old crops, are all difficult to practice effectively, except roguing. Distribution of the bacteria-free planting materials is scheduled to be planted by using the tip rooting method for local varieties.

Microbial gum composed of D-glucose, D-mannose, D-glucuronic acid, acetic acid, and pyruvic acid (Chen and Tsou 1974) is produced by *X. manihotis* in a sucrose medium. It is not surprising that bacteria are used to produce gum, such as *X. campestris*, the causal agent of black rot disease of crucifer, used to produce Xanthan gum (Rogovin et al. 1961). The gum probably protects the live bacteria when it is dry and releases the bacteria when it is wet.

This systemic bacterial disease is the biggest problem for cassava growers in Taiwan at the present time.

Chen, W. P., and Tsou, C. H. *Microbial gum: a potential new product from sucrose*. Proc. Int. Soc. Sugar Cane Technol. 15, 1974, 1877–1881.

Elliott, C. *Manual of bacterial plant pathogens*. Chronica Botanica Co., USA, 1951, 186p.

Leu, L. S., and Chen, C. T. *Bacterial wilt of cassava (Manihotis utilissima Pohl.) caused by Xanthomonas manihotis (Arthaud-Berthet) Starr*. Plant Prot. Bull. 14, 1972, 17–26.

Lozano, J. C., and Sequeira, L. *Bacterial blight of cassava in Colombia: I. Etiology*. Phytopathology, 64, 1974a, 74–82.

Bacterial blight of cassava in Colombia: II. Epidemiology and control. Phytopathology, 64, 1974b, 83–88.

Lozano, J. C. *Bacterial blight of cassava*. PANS, 21, 1975, 38–43.

Mau, S. C. *Cassava in Taiwan*. Taiwan Special Crops, No. 8, Bank of Taiwan (In Chinese), 1951, 80p.

Rogovin, S. P., Anderson, F. F., and Cadmus, M. C. *Production of polysaccharide with Xanthomonas campestris*. J. Biochem. Microbiol. Tech. Eng. 3, 1961, 51–63.

Sawada, K. *Descriptive catalogue of Taiwan fungi. Part I*. Agric. Exp. Sta., Gov. Formosa Special Bull. No. 19, 1919.

Sawada, K. *Descriptive catalogue of Taiwan (Formosan) fungi. Part II*. Coll. Agric., National Taiwan Univ., Spec. No. 8, 1955, 268p.

Factors Affecting the Incidence of Cassava Bacterial Blight in Africa

E. R. Terry[1]

Cassava bacterial blight (*Xanthomonas manihotis*) is a widespread and damaging disease in Africa. Its severity in Africa varies with locality and climatic conditions. Factors that may affect its severity are soil type, climate, cultural practices, and varieties. Distribution and economic importance of CBB in Africa, and results of epidemiological studies, are included.

Cassava bacterial blight (CBB), caused by *Xanthomonas manihotis*, is a widespread and damaging disease in several countries of South America, Africa, and Asia (Lozano and Booth 1974). In Africa, it was first reported in Nigeria (Williams et al. 1973) and subsequently in Zaïre (Hahn and Williams 1973), Cameroon (Terry and Ezumah 1974), and Ghana and Togo (Persley unpublished data).

The extent of damage caused by CBB varies with locality and climate. The regions most severely affected are probably Zaïre and mid-western and eastern Nigeria. In West Africa, it is more prevalent during the rainy season (April–September).

The epidemiology of a disease may be affected by several, often interrelated, factors including soil type, climate, cultural practices, and crop variety.

The following terms are used according to definitions proposed by the Federation of British Plant Pathologists (1973): *Incidence* — frequency of occurrence of disease, expressed as the proportion of plants affected in a given population; *Severity* — intensity of disease in an individual plant expressed as a rating on a numerical scale.

[1]International Institute of Tropical Agriculture, P.M.B. 5320, Ibadan, Nigeria.

Table 1. Effect of soil type and fertilizer application on CBB incidence in box experiment.

	% Plants infected[a]		% Plants dead[a]	
Soil type	Control	Fertilizer[b]	Control	Fertilizer[b]
Egbeda	74	45	63	35
Ogbomosho	90	90	70	63
Warri[c]	74	74	74	63

[a]Two replicates, 10 plants per replicate.
[b]Fertilizer: N(Urea): 200 ppm N; S(SSP): 100 ppm P; K(KCL): 100 ppm K.
[c]Lime added to Warri soil at rate of 1 ton $Ca(OH)_2$ /ha.

