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Decomposition of cotton strips in soil: analysis of the world data set

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1 *Summary*

This paper reports the results from the statistical analyses performed on the cotton strip data set, obtained during the Symposium workshop on the use of cotton strip assay in decomposition studies. The data set, derived from various workers, contained information from 329 replicated cotton strip insertions. The data were examined using multiple regression, in an attempt to determine the factors which appeared to control the rate of decomposition of cotton strips in soil in a world-wide comparison.

Analysis of the large data set highlighted the problems associated with the limited geographical distribution of strip placement. Analysis of a subset of sites for which an increased number of variables were available revealed the importance of climatic factors in determining cotton strip decay rate. In particular, potential evaporation derived from literature values related very closely to decomposition rate.

2 *Introduction*

Many attempts have been made by soil ecologists to utilize standard substrates in organic matter decomposition studies, with the expectation that such substrates would enable inter-site comparisons of decomposition to be made, by removing the confounding effect of substrate quality (Swift *et al.* 1979). Substrates have ranged from shoe-laces (Rosswall 1974) through to matchsticks (Abrahamsen *et al.* 1975), with cellulose being the most widely used.

The cotton strip assay has been applied in a wide variety of situations around the world, both to compare effects of various treatments on rates of decomposition at a single site (eg Howson 1988) or at different sites (Heal *et al.* 1974). The inter-site study of Heal *et al.* (1974) compared tensile strength loss of cotton strips (CTSL) at a number of sites in the tundra biome and, although cotton strips have since been used more widely, that remains the only global survey of rates of decomposition using cotton strips.

Global comparisons and models of decomposition processes have been attempted by few workers (Esser *et al.* 1982; Berg *et al.* 1984), and such studies have been aggravated by the paucity of data for comparable substrates at sufficiently widespread locations. Therefore, the current Symposium was seen as an opportunity to collate the existing cotton strip data in order to determine those environmental factors controlling decomposition of this material at the global scale.

During the course of the Symposium, 2 workshop sessions were held in which interactive analyses of the available data were attempted. Suggestions were made by participants as to which analyses should be performed and, from these sessions, there arose several conclusions and suggestions for further work. The current paper is principally a report of the outcome of these workshop sessions and of subsequent re-analysis of the world-wide data set after additional information and amendments had been provided by the relevant authors.

3 *Methods*

3.1 Original data set

Delegates to the Symposium were asked, prior to the meeting, to provide data on the tensile strength loss following insertion of cotton strips into soils. The variables requested, together with the units of measurement, are outlined in Table 1. The data were collated into a standard tabular form, and then coded in a manner suitable for analysis using the GENSTAT statistical computer package (Alvey *et al.* 1983). All computations were carried out on a Honeywell 66/DPS-300, in batch mode.

A total of 329 cases was included in the full data set, with each case representing the mean value of replicated strips for the same site and treatment. The calculation of the standard cotton rotting rate (CRR), as described by Hill *et al.* (1985), was performed for each case to permit comparison of results, expressed on a yearly basis. Data sets outside the recommended limits of 10–90% tensile strength loss were rejected.

The mean, minimum and maximum values for each of the variables requested from the contributors (Table 2) revealed that several important variables were missing from the data set, either because they had not been measured, or because authors had failed to provide them. Unfortunately, no data were provided for assay period air temperature, soil temperature or soil moisture content for any of the cases, and the majority of contributors were unable to supply data for many aspects of soil chemistry.

3.2 Augmented data set

After the Symposium, the data sets were checked by authors and some further information was provided. It was also decided that estimates for certain variables could be obtained from published sources in order to explain the variance observed in CRR rates for as wide a range of sites as possible, in terms of climatic factors.

Table 1. The variables requested for the full data set

Mnemonic	Variable	Units
Details of strip placement		
DEPTH	Depth in soil	cm
TS	Mean tensile strength	kg
SE	Standard error of the mean of tensile strength	
FC	Field control tensile strength	kg
CLOC	Cloth control	
N	Number of samples	
WIDTH	Frayed width of tested substrip	cm
DAYS	Number of days in the field	
DAYNO	Standard day number when samples were placed	
YEAR	Year	
CLOTH	Cloth batch (colour code)	*
STRIP	Code number for strip	
NAME	Name of worker	*
Site characteristics		
SITE	Name of site	*
PLOT	Name of plot	*
SUBPLOT	Name of subplot	*
COUNTRY	Country	*
LAT	Latitude	
LONG	Longitude	
HABIT	Habitat type	*
VEG	Vegetation type	*
MAN	Form of management	*
ALT	Altitude	m
Climatic variables		
CLIM	Climatic zone	*
TEMP	Mean annual temperature	°C
RAIN	Total annual rainfall	mm
SOILT	Mean annual soil temperature	°C
SOILM	Mean soil moisture	% moist weight
PTEMP	Period mean temperature during strip insertion	°C
PRAIN	Period rainfall	mm d^{-1}
PSOILT	Period soil temperature	°C
PSOILM	Period soil moisture	% moist weight
Soil characteristics		
STYPE	Soil type	*
LOI	Loss on ignition	%
TOTN	Total soil nitrogen	%
EXTN	Extractable soil nitrogen	µg g^{-1}
TOTP	Total soil phosphorus	µg g^{-1}
EXTP	Extractable soil phosphorus	µg g^{-1}
CA	Total soil calcium	µg g^{-1}
EXTK	Extractable soil potassium	µg g^{-1}
PH	Soil pH	

* denotes an alphanumeric string

Table 2. Mean, minimum and maximum values for numerical data in the full data set. The mnemonics used to describe the variables are outlined in Table 1

Variable	Mean	Minimum	Maximum	Number of missing values
Details of strip placement				
DEPTH	8.65	1.50	18.00	0
TS	20.65	3.10	52.00	0
SE	1.94	0.13	5.54	0
FC	36.23	12.00	56.00	0
CLOC	*	*	*	329
N	10.72	4.00	20.00	0
WIDTH	4.02	3.00	5.00	0
DAYS	191.83	14.00	383.00	0
DAYNO	205.70	8.00	341.00	0
YEAR	1975.44	1968.00	1984.00	0
Site characteristics				
LAT	37.56	−65.25	71.28	0
LONG	−6.8	−113.00	156.68	0
ALT	396.09	5.00	1320.00	0
Climatic variables				
TEMP	5.54	−12.50	27.50	38
RAIN	979.91	108.00	2011.00	38
SOILT	34.32	23.00	48.00	190
SOILM	64.70	12.00	99.00	142
PTEMP	*	*	*	329
PRAIN	102.54	92.00	112.00	236
PSOILT	*	*	*	329
PSOILM	*	*	*	329
Soil characteristics				
LOI	57.97	1.00	98.50	37
TOTN	1.56	0.10	3.10	96
EXTN	431.50	2.00	1000.00	285
TOTP	530.59	1.00	1500.00	243
EXTP	66.21	4.00	220.00	69
CA	1561.04	68.00	7906.00	51
EXTK	344.66	1.40	1040.00	51
PH	4.49	3.00	9.20	95

*denotes missing values

Values of mean daily temperature, precipitation and potential evaporation calculated for the period of strip insertion were derived from the climatic compilation of Müller (1982), using data for the nearest climatic station at comparable altitude. Where possible, actual climatic data provided by the individual workers were used in preference to those derived from Müller (1982), and there was generally good agreement between these values where both were available.

