THE CORESTA COLLABORATIVE STUDY ON BACTERIAL WILT *(RALSTONIA SOLANACEARUM)* – 2001 REPORT

Anne Jack
Tobacco Research Board, P.O. Box 1909, Harare, Zimbabwe.

ABSTRACT

Results from the CORESTA collaborative study to collect information on bacterial wilt (*Ralstonia solanacearum*) resistance for the 1999/00 season in the southern hemisphere and the 2000 season in the northern hemisphere are presented for eight participants from six countries, with emphasis on the consistency of results.

The cultivar set comprised ten prescribed entries and up to two optional entries. It had a range of flue-cured, burley, air-cured and oriental cultivars from several countries. It included cultivars with all known sources of resistance; the polygenic resistance ex T.I.448A, the monogenic *Rps* resistance, the monogenic *Rxa* resistance and the combination of the polygenic and *Rps* resistance.

Disease pressure was very high in China, high in the USA, moderate in Brazil and low in Zimbabwe and South Africa; some of these results were not consistent with previous years. No disease symptoms were recorded in Bulgaria.

Oxford 207 and Enshu FC were consistently the most resistant cultivars over all sites; at some sites they were better than the resistant control. Xanthi was consistently the least resistant cultivar, except for the USA NCSU site, where it seems to behave anomalously. The burley KB 101 does not appear to have much resistance; it was no different from the susceptible control at many of the sites. In most cases, the F_1 was closer to the mid-parent value than to either parent, indicating additive resistance. These results are consistent with previous years.

Results were generally consistent across sites. Most anomalies could be explained in terms of disease pressure (Zimbabwe, China) or other diseases (South Africa). However, there was no obvious explanation for the anomalies at the NCSU site.

INTRODUCTION

The CORESTA bacterial wilt collaborative subgroup was set up in 1994 at the Harare CORESTA Congress, and the first trials were grown in the Southern hemisphere in the 1995/96 season. The mandate was to collect information on bacterial wilt (*Ralstonia solanacearum* (Smith) Yabuuchi *et al*.), in particular on the response of resistant cultivars in different parts of the world. Resistant cultivars are of particular interest because there is no other effective means of controlling this disease.

This is the seventh report to be presented (Jack and Robertson, 1995, 1996, 1997, 1998; Jack, 1999, 2000), covering the results from the 1999/00 and 2000 seasons. All the original objectives of this subgroup have been met (Jack, 2000) and the optional entries have been discussed (Jack, 1999).

MATERIALS AND METHODS

Participants

Ten participants registered for the 1999/00, 2000 seasons, and we have received data from eight of them (Table 1). One of our regular participants did not take part in the trial this year because he did not receive his seed.

Table 1: Participants in the CORESTA Bacterial Wilt Collaborative Study in the Southern Hemisphere (1999/00) and the Northern Hemisphere (2000)

Country	Organisation	Results
Southern Hemisphere (1999/00)		
Brazil	DIMON do Brasil Tabacos Ltda (Dimon)	Withdrawn[#]
	ProfiGen do Brasil Ltda (Profigen)	Received
South Africa	Lowveld Tobacco Growers Association (LTGA)	Received
	Institute for Industrial Crops (IIC) *	Received
Zimbabwe	Tobacco Research Board (TRB)	Received
Northern hemisphere 2000		
Bulgaria	Tobacco and Tobacco Products Institute (TTPI)	Received
China	Qingzhou Tobacco Research Institute (QTRI)	Received
Iran	Tirtash Tobacco Institute (Tirtash)	Pending
USA	Oxford Tobacco Research Station, N.C. State University (NCSU)	Received
	Pee Dee Centre, Clemson University (PD)	Received

[#] Temporary withdrawal - did not receive seed * Greenhouse trial

Cultivar set

Each participant grew ten prescribed cultivars (Table 2) and up to two optional local cultivars. When compiling the cultivar set, the objectives were to include all known sources of resistance, to include material from as wide a range of countries as possible, and to include material from all three major types of tobacco, flue-cured, burley and oriental. This cultivar set includes all three known sources of resistance, has material from six countries and has one burley, one oriental, two air-cured and six flue-cured entries.

Table 2: Prescribed Cultivar Set for 1999/00, 2000 Seasons

Cultivar	Origin	Type	Resistance
Hicks (S control)	USA	Flue-cured	Susceptible
NC 95 (R control)	USA	Flue-cured	Polygenes ex T.I.448A
F_1 (NC 95 x Hicks)	–	Flue-cured	F_1 (R x S)
KB 101	Korea	Burley	Polygenes ex T.I.448A
ADT 108/B40	South Africa	Flue-cured	Polygenes ex T.I.448A
Oxford 207	USA	Flue-cured	Polygenes ex T.I.448A
Xanthi	Turkey	Oriental	*Rxa* gene
Kokubu	Japan	Air-cured	*Rps* gene
Enshu AC [#]	Japan	Air-cured	*Rps* + polygenes
Enshu FC *	Australia ?	Flue-cured*	*Rps* + polygenes ?

