1	-0.1	0.6	

Table 14. Climatological normals for the period 1961-1990 for mean air temperature (°C) and amount of precipitation (mm) in England, the Netherlands and Sweden.

	Birmingham, England		De Bilt, the Netherlands		Stockholm, Sweden	
Month	Temp.	Precip.	Temp.	Precip.	Temp.	Precip.
January	3.1	57	2.2	69	-2.8	39
February	3.1	48	2.5	49	- 3.0	27
March	5.2	51	5.0	66	0.1	26
April	7.6	49	8.0	53	4.6	30
May	10.6	56	12.3	61	10.7	30
June	14.0	56	15.2	70	15.6	45
July	15.8	46	16.8	76	17.2	72
August	15.4	66	16.7	71	16.2	66
September	13.2	54	14.0	67	11.9	55
October	10.0	52	10.5	75	7.5	50
November	6.0	59	5.9	81	2.6	53
December	4.2	66	3.2	83	-1.0	46