Statistical Checklist 4

PLANT GROWTH ANALYSIS

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Stating the objectives

1. Have you stated clearly and explicitly the objectives of your research and the reasons for doing it?
2. Have you translated these objectives into precise questions that the research may be expected to answer?

Relevance of plant growth analysis

3. Is your research expected to involve plant *growth* or *decay*, ie irreversible change in size or shape (however measured), or change in number?
4. Do the questions you are asking require more *detailed* answers on plant form and function than would be available from studies in the fields of *production ecology* or *plant demography?*
5. Do the questions you are asking require more *broadly-based* answers on plant form and function than would be available from studies in the field of *environmental physiology?*
6. In particular, do you require an integrated assessment of the performance of *whole* organs, individuals, populations or communities?
7. Do you require this assessment to be made across ecologically- or agronomically-meaningful periods of time?
8. Would it be useful to you to express plant performance in terms of *derivates* which are independent of the size of the system under study?
9. Are any of the standard types of derivate in plant growth analysis useful to you either *per se* or as synthetic or comparative tools? For two generalized plant variates, y and z, and for time t, the commonest derivates are:

   absolute growth rates : dy/dt
   relative growth rates : $(l/y)\,(dy/dt)$
   simple ratios : z/y
   compounded rates : $(l/z)\,(dy/dt)$
   integral durations : $\int_{t_1}^{t_2} y\,dt.$

10. Are *interrelationships* between these derivates in the form of economic analogies likely to be useful?

    For example: $(l/y)\,(dy/dt) = z/y \times (l/z)\,(dy/dt)$
    (*efficiency*) = (*manpower*) × (*manpower productivity*).

Choice of approach

11. Are you interested only in the net or final results of growth or decay over a longish period of time?
12. Are you interested in the detailed time-course of growth or decay, but know enough about this already to need only the level of definition provided by infrequent sampling?
13. If the answer to 11 or 12 is 'yes', can you settle for the *classical approach* to plant growth analysis, in which mean values of derivates are obtained for the harvest-intervals between large, relatively infrequent samples?
14. Are you unable to accept the *assumptions* implicit in the use of the classical harvest interval formulae (in particular, the problems of assembling accurate interrelationships as in 10)?

15. Do you know little or nothing about the *time-course* of the growth or decay you wish to study?
16. Do you require the most detailed picture possible, perhaps because you expect that species- or treatment-comparisons will be finely balanced?
17. *If the answer to 14, 15 or 16 is 'yes', can you settle for the functional approach* to plant growth analysis in which frequent, small harvests supply data for statistical curve-fitting?
18. Are any of the following requirements also convincing arguments for the functional approach? Great condensation of primary data; all sampling occasions in use for all comparisons; minimal physical risk or effort per harvest; unequal replication between harvests; unequal harvest intervals; interpolation; smoothing; integral statistical analysis.

Experimental design and sampling

19. In general, can you select the right experimental material and use it in such a way as to get down on to paper the best possible data for deriving answers to your original questions?
20. Have your read *Statistical Checklist 1* on experimental design?
21. Have you read *Statistical Checklist 2* on sampling?
22. Have you read Evans (1972, pp 39-185) on measurement?
23. Have you examined the question of destructive versus non-destructive sampling?

Inspection of data

24. As plant variability is commonly value-dependent, do you agree that the natural logarithmic transformation, normally necessary for other reasons, *also renders the data homoscedastic*, with Gaussian distributions within each harvest subset?
25. (Rarely) is such a transformation harmful to, or within, any of your data sets?

Computing

26. Have you investigated the locally-available computing or calculating facilities to see what possibilities are available?
27. Have you read *Statistical Checklist 3* on modelling, questions 71-76?
28. *Have you decided on whether to write your own* program, use a library facility or borrow a program from another worker in the field?
29. If proceeding with any of 28, can you be sure of obtaining all of the necessary values, derivates and limits from your chosen method?
30. Do your computing facilities, as a whole, provide the best possible combination of availability, suitability and turnaround, or must some trade-off of one against another be achieved?

Classical analytical methods

31. Have you obtained the appropriate *classical formulae*, perhaps from a source such as Evans (1972) or Hunt (1978)?
32. Do you fully understand the *assumptions* involved in the use of each of these formulae?
33. Can you *pair* your samples satisfactorily across each harvest interval?
34. Can you assemble your classical derivates into populations which permit *statistical analysis?*
35. Is there evidence of random instability in your classical derivates or can you genuinely believe what you see?

