LCOR2—Spatial Correlation Analysis Software for the Personal Computer

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ABSTRACT

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A software program for the personal computer, written in the 'C' language, was developed to analyze spatial patterns of plant disease and pathogen propagules. The program was adapted from a previous mainframe version and is based on the Modjeska and Rawlings model for spatial correlation analysis of uniformity data. The mainframe program was improved by addition of degrees of freedom and significance tables to test correlation coefficients at each spatial lag position. The LCOR2 program will accommodate data files of up to 10,000 points. The LCOR2 program and user guide are available free of charge.

Analysis of spatial patterns of plant disease is becoming increasingly important in the interpretation of disease dynamics. Many pathogens and diseases display clustered or aggregated patterns of incidence (1,2). The spatial relationship among diseased individuals, when combined with biological and environmental knowledge about the pathosystem, can often provide insight as to how a particular disease may progress and what factors may influence disease spread.

Numerous analytical procedures exist to determine whether or not diseased individuals are aggregated, the relative strength of aggregation, and directionality or orientation of aggregation (1–3,7,8,10). One useful spatial correlation (lag correlation) analysis (7) was originally developed to characterize field variation (of disease, growth, fertility pattern, yield, etc.), i.e., the nature and orientation of patterns in the field, and to provide guidance for determination of optimum plot size and shape. This analysis has been successfully applied in several pathosystems (1,4–7) to characterize the spatial pattern of diseases and pathogen propagules. Data are collected from rectangular field plots as counts of diseased plants, diseased leaves, lesions, or propagules per unit of soil within quadrats. All counts or quadrat values are then compared with all others in the matrix of quadrats (1,7,9). The lag correlation program (7) was originally written in the FORTRAN language and modified with a SAS data interface (SAS Institute, Cary, NC) for a mainframe computer.

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The LCOR2 program described here is an adaptation of the original FORTRAN program, written and compiled in the 'C' language (Turbo 'C++' Version 1.0, Borland International, Scotts Valley, CA) for 8088/80286/80386/80486 personal computers. The purpose of this work was to adapt and improve on the original mainframe program, making it more flexible and accessible to the personal computer user.

The Modjeska and Rawlings model. The spatial correlation model assumes that all pairs of observations or counts that have the same spatial relationship have the same correlation (7). The subscripts i and j denote the position of quadrats within the rectangular grid such that $i = 1, 2,...$ and $j = 1, 2,...$ designate row and column numbers, respectively. The correlations at the various distances are then $\rho(l,k)$, where $l = i'-i$ and $k = j'-j$ define the two-dimensional lags or number of quadrats from quadrat (i,j) across rows and across columns, respectively, to quadrat (i',j'). Because of the assumed symmetry of the correlations, $\rho(l,k) = \rho(-l,-k)$ and $\rho(l,-k) = \rho(-l,k)$. Thus, three spatial correlations are defined: $\rho^+ = \{\rho(l,k)\}$, $\rho^- = \{\rho(l,-k)\}$, and $\rho = 1/2(\rho^+ + \rho^-)$. The first row and column of ρ^+ and ρ^- (where $l = 0$ and $k = 0$) are identical. For $l,k > 0$, ρ^+ and ρ^- contain spatial correlations for lags in different diagonal directions across the field (7).

Data format and input requirements. The LCOR2 program requires DOS 2.0 or higher, a math coprocessor, and color EGA or VGA graphics adapter; a mouse pointing device is optional. Data for use with LCOR2 can be prepared with the aid of any word processor, spread sheet, or database program that can output files in ASCII (American Standard Code for Information Interchange). Input data sets are arranged in columns. The first two columns contain x and y coordinates of spatial position associated with individual quadrats or counts; successive columns can represent replications, different sampling dates, different fields, etc. Data matrix size for program input is limited to 100×100 counts, which is 10,000 individual data points with no dimension greater than 100. Column headings can be used but are ignored by the program, which considers only integers ≥ 0. Thus, the only restriction is that column headings cannot be integers.

