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The Northumberland epidemic of foot-and-mouth disease, 1966

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SUMMARY

The spread of foot-and-mouth disease during an epidemic in Northumberland in July, August and September 1966 was analysed. Although strong emitters, for example pigs, were not involved, in 18 of the 32 outbreaks spread could be attributed to the airborne route and in another 4, spread by this route was the most likely. Airborne spread was in general between 1 and 8 km but on two occasions as much as 20 km. Other means of spread included movement by animals, people and vehicles and carriage of virus between animals in neighbouring fields. No spread by milk or milk lorries took place. Sheep were involved in 9 farms; on each, lesions older than 48 h were found and it is likely that the sheep were the source of virus for other animals, especially cattle, on the farm and on neighbouring farms. The analysis suggests that control measures such as slaughtering direct contacts, as used in this epidemic, or ring vaccination as well as movement control would be effective in limiting spread.

INTRODUCTION

In July, August and September 1966 there was an epidemic of foot-and-mouth disease (FMD) due to type O_1 in Northumberland. A total of 289 cattle and 73 sheep were observed to have FMD in 32 outbreaks. In all, 5753 cattle, 38448 sheep and 714 pigs were slaughtered in the course of eradication (Report on the Animal Health Services in Great Britain, 1966).

Investigations into the 1967–8 epidemic of FMD showed that the disease could be spread by the airborne dispersal of the virus as well as by movement of animals, vehicles and people and feeding of infected meat and milk (Henderson, 1969; Smith & Hugh-Jones, 1969; Wright, 1969; Hugh-Jones & Wright, 1970; Sellers & Forman, 1973). In these epidemics (Hampshire, 1967; Oswestry, 1967–8 and Worcester, 1967) FMD started in pigs, which have been found to be good emitters of the virus (Sellers & Parker, 1969) and hence favour the spread of the disease by the airborne route. However, in the Northumberland outbreak pigs were not directly affected and it is the object of this investigation to analyse the spread of the disease in the absence of strong emitters of the virus.

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Sources of information

(*a*) The files on each infected premises and the summaries, maps and plans prepared by the Animal Health Division of the Ministry of Agriculture, Fisheries and Food.

(*b*) The three-hourly weather records from Acklington and Seahouses, Northumberland; Daily Weather Reports prepared by the British Meteorological Office and sea temperatures from the Marine Division of the Meteorological Office.

(*c*) Visits to the area and interviews with Divisional Veterinary Officers and Veterinary Officers and others concerned with the outbreaks.

Summary of the epidemic and its geographical location

This, adapted from the Report on the Animal Health Services in Great Britain (1966), may be summarized as follows:

'The first case was reported on 18 July at a farm in Flotterton, a hamlet in Coquetdale (1) and during the next few days further cases were reported on three other farms in Otterburn parish (2), Yetlington hamlet (3) and Harbottle parish (4), which belonged to the farmer or his brother-in-law. Eighteen further outbreaks occurred in Coquetdale, the last being confirmed on 27 August. One further outbreak (17) was confirmed in the Otterburn area on 2 August, but there was no spread from the case at Harbottle. On 9 August the disease was found on a farm (20) in Chathill parish 20 km northeast of Yetlington and seven further cases occurred in this area, the last on 5 September. On 10 August disease occurred on a farm near Felton village (21), 20 km southeast of Flotterton. No spread of disease occurred from this farm. Infected area restrictions were withdrawn on 27 September.'

The largest number of outbreaks (1–3, 5–16, 18, 19, 22, 23, 25, 27 around Flotterton and Yetlington) were in the Coquet valley, which lies between the Northumberland National Park (Cheviots) to the north and west, the Simonside hills to the south and Long Crag hills to the east, and at the head of the Aln valley in the gap between the Cheviots and Long Crag hills. One outbreak (4) was in Upper Coquetdale and two (2, 17) in the valley of Durtrees burn north of Otterburn. One (21) was on the coastal plain near Felton, 13 km north of Morpeth, and the remaining eight (20, 24, 26, 28–32) on the coastal plain 1 to 10 km south of Bamburgh (see Fig. 1).

