168

Merlewood Research and Development Paper
Number 63

AN APPLICATION OF TREND SURFACE ANALYSIS TO THE INTERPRETATION OF VARIETAL TRIALS

J. N. R. Jeffers, FIS, AMBIM, FIBiol.

R & D. 75/63
June 1975

1. Introduction

Although efficient experimental designs exist for the comparison of relatively small numbers of new varieties, the simultaneous comparison of large numbers of varieties - several thousand new entries in any one year - still presents practical problems for the plant breeder. Even where designs for the appropriate numbers of varieties, replications, and numbers of plots per block exist, unavoidable differences in the availability of experimental material, or restrictions on the availability of suitably homogeneous trial areas may preclude the use of such designs. In this situation, plant breeders frequently revert to completely randomized trials in which a control variety is intensively replicated. Comparison of the yield of new varieties is then made with the yield of neighbouring plots of the control variety in an attempt to reduce, if not eliminate, the effects of site variability. A typical trial of this kind is shown in Figure 1, where the trial has 132 plots of a control variety distributed over the area of a 12 x 112 variety trial.

This paper gives examples of the application of trend surface analysis to the interpretation of variety trials of the kind illustrated in Figure 1. It does not consider the use of more effective designs for such trials through the use of incomplete blocks or some similar design, but confines its attention to the problems of interpretation of the comparisons of the yields of new varieties with appropriate measures of the yields of the control variety.

2. Initial plotting of data

Data for the controls of an actual trial of winter wheat varieties with the design of Figure 1 are plotted in Figure 2. The symbols used are chosen for the convenience of plotting the trend surfaces later fitted to the data, and each symbol represents a range of 0.5 kg/17 m^2, i.e.

0 for < 10.00 kg/17 m^2

= for 10.01 - 10.50 kg/17m^2

1 for 10.51 - 11.00 "

\- for 11.01 - 11.50 "

2 for 11.51 - 12.00 "

. for 12.01 - 12.50 "

3 for 12.51 - 13.00 "

\# for 13.01 - 13.50 "

4 for > 13.50

No obvious trends are shown by the plotting of the data in this way except for a general tendency towards relatively high values near the centre of the trial and relatively low values towards the high-numbered E-W co-ordinates. Visual inspection of the values does not, however, give any very clear impression of the spatial trends.

3. Trend surface analysis

Trend surfaces of three different levels of complexity were next fitted to the yields of the control variety, expressing the regression of these yields on linear, quadratic and cubic terms of the co-ordinates of the control plots. The three basic equations used in these calculations were as follows:-

$$Y = c_0 + c_1E + c_2N \qquad (1)$$

$$Y = c_0 + c_1E + c_2N + c_3E^2 + c_4N^2 + c_5E.N \qquad (2)$$

$$Y = c_0 + c_1E + c_2N + c_3E^2 + c_4N^2 + c_5E.N + c_6E^3 + c_7N^3 + c_8E^2N + c_9\ E.N^2 \qquad (3)$$

where Y = yield of control variety in $kg/17m^2$

E = E-W plot co-ordinate

N = N-S plot co-ordinate

$c_0, c_1, c_2 \ldots c_9$ are partial regression coefficients.

Although the distributional assumptions of the tests will only rarely be justified, particularly because of the spatial autocorrelation amongst the residuals, conventional analysis of variance using the ratio of "explained" to "unexplained" variance is sometimes useful as an overall test for P parameters and for the necessity of including additional parameters. Table 1 gives the analysis of variance of the contributions of the various regression equations and suggests that the addition of the quadratic terms, at least, is probably worthwhile in the search for a trend surface of control values over the area of the trial.

Alternative expressions of the various terms of the regressions are given in Tables 2 and 3. No attempt has been made to indicate the "significance" of the estimated regression coefficients of Table 2, because of the high degree of intercorrelation between the regressor variables. Table 3 shows a continuing reduction in the standard deviation from regression, the cubic trend surface accounting for nearly 32 per cent of the total variability in the yields of the control variety. While there is, perhaps, relatively little justification for going beyond the quadratic trend surface, accounting for 27.5 per cent of the variability of the yields of the control, most exponents of trend surface fitting would probably use the cubic trends in this case.