[#] New entry

* This accession, obtained from Australia, is a flue-cured cultivar, but the original Japanese accession (Enshu AC) is air-cured.

NC 95, KB 101, ADT 108/40 and Oxford 207 carry the polygenic resistance derived from T.I.448A (Smith and Clayton, 1948). NC 95 is a USA cultivar released almost 40 years ago. KB 101 is a Korean burley cultivar with resistance derived from Burley 64, and is one of the

few burley cultivars reported to have resistance to bacterial wilt (Kim, 1993). ADT 108/B40 is a South African breeding line with resistance derived from Speight G28 and Speight G108. Oxford 207 is a recently released USA flue-cured cultivar, reported to have the highest resistance of all flue-cured cultivars (Sisson, 1999).

Xanthi, an oriental cultivar from Turkey, carries the monogenic partially dominant *Rxa* resistance (Matsuda, 1977), reported to be only moderately resistant (Clayton and Smith, 1942). Kokubu, a Japanese air-cured type carries the monogenic partially dominant *Rps* resistance, also reported to be only moderately resistant (Matsuda and Ohashi, 1973).

Enshu, reported to be highly resistant, carries the *Rps* resistance gene as well as the polygenes found in the other cultivars (Matsuda and Ohashi, 1973). However, the Enshu initially used in this study, designated "Enshu FC", is a flue-cured accession obtained from Australia, which bears no resemblance to the original Japanese air-cured Enshu. It was initially entered in the trial under the mistaken assumption that it was the Japanese cultivar, and was assumed to carry the *Rps* gene plus polygenes, but as its pedigree is unknown, we have no way of knowing if this is the case. The air-cured Enshu, designated "Enshu AC" has been included in the 1999/2000 trials for the first time; it was not available earlier.

Design and assessment

The trial design was eight complete randomised blocks, with 10 to 12 entries, depending on the number of optional entries. The plots consisted of six plants each; small plots were recommended because of the characteristically patchy distribution of bacterial wilt. The normal recommended agronomic practices in each country were followed.

A stand count was done at two weeks after planting (w.a.p.), and plants were assessed then and at monthly or fortnightly intervals. Wilting and yellowing can occur due to factors other than bacterial wilt infection; therefore, plants were scored/counted as infected only if they exhibited vascular streaking. Participants were given the choice of two assessment methods (Table 3), either scores or counts. Because of the unilateral nature of bacterial wilt symptoms, the scoring is based on the progression of the symptoms up the plant, as well as on the number of leaves affected.

Table 3: Assessment Methods

Method I - Scores	Method II - Counts
0 = no symptoms 1 = 1 leaf yellow or wilted 2 = f 2 leaves wilted, > 3 leaves at top of plant healthy 3 = 3 leaves at top of plant healthy 4 = plant dead	No. of plants with f 2 leaves yellow or wilted (i.e., classes 2,3,4 of Method I)

The scores were expressed as Disease Severity (% infection) and the counts as Disease Incidence (% infected plants) for each assessment date.

Data analysis

The following formulae were used to calculate:

(1) Disease Severity (% infection) $= \sum \frac{(n \times v)}{(Z \times N)}$ %

where n = no. of plants in assessment class
v = score (0 – 4)
Z = highest numerical value of the disease scale (4)
N = total no. of plants

(2) Disease Incidence (% infected plants) $= \frac{n}{N}$ %

where n = counts of infected plants or no. of plants in assessment classes 2 – 4
N = total no. of plants

(3) AUDPC: area under the disease progress curve for Disease Severity (% infection)

$$= \sum_{i=1}^{n} [(Y_{i+1} + Y_i)/2] [X_{i+1} - X_i]$$

where Y_i = % infection at the ith observation
X_i = time (weeks) of the ith observation
n = total number of observations

Data were analysed using the GLM procedure. In those analyses where the F-values indicated significance ($p < 0.05$), Fisher's protected least significance difference (LSD) was calculated for pairwise comparison of the means for each treatment (Steel and Torrie, 1981). Arcsine transformations were done on data which were not normally distributed (USA PD site).

For those participants who recorded counts, only Disease Incidence data are presented. For those participants who recorded scores, Disease Incidence, Disease Severity and AUDPC data are presented.

RESULTS AND DISCUSSION

Results are presented in Tables 4 and 5 for all sites except Bulgaria, where no disease was recorded. Disease Incidence at final assessment (Table 4) is based on a count of plants showing symptoms. Disease Severity at final assessment (Table 5) is a finer measurement, based on scores, and takes into account the severity as well as the presence of symptoms. AUDPC, or area under the disease progress curve (Table 5), is the most comprehensive measurement, and takes into account the timing as well as the presence of symptoms and severity of infection.