The augmented data set was restricted to data for decomposition rates of strips in the top 2 cm of the soil, and to strips not receiving any additional form of treatment. Duplicate site cases were only used if they represented results from insertions during different periods of the year, and this resulted in the selection of 48 cases, representing all of the sites identified in Figure 1.

4 *Results of analyses*

4.1 Original data set

The analyses of the basic data set are described in 3 sections: (i) a brief discussion of the choice of parameters used to describe the rate of cotton strip rotting; (ii) a brief description of some sample analyses performed during the workshop; and (iii) a more comprehensive investigation of the data set undertaken after the workshop, with the benefit of experience of the analyses done during the workshop. As a result of this latter analysis, several difficulties in analysing

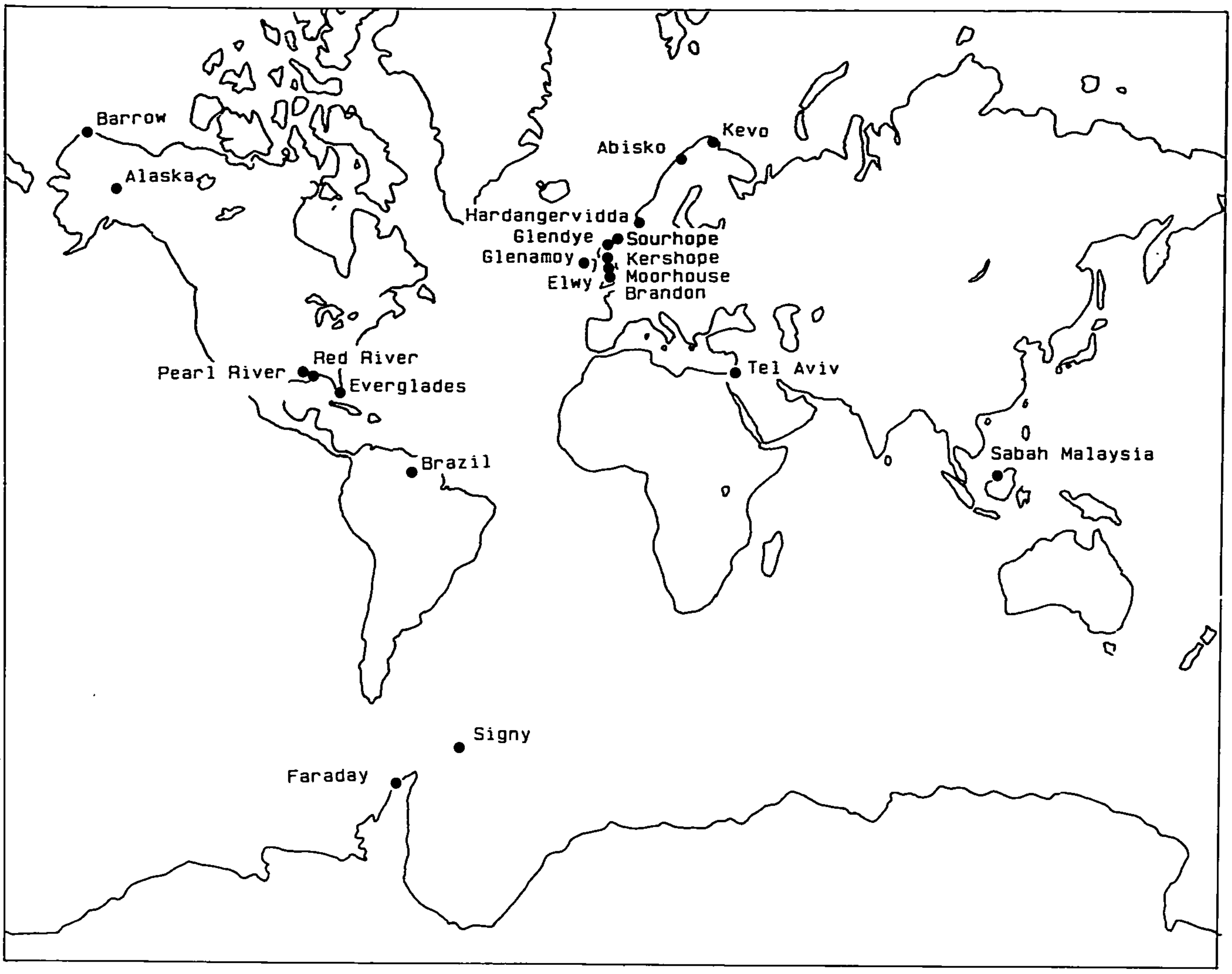

Figure 1. Sites where the cotton strip assay for decomposition rate has been used (●)

