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PII: S0261-2194(98)00037-4

Crop Protection Vol. 17, No. 5, pp. 427–439, 1998

Printed in Great Britain
0261-2194/98 $19.00 + 0.00

Occurrence and distribution of *Peronosclerospora sorghi* [Weston and Uppal (Shaw)] in selected countries of West and Southern Africa

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Surveys of sorghum and maize crops were undertaken in Nigeria, Zimbabwe, Zambia, Mozambique and Rwanda during 1991 and 1992. The occurrence and prevalence of sorghum downy mildew (SDM) caused by *Peronosclerospora sorghi* [(Weston and Uppal) Shaw] was assessed in regions of each country. In Nigeria only maize was systemically infected in the southern humid zone, where rainfall was 1200–1800 mm and the altitude 300–1000 m. This epidemic zone appeared to be geographically isolated from other areas of Nigeria where SDM was observed. Within the southern epidemic zone, yield loss was estimated to be 11.7%. Individual fields had up to 95% incidence of systemically infected plants. In the arid north of Nigeria (rainfall <1300 mm, altitude 600–1200 m) both maize and sorghum were infected, and disease incidence was invariably low (<5%). Systemic SDM incidence on maize was negatively correlated with growth stage ($r = -0.7746$, $P = 0.01$). In Zimbabwe, Zambia, Mozambique and Rwanda sorghum and maize were infected with SDM in areas with an annual rainfall of 600–1200 mm and an altitude range of <300–1800 m. Incidence of infection within crops was generally low, and sites with infected crops were scattered in these countries. SDM local lesion infection was observed only on sorghum. Yield loss due to SDM in Zambia, Zimbabwe and Rwanda at the time of the survey was negligible. However, SDM is widespread in Africa and occurs in many different agricultural areas, and thus remains a threat to sorghum and maize production. Management of the disease using resistant varieties, cultural and chemical control should reduce the risk of future epidemics. Crown Copyright © 1998 Published by Elsevier Science Ltd. All rights reserved

Keywords: sorghum downy mildew; *Peronosclerospora sorghi*; Africa; GIS; survey

Introduction

Sorghum downy mildew (SDM) caused by *Peronosclerospora sorghi* [(Weston and Uppal) Shaw] infects sorghum [*Sorghum bicolor* (L.) Moench] and maize (Zea mays L.) crops and is widespread in tropical and subtropical parts of the world (Williams, 1984). In many areas detailed information on the distribution and economic impact on sorghum and maize is lacking. Only in the USA has the distribution and spread of SDM been monitored in detail (Freder-

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iksen, 1980a). This has provided information on dynamics of the distribution and the economics of grain yield loss associated with the pathogen. In 1969 in Texas alone the economic impact of sorghum downy mildew was estimated at US$2.5 million (Frederiksen *et al.*, 1969).

Infection of maize or sorghum with *P. sorghi* has been reported in several countries of sub-Saharan Africa (Cardwell, 1995; de Milliano, 1992; Doggett, 1970, King and Webster, 1970; Thomas, 1992), but little information is available on its geographic distribution or economic importance. Surveys to identify the distribution of the disease and assess its prevalence have been undertaken only in parts of South Africa (Van der Westhuizen, 1977) and in southern Nigeria (Fajemisin, 1980; Olanya and Fajemisin, 1993a).

The reports of the distribution of downy mildews infecting sorghum and maize in Nigeria suggest these diseases need close monitoring. In the south of Nigeria a downy mildew (DM) infecting maize was perceived to be spreading from an epidemic centre (Fajemisin, 1980; Olanya and Fajemisin, 1993a). The economic impact of this epidemic was reported in the Nigerian press (*Daily Sketch*, 19 June 1991), with a total loss of 15 000 metric tonnes valued at N37.5 million (US$1.5 million). Currently this pathogen is thought to be a maize infecting strain of *P. sorghi* (Anaso *et al.*, 1987), geographically isolated from other areas in Nigeria where SDM infects sorghum and maize (King and Webster, 1970; Olanya and Fajemisin, 1993a). Further observation of the pathogen and its distribution will help provide information on its current rate of spread and perhaps help elucidate its true identity.

In other countries, including Zimbabwe, Zambia and Rwanda, epidemics have been reported but the distribution of *P. sorghi* (sorghum/maize infecting strain) has not been documented in detail (Bandyopadhyay, 1987; de Milliano, 1992; Doggett, 1970; Kenneth, 1976). In Zimbabwe an extensive survey of the pests and diseases of all crops in all farming regions was undertaken by Page *et al.* (1985). The sorghum crops sampled during Page's survey showed *P. sorghi* occurred in a limited area from which there was no previous report. Information on the distribution, host range and economic impact of SDM on sorghum and maize crops remains scanty. Systematic surveys of these crops will contribute to our knowledge of these aspects as well as providing useful information on the range of habitats in which SDM occurs, and identify those regions where it poses a threat to sorghum or maize production.

Surveys were undertaken to assess the geographic distribution and prevalence of downy mildew on sorghum and maize in Nigeria (West Africa) and Zimbabwe (Southern Africa). Limited areas of Rwanda, Zambia and Mozambique were also surveyed to assess the prevalence of the pathogen in regions where it had previously been reported. In addition, samples of asexual spores were taken of the downy mildew of maize in Mozambique, where *P. philippinensis* was reported (Plumb-Dhindsa and Mondjane, 1984), and from the downy mildew of maize in southern Nigeria for comparison with typical *P. sorghi*.

Materials and methods

Survey sampling methods and disease assessments

Incidence of systemic DM was assessed by counting the number of infected plants in random transects chosen as described by Neuenschwander *et al.* (1989). Due to the number of sites, the time spent in each field was limited, but sampling transects of 10 plants provided a rapid yet accurate method for assessing the incidence of systemic infection. The transects were taken at regular intervals along each arm of a 'W' sampling pattern followed across each field. Presurvey samples of maize and sorghum crops in northern and southern Nigeria and in Zimbabwe were taken to identify optimal sample size and to confirm that disease incidence was reliably assessed. Five maize crops were assessed in southern Nigeria, one sorghum crop in northern Nigeria and four sorghum crops in Zimbabwe. Sixteen transects were taken in each of the 10 presurvey fields and the reliability of the estimate of the mean in relation to sample size was determined using the coefficient of variability (McSorley and Parado, 1983).

A score for local lesions of each incidence and severity of SDM and other foliar disease was recorded based on a scale described by Kranz (1988): 0 = no disease present, 0.1 = <1% of the population infected or leaf area diseased, 1 = 1–10% of the population infected or leaf area diseased, 2 = 11–25% of the population infected or leaf area diseased, 3 = >26% of the population infected or leaf area diseased. Insect damage (stem borers) was assessed for incidence only using this scale.