Statistical information about the outbreaks is shown in Table 1. The farms are given in chronological order of reporting disease.

ANALYSIS OF THE EPIDEMIC

Introduction

From previous investigations a correlation between wind direction and spread over short distance had been established (Henderson, 1969; Hugh-Jones & Wright, 1970; Sellers & Forman, 1973). In the analysis, therefore, where there was no clear evidence of spread by movement, wind was considered responsible. Farms where

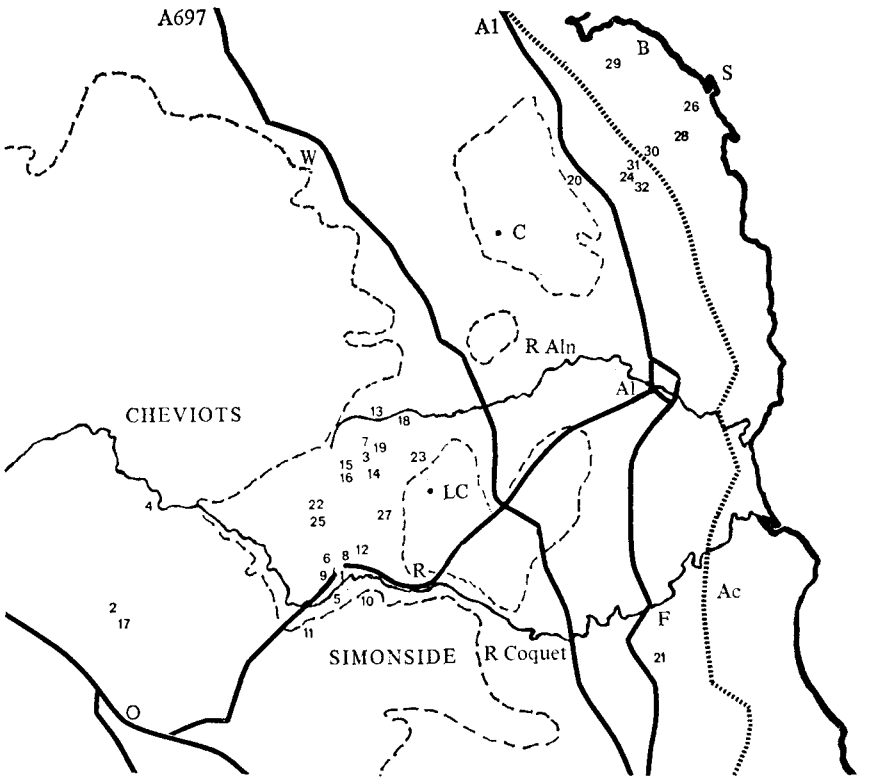

Fig. 1. Map of the area in Northumberland involved in the foot-and-mouth disease epidemic. Numbers 1–32 represent the locations of the affected farms. Ac = Acklington, Al = Alnwick, B = Bamburgh, C = Cateran Hill, F = Felton, LC = Long Crag, O = Otterburn, R = Rothbury, S = Seahouses, W = Wooler.

the disease was notified promptly were examined first, and the range of incubation periods found was used to establish the time of appearance of lesions on farms where disease was reported late or where spread had occurred over a long distance. In general, winds occurring less than 4 days or more than 14 days before an outbreak were disregarded.

There were nine farms in which movement of cattle, sheep, people and vehicles were involved (Table 2). These are described according to the likelihood of being involved in spread of disease.

Acklington lies 20 km approximately to the east of the initial outbreak and Seahouses 37 km approximately to the northeast. Although Seahouses is a substantial distance from the primary outbreak it is only a few kilometres from the outbreaks south of Bamburgh. In the subsequent analysis these distances and small-scale effects, for example modification to the weather by topography and sea breezes, have been taken into account.

