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Ash Dieback

A Survey of Non-Woodland Trees

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Front cover: An ash tree now isolated in an arable field, though located on the line of an old hedgerow removed many years ago. It shows moderately severe dieback and would have give a crown loss score of 50–59%. *(39437)*

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Summary

During the summer of 1987 a survey of dieback in non-woodland ash trees was undertaken in Great Britain. After excluding certain areas due to their known low ash population, two hundred 10 km squares were visited and detailed data collected on the condition of ash in a plot selected within each square. Information was obtained on 4454 ash trees, and also on 1022 oak trees which were encountered in the plots.

The overall incidence of dieback was 19% in the sample of ash and 18% in the sample of oak. In ash, the condition was found to occur mainly in the east of the country, with areas of greatest damage, both in terms of proportion of trees affected and degree of crown loss, being found in the south-east Midlands. The healthiest trees were found in the west of the country, in particular in Wales.

Large ash trees were found to be suffering more from dieback than small trees and single trees more than trees in groups. The condition was found to be more common on rendzina and gley soils than on brown earths, podzols and 'unclassified' soils. Trees in the countryside had a much higher incidence of dieback than did urban trees (20% compared with 11% respectively). Among rural trees, associations were found with various kinds of current agricultural practice. Thus the incidence of damage in trees surrounded by arable land was 38% compared with 10% for trees surrounded by grassland. There was also a greater incidence of damage in trees near to roads (23%) than in trees away from roads (12%). Finally, where there was an adjacent ditch, the likelihood of dieback was substantially increased.

The data for oak followed a similar pattern to ash except that no effect of the presence of a ditch could be detected.

Correlations of damage with rainfall and pollution variables were calculated. Ash dieback was negatively correlated with rainfall and several relationships emerged with pollution variables; the strongest being positive relationships for 'arable only' trees. With oak some negative correlations were found with rainfall and pollution.

Le Déperissement des Frênes – Un Relevé des Arbres Hors Forêt

Résumé

Pendant l'été 1987 on a fait un relevé du déperissement des frênes hors forêt dans La Grande-Bretagne. Après l'exclusion des certaines zones avec populations faibles des frênes, on a visité 200 des carrés (10 x 10 km), et on a ramassé des détails sur la condition des frênes sur une parcelle choisie dans chaque carré. On a obtenu des informations pour 4454 des frênes, et aussi pour 1022 des chênes trouvés dans les mêmes parcelles.

L'occurrence totale du déperissement etait 19% chez les frênes, et 18% chez les chênes. Chez la frêne, on a trouvé le déperissement surtout dans l'est du pays, avec les dégâts les plus importants (quant à la proportion des arbres affectés et aussi le degré de la perte des couronnes) dans le sud-est des comtés centraux de L'Angleterre. On a trouvé les arbres plus sains dans l'ouest, surtout dans le Pays de Galles.

Parmi les frênes, les grands arbres souffront du déperissement plus que les petits, et les arbres individuels souffront plus que les groupes des arbres. On a trouvé le déperissement plus souvent sur les rendzines et les sols à gley que sur les sols bruns, les podzols et les sols 'non-classifiés'. L'occurrence du déperissement était beaucoup plus grand chez les arbres dans les campagnes que chez les arbres urbains (20% contre 11% respectivement). Entre les arbres ruraux, on a trouvé des corrélations avec l'usage agricole actuel. Par exemple, l'occurrence du déperissement était 38% parmi les arbres entourés par terre arable, mais seulement 10% parmi les arbres entourés par les prés. L'occurrence du déperissement était plus grande chez les arbres près des routes (23%) que chez les arbres au loin des routes (12%). La probabilité du déperissement était aussi beaucoup plus grande a proximité d'un fossé.

Les données chez les chênes étaient semblables à celles chez les frênes, sauf qu'on n'a constaté aucune influence par la presence d'un fossé.

On a calculé des corrélations du déperissement avec précipitation et avec pollution. Le déperissement des frênes avait une corrélation negative avec pluie, et on a remarqué quelques relations avec les variables en ce qui concerne la pollution; les corrélations plus fortes étaient positives pour les arbres 'seulement arables'. Chez les chênes on a trouvé des corrélations negatives avec la pluie et avec la pollution.

Eschenabsterben – eine Aufnahme von Flurholzbäumen

Zusammenfassung

Im Sommer 1987 wurde eine Aufnahme vom Absterben der Eschenbäumen ausserhalb des Waldes in Grossbritannien unternommen. Nach Ausschliessen gewisser Gegenden, weil ihre Eschenbestand bekanntlich klein war, hat man 200 geographische Quadrate (je 10 x 10 km) besucht, und ausführliche Daten über den Zustand der Eschen auf einer Fläche innerhalb jedem Quadrat gesammelt. Informationen wurden für 4454 Eschen erhalten, und ebenfalls für 1022 Eichen, die auf den selben Versuchsflächen standen.

Die Absterbequote betrug 19% bei den Eschen und 18% bei den Eichen. Bei den Eschen wurde die Krankheit meistens im Osten gefunden. Die Gegenden mit grössten Schäden (sowohl der Anteil der kranken Bäume als auch der Kronenverlustprozent) waren im südostlichen Mittelland zu finden. Die gesündesten Bäume waren im Westen zu finden, besonders in Wales.

Grössere Eschenbäume leiden mehr am Absterben als kleinere; einzelne Bäume leiden mehr als Bäume in Gruppen. Die Krankheit war ausgeprägter auf Rendzina- und Gleiböden als auf Braunerden, Podsolböden und 'nichtklassifizierten' Böden. Bei den Landbäumen war das Absterben prozentuell grösser als bei den Stadtbäumen (20% bzw. 11%). Das Absterben der am Land stehenden Bäume hängt von verschiedenen gegenwärtigen landwirtschaftlichen Faktoren ab. Zum Beispiel, waren die Bäume mit Agrarböden umgegeben, so betrug der Schaden 38% gegenüber nur 10% bei solchen die mit Grasland umgeben waren. Grössere Baumschäden wurden auch in der Nähe von Strassen (23%) als von Strassen entfernt (12%) gefunden. War ein Graben dabei, so war die Absterbequote viel grösser.

Die Daten für Eichen waren ähnlich wie die der Eschen, mit der Ausnahme, dass kein Grabeneinfluss gefunden wurde.

Korrelationen zwischen Schäden und Niederschlags bzw. Emissionsfaktoren wurden gemessen. Das Eschenabsterben war negativ mit Niederschlag korreliert. Mehrere Zusammenhänge wurden auch mit Emissionsfaktoren gefunden; die engsten waren positive Zusammenhänge für 'nur Agrarbäume'. Bei Eichen kamen einige negative Korrelationen mit Niederschlag und Emission vor.

Ash Dieback – A Survey of Non-Woodland Trees

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Introduction and objectives

The survey was the main part of a project funded by the Department of the Environment (Air and Noise Division) in conjunction with the Forestry Commission and the University of Aberdeen. Its objective was to investigate the causes of dieback in hedgerow ash trees. This disorder has been known for many years but has only recently been the subject of serious study. The present project followed the work of Pawsey (1983), who undertook a survey of hedgerow ash trees in east central England by counting numbers of healthy and affected trees along a series of 10 km transects.

Pawsey found that in the area he investigated ash dieback was widespread and that it also showed much local variation in incidence. During the course of the survey he began to suspect that there was a link between the incidence of dieback and the intensity of arable farming in the locality, although data were not specifically recorded on this aspect. However, in two small subsequent surveys he showed the incidence of ash dieback to be eight times higher in rural areas than in villages and other built-up areas.

In his report, Pawsey discussed a number of factors which might be involved in the development of ash dieback. These included agricultural practices, atmospheric pollution, poor site and climatic conditions, pathogenic infections and insect infestations. He stated that initial dieback development was probably due to a complex of factors and that the condition might later be influenced by other secondary agents.

The present survey was designed to build on the foundation of Pawsey's work, to collect quantitative data on ash dieback and to examine the possible influences of various factors on the development of the condition.

The opportunity was also taken to collect information on the condition of oak trees which were encountered during the course of the ash survey. It was hoped that this would show if the development of dieback in oak followed a similar pattern to that in ash.

Method of survey

To expedite the survey it was decided to collect data only from trees which could be seen from places of public access such as roads or footpaths, so eliminating the lengthy process of contact with landowners. The implications of this procedure are considered in the discussion section.

The survey was conducted within 11 of the 12 regions that formed the basis of the main Forestry Commission Forest Health Survey (see Figure 3), each of these regions being characterised by a particular climate/pollution regime (Innes and Boswell, 1987).

On the grounds of low ash population (Anon., 1984), region 1, north-west Scotland was excluded from the survey. For the same reason, certain other areas in the remaining regions were also excluded. The soils in these areas were dominated by lowland and hill peats, 'mountain tops', and other thin soils. They were identified by reference to unpublished maps and data produced by the Census Branch of the Forestry Commission. (For reference to census procedures see Locke, 1987.)

The basic unit of the survey was a 10 km square as designated by the National Grid system. The selection of sample plots was undertaken following the procedure set out below.

1. Regional boundaries were drawn on to a 1:625 000 scale Ordnance Survey (OS) map so as to allocate squares appropriately.
2. Squares with more than 50% sea were excluded, as were squares with more than 50% of their area occupied by an excluded soil stratum.
3. Two hundred plots were then selected at random from the remaining squares ensuring that there were at least 10 plots present in each region. The distribution of these plots can be seen in Figure 3.

Field data were collected in two stages, firstly, in exactly the same way as Pawsey (1983), using a car to traverse a 10 km sample unit. Following secondary roads as far as possible, a route was planned across the square on a 1:50 000 scale OS map. During the transect separate counts were made of healthy and affected ash trees using two hand-held tally counters. Affected trees were defined as having 10% or more of the crown affected by dieback or with live shoots present only at the branch tips (Cooper and Edwards, 1981; Pawsey, 1983). To minimise the problem of observer bias, all plots were assessed by the first author.

The width of the 'observation corridor' within which trees could be accurately recorded, was by necessity variable. Generally, however, trees were included in the survey where they could be readily distinguished as being ash and where their crown condition could be assessed. In practice this usually meant hedgerow and other open grown trees within 150–200 m of the roadside. Trees less than 7m high were excluded from the survey as were those in woodlands greater than about 0.25 ha in area and more than 20 m wide. In addition to counts of trees, note was made of areas along each transect route, in which ash was common; i.e. those localities where ash was relatively frequent and that might form the basis of a plot from which detailed information could be efficiently collected. The predominant land use observed along the transects was also noted, together with the distance travelled.

On completion of the transect, the second stage of more detailed data collection involved returning to the nearest area in which ash was common. To maintain objectivity, the starting point for this second stage, (a road junction, woodland edge or other easily identifiable point on the ground), was chosen from the OS map before actually travelling to the area concerned. From this point, data were collected on foot using roads and public footpaths for access. As before, woodland trees were excluded from the survey but those on the edges of woodland were recorded where they were obviously part of an older hedgerow. Data were gathered for a minimum of 15, up to a maximum of 25 individuals in the case of ash, and up to the first 25 oak trees encountered *en route*. In many cases, the number of oak examined in detail was well below 25 in number, and often below 10. The careful use of binoculars was found to assist considerably in fast and accurate recording of trees. The distance walked in collecting data in the detailed plots varied considerably; in most cases it was less than 500 m but occasionally it was up to several kilometres.

The same information was collected for both ash and oak. This included an estimate of the tree's diameter at breast height together with an estimate of the amount of crown loss due to dieback. The dieback was recorded in 10% classes, i.e. trees with crown losses between 0% and 9% inclusive were entered into class 0, trees with crown losses between 10% and 19% inclusive were entered into class 1 and so on up to class 9 (see Plates 1-6). A record was also made of whether or not the dieback was recent (fine twigs present or absent) and on the abundance of secondary epicormic shoots (Plate 4). A tree was recorded as being single or grouped with other trees (crowns separate or touching) and in either a rural or urban location. This latter decision was based on careful consideration of the surroundings; trees adjacent to isolated buildings in the countryside were classed as rural but those associated with small villages and larger built-up areas, including public open spaces and the urban/rural fringe were considered to be urban. The current land use immediately surrounding each tree was described by selecting up to four out of a list of 16 possible categories (e.g. arable, grassland, roadside, etc.). The presence of a ditch within 5 m of the base of the tree was also noted. For full details of parameters assessed, see Appendix 1. In addition, a generalised soil type for the area covered by the detailed plot was obtained by referring to the relevant soil survey map (for England and Wales – Anon., 1983; for Scotland – Anon., 1982). All data were coded and entered on to specially designed forms.

Fieldwork began in early July 1987, by which time ash was fully flushed, and was completed by early autumn before the leaves began to fall. Three to four squares were covered each working day over a period of about 12 weeks, which included travelling time.

Results

Analysis of ash data by geographical region

Figure 1 shows the incidence of ash dieback as determined using the assessment procedures of Pawsey (1983), with the data obtained from the 200 transects interpolated by computer on a 20 km × 20 km square grid. The highest levels of damage are found in the east of the country in particular around the south-east Midlands. Within this area the distribution of dieback is similar to that found by Pawsey in his original survey, although maximum values were rather less.