A systematic method was used to choose sample sites. A single field was assessed every 20 km (or the nearest maize or sorghum field thereafter). Crops too young to show evidence of systemic infection (seedlings under 20 days) were not assessed. If a maize/sorghum intercrop was encountered, then both crops were assessed individually.

Survey variables measured

The following parameters were recorded at each site: (1) site location (km from start), (2) site topography (1 = flat, <50 m from water, 2 = sloping, >50 m water, 3 = hydromorphic zone, within 100 m of water), (3) surrounding vegetation type, (4) cropping system, (5) variety (1 = improved, 2 = local, 3 = unknown), (6) growth stage (for maize, 1 = early vegetative phase, 2 = early–mid stem extension, 3 = mid–late stem extension, 4 = silk, 5 = tassel, 6 = grain fill; for sorghum, 1 = early vegetative phase, 2 = tillering, 3 = early–mid stem extension, 4 = mid–late stem extension, 5 = booting, 6 = flower, 7 = grain fill), (7) soil type, (8) field size (1 = <100 m^2, 2 = 101–500 m^2, 3 = 501–1000 m^2, 4 = 1001–5000 m^2, 5 = >5000 m^2), (9) plant spacing (1 = <80 cm, 2 = 81–120 cm, 3 = 121–150 cm, 4 = >150 cm), (10) weediness of crop (1 = 0%, 2 = <10%, 3 = 11–25%, 4 = >25% ground cover),

(11) graminaceous weed species in crop, (12) principal graminaceous species in surrounding vegetation, (13) adjacent crop, (14) presence or absence of DM in adjacent crop, (15) presence or absence of DM in wild grass species, (16) incidence of systemic DM in crop being sampled, (17) symptoms of systemic DM infection (chlorosis, 1 = mild, 2 = severe; half-leaf symptom, 1 = present, 2 = absent; chlorotic streaking, 1 = present, 2 = absent; narrowing of leaves, 1 = present, 2 = absent; crazy top, 1 = present, 2 = absent; sterility, 1 = present, 2 = absent; leaf shredding 1 = present, 2 = absent), (18) incidence and severity of local lesion DM infection, and (19) incidence and severity of other pests and diseases. If the farmer was present, then further questions were asked, including (20) date of planting, (21) variety, (22) source of seed, (23) inputs and (24) cropping history of site.

Countries surveyed

Nigeria. Nigeria lies between 4.25N and 13.50N and 2.45W and 14.40W. Its elevation ranges from sea level to over 1800 m (although 80% of its area is less than 600 m), and the annual rainfall (which is bimodal in the south and monomodal in the north) from over 3000 mm in the wetter south to 650 mm in the drier north. In the south two principal cropping seasons commence in May and September, respectively, and in the north a single season commences in June. Two surveys were undertaken, the first from 4 to 25 June, and the second from 24 July to 10 August 1991.

Zimbabwe. Zimbabwe lies between 16.03S and 22.03S and 25.10E and 35.00E. The altitude ranges from <900 m to >1500 m. Annual rainfall ranges from 400 to 1400 mm. The principal cropping period coincides with the monomodal rains between November and April. The survey was undertaken from 14 to 29 January 1992.

Parts of Zambia, Rwanda and Mozambique. Zambia (8.05S–18.15S and 22.00W–33.50W) receives 400–1000 mm of rainfall and lies between 900 and 1300 m elevation. The rainfall is monomodal and ranges from 400–2000 mm. The major growing period is similar to that for Zimbabwe. The survey (8–14 February 1992) was in the area around the capital, Lusaka, and south towards the Zambezi Valley. Rwanda (1.04S–2.48S and 28.50E–30.54E) has an elevation of 1470–4507 m, and an annual rainfall of 800–2000 mm. The rainfall is bimodal and allows two periods of cropping, January–March and September–December. The survey was made from 13 to 19 March 1992. Mozambique (10.27S–26.52S and 32.12E–40.51E) rises from sea level to over 2000 m. Only fields at a government seed production farm (Umbeluzi) south of Maputo were sampled. The area is at c. 100 m elevation and receives 400–800 mm rainfall per annum. The major growing period is the same as for Zimbabwe. The survey was undertaken from 28 February to 3 March, 1992.

Dimensions of the asexual spores of the maize infecting downy mildew in Southern Nigeria and Mozambique

Samples of infected leaves were harvested, and incubated to produce conidia as described by Bock *et al.* (1998). The length and width of a sample of 50 conidia were measured to investigate whether the pathogen conformed to the morphology previously defined for *P. sorghi* (sorghum/maize pathotype; Weston and Uppal, 1932).

Data analysis

For surveys where there were sufficient sample sites (Nigeria and Zimbabwe) use was made of the ARC/INFO Geographic Information System at the Natural Resources Institute, Chatham, UK. This system allows mapping and classification of site data in relation to various parameters, including climatic variables, vegetation type and altitude. This is particularly useful where large data sets are concerned as it allows characterization of the location in which the pathogen is found. Vegetation data were derived from digitized vegetation maps (White, 1983). Climatic data was derived from up to 90-year averages for sites in these countries, which was interpolated using a technique known as 'kriging' to generate national coverages. Correlation analysis was used to investigate the relationship between disease incidence and various environmental and agronomic variables in Nigeria.

Results

Estimation of survey sample size

Figure 1a, b shows the effect of number of sample transects on the accuracy of the mean systemic DM incidence in maize and sorghum crops. The relationship was similar for both maize and sorghum. On the basis of this presurvey sample, 10 transects were taken per site to estimate disease incidence. If systemic infection was observed in a crop, but was not sampled in any transect, then the level of infection in the field was arbitrarily given an incidence of 1.0%.

Survey results

In Nigeria each survey was c. 10000 km, and covered 5×105 km^2 (*Figure 2a*). The disease distribution was similar in both surveys. An epidemic zone where only maize was infected existed in the southwestern region of the country (*Figure 2b*). There was little sorghum grown in this region. Incidence of systemic infection was observed to exceed 90.0% in several maize crops. On sorghum, disease incidence did not exceed 5%. In Zimbabwe (*Figure 3a*), the route was c. 5000 km, and covered 3.6×105 km^2. Infected maize and sorghum crops were found at only four sites (*Figure 3b*). Infected crops were found in limited areas of Zambia, Rwanda and Mozambique surveyed (*Figure 4a, b, c*, respectively). In Zambia the survey route was c. 400 km, covering an area of 9×103 km^2, whereas