The quadratic and cubic trend surfaces implied by the coefficients of Table 2 are plotted in Figure 2, using the same symbols as before. The differences between the two surfaces are not marked; both surfaces show a region of relatively higher yields towards the centre and left side of the trial, falling off at either end and to the right. Examination of the differences between the values predicted from the trend surfaces, both quadratic and cubic, did not reveal any clustering of positive and negative deviations, and this absence of systematic deviations or unconformities was confirmed by a series of tests of runs of positive and negative deviations along the N-S axis. The "control" values for each

Table 1. Analysis of variance for the contribution of linear, quadratic, and cubic regressions

Source	d.f.	Sums of sqs	Mean sqs	F
Linear regressions	2	6.3276	3.1638	5.64**
Deviations	129	72.4231	0.5614	
Quadratic regressions	3	15.3075	5.1025	11.26***
Deviations	126	57.1156	0.4533	
Cubic regressions	4	3.5099	0.8775	2.00
Deviations	122	53.6057	0.4394	
Total	131	78.7507	0.6012	

Table 2. Estimated coefficients of regression for linear, quadratic and cubic trend surfaces

Terms	Linear	Quadratic	Cubic
E	-3.600113×10^{-3}	0.025952	0.023077
N	-0.0571258	0.043471	0.625549
E^2	-	-3.153055×10^{-4}	1.233084×10^{-4}
N^2	-	-0.010758	-0.084426
$E \times N$	-	8.057329×10^{-4}	-5.469135×10^{-3}
E^3	-	-	-2.977575×10^{-6}
N^3	-	-	2.691044×10^{-3}
$E^2 \times N$	-	-	7.732739×10^{-6}
$N^2 \times E$	-	-	4.187235×10^{-4}
Constant	12.80247	12.08144	11.09900

plot in the variety trial were, therefore, computed from the cubic trend surface and these control values used to compare the yields of each of the candidate varieties. Those varieties showing yields greater than a pre-assigned multiple of the control values and also satisfactory in various other aspects were then included in the next stage of the varietal testing and selection.

Table 3. Regression statistics

Trend surface	S.D. from regression	R^2
Linear	0.749	0.0803
Quadratic	0.673	0.2747
Cubic	0.663	0.3193

4. Alternative forms of trend surface

The shape of the variety trial of Figure 1, as an elongated rectangle, poses some interesting questions about alternative forms of the trend surface to be fitted to the yields of the control plots. For example, effects with a marked periodicity may occur through the long axis of the trial, and a trend surface based on a Fourier series along this axis may be desirable, although, in this example, there is no evidence of such periodic effects. It is, however, one of the constraints of trend surface analysis that the model chosen for analysis may be inappropriate, and there is no obvious way in which an appropriate model can be chosen *a priori*.

Similarly, no attempt has been made, in this application of trend surface analysis, to fit trend surfaces with terms of higher degree than cubic. Not only do the problems of computation increase markedly with the introduction of terms of higher degree, but there is a danger of fitting the surface to minor changes in the yields of the controls.

A further possibility in the fitting of trend surfaces to elongated designs, like that of Figure 1, is the use of piece-wise fitting of a series of overlapping rectangles. Ten separate surfaces were therefore fitted to the trial design as overlapping rectangles of approximately 12 x 20 plots. The resulting composite trend surface was not greatly different from those obtained by fitting a single polynomial surface.

5. Subsequent trials

The means and standard deviations of control varieties in 12 further variety trials, harvested in 1974, are given in Table 4. There were considerable differences in the coefficients of variation for the various cereals, ranging from well below 10 per cent for spring barley to greater than 20 per cent for spring wheat, which to a large extent represented gross variation in site and date of sowing rather than major inherent differences between crops. For example, the winter wheat trials (A-D) were on a different site from those of winter wheat (E-F), the latter site having a markedly lower degree of variation.