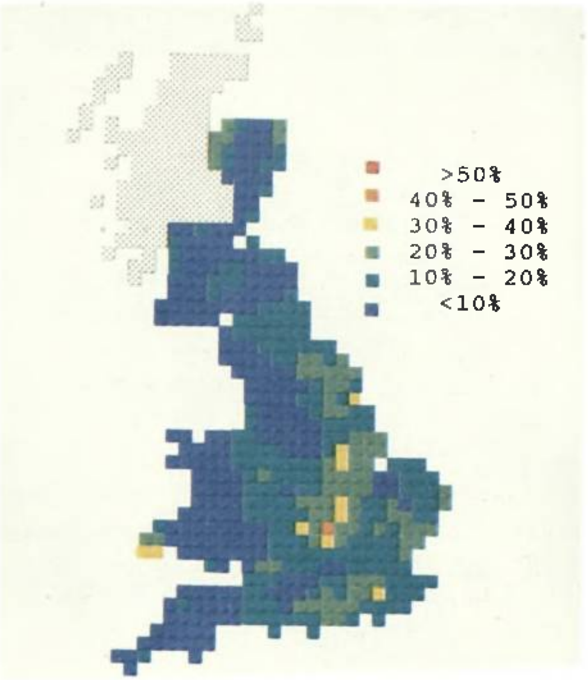


Figure 1. Incidence of ash dieback determined from transects across 10 km sample squares and interpolated on a 20 km × 20 km grid.

The data from the more detailed survey plots were summarised in three ways. First, in terms of the proportion of 'affected' trees, i.e. the proportion with at least 10% crown dieback; second, in terms of the proportion of 'severely affected' trees, i.e. the proportion with at least 30% crown dieback; third, in terms of a crown loss index. The latter was obtained using data from the dieback classes, whereby a tree in the

Table 1. Health of ash in the different climate/pollution regions

	Region												
	2	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*Sig.†*	*All regions*
Total ash sampled	284	231	231	217	1060	308	690	770	207	236	220		4454
No. ash affected	63	27	31	50	196	80	195	122	14	20	35	***	833
Per cent	22	12	13	23	18	26	28	16	7	8	16		19
No. ash severely affected	34	9	16	27	78	23	67	37	8	4	11	***	314
Per cent	12	4	7	12	7	7	10	5	4	2	5		7
Crown loss index	7	3	5	8	5	7	7	4	3	2	3	***	5

† The results of statistical tests of significance on data presented in this and subsequent tables are indicated thus: n.s. = not significant; * = significant at 5% level ($p < 0.05$); ** = significant at 1% level ($p < 0.01$); *** = significant at 0.1% level ($p < 0.001$).

Plate 1. *The tree in centre view shows the bunching of foliage at the branch tips that is one symptom of the ash dieback condition. The tree would have been given a crown loss score of between 10 and 19%. (39430)*

All photographs in this Bulletin were taken in Northamptonshire during late June 1990.

Plate 2. *Tree showing severe dieback of very recent origin: the fine twig structure is still intact. Some bunching of foliage is also present. This tree would have been given a crown loss score of 50–59%. (39438)*

Plate 3. *This roadside tree also shows recent dieback. It would have been given a crown loss score of 30–39%. (39440)*

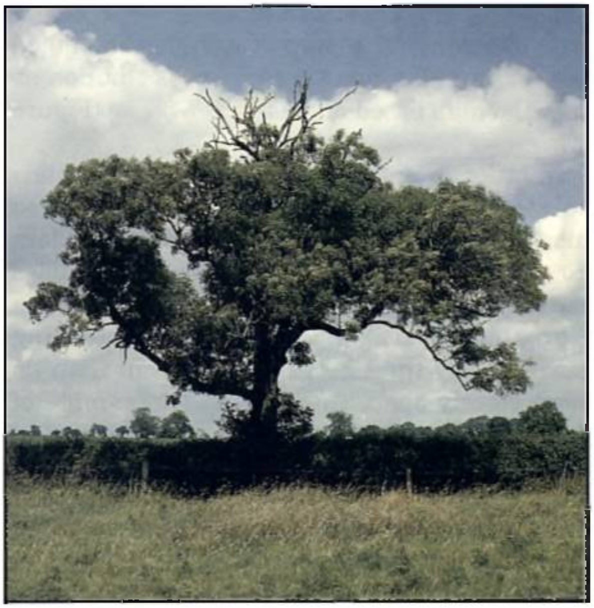
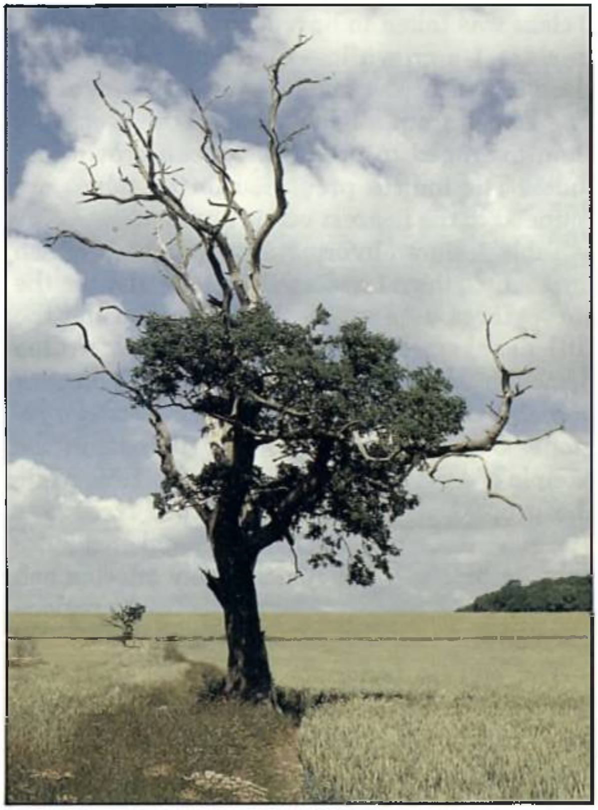


Plate 4. *Tree showing recovery from dieback. The foliage is carried almost entirely on secondary growth. The current crown loss score at 20–29% is probably lower that it would have been in the past. (39429)*



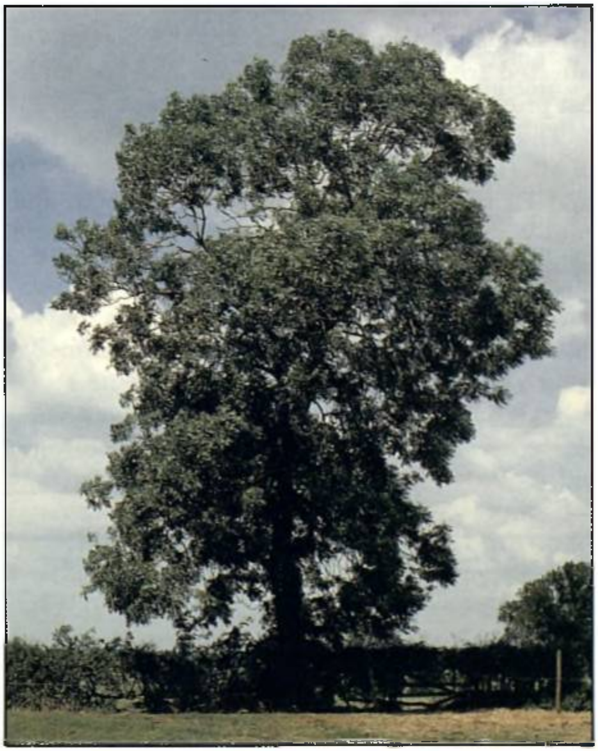


Plate 5. *Very severe dieback in a tree that was probably once part of a hedgerow. A few secondary shoots have been formed. The crown loss score would be 80–89%. (39435)*

Plate 6. *This is a relatively healthy tree. Although a little dieback is present it is insufficient to merit a crown loss score in the 10–19% category. (39433).*

0 class was taken to have a crown loss of 0, one in class 1 a crown loss of 10 and so on up to class 9, which was taken to have a score of 90. The scores from all the trees in the plot were then averaged to produce a mean crown loss index. The indices presented in the tables are rounded to the nearest whole number.

Table 1 shows information on dieback of ash for each of the 11 assessed regions and for the survey area as a whole, as obtained using the full assessment procedures. These tables demonstrate the widespread nature of dieback and also the considerable variation between regions. Overall the incidence of dieback in the sample of 4454 trees was found to be 19%, while the proportion of severely affected trees was 7%. A χ^2 test conducted on regional incidence data for both affected and severely affected ash showed a significant difference between regions ($p<0.001$).

The highest incidence of affected trees was found in regions 7 and 8, with 26% and 28% respectively of all sampled trees being damaged. These two areas comprise East Anglia, the south Midlands and south-east England. Regions 2 and 5, north-east Scotland and northern England, also had quite large proportions of affected trees, and these regions had the highest proportion of severely affected trees.

The healthiest ash in terms of the proportion of affected individuals were found in regions 10 and 11, followed by regions 3 and 4 (north and mid-Wales, south Wales; central Scotland and southern Scotland, respectively).

Figure 2A illustrates the distribution of affected ash trees interpolated from sample data. It shows a broadly similar situation to that indicated by Figure 1, namely a pattern of widespread dieback with a concentration of damage in the south-east Midlands and with some localised dieback in other, generally easterly, locations. The map of severely damaged ash (Figure 2B) shows a similar distribution as does the map based on mean crown loss (Figure 2C).

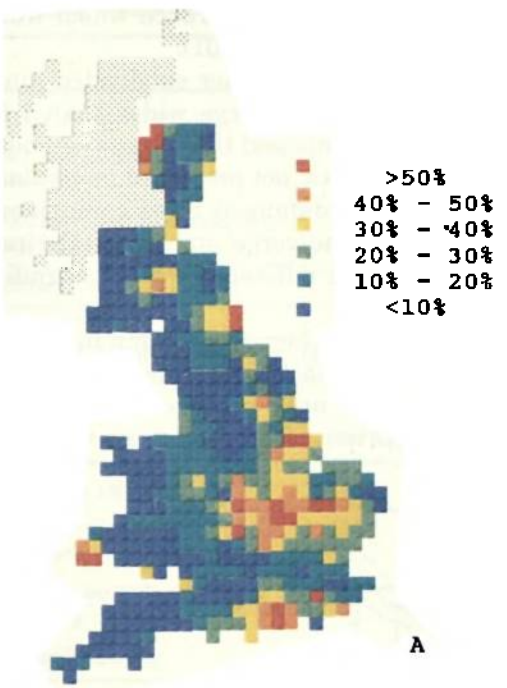
In order to aid interpretation of these interpolated maps the mean crown loss is also shown in Figure 3, but this time with the data from each plot entered separately. This enables one to see the way in which an isolated plot has a greater influence on the colour patterning generated by the interpolation system than do more closely spaced plots. A good example of the former is provided by the plot to the east of Inverness.

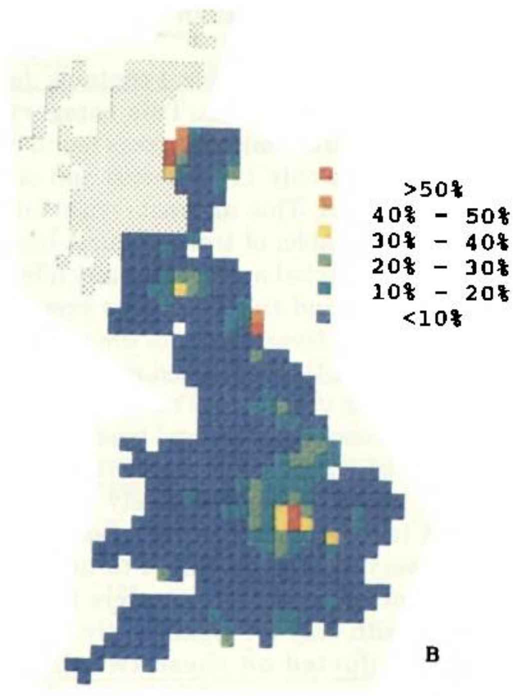
Analysis of ash data by tree size and position in relation to other trees

Table 2 tabulates the health of ash in relation to estimated stem diameter at breast height and shows that for trees under 10 cm diameter dieback is negligible. With increasing diameter there is a progressive increase in the incidence of both damaged and severely damaged trees. Table 2 also shows the incidence of damage in isolated trees to be higher than that in their grouped counterparts. The incidence of severely damaged trees is also greater.

Table 2. Health of ash in relation to estimated stem diameter at breast height and position in relation to other trees

	Diameter class				*Position*		
	<10 cm	*10–50 cm*	*50+ cm*	*Sig.*	*Isolated*	*Grouped*	*Sig.*
Total ash sampled	215	3832	407		1515	2939	
No. ash affected	2	665	166	***	393	440	***
Per cent	1	17	41		26	15	
No. ash severely affected	0	229	85	***	176	138	***
Per cent	0	6	21		12	5	
Crown loss index	0	5	13	***	8	4	***





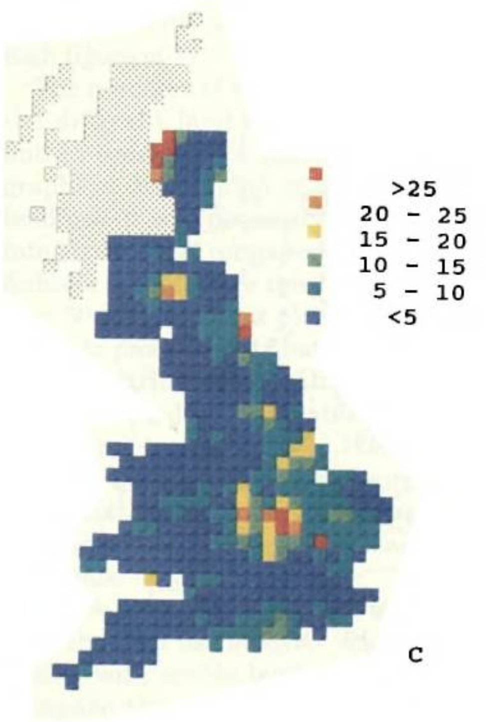


Figure 2. Ash; distribution of dieback obtained from the sample plot data interpolated on a 20 km × 20 km grid. A; percentage affected trees. B; percentage severely affected trees. C; mean crown loss index.