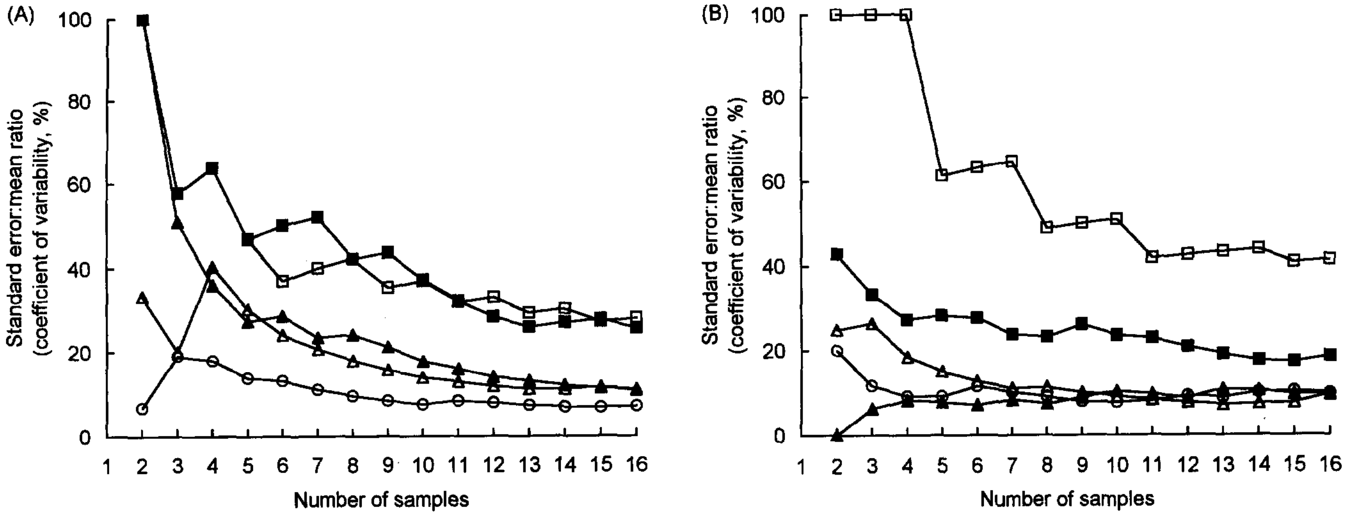

Figure 1. Presurvey results of the incidence of systemic infection with *Peronosclerospora sorghi* on (a) sorghum crops (□ Nigeria, 5.6% plants infected; ■ Zimbabwe, 8.1% plants infected; △ Zimbabwe, 38.8% plants infected; ▲ Zimbabwe, 40.0% plants infected; ○ Zimbabwe, 52.5% plants infected); and (b) maize crops (□ Nigeria, 3.8% plants infected; ■ Nigeria, 17.5% plants infected; △ Nigeria, 35.0% plants infected; ▲ Nigeria, 44.4% plants infected; ○ Nigeria, 58.1% plants infected) showing the relationship between sample size, mean disease incidence and reliability of the estimate of mean disease incidence.

in Rwanda, a 200 km route covered 500 km^2. Infected sorghum crops were scattered along the routes in both countries, but no infected maize was seen in the few maize crops assessed in either country. In Mozambique, several crops of maize and sorghum were infected at the single site visited.

Table 1 shows the number of maize and sorghum fields visited in each country, and the proportion of these infected with SDM. In Nigeria 16.3% and 22.9% of maize crops were infected with SDM in surveys 1 and 2, respectively. Only 0.9% and 3.1% of sorghum crops were infected in a localized area in the north. Maize was also infected in the same area. Local lesion infection was seen on all systemically infected sorghum crops, but not on maize. In Zimbabwe 2.2% of maize and 12.5% of sorghum fields sampled were systemically infected. Incidence of systemic infection on maize was <1% at all sites. On sorghum systemic SDM incidence ranged from 1 to 43.2%. Local lesion infection was seen on all systemically infected sorghum crops. In Zambia only sorghum was infected (40.9% of sorghum crops sampled). Of the infected sorghum crops, 56% had systemic infection. In Rwanda, 33.3% of sorghum crops were infected. Systemic infection was observed at 75% of these sites. Local lesion infection was observed at all sites where SDM was found. There was no significant difference between the mean incidence of systemic maize DM in southern Nigeria in surveys 1 and 2 in Nigeria ($P<0.05$, *Table 2*).

The incidence of local lesion infection of sorghum often exceeded 25% infected plants, but the severity was invariably below 10% leaf area infected. Systemic SDM infection observed on sorghum was typical, with 'half-leaf' symptoms, chlorosis, narrowing, and in the latter stages streaking of the foliage, and sterility. The infection culminated in oospore production and leaf shredding. Systemically infected maize plants in the north and south of Nigeria showed similar symptoms typical of SDM infection, with sterility of the floral organs often accompanied by vegetative proliferation of the ear and tassel. However, the degree of chlorosis of maize was invariably greater in infected plants in the south. No oospore production was observed in any maize crop and leaf shredding was absent. Conidial production was seen on all infected crops.

Only in Zambia, at Golden Valley, north of Lusaka was an infected collateral host [*Sorghum halepense* (Linn.) Pers.] observed. Field size ranged from c. 100 to 10000 m^2. Field management was variable. Cropping system did not appear to affect incidence of SDM (*Table 3*). However, growth stage of the maize crops in southern Nigeria was negatively correlated with incidence of systemic SDM infection ($r = -0.7746, P<0.01$).

Of the 22 states surveyed in Nigeria, maize was observed to be infected in seven: Ondo, Kwara, Osun, Oyo, Kogi and Edo in the south, and Kaduna in the north (*Table 4*). The greatest proportion of infected maize crops was in Osun state (80% of crops), which also had the greatest mean incidence of infected plants per infected crop (33.3%). Infected sorghum crops were observed in only two states: Kaduna and Niger. In Zimbabwe infected crops were found in four provinces only: Mashonaland Central, Mashonaland East, Matabeleland South and Midlands provinces (*Table 5*).

Disease distribution in relation to altitude

In Nigeria infected maize crops were between 300 and 1200 m elevation (*Figure 5*), but in the southern epidemic zone of Nigeria they were all below 1000 m. In the north the sites lay between 600 and 1200 m. Mean disease incidence was greatest in the 600–1000 m zone (29.0% plants infected). In Zimbabwe infected crops were found between 1000 and 1500 m. In Zambia the infected sorghum crops lay at elevations from 900–1300 m and in Rwanda between 1500 and 1800 m. In Mozambique the altitude was c. 100 m.