Soils

Field Observations

Surveys conducted in Nigeria and Zaïre suggest that CBB is more severe on cassava planted on infertile, sandy soils (Ezumah and Terry 1974). Glaser and Ogbogu (1974) also report that in Nigeria the disease causes greater crop loss on sandy soils and in fields under continuous cassava.

Effects of Soil Toposequence

Cassava variety Ojunkaiye was planted at IITA in mid March 1975 on six soil toposequences down a slope. There were four plots, each containing 16 plants. The toposequences varied from well-drained upper levels to poorly drained hydromorphic lower levels.

The plants were infected naturally with CBB and by August they showed severe symptoms. Individual plants were then rated for severity on a 0–5 scale: 0, no symptoms; 1, angular leaf spots; 2, leaf wilt, gum exudation; 3, defoliation; 4, some tip die-back; 5, death. The mean rating of four replicates was taken as the disease index for each toposequence. Groundwater levels were monitored at several positions on the slope at 4-day intervals during the season.

Results

There is a statistically significant difference ($p = 0.01$) in disease incidence between plants growing in waterlogged soil at the bottom of the slope (disease index 2.2) and those in better-drained soil further up the slope (4.4). Plants in waterlogged soil were smaller and less vigorous, but there was less defoliation and death due to CBB. Soil moisture changes along this slope were confounded with soil texture; wet soils near the bottom were sandy loams whereas the drier soils near the top were loamy sands.

Greenhouse Experiments

The effects of soil type and the addition of NPK fertilizers on disease development were investigated in two experiments, one conducted in pots, the other in boxes. Both experiments were in randomized complete blocks, with six soil treatments repeated twice with 10 plants per plot.

Three soils (Egbeda, sandy clay loam, pH 6.2; Ogbomosho, loamy sand, pH 6.3; Warri, loamy sand, pH 5.0) were used, with and without NPK fertilizer. Variety 60444 was used as an indicator for CBB. Cuttings were randomly selected from diseased plants. Plants were rated for disease symptoms on a 0–5 scale over 4 months.

Results and Discussion

There were no statistically significant differences among soil treatments in the pot experiment. However, there was a trend towards less infection and death in fertilized than in unfertilized soil for all soil types, especially in Warri soil.

In the box experiment (Table 1), there were significant differences ($p = 0.01$) among soil types and NPK treatments. There were fewer infected and dead plants in the Egbeda soil than in the Ogbomosho and Warri soils. Similarly, there were fewer infected and dead plants in the fertilized soils than the unfertilized soils.

These results suggest that the disease is most severe on plants grown in low-nutrient soils. The indication that the addition of NPK fertilizers may decrease the number of plants killed by CBB has implications for disease control and efficient resistance screening, and

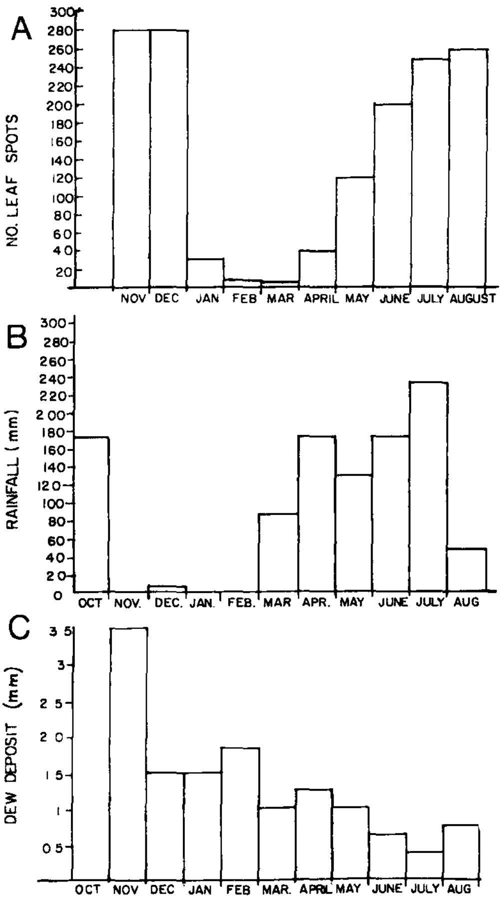

Fig. 1. (a) Seasonal distribution of leaf spots on Isunikakiyan; (b) monthly rainfall at IITA, Ibadan; (c) dew deposit distribution at IITA, Ibadan (data for 1973–1974).

suggests that there is a strong correlation between plant vigour and CBB resistance.

These trends are being further investigated with larger numbers of plants. The more precise effects due to single nutrient elements are also being investigated.