Table 4. Summary of variability of variety trials harvested in 1974

Trial	Size	No. of controls	Yield ($kg/17m^2$) Mean ± SE	SD	C%
WW/A	12 x 73	176	13.6 ± 0.17	2.24	16.5
WW/B	12 x 79	189	10.8 ± 0.12	1.63	15.1
WW/C	12 x 27	63	11.5 ± 0.20	1.61	14.0
WW/D	12 x 16	39	12.7 ± 0.33	2.06	16.3
WW/E	12 x 29	67	11.0 ± 0.11	0.89	8.1
WW/F	12 x 79	190	11.7 ± 0.07	0.97	8.3
WW/G	12 x 26	63	11.2 ± 0.15	1.21	10.8
SW/A	9 x 19	34	4.56 ± 0.17	0.97	21.2
SW/B	9 x 27	47	4.38 ± 0.14	0.99	22.7
SB/A	11 x 70	154	10.4 ± 0.06	0.76	7.2
SB/C	11 x 70	124	6.93 ± 0.05	0.54	7.8
SB/D	11 x 48	106	6.32 ± 0.06	0.61	9.6

WW = winter wheat

SW = spring wheat

SB = spring barley

Table 5. **Standard deviations from regression and percentage of variability accounted for by linear, quadratic, and cubic trend surfaces**

Trial	Standard deviatn	SD from regression:- Linear	Quad	Cubic	Proportion of variability accounted for:- Linear	Quad	Cubic
WW/A	2.23	1.61***	1.60	1.44***	0.48	0.50	0.60
WW/B	1.63	1.15***	1.15	1.14	0.51	0.52	0.54
WW/C	1.61	0.96***	0.89*	0.81**	0.66	0.72	0.79
WW/D	2.06	1.13***	0.96**	1.00	0.71	0.81	0.82
WW/E	0.89	0.89	0.85*	0.84	0.04	0.17	0.23
WW/F	0.97	0.93***	0.89**	0.82***	0.11	0.18	0.32
WW/G	1.21	1.16*	1.17	1.16	0.11	0.14	0.21
SW/A	0.97	0.73***	0.54***	0.48	0.47	0.73	0.82
SW/B	0.99	0.92*	0.88	0.78*	0.18	0.29	0.50
SB/A	0.76	0.72***	0.70**	0.67**	0.10	0.17	0.27
SB/C	0.54	0.49***	0.47**	0.43***	0.20	0.29	0.41
SB/D	0.61	0.40***	0.39	0.40	0.58	0.60	0.61

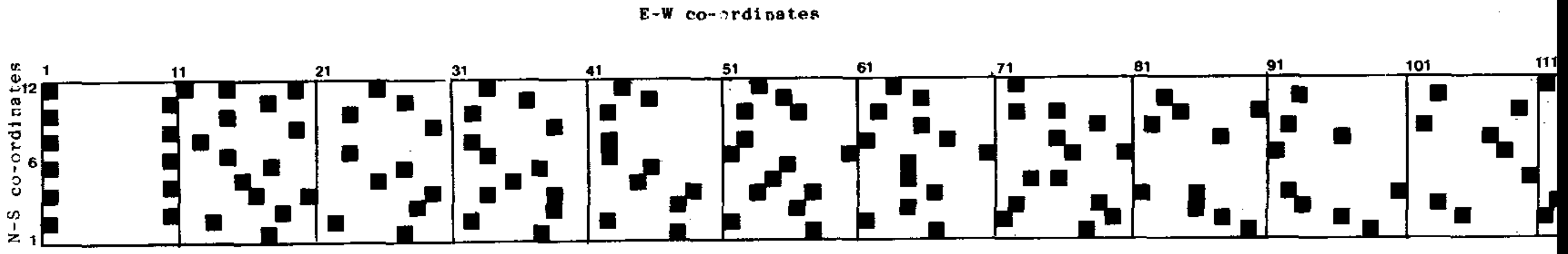
Stars indicate significance of linear, quadratic, cubic components,