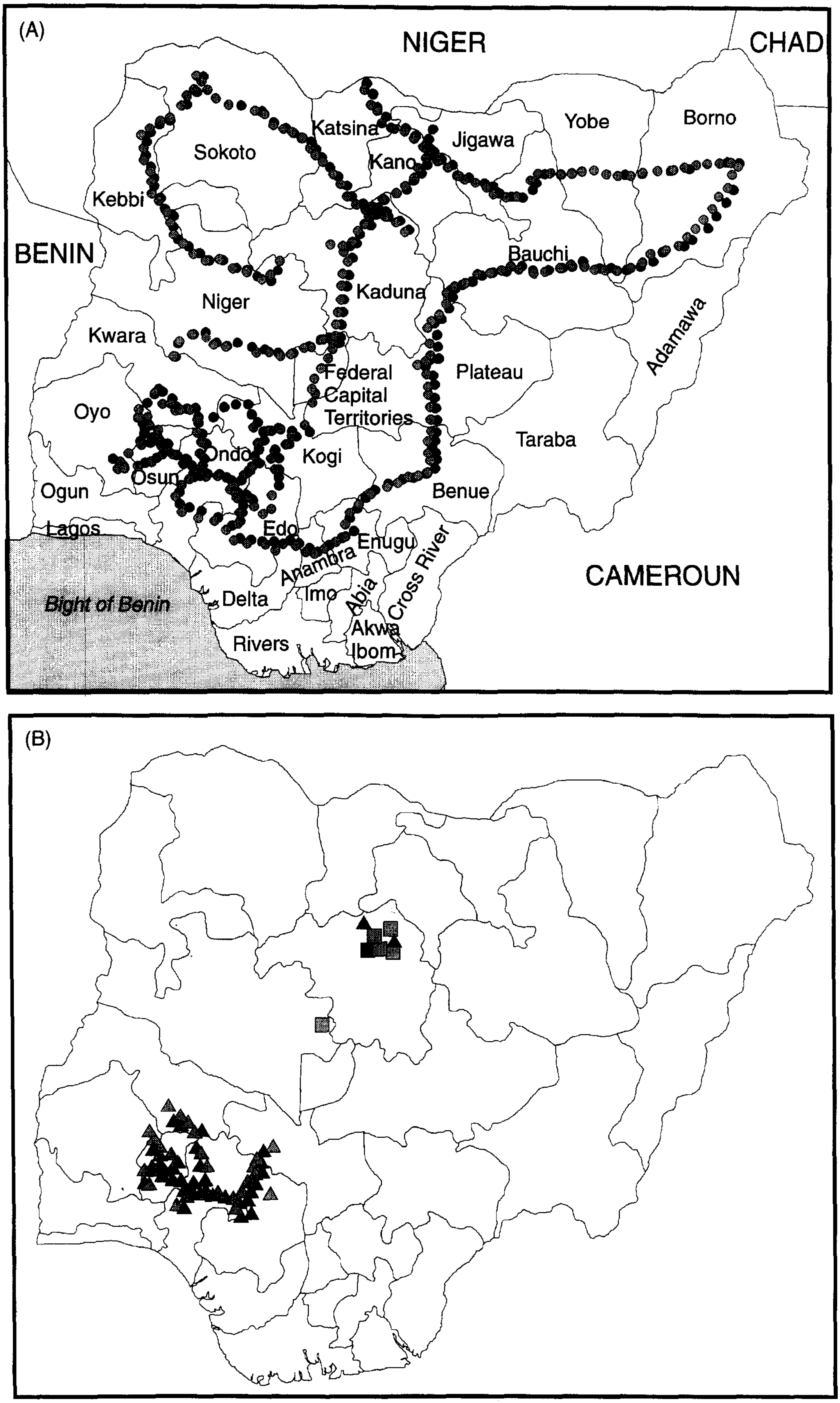

Figure 2. Maps of Nigeria showing (a) states and survey routes (survey 1: ●, and survey 2: ●); and (b) the maize and sorghum crops infected with *Peronosclerospora sorghi* during the surveys from 4 to 25 June and 24 July to 10 August 1991 (infected maize crops, survey 1: ▲; survey 2: ▲ ; infected sorghum crops, survey 1: ■; survey 2: ■).

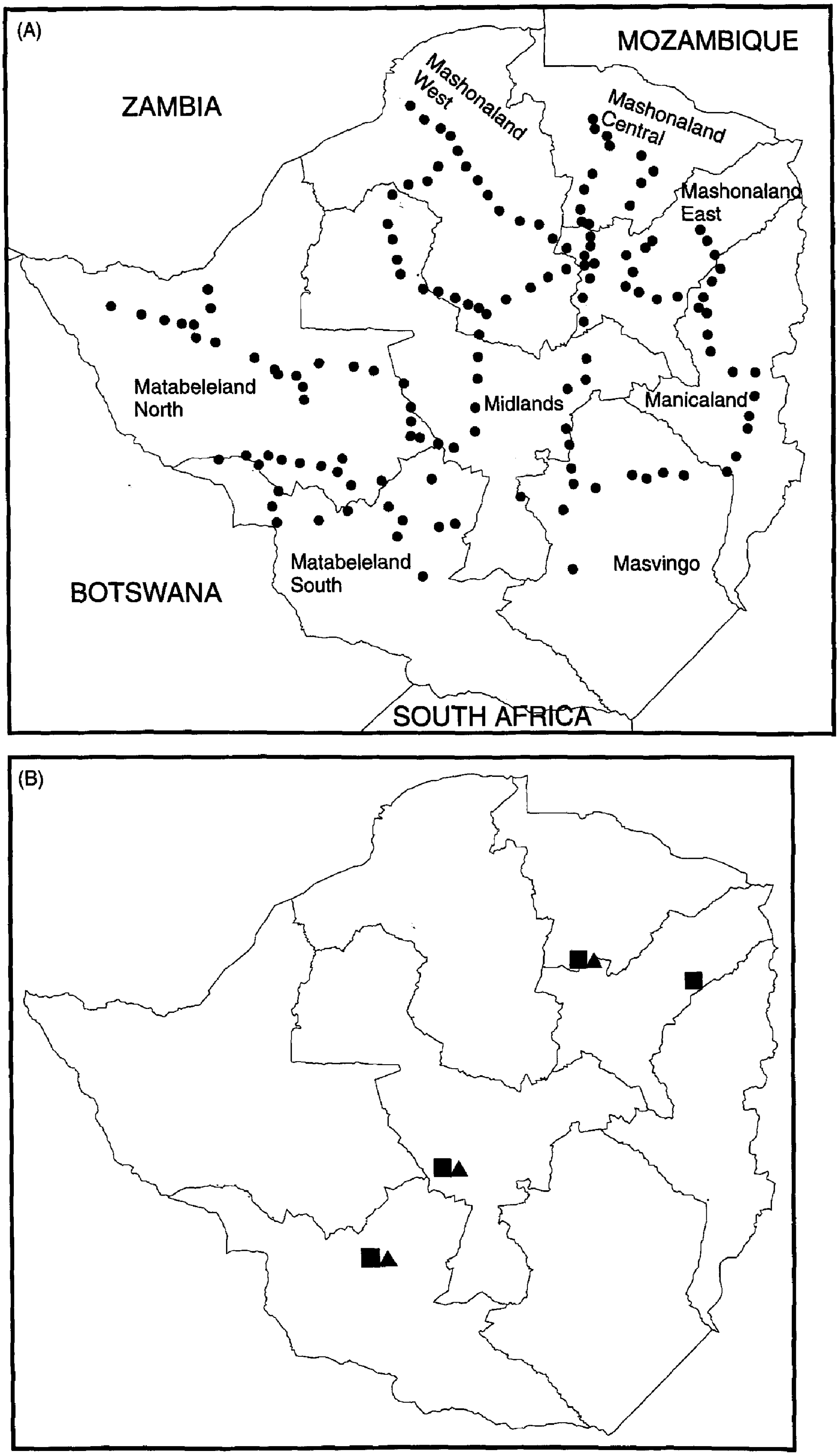

Figure 3. Maps of Zimbabwe showing (a) provinces and the survey route (●) and (b) the maize (▲) and sorghum (■) crops infected with *Peronosclerospora sorghi* during a survey from 14 to 29 January 1992.