Climate

CBB symptoms range from angular leaf spots to defoliation and death. However, angular leaf spots are the only continuing evidence of CBB since other symptoms occurring alone are not specific for CBB.

The incidence of CBB in a field of 288 plants of Isunikakiyan was assessed by counting the number of plants with angular leaf spots at monthly intervals from November 1973 to August 1974. Climatic data for the period, notably rainfall, temperature, relative humidity, and dew deposit were recorded.

Results

The seasonal distribution of CBB is illustrated in Fig. 1a and 2a. The total monthly rainfall (Fig. 1b), dew deposit (Fig. 1c), monthly relative humidity (Fig. 2b), and monthly mean temperature (Fig. 2c) are compared with the disease distribution.

There was a decrease in the incidence of angular leaf spots after the rains subsided in November. Leaf spot incidence remained low from November until March and then began to increase in April, and continued to do so until August of the following year. This cycle appears to be correlated with rainfall distribution, although the disease did not increase until about 1 month after the rains began in March.

During the dry season (November–March), dew deposit is an important source of leaf wetness (Fig. 1c) and is probably a vital factor in providing sufficient moisture for some bacteria to remain viable during this period.

Cultural Practices

The effects of cultural practices on the development of CBB were investigated. The practices considered were: (1) planting material: disease-free plants were raised by rooting shoot tips under mist, using the Lozano and Wholey (1974) method. These were compared with plants grown from infected cuttings, both being established in the field in April, at the beginning of the rains; (2) mulching; and (3) weed control.

For chemical weed control, a mixture of "Amiben" (Chloramben) and "Enide" (Diphenamid), at 2 kg/ha of each, was applied to the soil before the disease-free plants were transplanted. For cuttings, a mixture of "Lasso" (Alachlor) and "Cotoran" (Fluometuron) at 1 and 1.5 kg/ha, respectively, was applied to the soil as a preemergence treatment. A postemergence spray of "Paraquat" (3.75 l/ha) was also applied to plots with cuttings 90 days after planting. The effect of chemical weed control on CBB incidence was compared with that of hand-weeding.

Results

An average of 9.7 plants out of 24 per plot

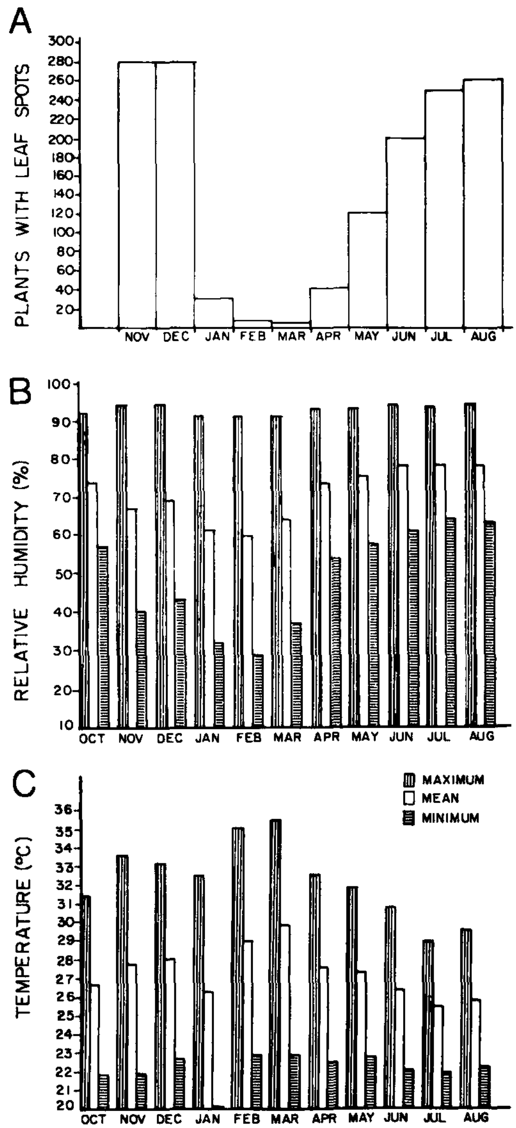

Fig. 2. (a) Seasonal distribution of leaf spots on Isunikakiyan; (b) monthly relative humidity, at IITA, Ibadan; (c) monthly mean temperatures at IITA, Ibadan (data for 1973–74).

raised from disease-free material showed CBB symptoms 55 days after planting, compared to only 3.6 raised from infected cuttings. After 85 days, 21.8 and 22.1 plants respectively showed CBB symptoms in the two treatments.