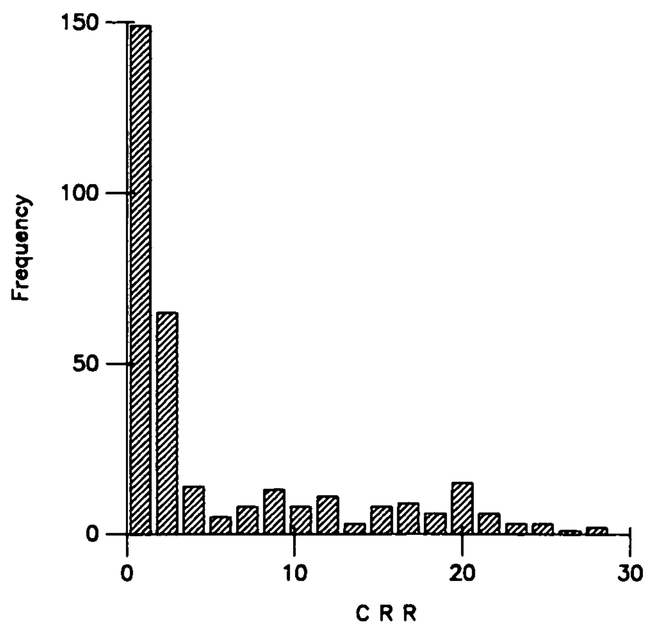

Figure 2. Frequency distributions of CRR values used in the original data set

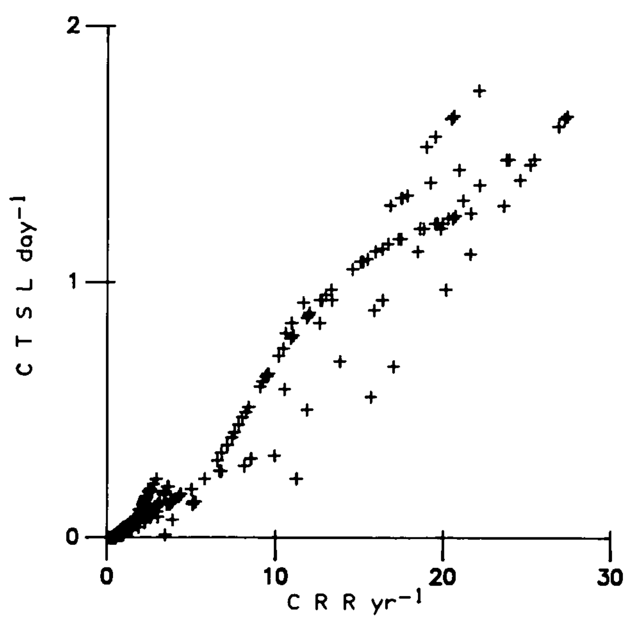

Figure 3. Relationship between CRR and tensile strength loss (CTSL) day^{-1} for the original data set

the original data set were revealed. The shortness of the section describing analyses requested by delegates during the workshop is largely due to our subsequent realization that the data set was often incompatible with the analyses which had been requested.

4.1.1 *Measurement of cotton strip decomposition*

The work of Hill *et al.* (1985, 1988) has established a 'cotton rotting rate' parameter (CRR), which was specifically designed to be less affected by the known technical difficulties of the procedure. In general, this parameter was used as the dependent variable, describing cotton rotting rates, throughout the analyses. A histogram of its distribution is given in Figure 2, and can be seen to be highly skewed, most values being of small magnitude from 0 to 5 (due to the predominance of cold sites), but with a very long tail to the right. During the workshop, one of the delegates requested the calculation of an earlier measure of cotton rotting rate, CTSL day^{-1}, and, having calculated this measure, we decided, for interest's sake, to see how closely it was related to the CRR parameter of Hill *et al.* (1985). The scatter diagram shown in Figure 3 reveals a surprisingly tight relationship. Indeed, the linear correlation between the 2 variables explains 96% of their variation, but the scatter plot reveals a sigmoid 'backbone' arising from the transformation equation applied by Hill *et al.* (1985), and suggests that the linearization of the decay curve is not fully achieved.

Table 3. CRR as a function of temperature, longitude, absolute latitude and the number of days of strip insertion

Regression coefficients: Y-variate = CRR

	Estimate	SE	t
Constant	30.82	3.39	9.1
TEMP	–0.49	0.13	–3.8
DAYS	–0.03	0.00	–9.3
ALAT	–0.31	0.04	–7.2
LONG	–0.02	0.01	–2.3

Analysis of variance

	Degrees of freedom	Sum of squares	Mean square
Regression	4	11299	2824.68
Residual	323	4972	15.39
Total	327	16271	49.76

Variation accounted for 69.1%

Correlation matrix: df = 326

	CRR	CTSL day^{-1}	TEMP	LONG	ALAT	DAYS
CRR	1.00					
CTSL day^{-1}	0.98	1.00				
TEMP	0.78	0.74	1.00			
LONG	–0.61	–0.57	–0.83	1.00		
ALAT	–0.75	–0.71	–0.94	0.80	1.00	
DAYS	–0.74	–0.71	–0.80	0.51	0.62	1.00

It is somewhat surprising that the less robust conventional measure, CTSL day^{-1}, is so highly correlated with the CRR measure that the 2 could almost be regarded as equivalent. In practice, given that the quality of the cloth is carefully controlled to give a standard tensile strength, and that all investigators endeavour to remove their cloth at a time when it is expected to be around 50% rotted, the correlation is perhaps rather less surprising with hindsight. It does, however, indicate that the procedural difficulties may, in practice, be rather less than were feared. In view of the fact that the CRR measure of Hill *et al.* (1985) is biologically sound and mathematically robust, we have preferred this measure in our subsequent analyses. However, for the benefit of investigators who have used the other method, or those who wish to compare previous results with the values of CRR given in this paper, the regression equation predicting CRR from CTSL day^{-1} was found to be:

$$CRR = 0.8433 + 14.5620 \times CTSL\ day^{-1}$$

4.1.2 *Examples of analyses requested during the workshop*

Several requests were made to investigate the relationship between CRR and fundamental environmental parameters, such as temperature and latitude. The example given below analyses CRR as a function of temperature, longitude, absolute latitude and the number of days the strips were in the soil. These 4 variables were derived from a step-wise regression. Absolute latitude (ALAT) is the latitude expressed as a positive number, representing degrees from the equator, regardless of whether in the northern or southern hemisphere. The analysis is given in Table 3, from which it can be seen that all 4 predictor variables are significantly related, and that the analysis is based on almost the entire data set (327 out of 329).

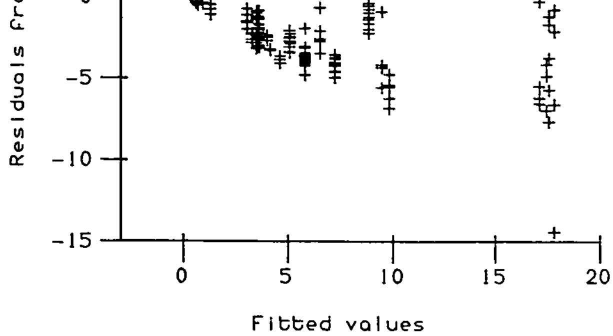

Figure 4. Scatter plot of residuals as a function of fitted values for the regression outlined in Table 3

While the relationship with temperature and latitude, which also has a temperature component, would be expected, the significant effect of the parameter for days is interesting, as the CRR variable would be expected to have removed the time component. Again, this relates to the way in which investigators endeavour to attain 50% CTSL, and reflects their *a priori* judgement of the time required to reach this rate. If we examine the scatter plot of the residuals against the fitted values, given in Figure 4, we see that the assumptions of the regression analysis have not been properly met: there is a broad trend for the residuals to decrease with the magnitude of the fitted values, while 2 (or more) data sets from particular regions give broad scatters of residuals for very similar magnitudes of the fitted values (these appear as vertical scatters of points at the centre and at the right of the diagram of Figure 4). We should further note, when examining the correlation matrix, that the regressor variables are themselves highly interdependent, a fact which makes the use of 'step-up' or 'step-down' procedures of multiple regression highly dubious to identify the better predictor variables. The reason is that multiple regression makes a largely arbitrary choice as to which of a set of highly interdependent variables to include, depending on minor and insignificant differences in the structure of the correlation matrix.