Analysis of ash data in relation to local site factors

The relationship between ash health and soil type, as determined from soil survey maps, is shown in Table 3. Considerable variation was found between the five broad soil classes with only 6% of trees affected on unclassified soils compared to 24% on rendzinas. The unclassified category comprises soils not surveyed by soil scientists, and is made up almost exclusively of built-up areas and other non-agricultural land. Trees on podzols showed a relatively small incidence of dieback whereas the frequency of damage on brown earths and particularly gleys, approached that of rendzinas. There was no significant difference between rendzina and gley soils, but there was a difference between these two soils and the others ($p<0.001$).

The effect of land use is examined in Table 4 which contains data for several different categories of management. Each was selected after consideration of the many possible combinations that could be obtained with the 16 land uses recorded. A comparison of urban land with that used for various types of agriculture was of obvious interest in view of Pawsey's study.

The first column in Table 4 contains data for trees in urban locations. This category contained some of the healthiest trees found during the survey with only 11% affected and only 3% severely affected. This contrasts with data, not shown in this table, of trees in rural locations; 20% of trees affected and 7% severely affected.

The second and third columns respectively contain data for trees where all the surrounding land was currently being used either for arable farming or was grassland. The high incidence of damage with this 'arable only' land use is striking; 38% of these trees exhibited signs of dieback, and 10% were severely affected. By contrast trees surrounded by 'grassland only' were in very similar condition to urban trees; only 10% of the assessed trees were found to be damaged with only 3% significantly affected. A χ^2 test conducted on these two data sets, showed that there was a highly significant difference in both affected and severely affected trees ($p<0.001$)

As there were relatively few 'arable only' and 'grassland only' trees it was decided to examine the situation in the expanded categories 'some arable' and 'some grassland'. These included the data for the 'arable only' and 'grassland only' trees, but also included data on the very much larger numbers of trees where arable or grassland was present either with some other land use, or in a situation where the full land use could not be recorded because hedges or other obstacles obscured the view. The result of this analysis, in columns 4 and 5 of Table 4 shows that the percentage of affected trees in the 'some arable' category was slightly lower than in the 'arable only' category. However, the proportion of severely affected trees was slightly higher. Trees in the 'some grassland' category were slightly worse in all respects than trees where grassland was the only surrounding land use.

The sixth and seventh columns contain data in relation to the presence or absence of a nearby road. The incidence of both affected and severely affected trees was approximately twice as high in roadside trees as in trees that were remote from the road, a difference which was found to be significant ($p<0.001$).

Roadside trees were further subdivided into those with an adjacent verge wider than 1.5 times the crown radius and those trees without such a verge. The data, not presented in tabular form, showed that damaged trees comprised 20% of the total in the 'verge' and 23% in the 'no verge' category. This difference was not significant.

Finally in Table 4, there is a column in which data are presented on trees where arable and roadside were the only recorded land uses. While the proportion of affected trees was not

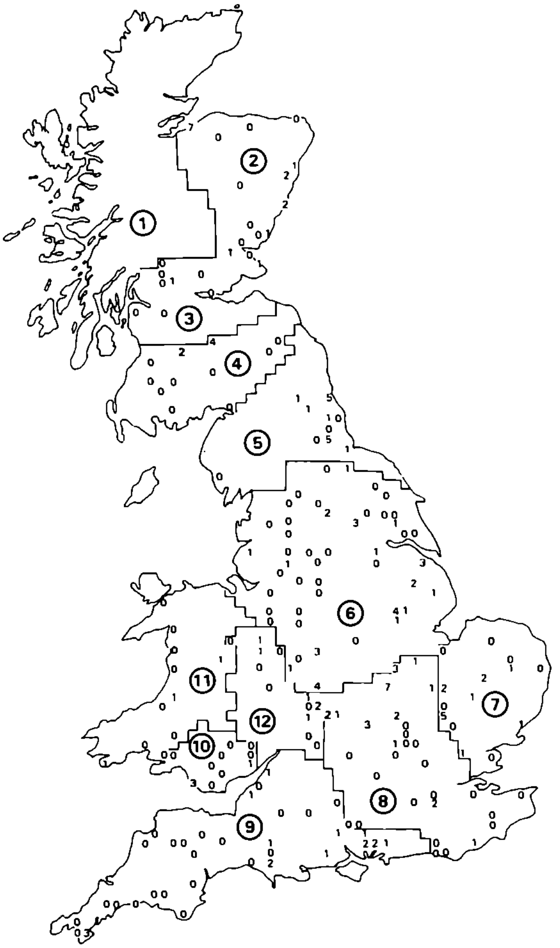


Figure 3. Distribution of sample plots showing the mean crown loss index for ash. (Scale: 0 = mean crown loss index of 0–5; 1 = 6–10; 2 = 11–15 etc.) The climate/pollution regions of Innes and Boswell (1987) are also shown.

Table 3. Health of ash in relation to soil type

	Rendzina	*Brown earth*	*Podzol*	*Gley*	*Unclassified*	*Sig.*
Total ash sampled	501	1904	396	1469	184	
No. ash affected ·	119	337	40	326	11	***
Per cent	24	18	10	22	6	
No. ash severely affected	39	125	22	124	4	**
Per cent	8	7	6	8	2	
Crown loss index	6	5	4	6	2	***

Table 4. Health of ash in relation to its surrounding land use

	Urban	*Arable only*	*Grassland only*	*Some arable*	*Some grassland*	*Some roadside*	*No roadside*	*Arable and roadside only*
Total ash sampled	448	297	786	1339	2338	2050	2026	563
No. ash affected	49	112	77	415	331	465	252	197
Per cent	11	38	10	31	14	23	12	35
No. ash severely affected	15	29	27	169	124	203	72	97
Per cent	3	10	3	13	5	10	4	17
Crown loss index	3	8	3	9	4	7	3	11

as high as with 'arable only' trees, there was a high figure of 17% for severely affected trees.

The numbers of trees associated with some of the different land uses were relatively small and in order to get some measure of the geographical distribution of damage in relation to land use, it was necessary to pool the plot data into larger units composed of 25 10 km squares. Subsets of data were then analysed using these new 50 km × 50 km plots and interpolated as before to produce distribution maps.

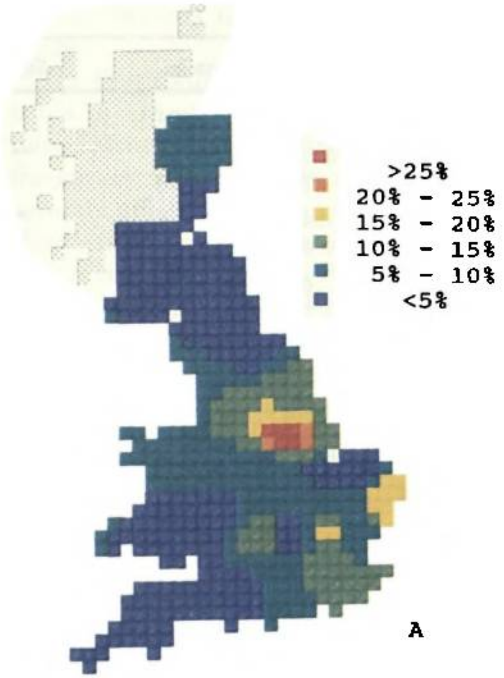
The distribution of ash dieback in terms of mean crown loss in 'arable only', 'grassland only' and 'some arable' trees is shown in Figures 4A, 4B and 4C. Not surprisingly there are variations between the maps, although all show a concentration of dieback in the east Midlands.

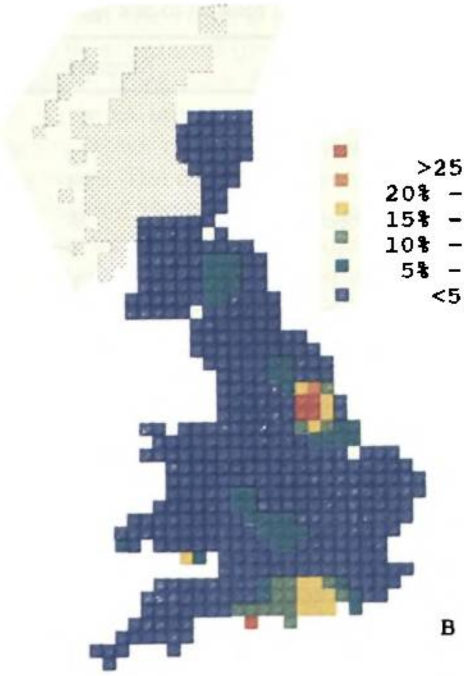
As the most striking single feature to emerge from the land use analysis was the strong association with arable land use, it was decided to compare the incidence of dieback in 'some arable' and 'no arable' trees within each of the pooled 50 km × 50 km plots, rejecting any where there were fewer than three trees in either category. The percentage of affected trees was higher in the 'some arable' category in 30 out of the 40 eligible squares, this effect being significant at $p<0.05$. These plots were distributed throughout the survey area (Figure 6) although there was part of southern England where they were not well represented.

An analysis of damage associated with 'arable only' and 'some arable' land use in terms of soil type is shown in Tables 5 and 6, respectively. With the 'arable only' classification (Table 5), only 297 trees were involved and there were no clear differences between the three soil types that were encountered.

By contrast, with the 'some arable' trees (Table 6) a statistically significant difference was found between soil types; this effect being due to the high proportion of damaged trees on podzols. However, the relatively small sample size indicates that further observations of trees on this soil type may be needed to corroborate this evidence. Levels of damage among the other three soil types were very similar.

The land use effects which were studied in Table 4 were examined further by means of a sub-division into trees with and without a ditch within 5 m of the base of the tree. The analysis





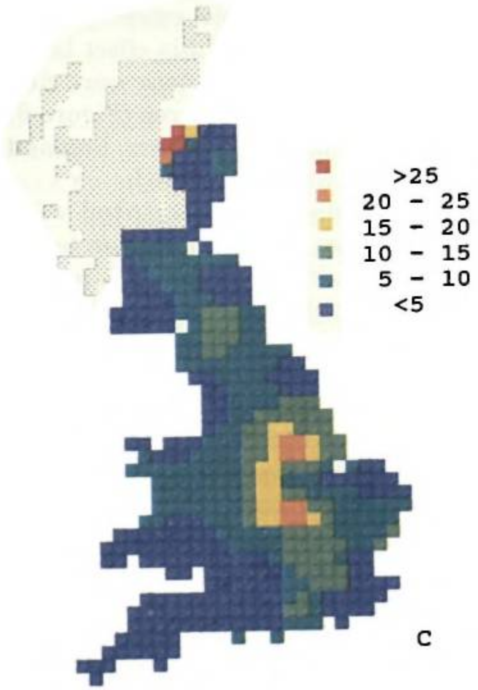


Figure 4. Ash; mean crown loss index in relation to land use. Distribution obtained from pooled sample data interpolated on a 20 km × 20 km grid. A; 'arable only'. B; 'grassland only'. C; 'some arable'.

is shown in Table 7. Urban trees were not considered as few ditches were found in urban situations. With the 'arable only' land use, there seems to be no relationship between the condition of the tree and the presence or absence of a ditch. With 'grassland only', there was an indication of an effect, but this was not statistically significant. However, in all the other circumstances examined, the presence of a ditch was associated with a significant increase in the proportion of damaged trees. In many instances, the proportion of severely affected trees in the presence of a ditch was more than twice that occurring where no ditch was recorded. Comparison of crown loss indices followed a similar pattern.

Analysis of ash epicormic shoot data

Data on the presence of epicormic shoots are shown in Table 8. In a whole range of broadleaved trees the production of epicormics is a common response to dieback. It is therefore not surprising to find that on trees with more dieback the occurrence of these shoots was more frequent. There was also a difference in terms of the proportion of trees in which epi-

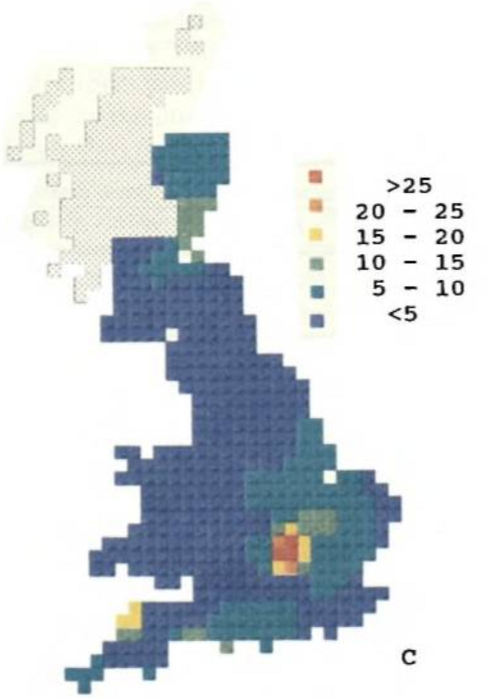


Figure 5. Oak; distribution of dieback obtained from the sample plot data interpolated on a 20 km × 20 km grid. A; percentage affected trees. B; percentage severely affected trees. C; mean crown loss index.