Disease distribution in relation to rainfall

The incidence of systemically infected crops as affected by mean annual rainfall totals is shown in *Figure 6*. In Nigeria SDM infected maize crops were observed in areas receiving between 1200 and 1800 mm per annum. The greatest mean disease incidence was where rainfall was 1500 mm (29.5% plants infected). In northern Nigeria sorghum crops were infected in areas receiving 1200–1300 mm of rainfall per annum, while in Zimbabwe infected crops received 600–900 mm.

Disease distribution in relation to vegetation zone

The incidence of infected crops in each of the principal vegetation zones surveyed is shown in *Table 6*. In Nigeria the greatest proportion of infected maize crops was in the Guineo–Congolian Lowland Rainforest zone (42.6%). In the drier Sudanese Woodland (*Isoberlinia* dominated) zone only 3.4% of crops were infected. Infected sorghum crops were observed in the mosaic of Guineo–Congolian Rainforest, Woodland and Savannah zone (1.0%) and in the Sudanese Woodland (*Isoberlinia* dominated) zone (9.4%). In Zimbabwe infected crops were found only in the Drier Zambezian Miombo Woodland and the North Zambezian Undifferentiated Woodland zones.

Other major pests and disease

Many other pests and diseases were common in maize and sorghum fields (*Table 7*). Maize streak virus and *Exserohilum turcicum* were encountered at the greatest proportion of sites (35.8% and 23.1% of sites). On sorghum *E. turcicum*, *Ramulispora sorghi*, *R. sorghicola* and *Cercospora sorghi* were observed at 27.6, 21.1, 16.1 and 55.2% of sites, respectively. In Zimbabwe stem borers caused 49.3 and 43.8% damage to maize and sorghum, respectively, at the sites surveyed. On maize, maize streak virus (17.4% of sites) and *Puccinia polysora* (14.5% of sites) also infected several crops. Apart from stem borer infestation, sorghum crops were often infected by *E. turcicum* (59.4% of sites) and *Colletotrichum graminicola* (43.8% crops infected). In Zambia *E. turcicum*

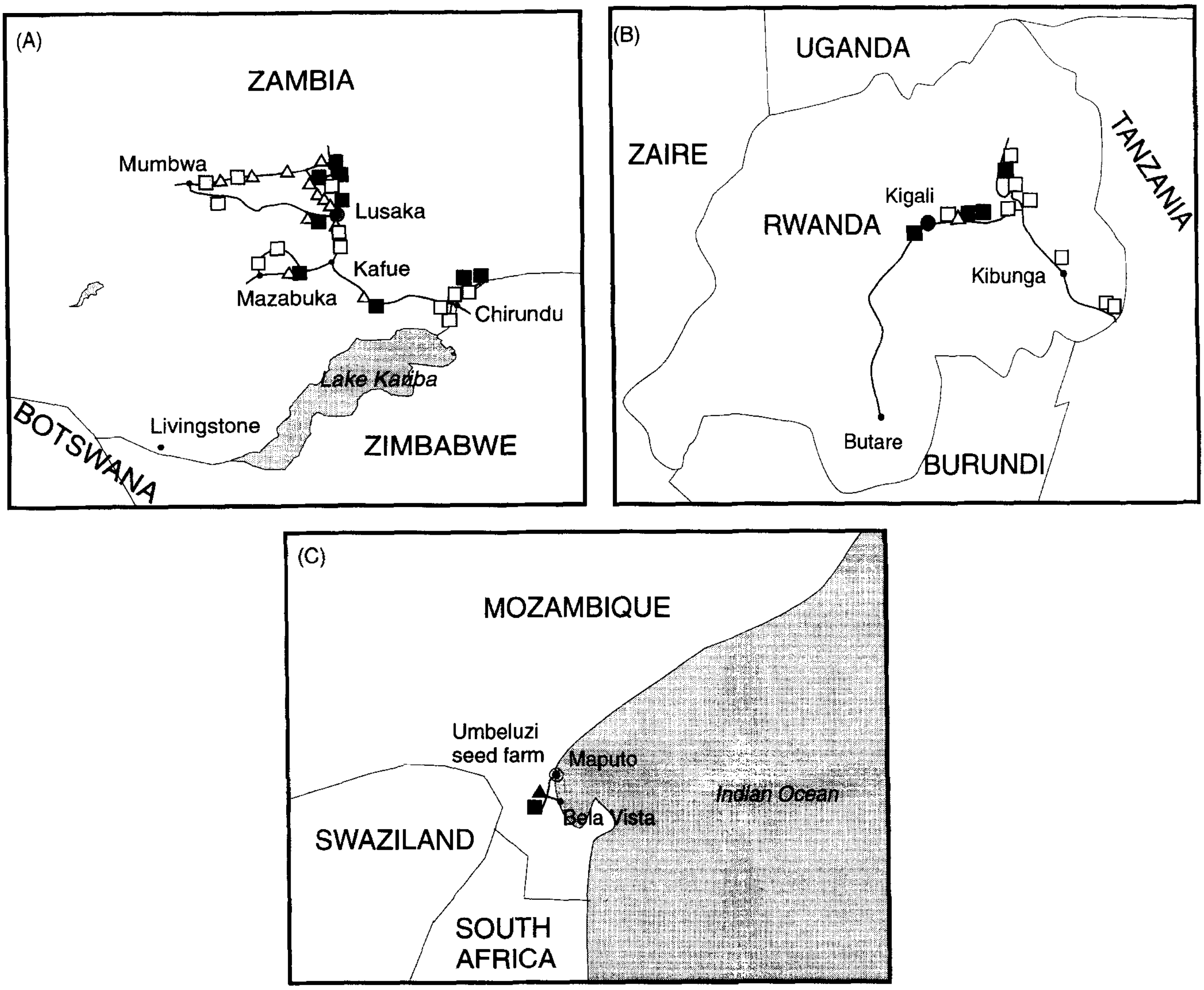

Figure 4. Maps of (a) Zambia, (b) Rwanda and (c) Mozambique showing survey sites and the location of maize and sorghum crops infected with *Peronosclerospora sorghi* in 1992 (infected maize site: ▲; no infection: △; infected sorghum site: ■; no infection: □).