A second analysis was requested, directed more biologically at understanding the process of cotton decomposition, and this analysis examined the relationship between the $\log_e$ CRR and temperature, subsequently adding the $\log_e$ carbon/nitrogen ratio (LGCN) and pH. The scatter diagram of $\log_e$ CRR on temperature is given in Figure 5, from which a broad relationship is evident, explaining 40% of the variation (Table 4). In the full model (CRR = f(temperature, LGCN, pH)), the effect of pH was not significant, but the effects of both temperature and LGCN were as indicated in Table 5, and together explained 43% of the variance in CRR.

4.1.3 *Examination of the original data set*

Straightforward interpretation of multiple regression analyses requires the regressor, or predictor, variables to be uncorrelated and the data set to have multivariate normal distribution. We have already indicated above that many of the variables in the present data set are inter-correlated, which makes interpretation difficult. Furthermore, many of the biologically more interesting variables were not available from many locations represented by this data set. Accordingly, analyses which include the more interesting parameters are perforce restricted to a subset of the data which will often not be representative. We illustrate this difficulty by presenting 2 correlation matrices as Table 6. The full data set comprises 329 sites and, if we confine our interest to 7 basic variables, we are able to utilize information from 236 of these; adding 4 commonly recorded, but not especially interesting, biological variables only reduces the number of sites to 231, but

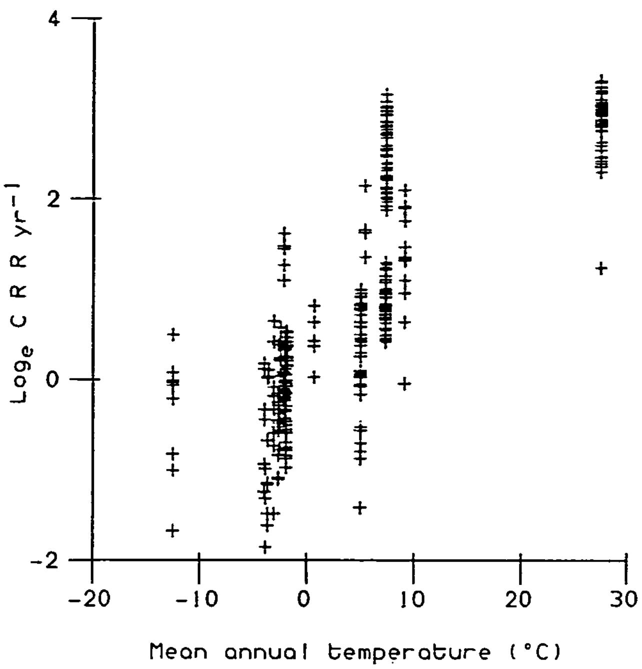

Figure 5. Scatter plot of $\log_e$ CRR against mean annual temperature for the original data set

Table 4. Relationship between $\log_e$ CRR and mean annual temperature

Regression coefficients: Y-variate = $\log_e$ CRR

	Estimate	SE	t
Constant	0.08	0.04	2.1
TEMP	0.09	0.01	12.4

Analysis of variance

	Degrees of freedom	Sum of squares	Mean square
Regression	1	59.60	59.60
Residual	233	89.81	0.38
Total	234	149.41	0.64

Variation accounted for 39.6%

Table 5. Relationship between $\log_e$ CRR, mean annual temperature and LGCN

Regression coefficients: Y-variate = $\log_e$ CRR

	Estimate	SE	t
Constant	1.37	0.33	4.1
TEMP	0.10	0.01	13.1
LGCN	−0.40	0.10	−3.9

Analysis of variance

	Degrees of freedom	Sum of squares	Mean square
Regression	2	65.11	32.55
Residual	232	84.30	0.36
Total	234	149.41	0.64

Variation accounted for 43.1%

Table 6. Correlation matrices demonstrating the effect of sample size reduction on correlation coefficients

	ALAT	LONG	ALT	TEMP	RAIN	LOI	TOTN	EXTP	CA	EXTK	PH	SOILT	SOILM	EXTN	TOTP
Data sets = 231															
ALAT	1.00														
LONG	0.20	1.00													
ALT	−0.23	−0.41	1.00												
TEMP	−0.79	−0.48	−0.06	1.00											
RAIN	−0.81	−0.32	0.27	0.77	1.00										
LOI	−0.19	−0.02	−0.11	0.29	0.32	1.00									
TOTN	−0.09	−0.02	0.11	0.12	0.12	0.56	1.00								
EXTP	0.31	0.19	−0.20	−0.36	−0.45	−0.12	−0.07	1.00							
CA	0.08	−0.18	0.48	−0.25	−0.04	0.32	0.51	−0.07	1.00						
EXTK	−0.00	−0.02	0.20	−0.16	−0.06	0.19	0.05	0.66	0.17	1.00					
PH	0.16	0.31	−0.068	−0.40	−0.51	−0.49	−0.08	0.26	0.19	−0.03	1.00				
Data sets = 20															
ALAT	1.00														
LONG	1.00	1.00													
ALT	−0.32	−0.32	1.00												
TEMP	0.99	0.99	−0.38	1.00											
RAIN	−1.00	−1.00	0.32	−0.99	1.00										
LOI	−0.23	−0.23	−0.50	−0.12	0.23	1.00									
TOTN	0.18	0.18	−0.99	0.24	−0.18	−0.48	1.00								
EXTP	0.29	0.29	0.22	0.25	−0.29	0.17	−0.28	1.00							
CA	−0.04	−0.04	−0.72	0.03	0.04	−0.34	0.76	−0.72	1.00						
EXTK	0.24	0.24	0.09	0.23	−0.24	0.31	−0.13	0.87	−0.58	1.00					
PH	−0.17	−0.17	−0.87	−0.09	0.17	−0.31	0.93	−0.39	0.78	−0.21	1.00				
SOILT	−0.84	−0.84	−0.24	−0.80	0.84	−0.04	0.38	−0.42	0.45	−0.30	0.67	1.00			
SOILM	0.26	0.26	−0.99	0.30	−0.26	−0.60	0.98	−0.22	0.71	−0.11	0.87	0.30	1.00		
EXTN	0.65	0.65	−0.06	0.63	−0.65	−0.20	−0.03	0.21	−0.20	0.01	−0.27	−0.63	0.03	1.00	
TOTP	−1.00	−1.00	0.32	−0.99	1.00	0.23	−0.17	−0.29	0.04	−0.24	−0.18	0.84	−0.25	−0.65	1.00

adding a further 4 variables which are biologically important (period soil temperature, period soil moisture, extractable nitrogen, and total phosphorus) dramatically reduces the available data to only 20 sites. By referring to the correlation matrices given in Table 6, we can see that it would be difficult to interpret multiple regression analyses due to inter-correlations between the predictor variables. However, if we investigate pairs of predictor variables in more detail, a further difficulty becomes apparent.