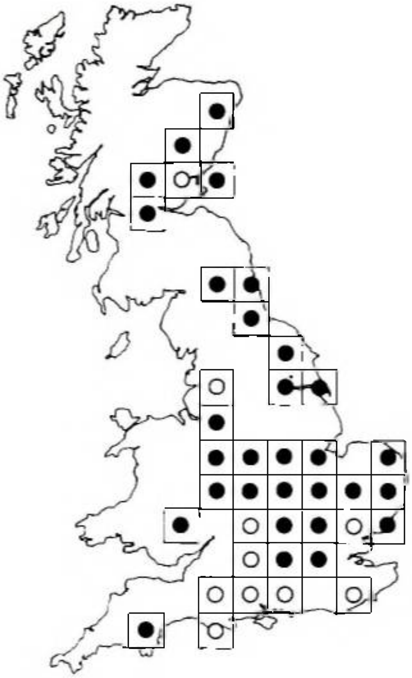


Figure 6. Distribution of 50 km × 50 km squares within which the incidence of dieback in 'some arable' and 'no arable' ash trees was compared. Open circle; 'no arable' worse than 'some arable'. Closed circles; 'some arable' worse than 'no arable'. For further explanation see text.

Table 5. Health of ash with 'arable only' land use, in relation to soil type

	Rendzina	*Brown earth*	*Podzol*	*Gley*	*Unclassified*	*Sig.*
Total ash sampled	97	114	0	86	0	
No. ash affected	39	41	0	32	0	n.s.
Per cent	40	36	0	37	0	
No. ash severely affected	8	12	0	9	0	n.s.
Per cent	8	11	0	10	0	
Crown loss index	9	8	–	8	–	n.s.

Table 6. Health of ash with 'some arable' land use, in relation to soil type

	Rendzina	*Brown earth*	*Podzol*	*Gley*	*Unclassified*	*Sig.*
Total ash sampled	328	531	39	441	0	
No. ash affected	95	154	20	146	0	*
Per cent	29	29	51	33	0	
No. ash severely affected	30	61	15	63	0	***
Per cent	9	11	38	14	0	
Crown loss index	7	8	23	10	–	***

Table 7. Health of ash in relation to land use and presence or absence of ditches

	Arable only			*Grassland only*			*Some arable*			*Some grassland*		
	P	*A*	*Sig.*	*P*	*A*	*Sig.*	*P*	*A*	*Sig.*	*P*	*A*	*Sig.*
Total ash sampled	45	144		13	745		228	852		143	2057	
No. ash affected	16	54	n.s.	2	67	n.s.	96	227	***	41	259	***
Per cent	36	38		15	9		42	27		29	13	
No. ash severely affected	7	14	n.s.	0	24	n.s.	50	89	***	17	95	***
Per cent	16	10		0	3		22	10		12	5	
Crown loss index	10	8	n.s.	2	2	n.s.	15	7	***	8	3	***

	Some roadside			*No roadside*			*Arable and roadside only*		
	P	*A*	*Sig.*	*P*	*A*	*Sig.*	*P*	*A*	*Sig.*
Total ash sampled	307	1743		78	1948		144	409	
No. ash affected	108	357	***	29	223	***	64	128	***
Per cent	35	20		37	11		44	31	
No. ash severely affected	55	148	***	12	60	***	36	58	**
Per cent	18	8		15	3		25	14	
Crown loss index	12	6	***	12	3	***	16	9	***

P = ditch present; A = ditch absent

Table 8. Distribution and abundance of secondary shoots on ash

	Total no. of trees	*No. with secondary shoots*		
		Absent	*Present*	*Abundant*
Healthy ash	3615	3532 (98)†	57 (2)	26 (<1)
Affected ash	821	496 (60)	172 (21)	153 (19)
Severely affected ash	302	90 (30)	89 (29)	123 (41)

† Percentage figures in parentheses

cormic shoot production was classified as 'abundant' rather than merely as 'present'. Statistical analysis showed these results to be highly significant.

Analysis of oak results

The overall incidence of dieback in the oak encountered in the survey was 18%, a similar figure to that for ash. However, because the numbers of oak assessed in several regions were small, comparison between the two species at regional level should be undertaken with care. In Table 9 the data in regions 2, 3 and 4 (Scotland) have been combined as have those in regions 10 and 11 (Wales). The table shows that for oak, the worst affected areas are regions 7 (East Anglia), 8 (south Midlands and south-east England) and 9 (south and south-west England) and the best, the combined regions 10 and 11 (Wales).

The distribution of affected oak (trees with 10% or more crown loss) is shown in Figure 5A. This was drawn using data pooled into 50 km × 50 km squares. As with ash, the damage is widespread but shows a concentration around two areas: East Anglia and central England, and eastern Scotland. The most severely affected trees (more than 30% crown loss) were recorded in the south-east Midlands (Figure 5B) and this effect is also shown with the mean crown loss data in Figure 5C.

For those plots in which 10 or more oak were assessed, a comparison was made to determine which of the two species was the worse affected in terms of mean crown loss. The total was tabulated for each region and the results presented in Table 10. Ash was more affected than oak in 22 out of the 32 plots eligible for comparison, a difference which was found to be significant ($p < 0.05$).

With the much smaller number of oak trees examined, it was not possible for the data for oak to be examined in such great detail as those for ash. In general, a very similar situation was

Table 9. Health of oak in the different climate/pollution regions

	Region									
	2, 3 & 4	*5*	*6*	*7*	*8*	*9*	*10 & 11*	*12*	*Sig.*	*All regions*
Total oak sampled	73	36	220	101	160	236	124	72		1022
No. oak affected	11	5	35	31	32	48	7	10	***	179
Per cent	15	14	16	31	20	20	6	14		18
No. oak severely affected	7	1	6	9	9	22	1	4	**	59
Per cent	10	3	3	9	6	9	<1	6		6
Crown loss index	5	3	3	7	5	6	1	3	***	9

Table 10. Comparison of the amount of dieback in ash and oak in the different climate/pollution regions

No. of plots where mean crown loss is higher	*Region*												
	2	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*Total*	*Sig.*
in ash	0	1	0	1	6	1	3	6	2	0	2	22	*
in oak	0	1	0	0	1	2	2	1	0	2	1	10	

Note: Comparison made only where minimum of 10 or more oak were assessed in a plot

Table 11. Health of oak in relation to estimated stem diameter at breast height and position in relation to other trees

	Diameter class				*Position*		
	<10 cm	*10–50 cm*	*50+ cm*	*Sig.*	*Isolated*	*Grouped*	*Sig.*
Total oak sampled	10	674	338		419	603	
No. oak affected	0	86	93	***	81	98	n.s.
Per cent	0	13	28		19	16	
No. oak severely affected	0	29	30	***	34	25	*
Per cent	0	4	9		8	4	
Crown loss index	0	3	7	***	5	4	n.s.

Note: In the significance tests in this table, the <10 cm and the 10–50 cm diameter classes were combined to give two resulting classes; <50 cm and 50+ cm

Table 12. Health of oak in relation to soil type

	Rendzina	*Brown earth*	*Podzol*	*Gley*	*Unclassified*	*Sig.*
Total oak sampled	57	403	57	466	39	
No. oak affected	11	85	5	76	2	*
Per cent	19	21	9	16	5	
No. oak severely affected	5	27	1	26	0	n.s.
Per cent	9	7	2	6	0	
Crown loss index	5	5	2	4	1	n.s.

Table 13. Health of oak in relation to its surrounding land use

	Urban	*Arable only*	*Grassland only*	*Some arable*	*Some grassland*	*Some roadside*	*No roadside*	*Arable and roadside only*
Total oak sampled	73	91	233	344	516	472	470	143
No. oak affected	12	21	26	89	62	105	57	42
Per cent	16	23	11	26	12	22	12	29
No. oak severely affected	3	9	8	34	23	30	21	16
Per cent	4	10	3	10	4	6	5	11
Crown loss index	3	7	3	7	3	5	3	7

found for the two species. Thus, there was no significant dieback in the smaller oaks and a progressive increase in damage with increasing size (Table 11). Isolated trees showed a somewhat higher incidence of dieback symptoms than did trees in groups (Table 11) but the result was significant only for severely affected trees. Trees on unclassified soils were healthier than trees on other types of soils (Table 12).

Both grassland land use categories, together with trees away from the roadside, were found

Table 14. Distribution and abundance of secondary shoots on oak

	Total no. of trees	*No. with secondary shoots*		
		Absent	*Present*	*Abundant*
Healthy oak	843	664 (79)†	151 (18)	28 (3)
Affected oak	179	31 (17)	56 (31)	92 (52)
Severely affected oak	59	2 (3)	8 (14)	49 (83)

† Percentage figures in parentheses

to be in relatively good health (Table 13). In contrast, higher levels of damage occurred on arable land and in trees next to roadsides. However, unlike the situation for ash, there was no indication that the presence of an adjacent ditch had any effect on dieback in oak; 17% of the trees being affected whether or not a ditch was present.

The data on the presence of epicormic shoots (Table 14) show a broadly similar situation to that described for ash with the qualification that in oak the shoot production was both more frequent and more abundant than in ash.

Analysis of ash and oak data in relation to selected environmental variables

The data obtained during this survey on the distribution of trees with crown dieback could be analysed in relation to an almost infinite number of geographically distributed variables. Having considered the fact that the survey was concerned with lowland hedgerow trees it was decided that annual rainfall, summer rainfall, soil moisture deficit and soil water availability would be of interest. Mean values for these parameters were obtained for each plot from published maps (Anon., 1979 a and b; Anon., 1980; Birse and Dry, 1970) and from Soil Survey reports (Findlay *et al.*, 1984; Hodge *et al.*, 1984; Jarvis, M.G., *et al.*, 1984; Jarvis, R.A., *et al.*, 1984; Ragg *et al.*, 1984; Rudeforth *et al.*, 1984). When considering pollution, the fact that the investigation was initiated at least in part as a result of concern over the impact of air pollution on trees, a less selective approach seemed appropriate. Accordingly, pollution data prepared by Warren Spring Laboratory and used in the 1987 Forestry Commission Forest Health Survey were employed. For details on the collection and preparation of pollution data, see Devenish (1986) and on the application of modelled data to tree health studies, see Innes and Boswell (1988).

The nationwide pollution data, provided on a regular grid basis, were interpolated by computer to provide a value for each of the 200 plots visited in the survey. This figure was then used together with the mean crown loss index in each plot in a simple correlation analysis. For an analysis of the smaller number of trees asso-

Table 15. Correlation analysis for plot mean crown loss and listed environmental variables in various ash and oak data sets

	Ash			*Oak*	
	All ash	*Arable only*	*Some arable*	*All oak*	*Grassland only*
S deposition†	–	–	–	–	–
H concentration	0.1935**‡	0.5776**	0.2737*	–	–
H deposition	–	0.5130**	–	–	–
NH_4 concentration	0.1603*	0.3730*	–	–	–
NH_4 deposition	–	–	–	–	–
Non-marine SO_4 concentration	0.1504*	0.5487**	–	–	–
Non-marine SO_4 deposition	−0.1451*	0.5001**	–	–	–
NO_3 concentration	0.1941**	0.4138*	–	–	–
NO_3 deposition	–	–	–	–	–
Total SO_4 concentration	–	0.5451**	–	–	–
Total SO_4 deposition	−0.2496**	0.4111*	−0.2817*	–	−0.3615*
SO_2 concentration	–	0.4093*	0.3461*	–	–
Mean annual rainfall	−0.3451***	–	−0.3671**	−0.2362*	–
Mean summer rainfall	−0.3197**	–	−0.3306*	−0.2360*	–
Mean soil moisture deficit	0.2410**	–	–	–	–
No. trees sampled	4454	297	1339	1022	233
No. plots	200	30	53	121	32

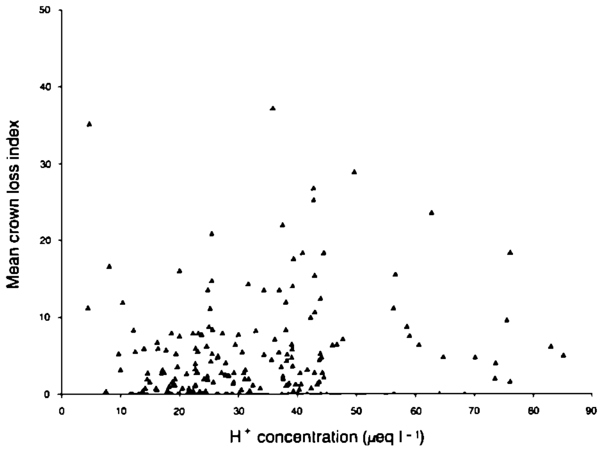
† For details of sources of environmental data see Appendix 3.

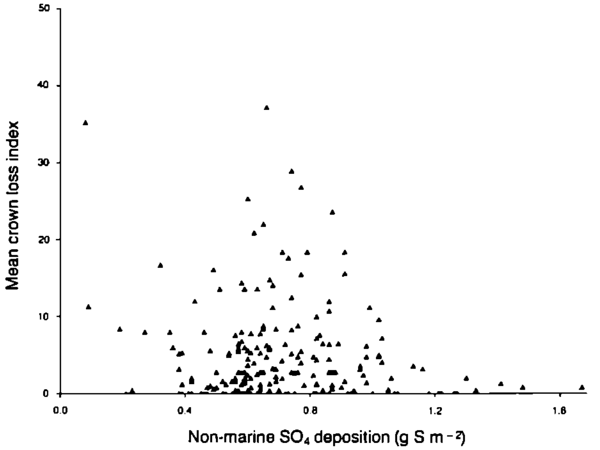
‡ Coefficients listed only where statistically significant, i.e. $p < 0.05$ or better.