The LCOR2 program processes each data column with reference to the first two columns, which indicate spatial location. The program can be run interactively through the main menu either from the keyboard or via a mouse. When the program is running, a program processing bar is displayed that dynamically indicates the progress (percent completion) of the analysis. Data sets of a 20×20 matrix of quadrats require 2–30 sec to process, depending on the speed of the computer's microprocessor. Alternatively, a set of simple batch commands can be written that will perform numerous analyses sequentially. The batch commands take the following form:

```
LCOR(INPUT FILESPEC)#(OUTPUT FILESPEC),
```

in which the command LCOR initializes the program and the file specifications direct where the input is to be found and output saved, respectively. The integer separating the file specifications indicates which data column is to be processed. Thus, the following set of batch commands:

```
LCOR C:\FIELD\DAT\TEST27.DAT 2 ...
    ... A:TEST27-2.OUT
LCOR C:\FIELD\DAT\TEST27.DAT 3 ...
    ... A:TEST27-3.OUT
LCOR C:\FIELD\DAT\TEST27.DAT 4 ...
    ... A:TEST27-4.OUT
```

Table 1. Sample output file of data processed by LCOR2 in a matrix of 11 × 11 quadrats

"FILENAME: cggl4.out DATE: 9-20-1990 TIME: 1:26"
"DATA from cgg.dat for DAY 14"

"Axes"	1	2	3	4	5	6	7	8	9	10	11
1	0	0	7	7	0	0	0	0	0	0	20
2	0	4	3	8	6	27	70	4	0	40	0
3	3	10	34	109	105	20	0	17	20	15	0
4	15	11	163	86	160	7	20	10	75	12	0
5	2	16	125	0	95	42	33	0	0	47	36
6	16	18	34	50	40	103	238	70	75	45	17
7	7	11	36	23	95	53	160	9	15	0	53
8	0	6	65	29	27	58	20	0	0	13	0
9	6	22	31	50	0	12	0	0	11	0	0
10	28	4	0	60	8	0	10	5	1	0	0
11	5	6	14	16	0	20	0	0	0	0	7

"RHO-BAR"

"Axes"	0	1	2	3	4	5	6	7	8
0	1.00000**	0.33498**	0.26740**	0.03124	0.07209	−0.01652	0.03001	0.04501	0.0490
1	0.43059**	0.19675*	0.16458	−0.00526	0.06062	−0.02939	−0.04222	0.09058	−0.0286
2	0.03333	0.01445	0.09523	0.00238	0.03449	−0.06455	−0.04447	0.10100	−0.0443
3	−0.04023	−0.13245	−0.01118	−0.04367	−0.09951	−0.20942	−0.15572	0.02817	−0.03190
4	−0.00523	−0.07202	−0.15474	−0.11734	−0.31905*	−0.31840*	−0.17415	−0.12113	−0.18188
5	−0.13800	−0.11020	−0.24973	−0.27401	−0.28721	−0.27332	−0.24207	−0.24514	−0.4307
6	−0.06201	−0.03153	−0.23430	−0.22623	−0.15065	−0.18658	−0.20235	−0.14613	−0.0588
7	−0.00303	−0.03723	−0.21980	−0.10467	−0.17212	−0.17420	−0.10698	−0.16623	0.14243
8	−0.04157	−0.05510	−0.04055	−0.06901	−0.32650	−0.26318	0.22517	0.00863	0.05909

"DEGREES OF FREEDOM"

"Axes"	0	1	2	3	4	5	6	7	8
0	119	108	97	86	75	64	53	42	31
1	108	98	88	78	68	58	48	38	28
2	97	88	79	70	61	52	43	34	25
3	86	78	70	62	54	46	38	30	22
4	75	68	61	54	47	40	33	26	19
5	64	58	52	46	40	34	28	22	16
6	53	48	43	38	33	28	23	18	13
7	42	38	34	30	26	22	18	14	10
8	31	28	25	22	19	16	13	10	7

"SIGNIFICANT CORRELATION LEVEL (5%)"