Functional analytical methods

36. Do you know where, on the continuum between *mechanism* and *empiricism, your modelling* (in the form of curve-fitting) is likely to lie?

37. If you have firm *mechanistic* beliefs or hypotheses about the processes underlying the growth or decay that you are studying, can you select or devise a mathematical function which provides a convenient analogue of those processes?
38. Can you *fit* such a function to your data?
39. Can you then proceed to the required *derivates*, with statistical limits if possible?
40. If you have no mechanistic beliefs or hypotheses about your system but merely require a suitable statistical *approximating function*, can you select or devise a mathematical function which provides a convenient representation of your system?
41. Can you *fit* such a function to your data?
42. Can you then proceed to the required fitted *derivates*, with statistical limits if possible?
43. Are any of the following functions likely to be of value to you?

    (*An exponential function is a function fitted to logarithmically-transformed data.*)

First-order polynomial exponential	: for log-linear ('exponential') growth or decay;
Second-order polynomial exponential	: for simply-curving progressions;
Third-order polynomial exponential	: for S-shaped progressions, or those with linearly-changing curvature;
High-order polynomial exponentials	: for complex curves, but beware of unstable derivates and limits;
Monomolecular	: asymptotic, but without an inflection;
Logistic (autocatalytic)	: asymptotic, with an inflection mid-way;
Gompertz	: asymptotic, with an early inflection;
Richards	: asymptotic, with a variable inflection;
Segments	: chains of simple functions fitted to complex data, but with 'lumpy' derivates;
Running re fit	: ditto, with smooth derivates, but costly in degrees of freedom;
Splines	: specially-joined polynomials, with seamless derivates and advantageously-treated degrees of freedom;
Time Series Analysis	: for vast data sets with recurrent internal trends.

44. Have you closely examined the question of *determinate growth* and of asymptotic versus non-asymptotic functions?
45. If used, have you sought incidental biological relevance in the parameters of the simpler functions listed in 43?
46. Have you balanced to your own satisfaction the often conflicting requirements of *biological expectation* and *statistical exactitude*?
47. Are you aware of the dangers of *over-fitting* your data?
48. Are you aware of the dangers of *under-fitting* your data?
49. Have you used progressions of the *derivates* as incidental or alternative indications of goodness or suitability of fit?
50. For low-order polynomials, is the *stepwise principle* of any value?
51. If it is, can you accept a variety of types of fit within your collection of data sets, or must they all be similarly treated for any reason?

Post-analysis: assessment and presentation

52. Have you applied *Occam's razor* wherever possible (accepting the simplest of alternative explanations)?

53. Has your analysis created a *Procrustean bed* (an abuse of certain data sets in pursuit of over all uniformity)?
54. Have you got everything you wanted from the analysis?
55. Must you return to another method, perhaps because of the unavailability of meaningful derivates or statistical limits?
56. If your derivates are time-based, can you gain additional information by plotting them not against time but against some *other measure of progress*, such as total dry weight?
57. Can you incorporate such an alternative measure directly into any of the calculations?
58. If you have experimental treatments based not upon multi-state but upon continuous variables, can you incorporate either the primary or derived data into a *response surface* involving independent variables in addition to time?
59. If your original design admits both classical and functional methods of analysis, can additional information be gained by performing both?
60. Will you present each classical rate-derivate not as single points on a progression in time, but as a *histogram* with a class-interval equal to the harvest-interval?
61. Will you need to present *all* of the statistical limits calculated for fitted derivates or can economy of presentation be achieved by giving only the 'control', or perhaps the widest, set of limits?
62. Can values of derivates from empirical work be used to set values or limits to *state variables* or *rate equations* in subsequent mechanistic work?

The final (and most important) question

63. If you are in any doubt about the purpose of any of the questions in this checklist, should you not obtain some advice from a worker with experience of plant growth analysis before continuing?

There is usually little that an expert advisor can do to help you once you have committed yourself to a faulty approach.

Bibliography

(Indicating the relevance of each publication in brackets)

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4. The checklists so far issued include:
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5. ITE welcomes comments and suggestions on the checklists in this series. Please write to the Director, Institute of Terrestrial Ecology, Merlewood Research Station, Grange-over-Sands, Cumbria, LA11 6JU.
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