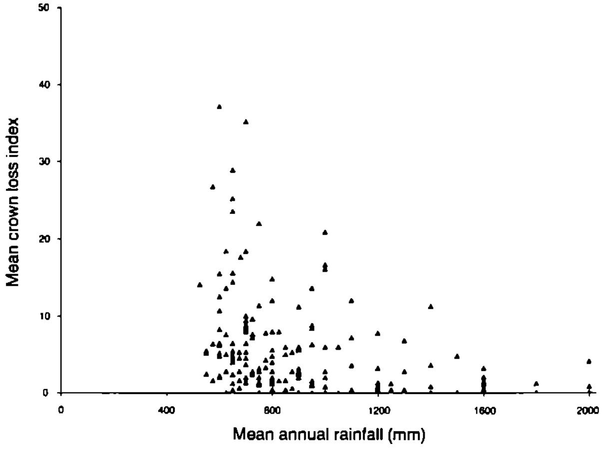
ciated with particular land uses, for example 'arable only' trees, data were pooled into larger units of 50 km × 50 km squares as before. Mean crown loss figures were recalculated and the environmental variables reinterpolated defining the centre of each large square as the plot reference point. If any of these points now occurred over the sea, they were moved so that they were in the centre of the land area circumscribed by the coastline and the perimeter of the square. A similar analysis was undertaken using the data obtained for oak.

Table 15 shows any statistically significant correlations that were found for pollutant, rainfall and soil moisture variables used in this study. Figures 7 to 10 show these relationships in graphic form.

When the data for 'all ash' trees were examined, even though many correlation coefficients were of low value, a number of significant relationships emerged. The highest correlations with damage were with mean annual rainfall and with mean summer rainfall (*r*= –0.35 and *r*= –0.32 respectively); crown loss increasing with decreasing rainfall. Correlations were also found with several pollutants. The strongest, also being negative, was with total wet deposited sulphate (*r*= –0.25). A positive correlation was obtained with soil moisture deficit (*r*= 0.24). For trees with 'arable only' land use, a different situation was found. Here, there was no correlation with rainfall but damage was correlated fairly strongly with several pollutants, most notably hydrogen ion concentration and deposition, non-marine sulphate concentration and deposition and total sulphate concentration (all above *r*= 0.5). For 'some arable' trees the situation was more like that found with the population as a whole than with the 'arable only' population. Negative correlations were found with rainfall (*r*= –0.37 for annual rainfall and *r*= –0.33 for summer rainfall) and with total sulphate deposition (*r*= –0.28). Sulphur dioxide concentration was positively correlated with dieback (*r*= 0.35), as was hydrogen ion concentration (*r*= 0.27). Total sulphate deposition was negatively correlated (*r*= –0.28) with damage. No significant relationships were found with the 'grassland only' data.







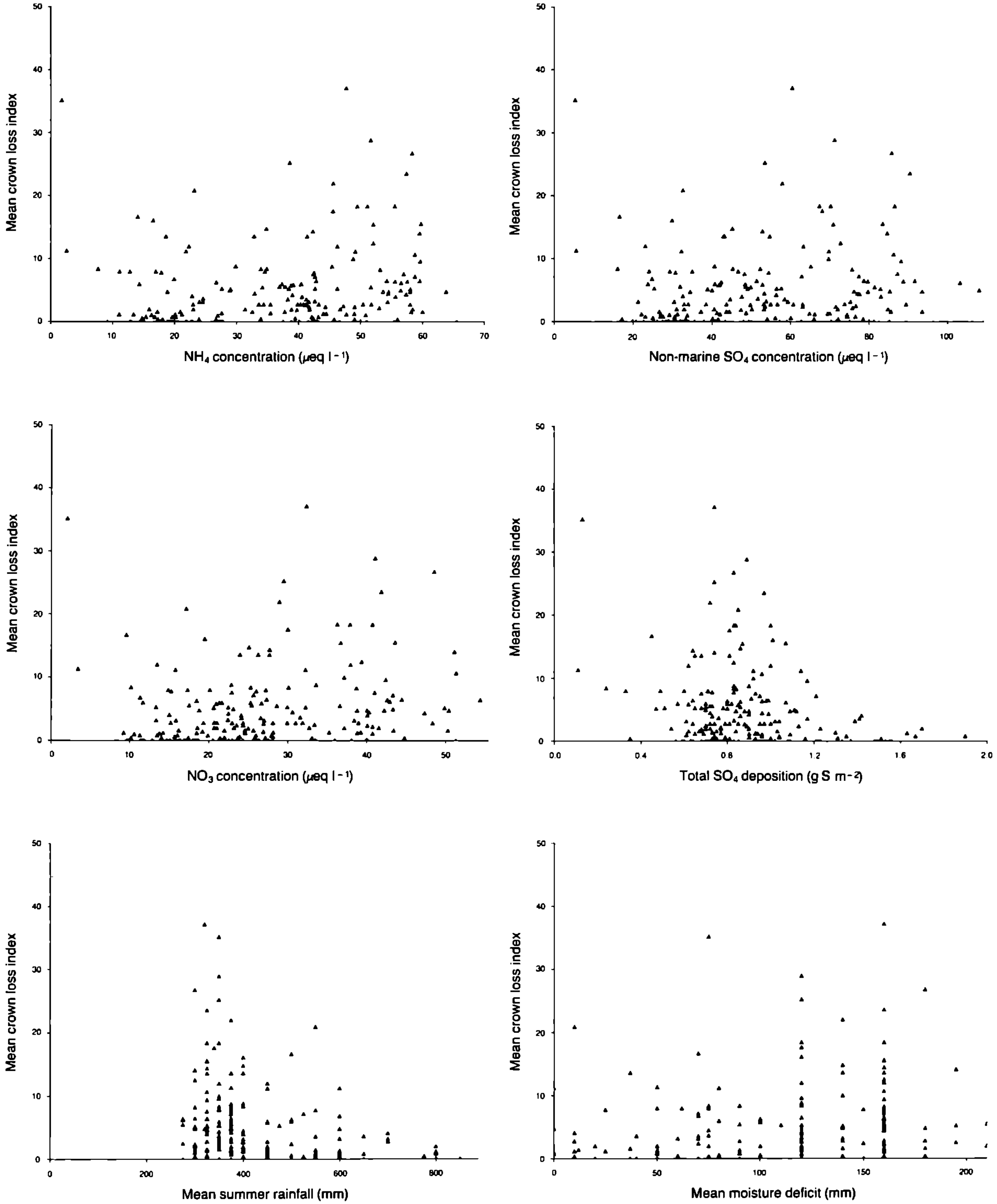


Figure 7. Scatter diagrams showing the relationships between certain environmental variables and mean crown loss for ash. Data from individual sample plots. See Appendix 3 for details of environmental variables.

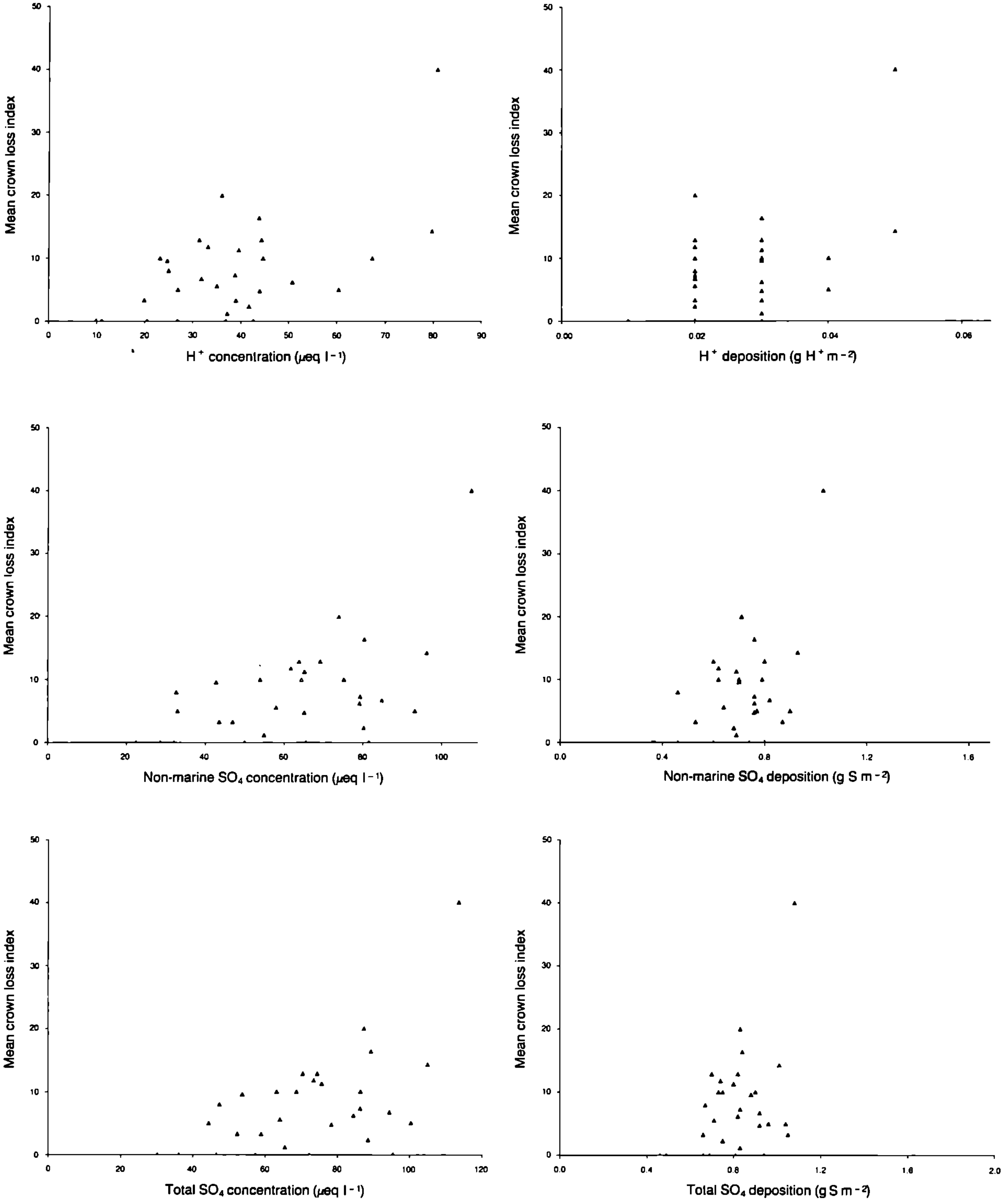
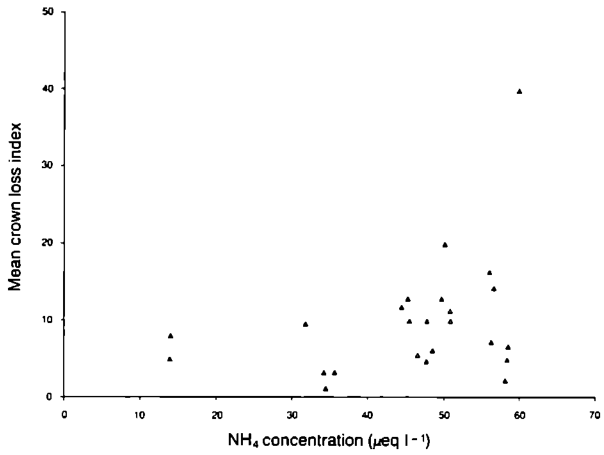
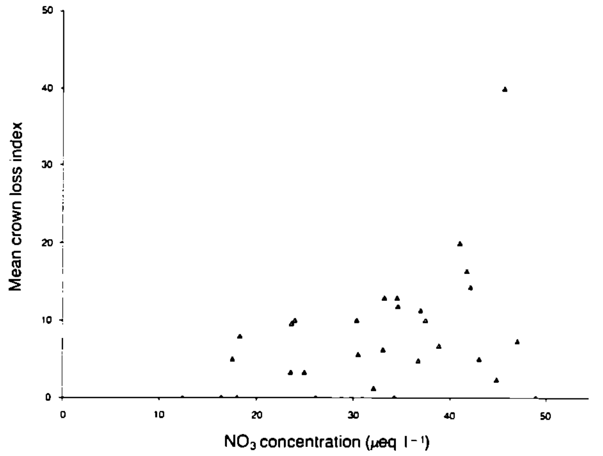
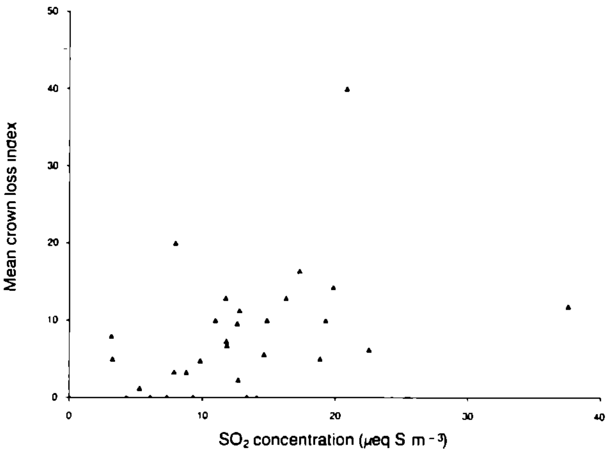


Figure 8. Scatter diagrams showing the relationships between certain environmental variables and mean crown loss for ash surrounded by 'arable only' land. Data from pooled sample plots. See Appendix 3 for details of environmental variables.