In Figure 6 i, we plot absolute latitude against temperature, and most of the values appear in the top left of the Figure, with an indication that temperature decreases with latitude, as would be expected; however, the form of this relationship, whether it is assumed to be linear or not, will be highly affected by a set of 9 values at low latitude, with corresponding high temperature, appearing as a single cluster of points in the bottom right of the Figure. Even more dramatic discrepancies can be seen in Figures 6 ii and 6 iii, which plot absolute latitude against, respectively, altitude and loss-on-ignition. Both these Figures reveal a broad scatter of points, largely uncorrelated, at high latitudes, an absence of information at intermediate latitudes, and a confined spread of points at low latitudes; such distributions are far from a bivariate-normal distribution, and, in the cases of Figures 6 i and 6 iii, could give rise to apparent correlations between the 2 variables, which are largely dependent on the absence of intermediate values.

Similar discontinuous distributions can be seen for the biological parameters, as illustrated in Figures 7 i and 7 ii, which plot loss-on-ignition against, respectively, pH and total phosphorus. There is thus a dual problem with the data set: first, some of the biologically more interesting parameters are only recorded for a minority of sites, which may well not be representative (the percentage of variation of CRR explained for the subset cannot be expected to be the same for the whole data set); second, within the minority of sites for which some parameters are recorded, it appears that there are frequently sites which are atypical of the others; indeed, they may have been specifically selected as representing extreme, but interesting, circumstances; thus, any predictor variable for which these sites also have unusual values (as illustrated in Figures 6 & 7) could statistically act simply to distinguish these sites from the others (as binary variables would do), rather than indicating a true functional relationship between the parameter and CRR.

In Figure 8, we confirm that this possibility is a real risk with the present data set by showing scatter diagrams of CRR against 2 physical parameters, absolute latitude and temperature, and 2 chemical parameters, loss-on-ignition and pH. Examination of other scatter plots not shown in this paper shows that most of the regressor variables have very odd distributions with CRR, and that problems of outlying values are frequent. Indeed, the distributions of bivariate plots, and the frequency and magnitude of outlying sets are

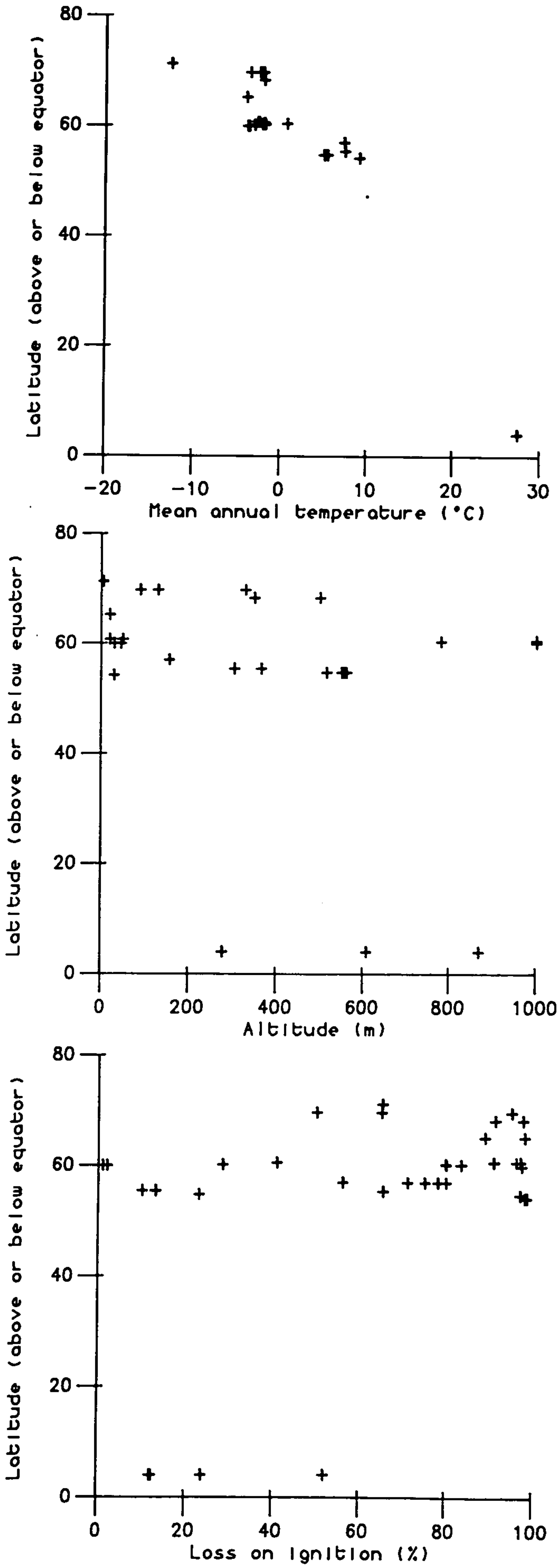

Figure 6. Scatter plots showing the relationship between absolute latitude and mean annual temperature, altitude, and loss-on-ignition

such that it is not possible to suggest useful non-linear transforms.

Unfortunately, the only feasible solution to these difficulties is to obtain more data to fill the gaps. If all the sites which were extreme in any parameter are omitted, the resulting data set is very small and almost certainly unrepresentative. Had the data set represented a more comprehensive series of sites (effectively filling in the gaps between the majority of sites and some of the extreme ones), a multivariate technique, such as principal component analysis, used on the predictor variables might perhaps have overcome statistical difficulties. However, principal component analysis does itself require a full data set in order to ordinate any one set, and would also be prone to giving undue weight to extreme values in any variable. Thus, in the analyses described below, we have felt obliged to confine our remarks to the broader trend exhibited by the fundamental physico-chemical parameters which are recorded for the great majority of data sets. Even so, our conclusions have to be modified in the light of which data sets were actually included in which analyses.