The differences were statistically significant ($p = 0.01$) at 55 days but not at 85 days after planting. This surprising result suggests that rooted shoot-tips are initially more susceptible to infection than cuttings and should first be established in an area free of CBB if they are to be used as a source of disease-free planting material.

In the hoe-weeding treatment performed 50 days after planting, there was a significant difference ($p = 0.01$) in CBB incidence before weeding and 6 days after. A mean of 4.5 plants out of 24 in the treatment subplots showed symptoms the day before weeding, whereas 6 days after weeding, the mean had increased to 8.8. No such differences were observed when the plots were weeded 80 days after planting. This high incidence of CBB after weeding was probably due to mechanical spread of bacteria during weeding.

Mulching versus non-mulching and hoe-weeding versus chemical weed control had no significant effects on CBB incidence.

Varieties

The incidence and severity of CBB on three varieties (Isunikakiyan, 60444, and 53101) were compared. All three varieties were planted in October 1974 in a 3 × 3 Latin square, with 8 replicates and 15 plants per plot.

Incidence was measured as the number of infected plants per plot. Severity was assessed on a 1–5 scale, where 1 represented no symptoms; 2 angular leaf spots; 3 extensive wilting; 4 defoliation and partial die-back; 5 death.

Ratings were made 5, 7, 9, and 11 months after planting and root yields were recorded after 12 months. These yields were compared to the average yield obtained from these varieties at IITA in October 1972 after 12 months growth, during which time the incidence and severity of bacterial blight was low. The disease ratings recorded in September 1975 (11 months) and root yields are recorded in Table 2.

The varieties differed in the extent of infection and losses sustained. Cultivar 60444 (yield 8.8 t/ha) was more susceptible than 53101 (yield 9.7 t/ha) or Isunikakiyan (yield 12.2 t/ha). The 1971–72 yields of the same varieties ranged from 19 to 21 t/ha. While there are other factors which may have contributed to the yield reduction, it seems likely that CBB infection is at least partially responsible.

Resistance Screening

Varieties were rated on a 1–5 scale of in-

Table 2. Effects of CBB on yield.

Variety	Incidence[a]	Severity[b]	Yield (1975) (t/ha)	Yield (1972) (t/ha)
Isunikakiyan	13.8	2.8	12.2	19
604444	14.7	3.2	8.8	21
53101	13.6	2.9	9.7	20

[a]Mean number of infected plants out of 15 per plot.
[b]1–5 scale of increasing severity (see text).

Table 3. Resistance ratings of clones at three sites in Nigeria.

Disease rating	% Clones		
	Mokwa (north)	Warri (midwest)	Umudike (east)
1	10.0	3.6	0.0
2	82.5	72.6	64.1
3	5.5	17.4	30.5
4	2.0	5.7	5.0
5	0.0	0.7	0.4

creasing severity after natural infection at four sites in Nigeria and one in Zaïre.

The ratings of selected clones at three Nigerian sites are recorded in Table 3. At Warri (midwestern Nigeria), 7, 36, 45, and 12% of 202 local cultivars were rated 2, 3, 4, and 5 respectively for CBB resistance.

The data from field screening for CBB conducted at IITA and M'Vauzi (Zaïre) during the 1975 season are summarized in Table 4. More than one half of the IITA families were rated 1 (no symptoms) and 2 (angular leaf spots only), suggesting that breeding has considerably improved the resistance of these families to CBB.

Discussion

The above results indicate that soil type and fertilizer levels are important factors affecting the severity of CBB although the nature of their effect is not known. Nutrients play an important role in the reduction in severity of many plant diseases but the mechanism of action is often obscure (Goss 1968). Gallegly and Walter (1949) found disease development in bacterial wilt of tomatoes (caused by *Pseudomonas solanacearum*) increased at low K levels and decreased at high N levels. Their results showed the need for medium to high levels of N and K to minimize the effects of this disease, and also indicated that N, P, and K must be balanced.

Applications of high levels of nitrogen or unsuitable combinations of N, P, and K increase the severity of bacterial leaf blight of rice, caused by *Xanthomonas oryzae*, while potassium decreases it (Mizukami and Wakimoto 1969). This decrease is more severe on sandy loam or clay soils than sandy soil, in contrast to the situation with cassava bacterial blight.

While CBB was more severe on low-fertility soils in greenhouse experiments, it was observed on the soil toposequences that plants of low vigour had less CBB. A similar effect has been seen in a resistance trial (Jennings, personal communication). The less vigorous plants may be less attractive to insect vectors; however this observation needs to be more closely investigated.