i.e. * significant at 0.05

** significant at 0.01

*** significant at 0.001

Figure 1. Example of variety trial with highly replicated controls



Individual plots are $17m^2$ in area

Control plots indicated by ■

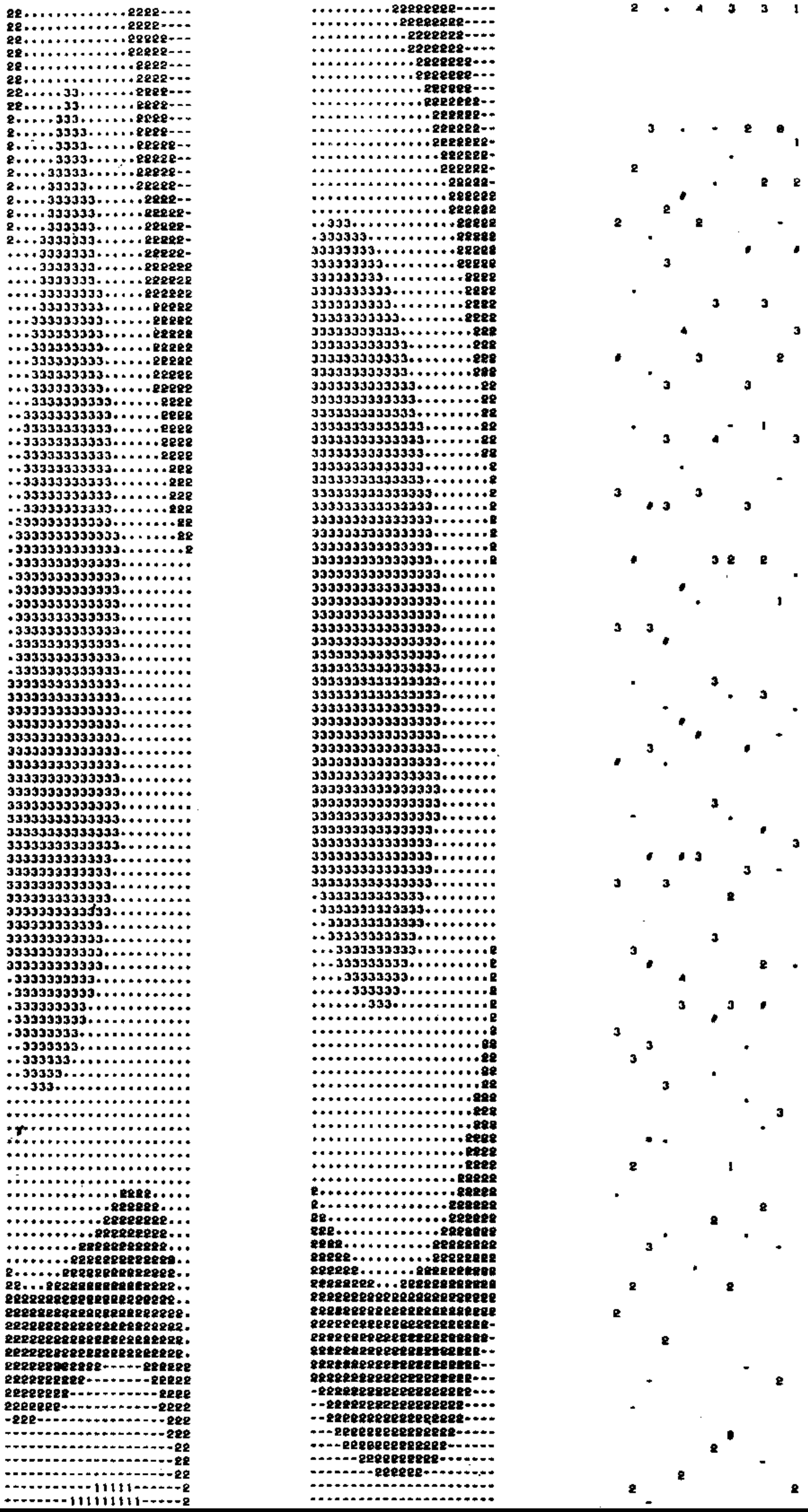


Figure 2 Plotted values of control yields and of quadratic and cubic trend surfaces