Final assessments, at 16 weeks after planting (w.a.p.), are not presented for Brazil's, China's and Zimbabwe's Disease Incidence, and for China's and Zimbabwe's Disease Severity. Earlier assessments are presented for Brazil and China (12 w.a.p. for Brazil, 8 w.a.p. and 10 w.a.p. for China), because the disease pressure was so high at the end of the season that few differences were apparent at the final assessment. The penultimate assessment was presented for Zimbabwe, because at the final assessment, KB 101 and Xanthi had senesced to such an extent that they could not be assessed.

Table 4: Disease Incidence for bacterial wilt: 1999/00, 2000 seasons

Cultivar	Disease Incidence at final assessment (% infected plants)							
	Brazil Profigen [$] 12 w.a.p.	China QTRI [$] 8 w.a.p.	S Africa LTGA 18 w.a.p.	S Africa IIC #	USA NCSU 9 w.a.p.	USA PD [+] 10 w.a.p.		Zimbabwe TRB [$] 14 w.a.p.
Hicks	66.7	100.0	22.9	82.8	93.8	98.8	(1.52)	100.0
NC 95	8.3	63.5	6.3	40.6	29.2	55.5	(0.87)	10.4
F_1	43.8	95.8	12.5	65.6	76.7	70.6	(1.02)	45.8
KB 101	25.4	97.9	18.8	64.1	80.8	97.4	(1.49)	91.3
ADT	8.3	37.5	-	68.8	66.7	53.7	(0.83)	0
Ox 207	4.2	33.3	6.3	60.9	35.4	17.3	(0.41)	25.4
Xanthi	66.7	100.0	89.6	59.4	85.4	94.1	(1.44)	28.1
Kokubu	46.3	85.4	75.0	92.2	66.7	75.3	(1.13)	12.1
Enshu AC	-	60.4	-	29.7		54.6	(0.83)	0.0
Enshu FC	0.0	56.3	8.3	51.6	42.5	41.1	(0.69)	20.0
Mean	30.6	73.4	26.3	64.4	60.3	60.8	(0.95)	38.9
$LSD_{0.05}$	20.02	15.10	16.01		27.04		(0.387)	17.11
F	*	*	*		*		*	*
CV%	65.6	20.6	61.0		44.9		(28.2)	44.1

[$] final assessment at 16 w.a.p. - entry not grown # greenhouse trial
[+] % dead plants ( ) arcsine transformation
No disease symptoms were recorded at the Bulgaria (TTPI) site

Table 5: Disease Severity and AUDPC for bacterial wilt: 1999/00, 2000 seasons

Cultivar	Disease Severity at final assessment (% infection)					AUDPC (area under disease progress curve)			
	Brazil Profigen 16 w.a.p.	China QTRI [$] 10 w.a.p.	S Africa IIC #	USA NCSU 9 w.a.p.	Zimbabwe TRB [$] 14 w.a.p.	Brazil Profigen	China QTRI	USA NCSU	Zimbabwe TRB
Hicks	73.7	75.5	68.8	87.8	69.2	292.2	821.9	293.9	366.1
NC 95	36.0	33.9	43.0	23.4	2.6	86.7	464.6	64.8	9.4
F_1	59.3	42.7	58.6	65.7	15.6	197.7	605.7	200.7	77.1
KB 101	46.4	57.3	57.8	77.1	52.5	128.5	652.1	229.1	190.8
ADT	28.6	26.6	50.4	57.3	0	65.6	356.8	181.4	0
Ox 207	21.1	15.6	53.9	27.1	7.4	48.5	264.1	72.9	28.9
Xanthi	85.3	65.3	61.3	51.7	22.0	340.6	754.6	140.6	86.7
Kokubu	49.1	38.5	79.7	50.7	6.0	185.2	535.4	156.6	40.2
Enshu AC	-	22.4	34.8	63.4	0.0	-	290.6	171.6	0.0
Enshu FC	21.3	30.2	52.7	37.2	8.0	42.5	389.6	119.9	30.9
Mean	43.9	39.7	58.5	51.7	20.1	145.1	503.9	155.4	89.5
$LSD_{0.05}$	10.49	8.22		24.80	9.53	63.82	55.38	84.74	49.70
F	*	*		*	*	*	*	*	*
CV%	24.8	20.8		48.1	47.5	44.1	11.0	54.6	55.6

[$] final assessment at 16 w.a.p. - entry not grown # greenhouse trial
No disease symptoms were recorded at the Bulgaria (TTPI) site

Enshu AC was not grown in Brazil, and ADT 108/B40 and Enshu AC were not grown in South Africa at the LTGA site, because of germination problems.