For oak the only significant relationships for the whole population were with annual and summer rainfall ($r = -0.24$ in both cases). Examination of 'grassland only' data resulted in only one negative correlation; this being with total sulphate concentration ($r = -0.36$). No significant associations were obtained with arable data sets.

Discussion

The nature of the survey results

In considering these results it is important to recognise that while the survey covered a wide geographical area it was conducted on a partially selective basis. In particular the plots of 15–25 trees within each randomly chosen 10 km square comprised only trees that could be seen from a road or other place of public access. The importance of this point is evident when it is noted that the incidence of dieback is twice as high for trees in the 'some roadside' category as in the 'no roadside' one (Table 4).

It follows from the above that while a valid analysis of the relationship between various factors and dieback can be made from the data it must not be thought that a simple relationship exists between the 4454 trees investigated and the UK hedgerow ash population as a whole. With oak this is even more true, as the 1022 trees recorded in the survey were only those encountered in plots selected as being acceptable for the assessment of dieback in ash.

Factors affecting the dieback of ash

This survey has substantially extended our knowledge of the distribution and severity of ash dieback in Great Britain. It is clear that it is a widespread condition and one which is particularly common in the east Midlands – indeed in just the area where it first aroused attention almost 30 years ago. It must be emphasised that it will have taken some of the trees many years to reach their present condition and that as outlined in the introduction, many factors acting separately or together may well have been important in the decline of an individual tree at a particular locality. In discussing the re-

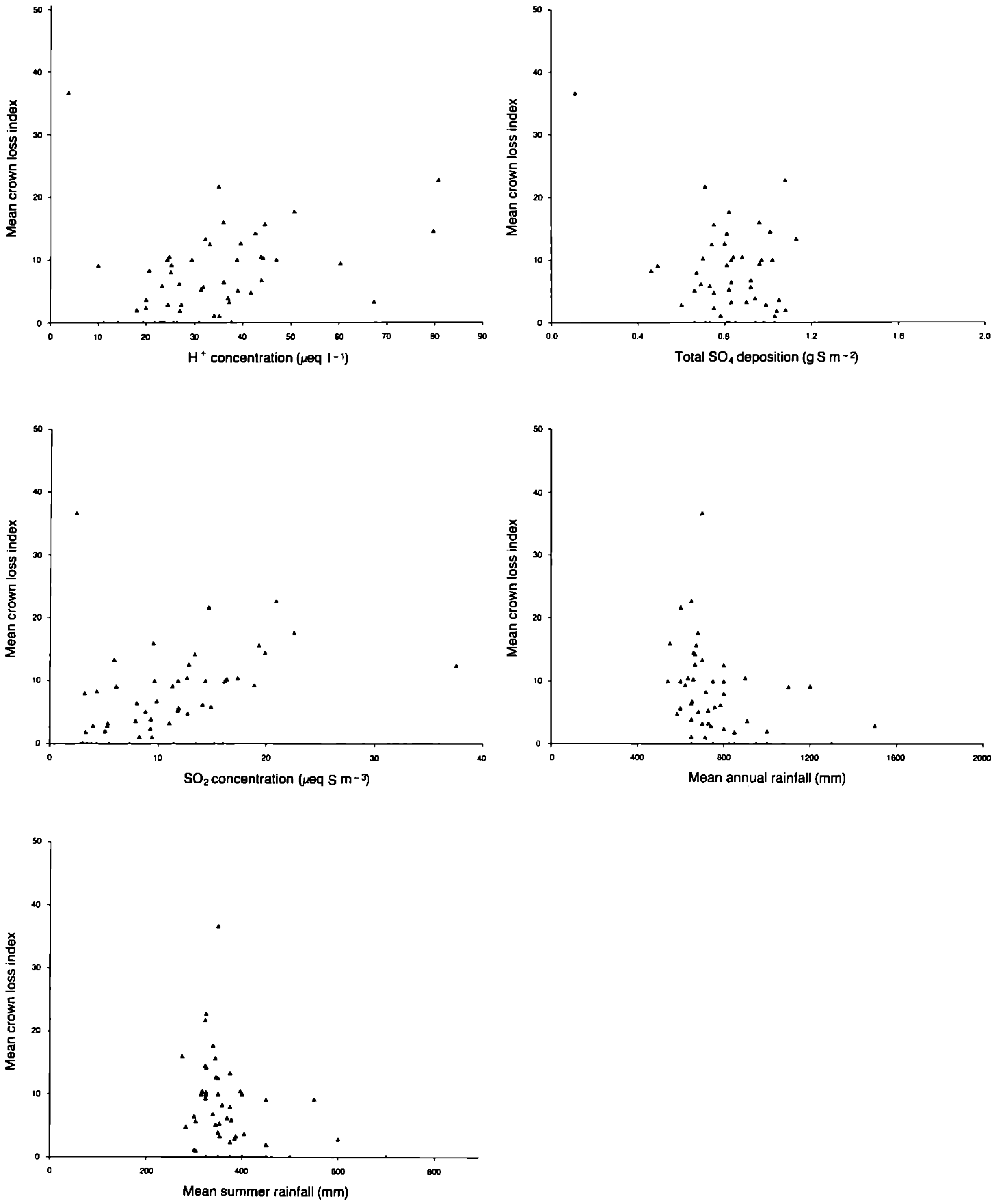


Figure 9. Scatter diagrams showing the relationships between certain environmental variables and mean crown loss for ash surrounded by 'some arable' land. Data from pooled sample plots. See Appendix 3 for details of environmental variables.

sults it seems appropriate to concentrate first on the relationships that have been found between the incidence of dieback and the local environmental factors assessed and then to progress to more general influences such as those of climate.

Some of the most interesting results to emerge are those relating to the association between dieback and the way land is managed around the tree, in particular, the high level of damage in trees adjacent to arable land as opposed to grassland and 'urban' land.

Ash dieback and arable land use

Considering first the question of arable land, a number of factors are worthy of discussion. These include the effects of: 1) careless stubble burning, 2) the use of herbicides and other agrochemicals, 3) the processes of soil tillage.

Influence of stubble burning

The effects of uncontrolled stubble burning have aroused considerable public concern over the last two decades and while travelling between survey plots a number of incidents were observed. Several of these had resulted in extensive local damage to hedgerow trees, even though farmers had taken the precaution of ploughing a fire break around field edges. Leaf scorching rather than burning was the main phenomenon and this often extended high into the crown.

In the absence of detailed studies on the long-term consequences of stubble burning damage (particularly if repeated year after year), it is difficult to assess its role in the ash dieback problem. However, the fact that twigs and dormant buds often appeared to be undamaged despite the destruction of adjacent leaves, leads the authors to believe that it is not of primary importance. In addition unidirectional damage is not a feature of ash dieback in the way that might be expected if stubble burning was a major factor.

Influence of agrochemicals – herbicides

Herbicides have an obvious potential for damage to hedgerow trees but their effects are difficult to diagnose unless foliage or shoot symptoms are present. Although, during the course of the survey, only one tree was observed to be showing the possible effects of current herbicide damage, experience in the Pathology Branch of the Forestry Commission suggests that agricultural herbicides such as glyphosate and the hormone herbicides such as 2,4-D can quite often affect hedgerow trees. With herbicides in granular form, incorrect placement is likely to be the main problem, but it should be noted that even correctly placed herbicides can volatilise in warm weather and affect adjacent crops (R. J. Froud-Williams, personal communication). It is possible that intervening hedgerow trees could be affected in this way.

As well as causing acute foliar damage to trees, herbicides may also affect trees by interacting with other stressing factors causing more chronic problems. Thus Sinclair *et al.* (1987) describe a decline of trees on the Great Plains of North America where it is postulated that sublethal doses of herbicides result in reduced winter hardiness and attack by opportunistic fungal pathogens.

In addition to immediate effects there is also the question of possible long-term problems resulting from the build-up of herbicide residues in the soil. The physical, chemical and biological properties of the soil, together with climate, are obviously important in determining the fate of these chemicals (McMinn and Roberts, 1983). At present information regarding the degradation of herbicides is available for only very few top soils: moreover most of the data come from laboratory tests and not from field studies.

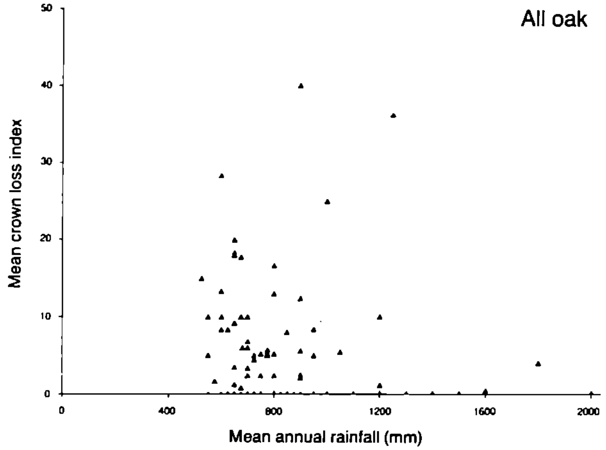
Influence of agrochemicals – fertilisers

The results of annual surveys of fertiliser use (Chalmers *et al.*, 1988) show that in England and Wales during the period 1970–87, the overall use of nitrogenous fertiliser on farmland increased by over 80%. Any uptake of nitrogen by adjacent trees might be expected to be generally beneficial to their growth, but this may not necessarily be the case. For example, trees may be made more susceptible to adverse biotic and abiotic factors (Alden and Hermann, 1971; Nihlgard, 1985; Van Breemen and Van Dijk, 1988).

In a review of tree responses to fertiliser treatments, Miller and Miller (1988) suggest that growth abnormalities (e.g. bud necrosis and loss of apical dominance) which are occasionally expressed after heavy application of nitrogen, could be explained by some new secondary nutrient deficiency, the supply of which had been sufficient prior to fertilisation.

Influence of tillage

In a literature review of the effects of soil compaction and aeration on tree roots, Ruark *et al.* (1982) cite several authors and report that "60–80 per cent of [tree] root volume is to be found in the top 20 cm of soil"; this effect being even more marked for fine roots. The ploughing process inverts soil to a similar depth and the use of such implements together with the practice of ploughing close to field edges must have great potential for causing damage to tree rooting systems.



Once land is under an arable management regime, the effects of ploughing could be exacerbated when regenerating tree roots are damaged repeatedly. The uptake of water and minerals might be seriously reduced and food reserves laid down in the root system could be lost.

Since the late 1940s there has been an increasing use of deep cultivating implements or sub-soilers, the aim of which is to loosen compacted areas within the soil profile down to depths of 60 cm or more, so improving drainage and crop growth (Swain, 1975). The use of this technique could well cause considerable damage to roots if carried out near trees.

It would seem quite possible that continued root disturbance by ploughing and sub-soiling, with the associated exposure of broken root surfaces to infection by pathogenic fungi, could start a tree on the downward path of decline.

This discussion of the effects of tillage would

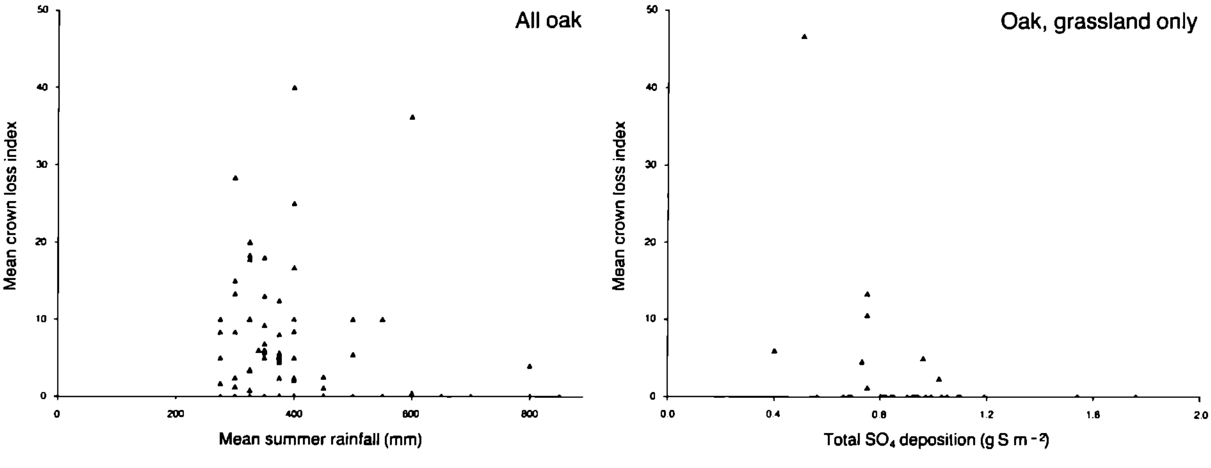


Figure 10. Scatter diagrams showing the relationship between certain environmental variables and mean crown loss. Data for 'all oak' from individual sample plots, data for 'grassland only' oak from pooled plots. See Appendix 3 for details of environmental variables.

apply not just to ash but as this species has the reputation of having a relatively shallow and extensive rooting system (Le Sueur, 1924; Safar, 1951), it may be more likely to sustain damage from this cause than other fieldside trees.