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Table 1. *Farms, dates and animals affected during the Northumberland epidemic*

Outbreak no.	Date of reporting	Cattle	Sheep	Pigs	Number affected
1	18. vii. 66	184	697	—	45c*, 6s†
2	21. vii. 66	213	1983	—	27c†
3	21. vii. 66	205	1046	—	32c, 3s
4	22. vii. 66	288	2778	—	12c
5	23. vii. 66	69	518	—	2c
6	25. vii. 66	122	883	—	2c
7	25. vii. 66	87	692	8	16c, 20s†
8	25. vii. 66	98	1081	—	1c
9	26. vii. 66	231	1065	—	12c
10	27. vii. 66	81	675	—	9c
11	28. vii. 66	5	29	—	1c
12	28. vii. 66	88	848	—	1c
13	29. vii. 66	77	523	71	3c
14	30. vii. 66	108	575	—	3c, 7s†
15	1. viii. 66	95	806	—	4s
16	2. viii. 66	139	481	—	3c
17	2. viii. 66	58	13	—	1c
18	4. viii. 66	66	—	—	1c
19	7. viii. 66	111	1135	23	1c
20	9. viii. 66	173	1546	—	26c, 23s†
21	10. viii. 66	164	247	—	31c
22	16. viii. 66	98	441	—	22c
23	17. viii. 66	113	1368	—	5c, 1s†
24	17. viii. 66	168	872	—	12c, 6s†
25	23. viii. 66	296	1350	—	6c
26	24. viii. 66	109	700	—	1c
27	27. viii. 66	194	1577	7	1c
28	27. viii. 66	380	769	—	8c
29	28. viii. 66	166	594	—	1c
30	1. ix. 66	34	207	—	1c
31	1. ix. 66	179	406	—	1c, 3s†
32	5. ix. 66	60	66	—	2c

* c = cattle, s = sheep. † Lesions over 48 h old reported.

Note: In addition 1294 cattle, 12447 sheep and 605 pigs were slaughtered as 'direct contacts'.

Origin and initial infection

The origin of the FMD virus (type O_1) was not established at the time of the epidemic, but the most likely source was infected meat or offal from overseas, with which cattle on farm 1 had come into contact. There was movement of stock between farms 1, 2, 3 and 4, and some of these animals were infected at the time of movement; thus at the time of confirmation of foot-and-mouth disease on 21 July there were infected cattle and sheep on these four farms. It seems likely that disease was present on farm 1 on 11 July (Report, 1966).

Table 2. *Movement of animals, vehicles or people in the areas*

Farm	
2***	Cattle from farm 1, 12 July (disease interval ⩽ 9 days)
3***	Cattle from farm 1, 16 July (disease interval ⩽ 5 days)
4***	Cattle from farm 1, 15 July (disease interval ⩽ 6 days)
11**	Person visit to farm 1, 22 July (disease interval 6 days)
16*	Person lived at farm 7 until 25 July (disease interval 8 days)
18*	Person from farm 7 visited on 22 July (disease interval 13 days)
19*	Person went daily to farm 3 until 21 July (disease interval 19 days)
24**	Lambs collected on lorry which had just visited farm 20, 4 August (disease interval ⩽ 13 days)
32*	Owner farm 31 visited on 1 September (disease interval 4 days)

*** Most likely reason for spread. ** Possible reason for spread. * Unlikely reason for spread.

Subsequent spread

The farms involved in the epidemic can be assigned to six areas:

(i) the outbreak at 1 and the neighbouring farms 5, 6, 8, 9, 10, 11, 12 (18 July to 29 July) (Flotterton area);

(ii) the outbreak at 3 and the farms 7, 13, 14, 15, 16, 18, 19, 22, 23, 25, 27 (21 July to 27 August) (Yetlington area);

(iii) farms 2 and 17 (21 July to 2 August) (Otterburn area);

(iv) farm 4 (22 July) (Harbottle);

(v) the spread to farm 20 and the outbreaks on farms 24, 26, 28, 29, 30, 31, 32 (9 August to 5 September) (Chathill and coastal area);

(vi) the spread to farm 21 (10 August) (Felton area).

