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ΓΕΩΠΟΝΙΚΗ. —**Advances in the Analysis of Field Experiments,** by *J. Papadakis* *.

ABSTRACT

In 1937 I presented a method of analysis of field experiments, which increases appreciably accuracy of treatment estimation. After more than 30 years of neglect, following the second world war, attention has been drawn to it in recent years; at least 9 papers appeared on it, and mathematicians have been appointed in Great Britain to work on it. But all these scientists have only read my papers of 9 pages of 1937, and/or that of Bartlett (1938) on it; they have not read my subsequent papers (Papadakis 1940, 1954, 1970), and consequently ignore some improvements, that greatly improve its accuracy. The object of this communication is to present these improvements, and discuss some other aspects of the question. They may be summarized as follows: 1) By designing hypothetical experiments on uniformity trials, we can determine "real" error, and compare "experimentally" different methods; in this way I have proved, that my method is more accurate than the classical ones, which are moreover inaccurate in the determination of the error. 2) In the field there is correlation between the productivity of nearby plots, and accuracy of whatever method depends on the advantage it takes of such correlation; correlation is maximum between adjacent plots, and that is why my method is the more accurate. 3) In the field there are gaps (sudden changes of productivity) between adjacent plots, and abnormal plots, whose productivity differs greatly from both adjacent and their average; the method permits to determine them objectively and increase accuracy. 4) Yield adjustment can be also done on the basis of edaphic and other criteria, and such adjustment can be combined with that on adjacent plots, this is promising. 5) To compute error, the paper proposes a "simulation" method, which simulates the way, in which productivity deviations between plots compensate really one another, when treatment averages are computed; it reduces considerably the difference between computed and "real" error. 6) Low or negative corre-

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lation between adjacent plots is usually due to competition between border lines, long ago known as "inteference"; such competition distorts yield differences between treatments, and makes the experiment useless; measures are taken to minimize its effect; in the case of tree experiments it is very frequent, and can be avoided by separating plots with ditches sufficiently deep, to avoid the passage of roots from one plot to another. 7) For a long time analysis of field experiments has been based on purely theoretical considerations; but spatial distribution of soil heterogeneity is also important; combination of the two aspects may be useful.

Keywords: ANALYSIS OF FIELD EXPERIMENTS; ABNORMAL PLOTS; ADJUSTMENT METHODS; ADJUSTMENT ON OTHER CRITERIA; NEAREST NEIGHBOUR METHODS; PAPADAKIS'S METHOD; "REAL ERROR"; REITERATION; SIMULATION METHOD.

INTRODUCTION

In 1937 I have proposed a new method of analysis of field experiments, which increases appreciably accuracy, taking advantage of the correlation of productivity between adjacent plots. Bartlett (1938) published a paper on my method. In my "Ecologie Agricole" (1938) I commented it extensively; and it has been used extensively not only in Greece, but also in Belgium, France Belgian Congo (Zaire), etc. But with the second world war the staff of agricultural experiment stations suffered great changes; moreover the methods of analysis of variance have been universally adopted; and my method suffered a long period of neglect.

However in recent years many scientists have realized the advantages of the method, and several papers appeared on it: Atkinson (1969, 1978 and 1981), Yates (1970), Pearce and Moore (1976), Bartlett (1978, 1981), Kempton and Howes (1981), Wilkinson and others (1983), etc.; recently 3 mathematicians have been appointed in Great Britain to work on it.

However all these authors have only read my short paper of 9 pages of 1937· they ignore my extensive paper, 66 pages, published in 1940 in Argentina during the battle of England, and my extensive references to the method in my "Ecología de los Cultivos" (1954) and "Agricultural Research" (1970). Between 1937 and now I have studied and considerably improved the method. Therefore I consider useful to intervene in the discussion, presenting such research and improvements.

1. GENERAL CONSIDERATIONS

Field experiments are the principal tool of crop science. But the systems that such science studies are complex; numerous factors intervene and they interact to one another. That is why seldom a question can be solved with one only experiment. Many experiments under very different conditions are carried out; and it is the comparison of their results, taking account of the ecological conditions, that prevailed in each one, that permits to arrive to conclusions.