"Axes"	0	1	2	3	4	5	6	7	8
0	0.17825	0.18721	0.19757	0.20977	0.22442	0.24254	0.26580	0.29731	0.34372
1	0.18721	0.19656	0.20739	0.22013	0.23547	0.25444	0.27883	0.31191	0.36075
2	0.19757	0.20739	0.21876	0.23215	0.24828	0.26826	0.29398	0.32893	0.38067
3	0.20977	0.22013	0.23215	0.24633	0.26341	0.28460	0.31191	0.34912	0.40439
4	0.22442	0.23547	0.24828	0.26341	0.28167	0.30435	0.33364	0.37366	0.43300
5	0.24254	0.25444	0.26826	0.28460	0.30435	0.32893	0.36075	0.40439	0.46800
6	0.26580	0.27883	0.39298	0.31191	0.33364	0.36075	0.39599	0.44400	0.51400
7	0.29731	0.31191	0.32893	0.34912	0.37366	0.40439	0.44400	0.49700	0.57600
8	0.34372	0.36075	0.38067	0.40439	0.43300	0.46800	0.51400	0.57600	0.66600

"SIGNIFICANT CORRELATION LEVEL (1%)"

"Axes"	0	1	2	3	4	5	6	7	8
0	0.23282	0.24450	0.25793	0.27365	0.29242	0.31546	0.34480	0.38418	0.44154
1	0.24450	0.25663	0.27059	0.28694	0.30648	0.33050	0.36112	0.40230	0.46243
2	0.25793	0.27059	0.28518	0.30227	0.32272	0.34789	0.38002	0.42333	0.48676
3	0.27365	0.28694	0.30227	0.32025	0.34179	0.36834	0.40230	0.44818	0.51562
4	0.29242	0.30648	0.32272	0.34179	0.36468	0.39292	0.42914	0.47821	0.54900
5	0.31546	0.33050	0.34789	0.36834	0.39292	0.42333	0.46243	0.51562	0.59000
6	0.34480	0.36112	0.38002	0.40230	0.42914	0.46243	0.50541	0.56100	0.64100
7	0.38418	0.40230	0.42333	0.44818	0.47821	0.51562	0.56100	0.62300	0.70800
8	0.44154	0.46243	0.48676	0.51562	0.54900	0.59000	0.64100	0.70800	0.79800

"RHO-PLUS"

"Axes"	0	1	2	3	4	5	6	7	8
0	1.00000	0.33498	0.26740	0.03124	0.07209	−0.01652	0.03001	0.04501	0.04901
1	0.43059	0.17630	0.08205	−0.05288	0.09106	0.01678	−0.03765	0.21815	0.04556
2	0.03333	0.01598	0.15449	0.00545	0.15247	−0.01185	0.07419	0.07735	0.12015
3	−0.04023	−0.09062	0.11383	0.05108	−0.01035	−0.18583	−0.10749	−0.07636	0.05849
4	−0.00523	−0.03021	−0.12099	−0.12795	−0.31927	−0.35450	−0.25514	−0.07228	−0.27371
5	−0.13800	−0.13812	−0.30238	−0.33273	−0.30520	−0.34115	−0.30249	−0.33068	−0.31466
6	−0.06201	−0.09973	−0.30725	−0.24953	−0.25404	−0.27614	−0.23608	−0.24990	−0.13310
7	−0.00303	−0.10585	−0.21846	−0.14331	−0.26628	−0.28857	−0.17961	−0.09730	0.19703
8	−0.04157	−0.04609	−0.08162	−0.22247	−0.31138	−0.27234	0.08141	0.31876	0.31380

(continued on next page)

Table 1. (*continued from preceding page*)

"RHO-MINUS" "Axes"	0	1	2	3	4	5	6	7	8
0	1.00000	0.33498	0.26740	0.03124	0.07209	−0.01652	0.03001	0.04501	0.04901
1	0.43059	0.21719	0.24711	0.04235	0.03018	−0.07555	−0.04679	−0.03699	−0.10284
2	0.03333	0.01293	0.03597	−0.00069	−0.08349	−0.11726	−0.16313	0.12465	−0.20884
3	−0.04023	−0.17428	−0.13618	−0.13842	−0.18867	−0.23301	−0.20395	0.13269	−0.12229
4	−0.00523	−0.11383	−0.18849	−0.10673	−0.31883	−0.28230	−0.09317	−0.16998	−0.09005
5	−0.13800	−0.08229	−0.19708	−0.21529	−0.26291	−0.20550	−0.18164	−0.15960	−0.54693
6	−0.06201	0.03667	−0.16135	−0.20293	−0.04727	−0.09702	−0.16862	−0.04236	0.01533
7	−0.00303	0.03138	−0.22114	−0.06603	−0.07796	−0.05984	−0.03435	−0.23516	0.08782
8	−0.04157	−0.06411	0.00053	0.08444	−0.34163	−0.25403	0.36894	−0.30150	−0.19562

will run three sequential analyses, each on a different data column (columns 2, 3, and 4), drawing data from a single data file (TEST27.DAT) located in a sub-subdirectory (FIELD\DAT) on a hard disk drive (C:) and will output results of the three LCOR analyses to three files on a floppy disk drive (A:). The output files can then be stored or printed.