The South African IIC data were from a greenhouse trial, and the USA PD Disease Incidence was based on % dead plants, not on % diseased plants. The data from these two trials were, therefore, not strictly comparable with the data from the other trials.

Disease Severity and AUDPC data are not presented for LTGA (South Africa) and PD (USA), because only counts were done at these sites. AUDPC data are not presented for IIC (South Africa), because only one assessment was done. Data were collected fortnightly at all other sites except Brazil, where data collection was monthly.

As is usually the case with disease data, the variability in most trials was high.

Sites

In Brazil, Enshu AC was not included. All entries except Xanthi were more resistant than Hicks, and KB 101, ADT 108/40, Oxford 207 and Enshu FC were as good as or better than NC 95. The F_1 and Kokubu were more resistant than Hicks, but less resistant than NC 95.

In China, all entries were more resistant than Hicks when considering Disease Severity or AUDPC, but the F_1, KB 101 and Xanthi were similar to Hicks when considering the coarser variable, Disease Incidence. The low resistance of these cultivars is swamped later in the season, but is apparent in the earlier stages, or with a finer measurement. ADT 108/40, Oxford 207, Enshu FC and Enshu AC were as good as or better than NC 95.

At the South African LTGA site, ADT 108/B40 and Enshu AC were not included. Only NC 95 and Oxford 201 were more resistant than Hicks; Xanthi and Kokubu were more susceptible. At this site, these two cultivars have been worse than Hicks in every season. The site is known to have a high black shank pressure, and a large proportion of the apparently susceptible plants were subsequently found to be infected with black shank; it is possible that these two cultivars are particularly susceptible to black shank. All other entries, the F_1, KB 101, Oxford 207 and Enshu FC, were as resistant as NC 95, the resistant control. However, the disease pressure was so low at this site that one would not expect to find many significant differences between cultivars; the F_1, KB 101, and Enshu FC were different from neither the susceptible nor the resistant control.

The South African IIC trial was done in a greenhouse, and could not be analysed because of the nature of the data. Enshu AC was the best entry; ADT 108/B40, Oxford 207 and Enshu FC were similar to NC 95. The F_1, KB 101, Xanthi and Kokubu had low levels of resistance.

At the USA NCSU site, the F_1, KB 101 and Enshu AC were similar to Hicks for Disease Incidence and Disease Severity, but only KB 101 was similar to Hicks for the AUDPC. Again, this indicates that under high disease pressure, a low level of resistance is apparent only with a fine measurement such as the AUDPC. Oxford 207, Enshu FC and Xanthi were as good as NC 95 for the AUDPC, but Xanthi was not as good as NC 95 for Disease Incidence and Disease Severity, as its level of resistance was slightly less than the other two cultivars. Several anomalies are apparent at this site. It was the only site where Enshu AC and ADT 108/B40 were not as good as the resistant control. Over the years, ADT 109/B40 has consistently been worse than NC 95 at this site, and in most cases significantly so. This the is first time that Enshu AC has been grown at this site, so we do not yet know if this will be a consistent trend. It was also the only site (apart from the low pressure Zimbabwe site) where Xanthi was as good as the resistant control, and was one of the best entries; with the disease pressure at this site, one would not expect Xanthi to perform well. Xanthi has always performed well at this site; in one previous season, it was as good as the resistant control.

At the USA PD site, KB 101 and Xanthi were similar to the susceptible control. All other entries, the F_1, ADT 108/B40, Oxford 207, Kokubu, Enshu FC and Enshu AC, were as good as or better than the resistant control.

In Zimbabwe, Hicks was badly affected. A high level of infection on the susceptible control usually indicates a high disease pressure, as in China and both the USA sites. A low level of infection on the susceptible control usually indicates low disease pressure, as at the South African LTGA site. However, in Zimbabwe, both Disease Incidence and Disease Severity on the susceptible control were high (100% and 69.2%, respectively), but the level of infection in the rest of the trial was relatively low. This has generally been the pattern over the years, and is possibly connected to the late onset of the disease; cultivars with some resistance are well established before being infected. At this site, all entries were more resistant than Hicks for Disease Severity and AUDPC, but KB 101, with very low resistance, was similar to Hicks for Disease Incidence. ADT 108/B40, Oxford 207, Kokubu, Enshu FC and Enshu AC were as good as the resistant control, NC 95. The F_1 and Xanthi were better than Hicks, but not as good as NC 95.

Cultivars

The susceptible control, Hicks, had almost maximum infection at all sites except South Africa (final Disease Incidence in Brazil, at 16 w.a.p., was 100%; data presented are for 12 w.a.p.). It was the worst cultivar, as would be expected from the susceptible control, at all sites except South Africa, where Kokubu and Xanthi were worse.