As already indicated, intensively cultivated soils may suffer from compaction and this may, in various ways, reduce the growth and vitality of tree roots. Thus, Popert (1950) reports that ash does "not grow well on soils compacted by old arable cultivation". Compaction is the process whereby there is a breakdown in soil structure resulting from a decrease in the proportion of large pores between soil particles. It is these larger pores that are important in gas exchange and in the movement and storage of water (Greenland, 1977).

The passage of agricultural vehicles and machinery is currently accepted as the main cause of compaction on arable land. Much of this vehicle movement can be of a haphazard nature especially at harvest time (Simpson, 1983). Soane (1975) reports that up to 90% of an arable field surface may be covered by 'wheelings' during the course of traditional seedbed preparation and can result in compaction down to ploughing depth. The practices of 'Controlled Traffic', including 'tramlining' during sowing and spraying and confining non-essential vehicles to headlands during harvesting (Soane *et al.*, 1982) are finding increasing favour, and may help to reduce the area and severity of compaction. It might be the case though that these precautions, especially the latter, may not alleviate soil conditions as far as hedgerow trees are concerned. The interaction between compaction and soil type will be discussed later.

Ash dieback and grassland

Although the incidence of dieback is lower in trees adjacent to grassland than in those adjacent to arable land, some damage was still recorded. Part of the explanation may lie in the inclusion of some recently cultivated grass leys in the grassland category. An attempt was made at a separate classification of this type of land use in the survey but in practice, leys could not readily be distinguished from more permanent grassland. This was particularly true with older leys and with grassland distant from the observer.

However, the presence of leys cannot provide a complete explanation of the damage that was recorded. Some ash were observed to be in poor health adjacent to grass which had obviously not been ploughed for many years. In some cases there was still evidence of an ancient ridge and furrow system of cultivation. Here soil compaction could perhaps provide an answer. Thus, trampling by animals can result in compacted layers occuring down to 10–15 cm below the ground surface (Simpson, 1983; Thomas and Evans, 1975). Compaction on grassland is probably worse around hedges and trees where grazing animals often gather for shelter. Vehicle movements may also be a factor to consider, particularly where there are regular applications of fertiliser and manure or much tending of stock.

Ash dieback and 'urban' land

A comparison of trees in rural and urban locations revealed the health of trees in towns or villages to be better than those in the countryside. It should be remembered, however, that unhealthy trees in towns and villages are more likely to be regarded as safety hazards and removed, than are similar trees in rural areas. This will obviously have the effect of reducing the incidence of damage recorded in a survey of this type. Such damage to trees as was recorded on urban sites could have had many causes ranging from the effects of some drastic event in their immediate vicinity, such as the installation of underground services, to more chronic influences such as adjacent application of de-icing salt (Roberts, 1977; Tattar, 1981; Sinclair *et al.*, 1987).

The influence of roads and ditches

The relatively poor health of trees associated with roadsides compared with those remote from roads is not easy to interpret, especially when it is remembered that most roadside trees assessed during the survey were situated along minor roads. The amount of traffic-related fumes produced on such roads would be relatively small and there would be but little use of toxic materials such as de-icing salt. Similarly, pipe and cable laying is a relatively uncommon event along this type of road, although roadside ditch maintenance by local authorities may be a factor of some importance. More work is needed to examine this situation further. Away from roadsides, ditch management may again be a factor, although there is no supporting evidence for this hypothesis at present.

The influence of soil type

Although ash is native throughout Great Britain (Wardle, 1961), its performance varies according to site type; fertile, moist but well drained soils being preferred. Growth is less good on dry rendzina sites and poorly drained soils. Peace (1962) suggested a link between ash dieback and soil type, saying that ash on clay soils often showed signs of poor health, attributing this to the inability of older trees to tolerate the variations in soil water conditions characteristic of these soils. In addition he pointed out the unsatisfactory performance of ash on dry sites which results in ash going into 'check', a phase of stagnant growth.

As far as dieback in concerned there could well be an important interaction between soil type and farming practice; for example, ditching and drainage operations which may cause damage to trees, will be more likely to be carried out on poorly drained than on well drained soils. In addition, compaction is known to be worse on some soil types than on others. Thus in clay-type soils, structure deformation can take place because of the instability of soil particle bonds in wet conditions. These soils will tend to suffer more structural damage than would a more freely drained soil due to their being wetter for longer periods and so being more likely to be worked when conditions are unsuitable.

In the event, no distinct relationship between dieback and soil type has been shown in the present survey. Overall, thin rendzina soils and poorly drained gley soils were associated with a greater incidence of dieback than brown earths, podzols and 'unclassified' soils. However the effect was not observed when the data from 'arable only' or 'some arable' trees were examined. There was a high incidence of dieback in 'some arable' trees on podzols but the number of trees sampled on this soil type was very small. It should be remembered however, that the soil data came from small-scale maps and clearly more detailed information on the soils of the plots themselves is required if their significance for ash dieback is to be assessed .

The influence of exposure

A general factor meriting mention is the susceptibility of ash to sudden exposure. While many non-woodland ash trees will always have been somewhat exposed it is worth noting that the estimated loss of some 20 million hedgerow elms in southern Britain alone (Greig and Gibbs, 1983) during the late 1960s and 1970s will have removed shelter from many thousands of ash trees. A sudden environmental change such as this may affect ash in various ways. For example, increased wind exposure may cause a deficit of water in the shoots resulting in their dying back and in the failure of apical buds to flush the following spring (Wardle, 1961).

It is possible that data collected on the effect of tree position on ash dieback may provide evidence for the impact of exposure. Thus trees in groups, i.e. with other ash or with other species, were much less affected than single trees, and this could be because they afford each other some degree of protection; the protection increasing with larger groupings.

The influence of rainfall

It seems quite possible that the association between rainfall and dieback shown for 'all ash' and 'some arable' ash does reflect a causal relationship. This could be manifested directly through drought effects or indirectly through changes which might affect the trees' vulnerability to other agents of disease. Such a relationship has been postulated as an explanation of ash dieback in North America, where there is a suggestion of a link with drought years (Ross, 1964; Tobiessen and Buchsbaum, 1976). However, it is worth noting that a rapid revisit in August 1989 to the east Midlands and East Anglia did not indicate that the hot, dry summer of that year was having any significant deleterious effect on ash trees, at least in the short term.

The influence of soil water relations

Rainfall measurements reflect a very crude measure of the water available to a tree. Soil 'moisture deficit' and 'water availability' which take into account the effect of precipitation and transpiration (Bendelow and Hartnup, 1980) and the water in the soil actually available for plant use (Hall *et al.*, 1977) might be expected to be more sensitive measures of water stress. But both suffer from the disadvantage that they are based on data from within the shallow rooting depth of plants like grass rather than that of trees. In any case correlations were poor, no significant relationship being obtained for water availability and moisture deficit being significant only with 'all ash' data.

Falling soil water-tables have recently been implicated in the dieback of broadleaved trees in some parts of Europe, most notably in land influenced by the River Danube (E. Donaubauer, personal communication). In Britain there has been some concern over the reduced flow of some rivers, which has been interpreted as a symptom of falling water-tables due to ground water abstraction. Certain bore holes are regularly monitored by the Institute of Hydrology and the water authorities, and records show that the water level in aquifers can fluctuate over cycles of several years (R. A. Monkhouse, personal communication). Although some groundwater-tables have shown a fall in level, particularly near urban areas, others have tended to rise. Regionally there appear to be no general trends in the long term movement of water-table levels.

The influence of pollution

The interpretation of air pollution data is extremely complex, not least because the distribution of the various pollutants is highly intercorrelated and it is possible that they act synergistically. Moreover, in all cases where positive correlations with pollutants were found, the pollutants were themselves negatively correlated with rainfall. Nevertheless, it is interesting that the strongest positive correlations with pollution have been found in the 'arable only' ash, i.e. that part of the population which shows the highest incidence of dieback. It is conceivable that in this situation, pollution is acting to exacerbate the effects of other kinds of stress.

At the time of writing suitable data on the distribution of peak ozone levels were not available for use in a correlation analysis. This is unfortunate because there is some indication that the genus *Fraxinus* is intolerant to this pollutant (Karnosky, 1981; Karnosky and Steiner, 1981). It should be noted, however, that since the damage to ash recorded in this survey represents the cumulative effects of processes that have been going on over many years, the data could usefully be re-examined at any time if it proved possible to produce models for ozone levels during the past decades.

Although some plots were located in areas of heavy industry where the toxic effect of atmospheric pollution might be expected to damage trees, no obvious symptoms were observed during the course of the survey. Indeed, even in areas of particular industrial activity such as the south Bedfordshire brickworks, where fluoride emissions could be injurious, there was no significant difference between the condition of trees here and that of trees in other areas of high dieback incidence remote from specific pollutants.

Factors affecting the dieback of oak

In relation to site factors

The pattern of damage with oak encountered in the survey was broadly similar to that in ash; the chief exception being that no effect of an adjacent ditch could be detected. Differences in the rooting habits of these two species may explain this. Perhaps the tendency of oak to root more deeply than ash is an important factor.

In relation to rainfall and pollution

The small number of oak surveyed and their process of selection means that an analysis of the pollution and climatic relationships with regard to dieback has to be conducted with great care. The negative associations between dieback in 'all oak' and annual and summer rainfall could reflect causal relationships. However, the negative association found between dieback in 'grassland only' oak and deposition of total sulphate seems unlikely to be causally linked. Perhaps, as suggested by Innes and Boswell (1988), the general growth conditions for oak in the different parts of the country may be a more influential factor.

The future for ash dieback

Tree declines or diebacks result from a complex interactive set of factors, both biotic and abiotic, producing a gradual general deterioration in health and often ending in tree death (Houston, 1981). However, should one or more of these factors moderate in intensity, it would not be unreasonable to suppose that affected trees could, to some degree at least, enter a recovery phase. The occurrence of secondary epicormic shoots on ash might be evidence to support this hypothesis. A number of trees were seen during the survey where the original crown had died back almost to the main stem and where new branches were being formed from apparently healthy shoots. It would be of great interest for the development of these shoots to be monitored to determine if they continue to grow vigorously or decline once again.

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REFERENCES

ALDEN, J. and HERMANN, R.K. (1971). Aspects of the cold hardiness mechanism in plants. *Botanical Review* **37** (1), 37–142.

ANON. (1979a). *Average annual rainfall (mm). Period 1941–1970.* The Meteorological Office.

ANON. (1979b). *Average rainfall (mm). Period 1941–1970. Summer half year April to September.* The Meteorological Office.

ANON. (1980). *Average maximum potential cumulative soil moisture deficit.* Soil Survey of England and Wales, Harpenden.

ANON. (1982). *Soil Survey maps of Scotland. 1:250000 Scale.* Soil Survey of Scotland, Aberdeen.

ANON. (1983). *Soil map of England and Wales. 1:250000 Scale.* Soil Survey of England and Wales, Harpenden.

ANON. (1984). *Census of woodlands and trees 1979–82. North Scotland.* Forestry Commission, Edinburgh.

BENDELOW, V.C. and HARTNUP, R. (1980). *Climatic classification of England and Wales.* Soil Survey of England and Wales, Technical Monograph No. 15, Harpenden.

BIRSE, E.L. and DRY, F.T. (1970). *Assessment of climatic conditions in Scotland 1. Based on accumulated temperature and potential water deficit.* Macaulay Institute for Soil Research.

CHALMERS, A.G., LEECH, P.K. and KERSHAW, C.D. (1988). *Survey of fertiliser practice. Fertiliser use on farm crops. England and Wales 1987.* Rothamsted Experimental Station.

COOPER, J.I. and EDWARDS, M.L. (1981). Viruses of trees. In, *Forest and woodland ecology,* eds F.T. Last and A.S. Gardner. Symposium No. 8. Insitute of Terrestial Ecology.

DEVENISH, M. (1986). *The United Kingdom precipitation composition monitoring networks.* Warren Spring Laboratory Report, LR 584(AP).

FINDLAY, D.C., COLBORNE, G.J.N., COPE, D.W., HARROD, T.R., HOGAN, D.V. and STAINS, S.J. (1984). *Soils and their use in south-west England.* Soil Survey of England and Wales, Bulletin 14, Harpenden.

GREENLAND, D.J. (1977). Soil damage by intensive arable cultivation: temporary or permanent? *Philosophical Transactions Royal Society of London B* **281,** 193–208.

GREIG, B.J.W. and GIBBS, J.N. (1983). Control of Dutch elm disease in Britain. In, *Research on Dutch elm disease in Europe,* ed. D.A. Burdekin, 10–16. Forestry Commission Bulletin 60. HMSO, London.

HALL, D.G.M., REEVE, M.J., THOMASSON, A.J. and WRIGHT, V.F. (1977). *Water retention, porosity and density of field soils.* Soil Survey of England and Wales, Technical Monograph No. 9, Harpenden.

HODGE, C.A.H., BURTON, R.G.O., CORBETT, W.M., EVANS, R. and SEALE, R.S. (1984). *Soils and their use in eastern England.* Soil Survey of England and Wales, Bulletin 13, Harpenden.

HOUSTON, D.R. (1981). *Stress triggered tree diseases. The diebacks and declines.* United States Department of Agriculture, Forest Service, Booklet NE-INF-41-81.

INNES, J.L. and BOSWELL, R.C. (1987). *Forest health surveys 1987. Part 1: results.* Forestry Commission Bulletin 74. HMSO, London.

INNES, J.L. and BOSWELL, R.C. (1988). *Forest health surveys 1987. Part 2: analysis and interpretation.* Forestry Commission Bulletin 79. HMSO, London.