4.1.4 *Relationships with basic physico-chemical parameters*

During the workshop, a regression analysis on a large proportion of the data set indicated that 3 parameters, absolute latitude, temperature, and cotton strip depth, explained about 70% of the variance of CRR. During subsequent analyses, we noticed that this same equation explained 60% of the variation with a data set of 326, but only 34% with a data set reduced to 228 by the inclusion of additional interesting biological parameters. It appears, from a number of analyses, that temperature and absolute latitude are almost synonymous with regard to this data set, their intercorrelation explaining 60% of their variance. For several different, but large, subsets of data, absolute latitude and temperature are both highly significant predictors, but the accuracy of the prediction is not greatly affected by which is used, as might be expected given their high inter-correlation. For example, on a data set of 230, the relationship with the best 9 parameters (absolute latitude, temperature, rainfall, loss-on-ignition, total nitrogen, extractable phosphorus, calcium, total potassium and pH) is found to include temperature, rainfall and total nitrogen as having significant effects. However, the effects of rainfall and total nitrogen are only just significant ($P<0.05$, as opposed to the very highly significant effect of temperature, $P<0.001$), and the overall equation only explains 2% more variation than the correlation with temperature alone (which explains 35% variance).

A different, and somewhat larger, data set, with 325 degrees of freedom and using absolute latitude, temperature, rainfall and loss-on-ignition as predictor variables, ascribes highly significant effects to temperature, loss-on-ignition and rainfall, but not absolute

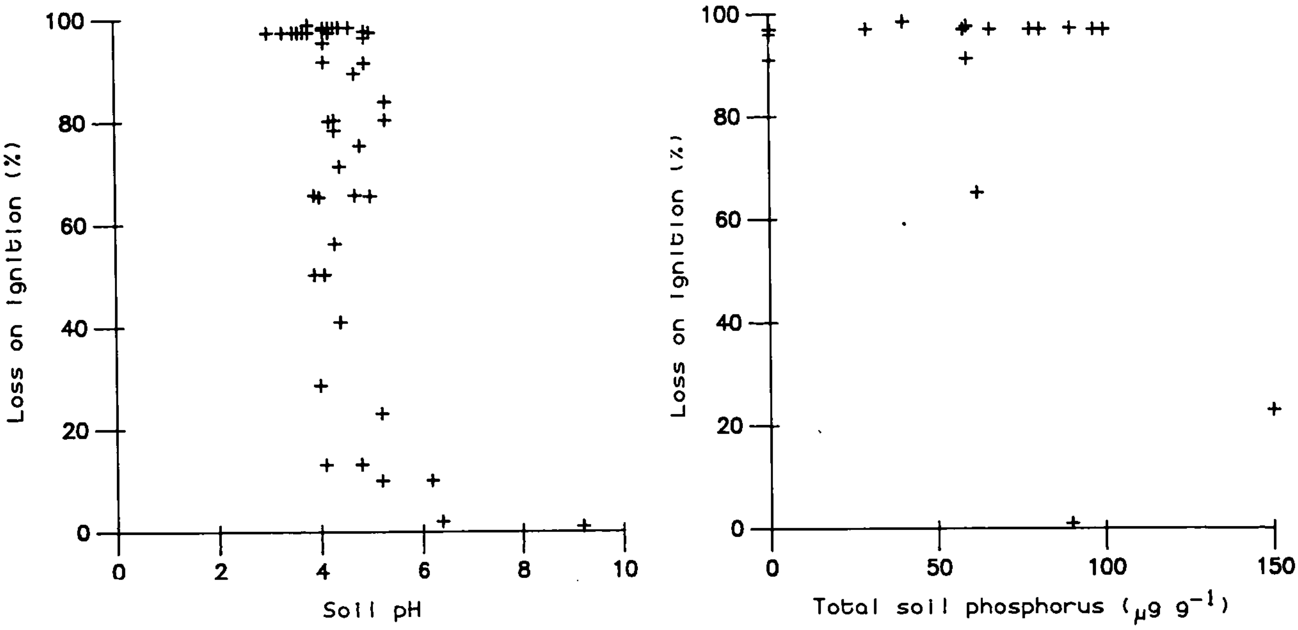

Figure 7. Scatter plots showing the relationship between loss-on-ignition with pH and total phosphorus

Table 7. Correlation matrix derived when attempting to provide a predictive equation for CRR, using 328 cases

	CRR	DEPTH	ALAT	TEMP	RAIN	LOI
CRR	1.00					
DEPTH	–0.20	1.00				
ALAT	–0.75	0.10	1.00			
TEMP	0.78	–0.14	–0.94	–1.00		
RAIN	0.48	–0.09	–0.72	0.79	1.00	
LOI	–0.65	0.07	0.50	–0.46	–0.19	1.00

Table 8. The analysis of variance table for the regression analysis shown in Table 7

Regression coefficients, Y-variate = CRR

	Estimate	SE	t
Constant	10.54	0.72	14.7
TEMP	0.55	0.04	14.2
LOI	–0.07	0.01	-9.5
RAIN	–0.00	0.00	–4.1
DEPTH	–0.11	0.04	-2.8

Analysis of variance

	Degrees of freedom	Sum of Squares	Mean Square
Regression	4	11939	2984.82
Residual	323	4332	13.41
Total	327	16271	49.76

Variation accounted for 73.0%

Table 9. Correlation matrix derived when attempting to provide a predictive equation for CRR, using 235 cases

	CRR	DEPTH	ALAT	TEMP	RAIN	LOI	TOTN
CRR	1.00						
DEPTH	–0.30	1.00					
ALAT	–0.43	0.11	1.00				
TEMP	0.57	–0.19	–0.79	1.00			
RAIN	0.42	–0.06	–0.82	0.77	1.00		
LOI	–0.01	0.01	–0.13	0.23	0.20	1.00	
TOTN	0.07	–0.05	–0.06	0.09	0.06	0.57	1.00

Table 10. The analysis of variance table for the regression analysis shown in Table 9

Regression coefficients, Y-variate = CRR

	Estimate	SE	t
Constant	2.42	0.26	9.4
TEMP	0.14	0.01	10.3
DEPTH	–0.05	0.01	-3.7
LOI	–0.01	0.00	-2.2

Analysis of variance

	Degrees of freedom	Sum of squares	Mean square
Regression	3	160.2	53.40
Residual	231	262.8	1.14
Total	234	423.0	1.81

Variation accounted for 37.1%

latitude, and explains 72% of the variation. Again, temperature explains a considerable proportion (60%) of the variation on its own. It is interesting to note that the larger data set (328 as opposed to 230) has nearly twice as much variance explained by the total model and by temperature alone (72% and 37% for the full model and 60% and 36% for temperature alone, respectively). Temperature appears to be the most important of the physico-chemical parameters recorded, with loss-on-ignition and rainfall also having significant predictive effects, but the importance varying considerably with the sets of data that are included in a particular analysis.