(81.8% of sites) and *C. graminicola* (95.5% of sites) were widespread on sorghum. On maize, maize streak virus (92.3% of sites), *P. polysora* (61.5% of sites) and *E. turcicum* (46.2% of sites) were the most commonly encountered pathogens. In Rwanda both *E. turcicum* and *C. graminicola* were observed on all sorghum crops assessed. Smuts were also commonly found on mature plants at and after flower.

Table 1. The number of maize and sorghum crops sampled, and the proportion infected with downy mildew (*Peronosclerospora sorghi*) in Nigeria, Zimbabwe, Zambia, Rwanda and Mozambique in 1991 and 1992

Country[a]	Total number of sites[b]	Number of maize sites	% maize sites infected	Number of sorghum sites	% sorghum sites infected
Nigeria (survey 1)	251	178	16.3	106	0.9
Nigeria (survey 2)	261	140	22.9	163	3.1
Zimbabwe	145	138	2.2	32	12.5
Zambia	22	13	0	9	40.9
Rwanda	12	1	0	12	33.3
Mozambique[c]	1			1	

[a]Survey dates: Nigeria, survey 1 from 4 to 25 June and survey 2 from 24 July to 10 August 1991; Zimbabwe 14–29 January 1992; Zambia 8–14 February 1992; Rwanda 13–19 March 1992; Mozambique 28 February - 3 March, 1992
[b]Total sites not equal to maize+sorghum sites as maize/sorghum intercrops were not considereed a single field but were assessed individually
[c]In Mozambique only one location was sampled, although several fields were visited. Both the maize and sorghum crops were infected

Dimensions of conidia of isolates of downy mildew from maize from southern Nigeria and Mozambique

The dimensions (mean l × w) of conidia from maize in southern Nigeria was 21.57 × 16.76 μm (standard deviation 3.19 and 1.90 respectively, range 14.8–28.8 μm and 13.7–22.4 μm, respectively). Those from maize in Mozambique measured 21.89 × 17.27 μm (standard deviation 2.69 and 2.09,

Table 2. The mean incidence of systemic downy mildew infection of maize at infected sites only in the southern epidemic zone during surveys 1 and 2 in Nigeria, 1991

Survey number	Mean systemic SDM incidence (% plants infected)	Number of observations	Standard error	*t*-value
1	18.8 (1.0–94.5%)[a]	27	4.7	−1.61[b]
2	30.0 (1.0–93.4%)	32	5.2	

[a]Figures in parentheses give range of incidence
[b]ns = not significant ($P = 0.05$)

Table 3. Correlations between the incidence of systemic maize DM in Nigeria[a] and various disease and crop variables in 1991

	Mean incidence of systemic DM	Cropping system	Crop growth stage	Sporulation	Planting density
Mean incidence of systemic DM	1.0000	−0.3078 ns[b]	−0.7746**[c]	−0.5219 ns	−0.6093 ns
Cropping system		1.0000	−0.0542 ns	0.0254 ns	0.0000 ns
Crop growth stage			1.0000	0.4910**	−0.0497 ns
Sporulation				1.0000	−0.1565 ns
Planting density					1.0000

[a]Data from both surveys 1 and 2 combined, mean disease incidence, cropping system, crop growth stage, sporulation and planting density based on the variables as described in materials and methods
[b]ns = not significant
[c]Significant at $P = 0.01$

Table 4. The incidence of maize and sorghum crops infected with downy mildew (*Peronosclerospora sorghi*) and the mean disease incidence in different states in Nigeria[a] in 1991

State	Maize				Sorghum			
	Number of sites	% infected	Mean disease incidence per infected site	Standard error	Number of sites	% infected	Mean disease incidence per infected site	Standard error
Kogi	23	17.4	1.0	[b]	7	0	0	
Ondo	43	65.1	22.5	5.2	0	0	0	
Osun	20	80.0	33.3	7.01	0	0	0	
Oyo	18	16.7	22.9	7.05	4	0	0	
Kwara	19	36.8	31.5	11.82	8	0	0	
Niger	27	0	0		32	3.2	1.0	
Kaduna	29	6.8	2.5	1.48	34	14.7	1.32	0.32
Edo	26	3.8	12.8		0	0	0	

[a]Data from both surveys 1 and 2 combined.
[b]Indicates insufficient data to generate a standard error as only one crop infected.

Table 5. The number of sorghum and maize crops assessed in each province and the number infected with sorghum downy mildew (*Peronosclerospora sorghi*) during the survey in Zimbabwe, 1992

Province	Number of maize crops	% maize crops infected	Number of sorghum crops	% sorghum crops infected
Manicaland	14	0	1	0
Mashonaland Central	13	7.7	3	33.3
Mashonaland East	19	0	4	25
Mashonaland West	25	0	5	0
Masvingo	11	0	0	0
Matabeleland North	28	0	14	0
Matabeleland South	12	8.3	4	25
Midlands	16	6.3	1	100

respectively, range 16.2–27.0 μm and 14.0–24.2 μm, respectively).

Discussion

These surveys indicate DM of maize and sorghum is generally sparse, of low incidence and highly localized in the north of Nigeria. In the south, where only maize was infected the epidemic zone was extensive and disease incidence frequently high. These observations on distribution and host range of DM of sorghum and maize in Nigeria confirm earlier reports (Anaso *et al.*, 1987; Fajemisin, 1980; King and Webster, 1970; Olanya and Fajemisin, 1993a). However the epidemic zone in southern Nigeria has

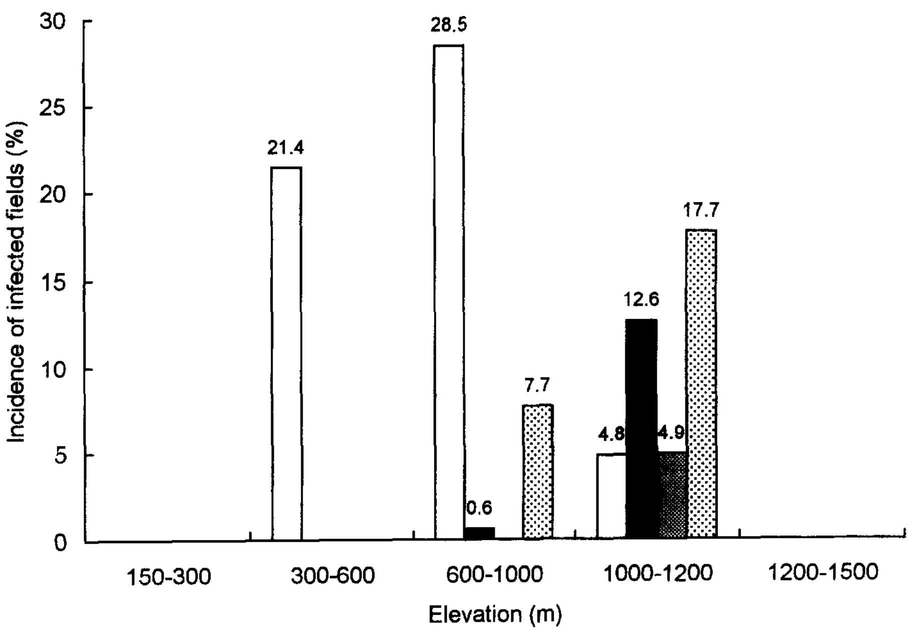

Figure 5. The incidence of maize and sorghum fields with crops infected by *Peronosclerospora sorghi* in areas at different elevations in Nigeria and Zimbabwe in 1991 and 1992 (□ maize, Nigeria; ■ sorghum Nigeria; ▩ maize, Zimbabwe; □ sorghum, Zimbabwe).