Outbreaks in the Otterburn and Harbottle areas

Farm 2 gave rise only to the outbreak at farm 17 after an incubation period of 11 days. Winds from the north would account for the spread, but further spread was unlikely as around farm 2 18 cattle, 1579 sheep and 2 pigs and around farm 17 260 cattle, 4080 sheep and 4 pigs were slaughtered as direct contacts. In addition, the land suitable for cattle in the valley was limited. There was no spread from 4, as the animals from this farm were spread over the valley and all were slaughtered. At the time of the height of infection the winds were from the north or west and were blowing the virus into high ground above the valley.

Spread around farm 1

Table 3 shows the days when winds could have carried infection from farm 1 to the others in the group together with the suggested incubation periods. FMD at farm 11 could also have come through movement (Table 2). No winds were recorded as available for the carriage of virus to farm 6, but the animals were in the next field to diseased animals on farm 1. All the farms in the area apart from one were affected. The disease did not spread into West Coquetdale beyond farms 6 and 9, probably because most of the winds during the outbreaks were from the

Table 3. *Probable times of infection and incubation periods for farms around farm 1*

Farm	Probable date of earliest lesion	Distance from farm 1 (km)	Bearing to farm 1	Date of winds	Incubation period (days)
5	23 July	1·3	330°	16–19 July	4–7
6	25 July	0·5	160°	—	—
8	25 July	0·9	240°	19 July	6
9	25 July	0·9	35°	18–21 July	4–7
10	26 July	2·5	305°	18–19 July	7–8
11	28 July	3·8	30°	18–21 July	7–10
12	28 July	1·9	240°	19 July	9

Table 4. *Probable times of infection and incubation periods for farms around farm 3*

Farm	Probable date of earliest lesion	Source	Distance from source (km)	Bearing to source	Dates of winds	Incubation period (days)
7	22 July	3	0·5	170°	—	—
13	29 July	7	1·8	220°	22–4 July	5–7
14	27 July	3	1·3	10°	19–21 July	6–8
15	27 July	3	1·9	50°	18–19 July	8–9
16	2 Aug.	15	0·2	340°	27 July	6
18	4 Aug.	13	1	270°	28–9 July	6–7
		14	2·8	210°	28 July	7
		15	4·8	225°	28 July	7
19	7 Aug.	14	1·9	210°	28–31 July	7–10
22	11 Aug.	15/16	2·5	60°	1–2 Aug.	9–10
23	11 Aug.	15/16	3·8	265°	1–2 Aug.	9–10
25	22 Aug.	22	1·5	360°	14–15 Aug.	7–8
27	27 Aug.	22	4·4	290°	15 Aug.	12

west, north or northeast; east or southeast winds were not seen until 2 August, by which time FMD had been eliminated from the area.

Spread around farm 3

Table 4 shows the days when winds could have carried the virus from farm 3 to others in the area, as well as the sources for subsequent outbreaks. In 5 of the outbreaks around farm 3 (7, 14, 15, 22, and 23) FMD was reported late and the dates of earliest lesions are based on descriptions of lesions given. No wind could be found to carry disease from farm 3 to farm 7, but the infected animals in farm 7 were in a field across the road from farm 3. On farm 15, the sheep became infected before 22 July, and passed the disease to others in the flock and to cattle on farm 16 in the neighbouring field; however, disease was recognized on farms 15 and 16 only on successive days. The longest incubation period was 12 days, which represented the furthest distance of spread and the last outbreak reported in the area.