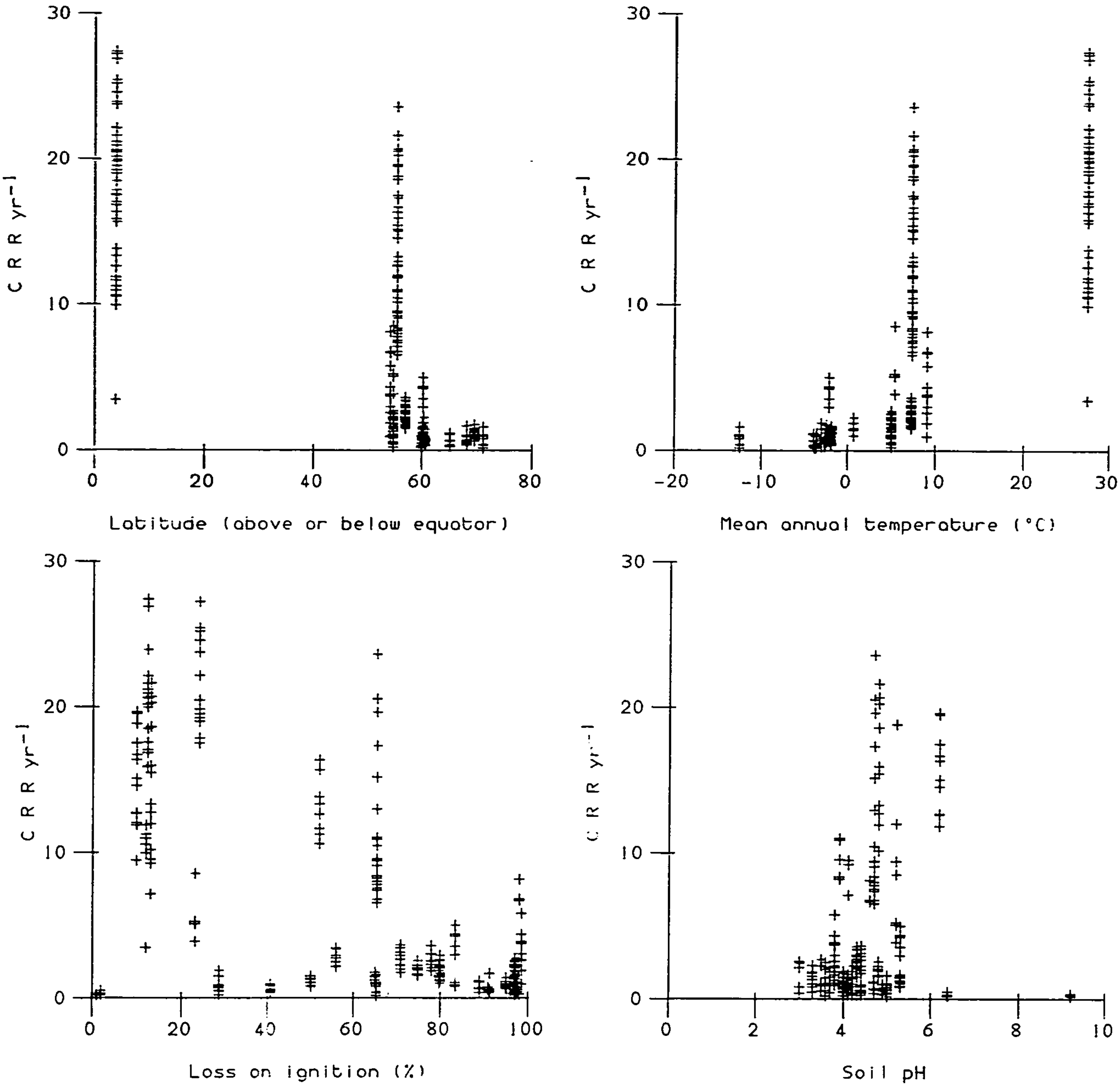

Figure 8. Scatter plots showing the relationship between CRR and absolute latitude, mean annual temperature, loss-on-ignition, and pH

In a final analysis, we attempted to find a good predictive equation for CRR based on variables which were recorded for 328 out of 329 of the data sets. CRR was predicted from depth of insertion, absolute latitude, temperature, rainfall, and loss-on-ignition. The first analysis included all 328 data sets; the correlation matrix is given in Table 7 and the analysis of variance for the regression analysis in Table 8. The 4 variables, temperature, loss-on-ignition, rainfall and depth, are shown to have significant effects, with slopes as given in Table 8. However, when the data set was reduced to two-thirds of this size, 235 data sets, and the analysis repeated, a somewhat different situation emerged. The correlation matrix is given in Table 9, and the analysis of variance for the final regression model in Table 10. The effect of rainfall is no longer significant, but the effects of temperature, depth and loss-on-ignition still are significant. However, it should be noted that the parameter estimates are sensitive to the data sets used, although the coefficients for the effects of loss-on-ignition are not dissimilar between the 2 analyses (328 versus 235 sets). The parameter estimates for the effects of temperature and depth of insertion vary considerably, and significantly, between the 2 analyses.

We concluded, with regret, that the data set here analysed, although extensive, is not sufficiently comprehensive (lacking values for many important biological parameters for many of the sites investigated) to permit firm conclusions to be reliably drawn (over and above the broad trends evident from Tables 8 & 10). Accordingly, we have attempted to estimate some of the missing data using a compendium of meteorological data, which allows us to estimate, albeit somewhat imprecisely, some of the missing values on the basis

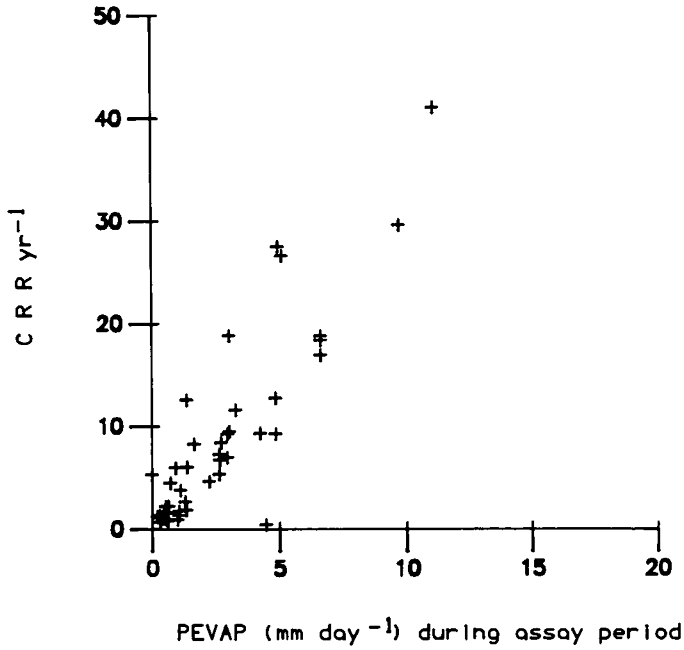

Figure 9. Scatter plot showing the relationship between CRR and period potential evaporation (PEVAP), using the augmented data set

of their geographic locations. This analysis is described below.