JARVIS, M.G., ALLEN, R.H., FORDHAM, S.J., HAZELDEN, J., MOFFAT, A.J. and STURDY, R.G. (1984) *Soils and their use in south-east England.* Soil Survey of England and Wales, Bulletin 15, Harpenden.

JARVIS, R.A., BENDELOW, V.C., BRADLEY, R.I., CARROLL, D.M., FURNESS, R.R., KILGOUR, I.N.L. and KING, S.J. (1984). *Soils and their use in northern England.* Soil Survey of England and Wales, Bulletin 10, Harpenden.

KARNOSKY, D.F. (1981). Chamber and field evaluations of air pollution tolerances of urban trees. *Journal of Arboriculture* **7**(4), 99–105.

KARNOSKY, D.F. and STEINER, K.C. (1981). Provenance and family variation in response of *Fraxinus americana* and *F. pennsylvanica* to ozone and sulfer dioxide. *Phytopathology* **71,** 804–807.

LE SUEUR, A.D.C. (1924). The common ash. *Quarterly Journal of Forestry* **18,** 217–227.

LOCKE, G.M.L. (1987). *Census of woodlands and trees 1979–82*. Forestry Commission Bulletin 63. HMSO, London.

McMINN, A.L. and ROBERTS, T.R. (1983). The fate of pesticides in soils. *Span* **26**(1), 38–40.

MILLER, H.G. and MILLER, D.J. (1988). Response to heavy nitrogen applications in fertiliser experiments in British forestry. *Environmental Pollution* **54,** 219–236.

NIHLGARD, B. (1985). The ammonium hypothesis – an additional explanation to the forest dieback in Europe. *Ambio* **14**(1), 2–8.

PAWSEY, R.G. (1983). *Ash dieback survey. Summer 1983*. Commonwealth Forestry Institute, Occasional Paper No. 24, Oxford.

PEACE, T.R. (1962). *Pathology of trees and shrubs*. Oxford University Press, Oxford.

POPERT, A.H. (1950). Sylviculture of ash in Great Britain. In, Symposium on 'Ash as a forest tree in the British Isles'. *Journal of Ecology* **38,** 409–412.

RAGG, J.M., BEARD, G.R., GEORGE, H., HEAVEN, F.W., HOLLIS, J.M., JONES, R.J.A., PALMER, R.C., REEVE, M.J., ROBSON, J.D. and WHITFIELD, W.A.D. (1984). *Soils and their use in midland and western England*. Soil Survey of England and Wales, Bulletin 12, Harpenden.

ROBERTS, B.R. (1977). The response of urban trees to abiotic stress. *Journal of Arboriculture* **3,** 75–78.

ROSS, E.W. (1964). Cankers associated with ash dieback. *Phytopathology* **54,** 272–275.

RUARK, G.A., MADER, D.L. and TATTAR, T.A. (1982). The influence of soil compaction and aeration on the root growth and vigour of trees – a literature review. Part 1. *Arboricultural Journal* **6,** 251–265.

RUDEFORTH, C.C., HARTNUP, R., LEA, J.W., THOMPSON, T.R.E. and WRIGHT, P.S. (1984). *Soils and their use in Wales*. Soil Survey of England and Wales, Bulletin 11, Harpenden.

SAFAR, J. (1951). O gospodarskom znacenju podzemnih organa sadnica i drveca. *Sumarski List* **75**(11), 363–373.

SIMPSON, K. (1983). *Soil*. Longman, New York.

SINCLAIR, W.A., LYON, H.H. and JOHNSON, W.T. (1987). *Diseases of trees and shrubs*. Cornell University Press.

SOANE, B.D. (1975). Studies on some soil physical properties in relation to cultivations and traffic. In, *Soil physical conditions and crop production*. MAFF Technical Bulletin 29, 160–182.

SOANE, B.D., DICKSON, J.W. and CAMPBELL, D.J. (1982). Compaction by agricultural vehicles: a review. III. Incidence and control of compaction in crop production. *Soil and Tillage Research* **2,** 3–36.

SWAIN, R.W. (1975). Subsoiling. In, *Soil physical conditions and crop production*. MAFF Technical Bulletin 29, 189–203.

TATTAR, T.A. (1981). Non-infectious diseases of trees. *Arboricultural Journal* **5,** 111–116.

THOMAS, R. and EVANS, C. (1975). Field experience on grassland soils. In, *Soil physical conditions and crop production*. MAFF Technical Bulletin 29, 112–124.

TOBIESSEN, P. and BUCHSBAUM, S. (1976). Ash dieback and drought. *Canadian Journal of Biology* **54,** 543–545.

VAN BREEMEN, N. and VAN DIJK, H.F.G. (1988). Ecosystem effects of atmospheric deposition of nitrogen in The Netherlands. *Environmental Pollution* **54,** 249–274.

WARDLE, P. (1961). Biological flora of the British Isles: *Fraxinus excelsior* L. *Journal of Ecology* **49,** 739–751.

Appendix 1

Non-woodland tree dieback survey 1987

Full list of data collected with assessment form codes

*Column numbers**	*Data type*	*Category*	*Code*
1–6	*Date*	*e.g. 10/08/87*	
7–12	Grid reference of SW corner of 10 km square	e.g. TL5030	
13–15	Number of healthy ash observed during 10 km transect		
16–18	Number of ash with dieback observed during 10 km transect		
19–21	Percentage incidence of ash dieback as seen along 10 km transect		
22	Predominant land use category seen along 10 km transect (see land use codes)		
23–25	Distance travelled by road during 10 km transect as measured on car odometer, in km		
26–29	Nominal distance walked to nearest 100 m, during assessment of detailed plot		
30–31	Pollution/climatic region		
32–33	Generalised soil type in detailed plot	Rendzina	1
		Brown earth	2
		Podzol	3
		Gley	4
		'Unclassified'	5
34–35 and 50–51	Tree species	Ash	AH
		Oak	OK
36 and 52	Trees situated as individuals or a group	Single	S
		Group	G
37 and 53	Diameter of tree at breast height	<10 cm	0
		10–50 cm	1
		>50 cm	5
38–39 and 54–55	Height class	<7 m	00
		7–12 m	07
		>12 m	12
40 and 56	Health class	Healthy	H
		Affected	A
		Dead	D
41 and 57	Foliage density	Dense	D
		Moderate	M
		Thin	T

---

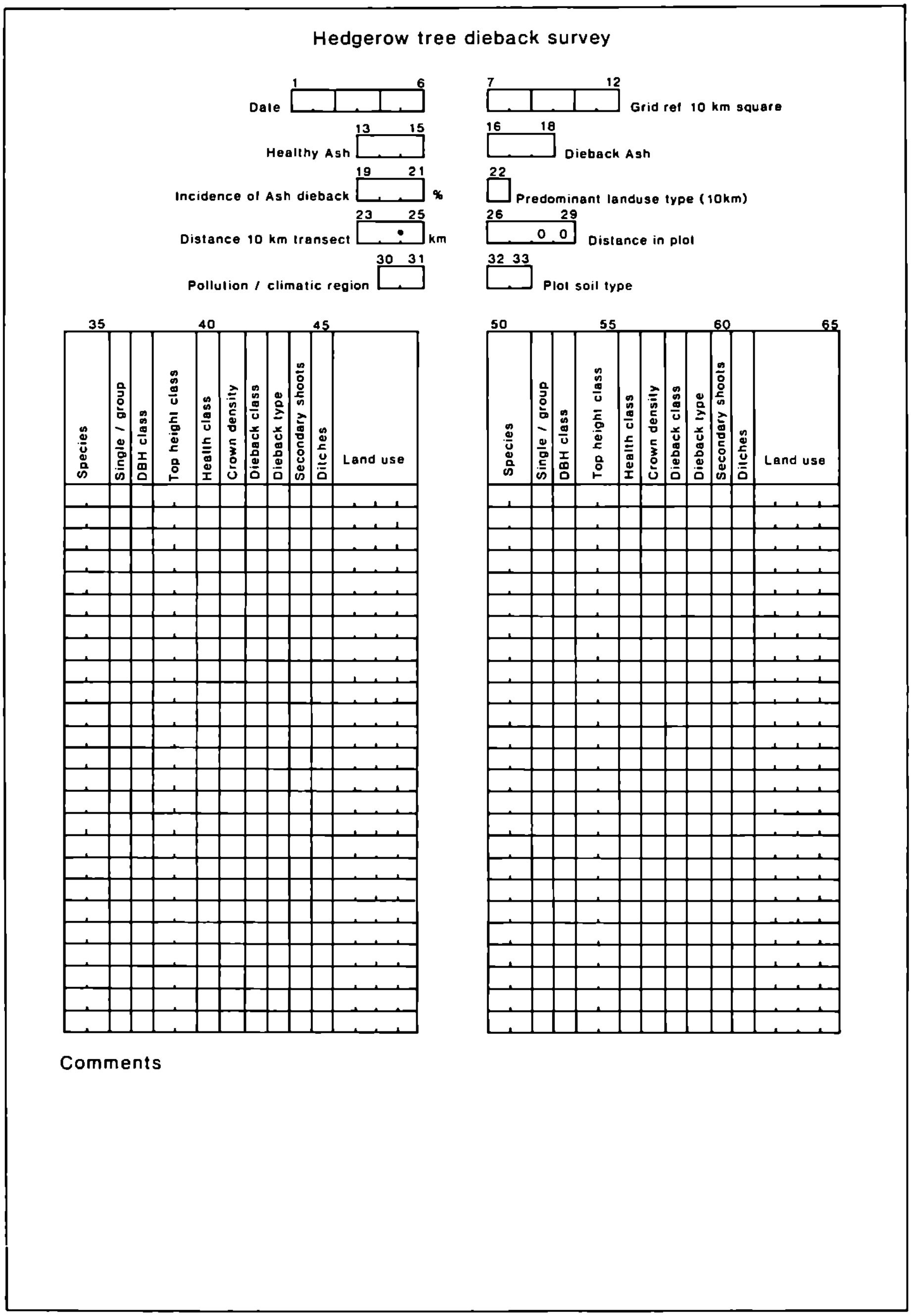
*See Appendix 2

Full list of data collected with assessment form codes – *continued*

Column numbers	*Data type*	*Category*	*Code*
42 and 58	Dieback class	Crown loss <10%	0
		10–19%	1
		20–29%	2
		30–39%	3
		40–49%	4
		50–59%	5
		60–69%	6
		70–79%	7
		80–89%	8
		90–99%	9
43 and 59	Dieback type	Recent	1
		Old	2
		Both	3
44 and 60	Secondary shoots	Absent	0
		Present	1
		Abundant	2
45 and 61	Presence of ditches	No ditch	0
		On one side	1
		On two sides	2
46–49 and 62–65	Land use (up to four around each tree)	Arable/cultivated	A
		Grassland/pasture	P
		Ley grass	L
		Roadside	R
		'Green road'/footpath	F
		Garden	G
		Verge	V
		Waterside	W
		Built-up/urban	U
		Urban open space	S
		Derelict	D
		Broadleaved woodland	B
		Coniferous woodland	C
		Orchard	T
		Quarry	Q
		Unable to see	X

Appendix 2

Survey assessment form



Hedgerow tree dieback survey

1 6 Date

7 12 Grid ref 10 km square

13 15 Healthy Ash

16 18 Dieback Ash

19 21 Incidence of Ash dieback %

22 Predominant landuse type (10km)

23 25 Distance 10 km transect . km

26 29 0 0 Distance in plot

30 31 Pollution / climatic region

32 33 Plot soil type

35 40 45

Species	Single / group	DBH class	Top height class	Health class	Crown density	Dieback class	Dieback type	Secondary shoots	Ditches	Land use

50 55 60 65

Species	Single / group	DBH class	Top height class	Health class	Crown density	Dieback class	Dieback type	Secondary shoots	Ditches	Land use

Comments

Appendix 3

Data sources for environmental variables used in correlation analysis

Pollution data from Warren Spring Laboratory

S deposition	Modelled dry deposited sulphur deposition (g S m^{-2}) for 1983.
H concentration	Precipitation weighted annual mean hydrogen ion concentration (μeq l^{-1}) for 1986.
H deposition	Wet deposited acidity (g H^+ m^{-2}) for 1986.
NH_4 concentration	Precipitation weighted annual mean ammonium concentration (μeq l^{-1}) for 1986.
NH_4 deposition	Wet deposited ammonium (g N m^{-2}) for 1986.
Non-marine SO_4 concentration	Precipitation weighted annual mean non-marine sulphate concentration (μeq l^{-1}) for 1986.
Non-marine SO_4 deposition	Wet deposited non-marine sulphate (g S m^{-2}) for 1986.
NO_3 concentration	Precipitation weighted annual mean nitrate concentration (μeq l^{-1}) for 1986.
NO_3 deposition	Wet deposited nitrate (g N m^{-2}) for 1986.
Total SO_4 concentration	Precipitation weighted annual mean total sulphate concentration (μeq l^{-1}) for 1986.
Total SO_4 deposition	Wet deposited total sulphate (g S m^{-2}) for 1986.
SO_2 concentration	Modelled near-surface sulphur dioxide concentrations (μeq S m^{-3}) for 1983.

Rainfall data from maps issued by Meteorological Office

Mean annual rain	Mean annual rainfall (mm) in period 1941–70.
Mean summer rain	Mean annual rainfall (mm) in period 1941–70, for half year April to September.

Soil data from map issued by Soil Survey of England and Wales

Mean moisture deficit	Mean maximum potential cumulative soil moisture deficit (mm).

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