The resistant control, NC 95, was among the best entries in South Africa, the USA NCSU site and Zimbabwe; in Brazil, China and the USA PD site, some entries were better.

The F_1 was no different from the mid-parent for almost all variables at all sites, and was different from both the resistant and susceptible parents. This indicates additive resistance and confirms a previous report (Jack, 2000).

Oxford 207 was the best cultivar at most sites, and was as good as or better than the resistant control at all six sites. It was better than the resistant control in Brazil, China and the USA PD site. The general trend over all sites was that Oxford 207 was better than the other highly resistant cultivars, Enshu FC, ADT 108/B40 and Enshu AC, confirming its reported high resistance (Sisson, 1999). The performance of this cultivar shows that it is possible to accumulate higher polygenic resistance than has been done in the past.

Enshu FC has consistently been one of the best entries in this trial, although it has generally not been quite as good as Oxford 207. It was as good as or better than NC 95 at all six sites, and was better than NC 95 in Brazil and China. This is a flue-cured cultivar which bears no resemblance to the original Japanese air-cured Enshu (designated Enshu AC). It was originally entered in the trial under the mistaken assumption that it was the Japanese cultivar, and was assumed to carry the *Rps* gene plus polygenes, but as its pedigree is unknown, we have no way of knowing if this is the case. However, the mistake has been a fruitful one, because Enshu FC has excellent resistance and is a flue-cured type. This cultivar may have great potential for flue-cured breeders. If a marker for the *Rps* gene could be identified, it would be possible to establish whether Enshu FC does indeed carry the *Rps* gene and if so, to stack the *Rps* resistance with the very high polygenic resistance found in Oxford 207, giving a level of resistance higher than any yet produced.

The South African breeding line, ADT 108/B40 was as good as or better than the resistant control at all sites except the USA NCSU site, where it has never performed well. It was better than NC 95 in China, where it has always performed particularly well. Overall, it was one of the best cultivars, although Oxford 207 and Enshu FC were generally better.

Enshu AC was one of the better entries in the trial, confirming its reported high resistance (Matsuda, 1977). However, the general trend was that Oxford 207 and Enshu FC had slightly better resistance than Enshu AC. It was as good as or better than the resistant control at three of the four sites where it was grown; only at the USA NCSU site was it not as good as NC 95. It was one of the best entries in China, where it was better than the resistant control. It has been grown for several years in Zimbabwe, where it has performed extremely well; there was never any infection at all recorded on it. It is clear that the *Rps* gene combined with polygenes gives very good resistance, as has been reported by Matsuda and Ohashi (1973). Enshu AC, although an air-cured type, could be of interest to flue-cured breeders because of the possibility of stacking the monogenic and polygenic resistance.

The Korean burley cultivar, KB 101, was as good as the resistant control only in Brazil (at the penultimate assessment) and in South Africa. In South Africa, the disease pressure was very low, and in Brazil, disease pressure was low at the penultimate assessment; KB 101 was very badly affected by the final assessment. This cultivar has been reported to be resistant (Kim, 1993) and it is likely that while it exhibits good resistance under relatively low infection pressure, it can be severely affected under the high pressure found at some of the sites in this study; it was as bad as the susceptible control at the high pressure sites in China and the USA. This is, of course, a feature of low resistance and has been reported in relation to bacterial wilt (Smith and Clayton, 1948).

Xanthi was generally the worst cultivar. It was no better than Hicks at four of the six sites, and was as good as NC 95 only at the USA NCSU site, where it appears to behave anomalously. Xanthi carries the monogenic *Rxa* resistance (Matsuda, 1977), and is reported to be moderately resistant only (Clayton and Smith, 1942). It is clear that while the *Rxa* resistance gives adequate resistance at low pressure sites, the resistance is overcome under moderate to heavy disease pressure, and is not sufficient for most sites. Although final assessments were as bad as those of Hicks, the low resistance was apparent at the earlier assessments; with the exception of South Africa, where Xanthi was worse than Hicks from an early stage. It is possible that this apparent extreme susceptibility in South Africa is actually due to black shank.

Kokubu has always been the most inconsistent cultivar over sites and years. In previous years, it was often no better than the susceptible control at many sites, but here it was better than Hicks at all sites except South Africa, where it was worse. South Africa was the only site where any entries were worse than Hicks, and again, it is possible that this is actually due to black shank. Kokubu was as good as the resistant control only in Zimbabwe and at the USA PD site. While Kokubu has always performed well in Zimbabwe, because of its low disease pressure; it has only once, over the years, been as good as the resistant control at PD, where the disease pressure was higher. We have no explanation for this inconsistency. The *Rps* resistance has been reported to be only moderate (Matsuda and Ohashi, 1973), and as with the *Rxa* gene, the resistance conferred is generally evident only under low disease pressure. It is usually overcome under high pressure and needs to be combined with polygenes to be effective. However, the *Rps* gene confers a higher level of resistance than the *Rxa* gene; Kokubu has consistently outperformed Xanthi. It is interesting to note that at sites with low disease pressure, such as Zimbabwe, Kokubu has consistently outperformed some of the cultivars with low to moderate polygenic resistance. However, these cultivars are usually better than Kokubu at sites with higher disease pressure.