4.2 *Augmented data set*

Analysis of the original data set had highlighted the over-riding importance of climatic factors in determining the rate of decomposition of cotton strips. In the analyses of the extended data set, soil chemical variables were not included, and period temperatures, rainfall and potential evaporation (PEVAP) were derived from published tables.

Table 11 shows the correlation matrix between the variables used in the multiple regression analysis, in which CRR was the dependent variable. From this matrix, the importance of PEVAP in explaining decomposition rate is apparent, and this importance is reinforced in Table 12, which shows the analysis of variance table and regression coefficients resulting from the step-wise multiple regression. Period potential evaporation explained 77% of the variance, yielding the equation:

$$CRR = 0.20 + 3.13 \text{ (PEVAP)}$$

Table 12. The analysis of variance table for the regression analysis of the extended data set

Regression coefficients, Y-variate = CRR

	Estimate	SE	T
Constant	0.20	0.92	0.2
PEVAP	3.13	0.26	12.2

Analysis of variance

	Degrees of freedom	Sum of Squares	Mean square
Regression	1	2796.0	2796.04
Residual	43	811.6	18.87
Total	44	3607.7	81.99

Variation accounted for 77.0%

Addition of other variables failed to improve significantly the explanation of residual variance, and Figure 9 shows the plot of CRR against PEVAP. Examination of the residuals failed to suggest any need for transformation, and they appeared randomly distributed.

5 *Conclusions*

One of the principal conclusions arising from this analysis of available cotton strip data is that it is very difficult to perform *a posteriori* multivariate analyses using a data set which is heterogeneous. The first part of the analysis revealed that apparent trends in the data were really a consequence of the few locations in which research effort had been made. This limitation severely affected the nature of the results, and their interpretation. It proved far more satisfactory to select a limited number of cases, examining these in more detail and extracting back-up information from published sources.

It is apparent from the analysis of the extended data set that the decomposition of cotton strips is strongly influenced by climate, and that the most useful climatic parameter for predicting cotton strip decay rate is PEVAP. In fact, the equation linking decomposition rate to PEVAP could be of use in deciding the time periods for inserting cotton strips at new sites.

The close relationship between PEVAP and decomposition rate is due to the fact that the 2 principal environmental controls on decomposition are temperature

Table 11. Correlation matrix derived when attempting to derive a predictive equation for CRR, using the restricted data set (df = 43)

	TS	CRR	DAYS	LAT	LONG	TEMP	PTEMP	RAIN	PRAIN	PEVAP	ALT
TS 1.00											
CRR	–0.16	1.00									
DAYS	–0.11	–0.68	1.00								
LAT	–0.24	–0.67	0.62	1.00							
LONG	–0.11	–0.07	0.11	–0.17	1.00						
TEMP	0.22	0.67	–0.70	-0.94	0.29	1.00					
PTEMP	–0.07	0.69	–0.70	–0.78	0.28	0.83	1.00				
RAIN	0.02	0.62	–0.67	–0.83	0.30	0.85	0.72	1.00			
PRAIN	–0.05	0.67	–0.63	–0.60	0.21	0.71	0.70	0.76	1.00		
PEVAP	0.00	0.88	–0.63	–0.78	–0.07	0.77	0.80	0.62	0.67	1.00	
ALT	–0.16	–0.39	0.45	0.37	0.15	–0.51	–0.38	–0.32	–0.40	–0.47	1.00

and moisture (Bunnell *et al.* 1977). The magnitude of PEVAP is dictated by rainfall and temperature, being large when rainfall and temperature are high, and lower when either of these factors decrease. Thus, conditions of high PEVAP are those which favour a high decomposition rate.

The current synthesis of data suggests that decomposition of a single substrate, when placed in a widely diverging range of environments, can be modelled with accuracy from readily available climatic data. Swift *et al.* (1979) suggested that decomposition rate is the product of the interaction of substrate quality, physical environment and decomposer organisms. Hill *et al.* (1985) concluded, from a mathematical model of the decay process of cotton in soil, that the rate of degradation depended mainly on the physico-chemical environment in the soil, and was insensitive to the size of the microbial inoculum.

In the synthesis presented here, the substrate quality has been kept constant between sites, and differences in cellulose decomposition rates at different sites are, therefore, due to a combination of physico-chemical environment and presence of decomposer organisms. The analysis further suggests that, of these 2 factors, a major component determining decay rate is physical environment, particularly temperature and moisture, as reflected by PEVAP. Residual values may well be a combination of discrepancies between published PEVAP values and actual site values, differences in site chemistry, or a measure of decomposer population differences. The simplest hypothesis necessary to explain the observed results is to assume that wherever a cotton strip is placed, it will select for a cellulolytic flora capable of cotton degradation, and that the subsequent rate of decay becomes a simple function of physico-chemical environment.

A major feature lacking in the current analysis is the detailed description of soil chemistry at each of the sites and, if the cotton strip method is to be used to increase our understanding of the controlling factors for cotton decay around the world, it is essential that workers make a full assessment and record of climatic and chemical parameters at their sites.

The results reported here lend support to the observations of Meentemeyer (1978) that decomposition on a regional scale relates to evaporative losses. The parameter investigated by Meentemeyer (1978) was actual evapotranspiration, to which potential evaporation, as used in this study, approximates. The more recent work of Berg *et al.* (1984) confirms that this approach is useful for furthering our understanding of the decomposition of standard litter material from Scots pine (*Pinus sylvestris*), yet he also emphasizes that local site variability, acting both through litter quality and microscale climate, can be extremely important in determining litter decomposition rates (Berg *et al.* 1982).

We emphasize that the rate of litter decay is determined by the *interaction* of substrate quality, physico-chemical environment and decomposer population. Although the use of a standard substrate can provide insights into the factors controlling the rates of decomposition, it is currently impossible to extrapolate such results to the natural substrates intrinsic to the site.

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