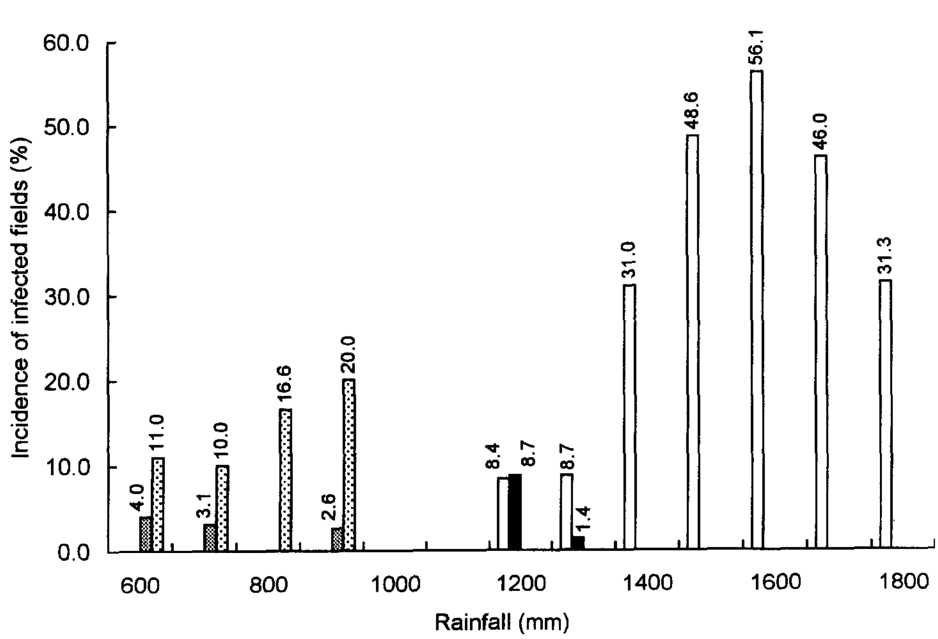

Figure 6. The incidence of maize and sorghum fields with crops infected by *Peronosclerospora sorghi* in areas receiving different mean annual rainfall in Nigeria and Zimbabwe in 1991 and 1992 (□ maize, Nigeria; ■ sorghum Nigeria; ▩ maize, Zimbabwe; □ sorghum, Zimbabwe).

Table 6. The number of maize and sorghum crops sampled in different vegetation[a] zones and the proportion of crops infected with downy mildew (*Peronosclerospora sorghi*) in Nigeria in 1991 and Zimbabwe, Zambia, Rwanda and Mozambique in 1991 and 1992

		Maize		Sorghum	
Country	Vegetation zone	Number of sites	% infected	Number of sites	% infected
Nigeria[b]	Lowland rainforest, Guineo–Congolian wet and drier types	106	42.6	1	0
	Mosaic of Guineo–Congolian lowland rainforest, woodland and secondary savannah	126	12.4	76	1.0
	Sudanian woodland with abundant *Isoberlinia*	59	3.4	49	9.4
	Undifferentiated Sudanian woodland	100	0	147	0
Zimbabwe	Undifferentiated afro-montane vegetation	2	0	0	0
	Mosaic of zambezian dry deciduous forest and secondary grassland and wooded grassland	13	0	5	0
	Drier zambezian miombo woodland	85	1.2	11	18.1
	Colophospermum mopane woodland and scrub woodland	15	0	6	0
	North zambezian undifferentiated woodland	23	8.7	10	20.0
Zambia	Drier zambezian miombo woodland	7	28.6	6	0
	Colophospermum mopane woodland and scrub woodland	6	33.3	0	0
	North zambezian undifferentiated woodland	7	71.4	7	0
	Edaphic grassland	2	0	0	0
Rwanda	East African Evergreen Bushland/2° Acacia wooded grassland	1	0	12	33.3
Mozambique	East African coastal mosaic (Tongaland/Pondoland type)	1	100	1	100

[a]Based on the vegetation categories proposed by White (1983).
[b]Data from both surveys 1 and 2 combined.

increased in size since the initial reports of Fajemisin (1980). The present study indicates an almost twofold increase in the area corresponding to the epidemic zone in the 12 years from 1980 to 1992, from approximately 3.0×10^4 km^2 (Fajemisin, 1980) to over 5.0×10^4 km^2. This suggests an annual increase of the epidemic area of approximately 1.5×10^3 km^2.

The populations of DM in the north and south of Nigeria may be geographically isolated. There is no indication of a continuum of infected crops between the epidemic zone in the south and infected maize or sorghum in the north of Nigeria. Despite possible geographic isolation, the pathogen in the south may be a strain of *P. sorghi* specific to maize (Anaso *et al.*,

Table 7. The incidence of pests and diseases infecting sorghum and maize crops during surveys in Nigeria[a], Zimbabwe, Zambia and Rwanda during 1991 and 1992

Crop	Pest or disease		Incidence in different countries (% sites with infected crops)			
			Nigeria[b]	Zimbabwe	Zambia	Rwanda
Maize	Pest	Stem borer	2.7	49.3	30.8	
	Disease	Maize streak virus	25.8	17.4	92.3	
		Exserohilum turcicum	23.1	3.6	46.2	
		Curvularia lunata	6.7	6.5		
		Physoderma maydis	6.1	0.7		
		Puccinia polysora	4.3		61.5	
		Fusarium moniliforme	3.8	0.7		
		Puccinia sorghi		14.5		
		Bipolaris maydis		2.9		
Sorghum	Pest	Stem borer	1.8	43.8	27.3	25.0
	Disease	*E. turcicum*	27.6	59.4	81.8	100.0
		Ramulispora sorghi	21.1	3.1	36.4	
		R. sorghicola	16.1			
		Gleocercospora sorghi	4.2			
		Cercospora sorghi	55.2			
		Colletotrichum graminicola	6.8	43.8	95.5	100.0
		Xanthomonas campestris pv holcicola	1.0			8.3
		Aschochyta sorghina		9.4	13.6	
		Puccinia purpurea			18.2	33.3
		Cercospora fusimaculans				41.7
		Sporisorium sorghi				25.0
		Sporisorium reilianum				25.0
		Tolyposporium ehrenbergii				16.7

[a]Survey dates: Nigeria, survey 1 from 4 to 25 June and survey 2 from 24 July to 10 August 1991; Zimbabwe 14–29 January 1992; Zambia 8–14 February 1992; Rwanda 13–19 March 1992; Mozambique 28 February–3 March, 1992.
[b]Data from both surveys 1 and 2 combined.