Disease pressure

When considering disease pressure at the various sites, we have found it best to use the NC 95 data; Hicks is so susceptible that the data preclude differentiation between sites. Also, the Hicks data were not always a true reflection of the disease pressure at a site. In Zimbabwe, both Disease Incidence and Disease Severity on Hicks were high (100% and 69.2%, respectively), but the level of infection in the rest of the trial was relatively low. The graph of Disease Incidence with time for the resistant control, NC 95, is shown in Figure 1. There was considerable variation in the disease pressure at the various sites; in the time of onset and rate of development of the disease, and in the final Disease Incidence.

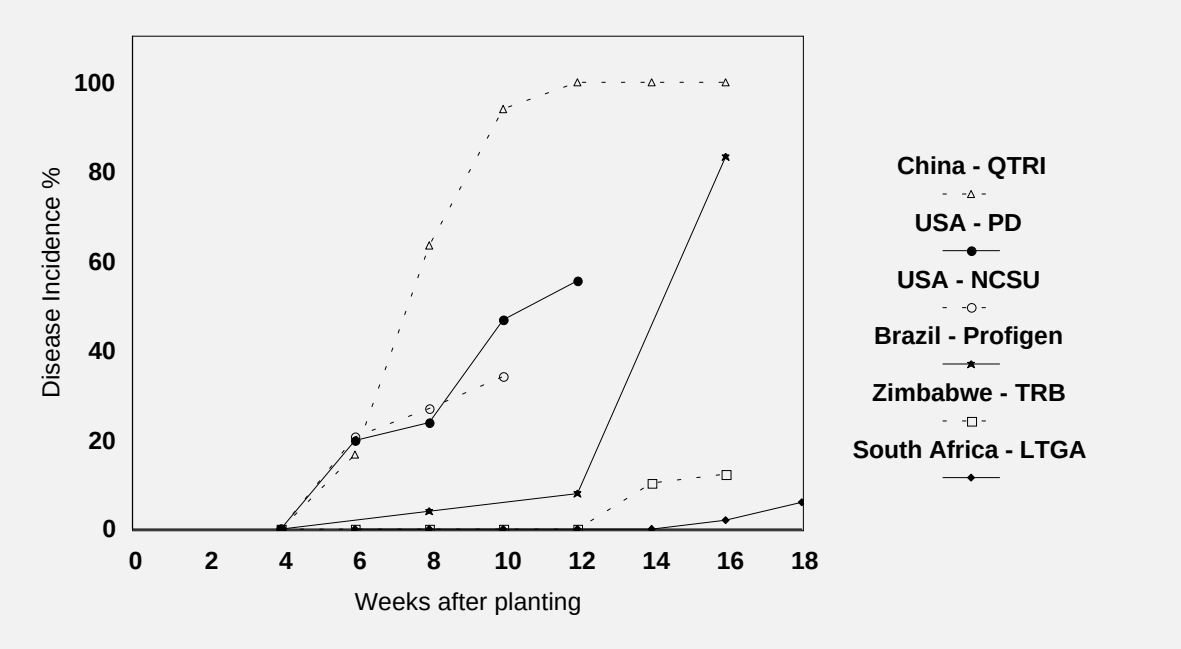

Figure 1: NC 95 - resistant control at all sites in 1999/00 and 2000. Disease Incidence (% infected plants).

The differences between sites are almost certainly a reflection of their different climates, because bacterial wilt development is very dependent on environmental conditions (Kelman. 1953: Robertson, 1998). The pattern was not entirely consistent with previous year.

China, as in all previous years, had extremely high disease pressure. As well as early onset and maximum final Disease Incidence, the curve was very steep, indicating rapid disease development.

The two USA sites had fairly high disease pressure, with early onset and moderately steep curves, although final Disease Incidence was only moderate. This was generally consistent with previous years.

Disease pressure in Brazil was moderate; although onset was early and final Disease Incidence was high, the initial development of symptoms was slow. This site has had high disease pressure in the past.

Disease pressure in both Zimbabwe and South Africa was low, with very late onset, very slow development of symptoms and a low final Disease Incidence. This late onset of infection has been found to be related to the prevailing environmental conditions in Zimbabwe, i.e., a long period of hot dry weather after planting (Robertson, 1997), and probably also applies to South Africa, which has similar climatic conditions. These results are typical of Zimbabwe, which has always had low disease pressure. However, South Africa has always had moderate disease pressure, despite late onset, and has always been worse than Zimbabwe.