Table 5. *Estimated output of FMD virus from farms around farms 1 and 3 (21 July–1 August)*

	Farms around 1		Farms around 3	
Date	Farms	Estimated output $\times 10^5$	Farms	Estimated output $\times 10^5$
21 July	1	63	3	41
22 July	1	63	3, 7	51
23 July	5	2	7	18
24 July	—	—	7	40
25 July	6, 8, 9	15	7	76
26 July	9, 10	21	7	40
27 July	10	9	14, 15	10
28 July	11, 12	2	14, 15	15
29 July	—	—	13, 14, 15	23
30 July	—	—	14, 15	66
31 July	—	—	15	40
1 Aug.	—	—	15	40

In the control of FMD many of the animals in neighbouring farms were slaughtered as direct contacts. No further spread occurred for this reason and for the further reason that at the time of virus excretion the winds were from the north or west and would have blown the airborne virus into areas that had previously been infected.

Spread to farms 20 and 21 from farms around 1 and 3

Perhaps one of the most interesting aspects of this epidemic is the way in which the virus spread to both farms 20 and 21, bypassing susceptible stock on its way. No vehicle or human movement could be found to cause the spread of the virus. The cattle and sheep with FMD on farm 20 were grazing in a field beside the main road (A1) and there is the possibility that they could have become infected from contact with people or discarded food wrappings coming from the infected area. On farm 21, the cattle were in a field which lay 2 km from the A1 road and was not easily entered. The only other possibility, other than by the airborne route, is carriage of the virus on sea birds. Sea birds live on the Farne Islands and fly inland to feed on fields around farms. Successful infection from this route depends on the birds carrying high-titre virus on themselves and settling on fields where cattle or sheep graze. This is a possible but less likely method of spread (Sellers, 1971); farm 21 is not on the direct route between the Coquetdale and the Farne Islands.

The lesions on both farms were old and more than one cycle of infection had occurred. If 3–6 days is accepted as the within-farm incubation period (Sellers & Forman, 1973) and 6–13 days as the between-farm incubation period for farms some distance apart, virus could have reached the farms 9–19 days previously, i.e. farm 20, 21–31 July and farm 21, 22 July–1 August.

The estimated excretion of FMD virus around farms 1 and 3 is given in Table 5.

Table 6. *Probable times of infection and incubation periods for farms around farm 20*

Farm	Probable date of earliest lesion	Source	Distance from source (km)	Bearing from source	Dates of winds	Incubation period (days)
24	13 Aug.	20	2·2	260°	5–6 Aug.	7–8
26	24 Aug.	24	5·7	220°	16–18 Aug.	6–8
28	26 Aug.	24	4·3	235°	16–17 Aug.	9–10
29	28 Aug.	24	7·3	175°	15–16 Aug.	12–13
30	1 Sept.	28	3·1	80°	26–7 Aug.	5–6
31	26 Aug.	24	1·4	190°	16–17 Aug.	9–10
32	5 Sept.	31	1·3	330°	31 Aug.	6
		30	1·5	350°	31 Aug.	6
		28	3·1	50°	26–7 Aug.	9–10

Maximum amounts around farm 1 occurred on 21–22 July and 25–26 July and around farm 3 on 22 July, 25 July and 30 July.

Two periods can be considered for the spread to farm 20; 22–25 July and 27–29 July. During both periods frontal systems with the required wind direction passed over the area. Although less virus was produced during the second period the meteorological conditions were slightly more favourable. During 28 July the wind was from the southwest, and this was associated with low cloud and frontal precipitation. The cloud base at Acklington and Seahouses was down to just over 1000 ft and may have been lower over the hillside next to farm 20. It is possible that the virus was blown to the area around farm 20 where it became part of the clouds, as the air was forced over the hill and fell as rain; alternatively the virus could have been washed out by precipitation. A further possibility is that the virus remained in the aerosol form until it reached farm 20.

The sources of virus for the spread on 28 July were farms 14 and 15; these farms were also probable sources for farms 18 and 19 on the same day (Tables 4 and 5). Thus on a line northeast (downwind) of farms 14 and 15 the situation on 28 July was as follows: animals on farms 3 and 7 already slaughtered and disposed of; farm 13 already infected (lesions on 29 July); infection being carried to farms 18 and 19; a gap of 18 km over land containing susceptible stock and infection being carried to farm 20.