1987). Despite the limited sample, the dimensions of the conidia of the maize infecting downy mildew in southern Nigeria were typical of the dimensions described for *P. sorghi*, sorghum/maize pathotype (Weston and Uppal, 1932). Oospores, important to the pathogenís survival during non-cropping periods (Williams, 1984), were not found in maize crops from the north or south of Nigeria, although they were commonly found in sorghum crops. Anaso *et al.* (1987) was also unable to find oospores in maize from southern Nigeria.

The ecological zones in which the maize infecting DM occurs were characterized. The epidemic is located in typical Guineo–Congolian Rainforest and Rainforest Transitional areas where annual rainfall ranges from 1200 to 1800 mm and the altitude 300 to 1000 m. The practice of 'fadama' maize (maize cropping in moist valleys during the dry season) takes place throughout the rainforest and transition zones in southern Nigeria and allows the pathogen to infect fresh hosts continuously by asexually produced conidia (Anaso, 1989). These agroecological zones extend into the Republic of Cameroun towards the east and the Republic of Benin towards the west, so the pathogen may continue to advance wherever refugia of fadama maize allow survival. For the perpetuation of the pathogen in the north oospores are likely to be important.

The high incidence on maize in southern Nigeria indicates DM is a major limiting factor to maize production. A linear relationship between disease incidence and yield loss has previously been demonstrated in Nigeria (Anaso *et al.*, 1989). The epidemic area where maize alone was infected covers approximately 5×10^4 km^2. The mean incidence of systemic DM on maize (all fields) in the epidemic area was 11.7%, which approximates yield loss. Disease incidence in infected crops frequently exceeds this figure, and at heavily infected sites farmers may abandon their fields so this may be a conservative estimate. Immediate action can alleviate the epidemic in southern Nigeria (Cardwell, 1995). Distribution of large quantities of resistant or metalaxyl treated seed to farmers will reduce the severity of the epidemic and may help contain it. Unfortunately, in the course of this survey few farmers were encountered who grew improved varieties of seed, and none used seed treatment. Cultural practise may also be beneficial. Farmers could be encouraged to plant early, oversow and rogue infected plants in an attempt to reduce epidemic potential. The negative correlation between disease incidence and older plants (-0.7746, $P = 0.01$) in this study suggests that early planted crops are at less risk of infection than later planted crops which is in agreement with the findings of Olanya and Fajemisin (1993a).

Much remains unknown about the maize DM from southern Nigeria. Information is needed on propagule dispersal and seed transmission (Adenele and Cardwell, 1996; Olanya and Fajemisin, 1993a; Frederiksen, 1980b). Is there an alternative host remaining to be identified? What environmental conditions are required for asexual reproduction? What is its true identity? What is the relationship between the pathogen in southern Nigeria and the recently designated *P. zeae* from Thailand (Yao, 1991), and that from maize in Zaire (Steyaert, 1937)? Olanya and Fajemisin (1993a) consider the pathogen in Nigeria to be endemic, rather than introduced. What has caused its dramatic spread from defined foci over the last two decades (Fajemisin, 1980; Cardwell, 1995)?

The results from the surveys in Zimbabwe, Zambia, Mozambique and Rwanda (and northern Nigeria) confirm SDM (sorghum/maize strain) is widespread on sorghum and maize, often of low incidence but occasionally causing epidemics (Bandyopadhyay, 1987; de Milliano, 1992; King and Webster, 1970). The vegetation zones were dominated by various kinds of dry woodland savannahs, typical of lower rainfall (600–1200 mm). The altitudes at which SDM was encountered ranged from just above sea level in Mozambique to at least 1800 m in Rwanda.

Severe drought in southern Africa during 1991/1992 may have influenced the prevalence of SDM. The 90-year mean for the growing season in Zimbabwe (October–April 1901–1991) is 662.3 mm rainfall. During 1991/1992 rainfall was 335.2 mm (or 50.6% of the mean annual rainfall, Department of Meteorology, Harare). These weather conditions are not conducive to the spread and development of epidemics caused by conidia of *P. sorghi* which requires moisture for spore production, dispersal and infection (Shenoi and Ramalingam, 1979). This probably explains the low incidence of plant diseases on maize and sorghum crops in Zimbabwe in 1991/1992. However, the occurrence of local lesions on the foliage of sorghum crops suggests that conidia are produced even when conditions are less than optimal. The data from Zimbabwe suggest a scattered distribution on both sorghum and maize crops. However, when conditions are more optimal for asexual sporulation, epidemics may occur (Bock *et al.*, 1998; Cohen and Sherman, 1977; Rajasab *et al.*, 1980).

The dimensions of the conidia sampled from maize in Mozambique were typical of those of *P. sorghi* (maize/sorghum pathotype). No conidia typical of *P. philippinensis* were observed (Plumb-Dhindsa and Mondjane, 1984; Weston and Uppal, 1932). A collateral host (*S. halepense*) for *P. sorghi* was found in Zambia, where it has previously been observed (Pande and Singh, 1992). This species, and other wild sorghums which have been shown to be susceptible to *P. sorghi* (Bonde and Freytag, 1979; Bock *et al.*, 1995; Olanya and Fajemisin, 1993b), occur widely in Africa (Doggett, 1988) and could act as collateral hosts in many regions. Both sorghum and maize were grown close to one another throughout the areas covered by these surveys, and thus either species could act as a source of inoculum. Sorghums, wild and cultivated, with a tendency for a perennial habit and propensity for oospore production are likely to play a major role in the epidemiology of *P. sorghi* in Africa.

These data highlight the widespread, if scattered, nature of SDM (sorghum/maize strain) in different countries of Africa. In areas where the disease is endemic planting date and material should be chosen with care, so as to avoid epidemics (de Milliano, 1992). The maize DM in southern Nigeria causes serious epidemics where it occurs. Integrated control (Odvody *et al.*, 1983) is probably the most rational approach to the management of downy mildew of maize and sorghum in Africa.

Acknowledgements

This project was funded by the Associate Professional Officers Scheme of the Overseas Development Administration, UK. We appreciate the assistance of Martyn Rothery (NRI) who helped with digitizing the maps for GIS. ICRISAT, IITA and National Research Programs in Nigeria, Zimbabwe, Zambia, Rwanda and Mozambique provided support during the surveys.

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Received 12 November 1997
Revised 7 April 1998
Accepted 23 April 1998