CONCLUSIONS

Most results were consistent with previous years. The level of disease pressure at the various sites mostly followed the same pattern as in previous years; very high in China, high in the USA, moderate in Brazil and low in Zimbabwe and South Africa; but disease pressure in Brazil and South Africa was lower than usual. The best entries were Oxford 207, then Enshu FC, then ADT 108/B40 and Enshu AC; the worst entries were Xanthi and KB 101. With a few exceptions, this trend was consistent over sites and years.

At certain sites, there are anomalies which have been consistent over many years. At the USA NCSU site, Xanthi always performs better than at other sites, and ADT 108/B40 is never as good as at other sites. We have no explanation for this anomaly. Oxford 207,

Enshu FC and ADT 108/B40 (and Enshu AC this first year) are always better than the resistant control in China; it is the only site where ADT 108/B40 is better than the resistant control. This is a function of disease pressure; a very high pressure (always found in China) is necessary to distinguish highly resistant cultivars from resistant cultivars. In South Africa, Xanthi and Kokubu are always worse than at the other sites, but it is possible that this is actually due to black shank. Kokubu and Xanthi have consistently performed better at the low pressure Zimbabwe site than at other sites; they are both always better than the susceptible control, and Kokubu is always as good as the resistant control. The moderate resistance of these two cultivars is evident only under low disease pressure (always found in Zimbabwe), and is swamped at the other sites with higher pressure. Most of these anomalies could be explained in terms of disease pressure (Zimbabwe, China) or other diseases (South Africa). However, there was no obvious explanation for the anomalies at the NCSU site; it seems that there is something unique at this site.

No major advance in bacterial wilt resistance breeding has been made since the release of NC 95 almost 40 years ago. No further sources of resistance have been identified and it has not been possible to breed cultivars with immunity. Small increments in the polygenic resistance have been made over the years, culminating in Oxford 207, which has the highest resistance yet produced.

1It is clear that the polygenic T.I.448A resistance is much superior to both monogenic sources of resistance, as previously reported by Clayton and Smith (1942) and Matsuda and Ohashi (1973). This is particularly evident under high disease pressure.

There is possibly scope for combining the *Rps* monogenic resistance with this high polygenic resistance. To do this, it would be necessary to identify molecular markers for the *Rps* gene; selection would otherwise be very difficult. The identification of quantitative trait loci (QTLs) as well would enable marker assisted selection for both sources of resistance. The combination of these two sources might produce a higher level of resistance than has been possible to date. Work also needs to be done to establish whether the flue-cured Enshu does indeed carry the *Rps* gene. Again, this would be possible with the use of molecular markers.

The resistance in burley cultivars has never been as good as that in the best flue-cured cultivars. It will probably be necessary to use flue-cured parents, or to combine the *Rps* resistance with the polygenic resistance, in order to improve resistance in burley cultivars.

ACKNOWLEDGEMENTS

I am greatly indebted to the following people:

All the participants in this collaborative trial, whose co-operation has made this report possible.

Mr B. Smeeton who has given me much guidance and advice.

Messrs A. Ravenscroft and P. Stuart, who have for many years allowed us to use their farm for bacterial wilt trials and have given us much assistance.

Our biometrician, Mr B. Chasekwa, who did all the analysis.

My assistant, Mr D. Shilline, who helped with the field work.

Miss L. McCusker, who helped with the data preparation.

REFERENCES

CLAYTON, E.E. AND SMITH, T.E. 1942. Resistance of tobacco to bacterial wilt (*Bacterium solanacearum*). *Journal of Agricultural Research* **65**: 547 – 554.

JACK, A.M. 1999. The CORESTA collaborative study on bacterial wilt *(Ralstonia solanacearum*) – 1999 report. *CORESTA Information Bulletin* **1999** (4): 45 – 58.

JACK, A.M. 2000. The CORESTA collaborative study on bacterial wilt *(Ralstonia solanacearum*) – 2000 report. *CORESTA Information Bulletin* **2000** (3/4): 37 – 44.

JACK, A.M. AND ROBERTSON, A.E. 1995. Collaborative experiment on Granville wilt, 1995 report. Unpublished report.

JACK, A.M. AND ROBERTSON, A.E. 1996. Collaborative experiment on Granville wilt, 1996 report. *CORESTA Information Bulletin* **1996** (3/4): 40 – 44.

JACK, A.M. AND ROBERTSON, A.E. 1997. The CORESTA collaborative study on bacterial wilt *(Ralstonia solanacearum*) – 1997 report. *CORESTA Information Bulletin* **1997** (3): 59 – 73.