Farm 21 could have become infected during the periods 22–24 July, 25 July, 31 July and 4 August. The first period is just possible but the second appears more likely as the winds were blowing from the west for part of the day. The aerosol would have been funnelled through the River Coquet gap. During that day there were several occasions when showers were observed in the Acklington area and one of these could have caused the outbreak at farm 21. The virus could have reached the ground either in the precipitation or as an aerosol in the air currents surrounding the showers.

It is just possible that the virus emitted from farms 14 and 15 was the cause of the outbreak at farm 21 on 31 July, but the route taken by the virus would have

Table 7. *Outbreaks on farms and reports of lesions in cattle and sheep kept in the same field*

Age of lesions	Farms with lesions in: Cattle only	Sheep only	Cattle and Sheep	
< 48 h	6, 8, 17, 26, 27, 22 (6)	0	Cattle 31 (1)	Sheep (0)
> 48 h	21, 22 (2)	15 (1)	Cattle 7, 14 20, 23, 24 (5)	Sheep 7, 14 20, 23, 24, 31 (6)

been complicated. A final possibility is that farm 18 could have been the source on 4 August, but this may be ruled out, as only one cattle beast had lesions on farm 18 and in addition the lesions at farm 21 were two generations old.

Spread around farm 20

Table 6 shows the possible days for airborne spread of the virus around farm 20. In farms 20, 24 and 31 the disease was reported late. The lorry which visited farm 24 after farm 20 on 4 August, also went north to Berwick, but there were no outbreaks in that area. The presence of a wood around the affected animals of farm 24 may have influenced the subsequent spread. However, without a detailed knowledge of the structure of the wood and the exact windflow pattern in and around the wood, it is impossible to determine accurately the effect of the wood in the spread of the virus.

There was contact between the affected animals on farm 24 and the sheep and cattle in a field on farm 31 on the other side of the wood, and these sheep and cattle were slaughtered as direct contacts. In the field next to the direct contacts were the animals on farm 31 which developed foot-and-mouth disease. These animals could have been infected either from direct contact on the same farm or by the airborne route from farm 24. As the disease was older than 48 h the animals on farm 31 could have been the sources of the virus for farm 30, which was in the next field across the railway line, and also for farm 32.

Further spread in the area did not occur, probably because too few animals were affected and the winds would have blown any airborne virus into areas which had previously had the disease.

Lack of spread around farm 21

There was no spread from farm 21 although the disease was probably in the animals by 7 August at the latest. From 6 to 10 August winds blew from the west and northwest and from the east and southeast. It is not apparent why other animals in the area did not catch the disease from this source.

Role of sheep in spread of disease

Although there are many sheep in the area a very small percentage compared with cattle was described as having lesions of FMD. This can probably be ascribed to the difficulty of seeing the lesions; however, in the absence of lesions, infected

sheep can excrete airborne virus (Sellers & Parker, 1969; Donaldson *et al.* 1970), which could be inhaled by cattle in the same or neighbouring fields. In table 7 it can be seen that where lesions older than 48 h were reported, cattle, sheep and both cattle and sheep were found to have them, but where early lesions were reported only cattle were affected. This emphasizes the difficulty of seeing the lesions in sheep, and often FMD is not recognized until cattle have the disease. On one farm (31) lesions older than 48 h were found in sheep and early lesions were found in cattle; it is likely that the sheep passed the disease to the cattle. This may also have happened with the other five farms in this group. In the one outbreak where sheep alone were found to have lesions (farm 15) it is suggested that the virus was passed to cattle on the neighbouring farm (16).

Lack of spread by milk or milk transport

The area affected was not a milk-producing area and only farms 14 and 21 of those having the disease produced milk. At farm 14 bullocks in a field had FMD, milk was collected in churns at the roadside and no further outbreaks occurred on the route. At farm 21 the non-milking herd was affected and the animals were grazing in a field away from the farm buildings.