LCOR2 program output. The output file contains the original data displayed in matrix format (Table 1). This is followed by a table of autocorrelation coefficients titled RHO-BAR ($= \rho$), in which a coefficient is given for each spatial lag position. Because of insufficient data to calculate correlation coefficients for the most distal lags, the output matrices are restricted to three lags less than the dimensions of the input matrix. Autocorrelation coefficients significant at $P = 0.05$ and $P = 0.01$ are indicated by single and double asterisks, respectively, for RHO-BAR output only. A table of degrees of freedom follows the autocorrelation coefficients. Individual degrees of freedom are calculated for each spatial lag position as $(n_1 - l)(n_2 - k) - 2$, where n_1 is the number of quadrats in one direction, n_2 is the number of quadrats in the other direction, and l and k are the distances from the origin in each direction, e.g., l across crop rows, k within crop rows. In the example in Table 1, the degrees of freedom for each position in the matrix is $(11 - l)(11 - k) - 2$. The degrees of freedom were utilized to determine significance of the correlation coefficients for each of the spatial lag positions at $P = 0.05$ and $P = 0.01$.

The next two analyses presented, RHO-PLUS (ρ^+) and RHO-MINUS (ρ^-), are tables of correlation coefficients representing effects of disease in the different diagonal directions. These matrices can be used to detect a skewness of the spatial pattern in relation to the axis of the field row. For instance, if the diagonal lag correlations for ρ^- decrease faster over lags than the lag correlations for ρ^+, then a skewness of the spatial pattern is suggested relative to the sides of the field (7).

Interpretation of sample output. The sample output represents an analysis of data taken from an epidemic of Asiatic citrus canker in a grapefruit grove in Entre Rios, Argentina, in 1987, 14 days after the start of the epidemic (Table 1). Data were collected as the number of diseased leaves per tree. Each tree had many leaves and thus was considered a quadrat. From the RHO-BAR it was concluded that diseased trees were positively correlated ($P = 0.05$) with those one tree away within row, two trees away across rows, and one tree away at a diagonal on the date of assessment. Figure 1 shows the proximity pattern that can be derived from the RHO-BAR correlation coefficient table. There was no clear indication that the RHO-PLUS and RHO-MINUS correlation coefficients decreased at different rates over the spatial lags; thus, no skewness to the proximity pattern relative to the tree rows was detected for this assessment date.

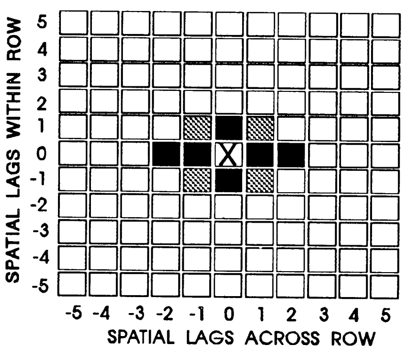

Fig. 1. Proximity pattern derived for LCOR2 RHO-BAR output of data from analysis of Asiatic citrus canker in a grapefruit grove in Argentina 14 days after the start of an epidemic. Data were counts of the number of diseased leaves per tree. Black, gray, and white boxes represent correlation coefficients significant at $P = 0.01$, significant at $P = 0.05$, and nonsignificant, respectively.

Discussion. LCOR2 has been used for analysis of spatial data relating to different pathogens of citrus (4–6). The program was especially useful for interpreting sequential data sets acquired from the same field over time. Processing time of the LCOR2 version for the personal computer is much improved over that of the original mainframe program. Improvements to the original program, such as the calculation of degrees of freedom and significance tables to test correlation coefficients at each spatial lag position, further enhance the utility of the LCOR2 program. The LCOR2 program and a brief user guide can be obtained free of charge by sending a 5.25- or 3.5-in. floppy disk with a self-addressed, stamped, diskette mailer to the first author.

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