Reports by Rotem and Palti (1969) suggest that dew is an important source of leaf wetness on many crops, especially during the dry season. Dew records in Ibadan (Fig. 1c) show that levels were highest in November after the rains cease, and there continues to be dew deposited throughout the dry season, thus pro-

Table 4. Cassava bacterial blight resistance screening, 1975 season

Location	Source	No. families	Disease rating				
			1	2	3	4	5
			%	%	%	%	%
Nigeria	Exotic	73	—	—	—	89.8	10.9
	Crosses from advanced yield trial	115	0.8	2.6	19.1	76.5	0.8
	Open-pollinated preliminary yield trial	310	1.2	4.1	18.0	76.4	—
	Low HCN	107	—	0.9	6.5	92.5	—
Zaïre	Zaïre locals	187	—	2.6	28.5	39.1	29.6
	IITA families	164	13.4	40.8	35.3	10.3	—

viding a source of moisture for any bacteria surviving on the leaves.

During hot and dry conditions, the microclimate in the field becomes the decisive factor affecting disease development, since the less favourable the microclimate, the more important becomes the macroclimate (Palti and Rotem 1973).

It is difficult to isolate a single climatic factor when considering its effects on disease development because the optimum conditions for the disease depend upon a complex of climatic factors. Extensive studies over several years with *X. oryzae* on rice in Japan show that a suitable combination of rainfall, humidity, temperature, flood, and typhoon during the growing season is necessary for the development of an epidemic (Mizukami and Wakimoto 1969). An analogous situation probably exists for CBB with some of these climatic factors, but the disease has not been sufficiently well studied for these effects to be known.

Investigations are in progress to determine more precisely the effects of environmental factors on CBB incidence and severity, the variability of the pathogen, and differences in varietal reaction of cassava to the pathogen. A better understanding of these factors is necessary to enable us to modify the farming system so as to favour the crop and not its pathogen.

This work was supported in part by the International Development Research Centre, Ottawa, Canada. The author is grateful to B. T. Kang and F. R. Moorman for information on soil characteristics. R. Dumsday and T. Lawson kindly supplied weather data. The technical assistance of S. Oshinnaiye is warmly acknowledged. I am also grateful to D. Allen, S. Sadik, and W. Steele for their critical reading of the manuscript.

Ezumah, H. C., and Terry, E. R. *Cultural considerations in control of cassava bacterial blight.* Proc. 1st Workshop on Cassava Bacterial Blight in Nigeria, 1974, 25–32.

Federation of British Plant Pathologists. *A guide to the use of terms in plant pathology.* Phytopath. Paper No. 17. Commonwealth Mycological Institute, London, 1973.

Gallegly, M. E., Jr., and Walker, J. C. *Plant nutrition in relation to disease development. V. Bacterial wilt of tomato.* Amer. J. Bot. 36, 1949, 613–23.

Glaser, H. J., and Ogbogu, F. C. *Problems and experiences of plant protection extension in the control of cassava bacterial blight in East Central State of Nigeria.* Proc. 1st Workshop on Cassava Bacterial Blight in Nigeria. Fed. Agric. Res. Stn., Umudike, Nigeria, 1974, 11–12.

Goss, R. L. *The effects of potassium on disease resistance.* In The role of potassium in agriculture. American Society of Agronomy, Madison, Wisconsin, 1968, 221–241.

Hahn, S. K., and Williams, R. J. *Report to Commissaire d'Etat à l'Agriculture Republic of Zaïre, March, 1973.* IITA, Ibadan, Nigeria, 1973, 12p.

Lozano, C., and Booth, R. H. *Diseases of cassava (Manihot esculenta Crantz).* PANS, 20, 1974, 30–54.

Lozano, C., and Wholey, D. W. *The production of bacteria-free planting stock of cassava (Manihot esculenta Crantz).* World Crops, 26, 1974, 115–117.

Mizukami, T., and Wakimoto, S. *Epidemiology and control of bacterial leaf blight of rice.* Ann. Rev. Phytopathol. 7, 1969, 51–72.

Palti, J., and Rotem, J. *Epidemiological limitations to the forecasting of downy mildews and late blight in Israel.* Phyto Parasitica, 2, 1973, 119–126.

Rotem, J., and Palti, J. *Irrigation and plant diseases.* Ann. Rev. Phytopathol. 7, 1969, 267–288.

Terry, E., and Ezumah, H. C. *Report on root crops disease survey and evaluation of production problems in Cameroon, 22–27th Aug. 1974.* IITA, Ibadan, Nigeria, 1974, 4p.

Williams, R. J., Agboola, S. D., and Schneider, R. W. *Bacterial wilt of cassava in Nigeria.* Pl. Dis. Rept. 57, 1973, 824–827.