A retail milk round delivering bottled milk visited 24 farms including farms 20, 24, 29 and 31, but no correlation could be made between the order of visiting and outbreaks of disease.

DISCUSSION

This analysis of the spread of FMD in Northumberland involved the use of data on the movement of animals, people and vehicles and on wind direction. In this way causes of spread could be ascribed in most outbreaks (Table 8). In five outbreaks (farms 6, 7, 16, 30, 31) the animals were in the next field to either infected animals or direct contacts. In two of these outbreaks (farms 6 and 7) no source of infection by wind could be traced, but over small distances it is impossible to determine from three-hourly wind observations whether virus from infected animals could be passed to susceptible animals; it would only have required a change in wind direction for a short period to cause infection.

Correlation of spread with time of rain was not found, and this is similar to that suggested by Smith & Hugh-Jones (1969) for this epidemic. Similarly there did not appear to be a clear correlation between speed and spread of the disease as suggested for the 1967–8 epidemic and for the Hampshire epidemic (Tinline, 1969; Sellers & Forman, 1973). However, with a speed of 6 knots the longest distance found in the epidemic (20 km) would be covered in 2 h.

Analysis of the interval between outbreaks indicated that the incubation period between farms where airborne spread probably occurred lay between 4 and 13 days, and for 56% of outbreaks between 6 and 8 days. The longest incubation period was found where the distance between farms in the areas around farms 3 and 20 was the greatest.

The outbreaks did not occur on the moorland areas where livestock density was low, but on the farms in the valleys or coastal plain. Where spread was ascribed

Table 8. *Suggested means by which the farms became infected*

Farm	Movement (Animals, people, vehicles, etc.)	Airborne route	Other
1	—	—	Possibly offal from overseas
2	Yes	—	—
3	Yes	—	—
4	Yes	—	—
5	—	Yes	—
6	—	—	Animals in next field to infected animals
7	—	—	Animals in field across road from infected farm
8	—	Yes	—
9	—	Yes	—
10	—	Yes	—
11	Yes	Yes	—
12	—	Yes	—
13	—	Yes	—
14	—	Yes	—
15	—	Yes	—
16	Yes (but unlikely)	Yes	Animals in next field to infected animals
17	—	Yes	—
18	Yes (but unlikely)	Yes	—
19	Yes (but unlikely)	Yes	—
20	—	Yes	—
21	—	Yes	—
22	—	Yes	—
23	—	Yes	—
24	Yes	Yes	—
25	—	Yes	—
26	—	Yes	—
27	—	Yes	—
28	—	Yes	—
29	—	Yes	—
30	—	Yes	Animals in field across railway line
31	—	Yes	Animals in field next to direct contacts
32	Yes (but unlikely)	Yes	—

to the airborne route, it was apparent that farms with large numbers of animals were affected and smallholdings escaped infection.

In a number of outbreaks lesions older than 48 h were found in cattle and sheep present on the same farm. The delay in observing lesions was probably due to the difficulty of recognizing lesions in sheep, and this emphasizes the role of cattle in acting as indicators of the disease (Sellers & Parker, 1969). In addition sheep have been found to excrete virus during the incubation period before lesions are observed, and this may have increased the amount of airborne virus released from some farms.

Although cattle and sheep emit, as an aerosol, 30- to a 1000-fold less FMD virus than pigs, there was still a significant quantity of virus at 20 km to cause

infection of the sheep on one farm. However, the concentration of virus at this distance favours inhalation rather than ingestion as the route of infection for the sheep and cattle. Given a dose of one infectious unit of virus per minute, an animal would receive a sufficient dose in 100 min by the respiratory route but would need 69 days by ingestion. Any virus deposited by precipitation would be made more effective as a result of splashing (Gregory, 1971) and subsequent inhalation.

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