JACK, A.M. AND ROBERTSON, A.E. 1998. The CORESTA collaborative study on bacterial wilt *(Ralstonia solanacearum*) – 1998 report. *CORESTA Information Bulletin* **1998** (3/4): 57 – 65.

KELMAN, A. 1953. The bacterial wilt caused by *Pseudomonas solanacearum*: a literature review and bibliography. *North Carolina Agricultural Experimental Station Technical Bulletin* 99, 194 pp.

KIM, D.S. 1993. A new burley tobacco, KB 101. *CORESTA Information Bulletin,* **1993** (3): 47 [Abstract].

MATSUDA, T. AND OHASHI, Y. 1973. Inheritance of resistance to bacterial wilt in tobacco. *Japanese Journal of Breeding* **23**: 175 – 180. English summary.

MATSUDA, T. 1977. Fundamental studies on the breeding of bacterial wilt resistant varieties in tobacco. *Utsunomiya Tobacco Experimental Station Bulletin* No. 15. 95 pp. English summary.

ROBERTSON, A.E. 1997. Factors affecting the population of *Ralstonia (Pseudomonas) solanacearum* in a naturally infested field planted to Tobacco. In: *Bacterial wilt disease: molecular and ecological aspects*. pp. 369 – 375. P. Prior, C. Allen and J. Elphinstone (Eds.). Springer/INCA, Berlin.

ROBERTSON, A.E. 1998. Characterisation, epidemiology and management of bacterial wilt of tobacco, caused by *Ralstonia solanacearum*, in Zimbabwe. MPhil. Thesis. University of Zimbabwe, 1998.

SISSON, V.A. 1999. Registration of "Oxford 207" tobacco. *Crop Science* **39**: 292

SMITH, T.E. AND CLAYTON, E.E. 1948. Inheritance of resistance to bacterial wilt in tobacco. *Journal of Agricultural Research* **76**: 27 – 32.

STEEL, R.G.D. AND TORRIE, J.H. 1981. *Principles and procedures of statistics: a biometrical approach*. McGraw-Hill, Singapore. pp. 173 – 177.

APPENDIX - PARTICIPANTS

Brazil, Dimon

Mr B Hoppe
Mr I Mallman

DIMON do Brasil Tabacos Ltda
BR 471 Km 48
Cep: 96835-640, Santa Cruz do Sul, RS Brazil

tel: + 55 513 718.7200
fax: + 55 513 718.7249
e-mail: bhoppe@dimon.com.br
imallmann@dimon.com.br

Brazil, Profigen

Mr E Weiss

ProfiGen do Brasil Ltda
P O Box 034
Santa Cruz do Sul, 96.800-970, RS - Brazil

tel: + 55 513 715.3309
fax: + 55 513 713.3866
e-mail: “Ernani Weiss”<profigen@viavale.com.br>

Bulgaria, TTPI

Mr H Bozukov

Tobacco & Tobacco Products Institute
4108 Plovdiv, Bulgaria

tel: + 359 32 672.364
fax: + 359 32 775.156

China, QTRI

Prof Z Xianchao

Qingzhou Tobacco Research Institute
11 Xiangshan Road
Qingzhou, Shandong, 262500, China

tel: + 86 536 328.0967
fax: + 86 536 328.0667
e-mail: "bh"<phyto@public.wfptt.sd.cn>

Iran, Tirtash

R A Mahtabi

Tobacco Research Institute of Tirtash
P O Box 48515 - 155
Behshahr, Iran

tel: + 98 1572 210.56
fax: + 98 1572 210.55

South Africa, LTGA

Mr A Scholtz

Lowveld Tobacco Growers Association
P O Box 60
Nelspruit
Mpumalanga 1200, South Africa

tel: + 27 13 752.8411
fax: + 27 13 752.2186
e-mail: AntonS@lk.co.za

South Africa, IIC
Mrs J Terblanche

Institute for Industrial Crops
P O Box 82075
Rustenburg 0300, South Africa

tel: + 27 14 536.3150
fax: + 27 14 536.3113
e-mail: jody@nitk1.agric.za

USA, PD
Prof B Fortnum

Pee Dee Centre
2200 Pocket Road
Florence SC, 29506 9706, USA

tel: + 1 803 662.3526 ext 235
fax: + 1 803 661.5676
e-mail: bfrtnm@clemson.edu

USA, NCSU
Dr V Sisson

Oxford Tobacco Research Station
P O Box 1555
Oxford, NC 27565, USA

tel: + 1 919 693.5151
fax: + 1 919 693.3870
e-mail: verne_sisson@ncsu.edu

Zimbabwe, TRB
Mrs A Jack

Tobacco Research Board
P O Box 1909
Harare
Zimbabwe

tel: + 263 4 575.289 / 575.536
fax: + 263 4 575.288
e-mail: anne_jack@kutsaga.co.zw