We should also not forget, that the object of field experiments is to study the relative yields of treatments, and their variation in function of ecologic factors. This is important, because relative yields are less variable than absolute yields; on the contrary with the methodology usually used the error of differences in yield between treatments is $\sqrt{2}$ times that of absolute yields.

Finally to determine accurately the probable error of an experiment is certainly important. But still more important is the accuracy in determining yield differences between treatments.

2. METHODOLOGY OF METHODS COMPARISON "REAL" ERROR

Uniformity trials make possible, to compare" experimentally" different methods. Hypothetical experiments are designed, according to different methods, on the trial; since the treatments are hypothetical, they should all give the same yield; and the standard deviation of computed yields in the "real" error (Papadakis 1940).

3. SPATIAL DISTRIBUTION OF SOIL HETEROGENEITY

Soil heterogeneity is due to numerous causes, each of which affects the yield of a spot. Some of these spots are considerably smaller than the width of the plots and they usually affect the yield of one only plot; to minimize their effect we should increase the number of repetitions and surface of each plot.

But other spots are greater that the width of the plots; they affect many nearby plots in the same time; and the smaller is the distance between two plots, and more narrow they are, the greater is such probability. They create a correlation between the yields of neighbour plots, and such correlation increases as the distance between plots decreases, being maximum between adjacent plots.

4. ADJUSTMENT BASED ON ADJACENT PLOTS

Since there is correlation between the productivity of adjacent plots, we may take advantage of it to adjust yields and reduce "real" error. That is why since the beginning of the century "controls" are used in field experiments; one treatment was repeated more frequently, and yields were adjusted on this basis.

When in 1923 - 4 I began to carry out varieties experiments, I intensified this system. Half of the plots were sown with 1 or 2 varieties, the others were repeated 3 - 5 times, depending on their importance or available seed, and the yield of each plot was adjusted on the basis of the yields of the two adjacent controls. This system was reducing considerably the error; still now it is the best method, when for lack of seed we cannot increase the number of repetitions, as it is often the case in plant breeding. Plots were always long-narrow, because in this way increases the probability of being affected by the same heterogeneity spots.

But since all treatments are repeated several times, they can serve as controls, although naturally a control repeated 4 times is less efficient than one repeated 20. This consideration conduced me, to suppress controls. All treatments serve as controls to one another.

No coefficient of covariation was computed. I was presuming, that the coefficient is always 1, although the correlation may vary considerably; and I was not far from the truth. Error was determined on the basis of the deviations of adjusted yields from their treatments averages. It is only later, than I began to compute a coefficient of covariation. In the mean time the methods of analysis of variance (randomised blocks, latin square, etc.) have been universally adopted; but they have never convinced me. Mathematically they are valid; but they do not take sufficiently in consideration the distribution in the field of soil heterogeneity, and the objectives and peculiarities of crop science experiments. To apply mathematics to a particular problem, understanding of the problem is also useful.

Using the methodology described in paragraph 2, I compared (Papadakis 1940) my method to randomized blocks, latin square, etc. "Real" error was always smaller with my method; see table 1. The difference in favour of

TABLE 1.

Comparison of calculated (c) and "real" (r) error (squares), with different methods. Adapted from Papadakis (1940).

Field	Classical Rand. blocks			Adjustment no "simulation"			Adjustment "simulation"		
	c	r	c/r	c	r	c/r	c	r	c/r
D4	3.78	6.62	0.52	3.63	2.13	1.70	3.45	2.13	1.62
D5	7.50	1.36	5.52	2.60	2.38	1.09	3.03	2.38	1.27
D5	7.08	2.68	2.64	2.23	4.55	0.49	3.09	4.55	0.68
D7	3.98	4.11	0.97	3.81	2.14	1.78	2.27	2.14	1.06
D8	2.73	4.18	0.65	2.77	1.66	1.68	1.92	1.66	1.16
Av.	5.01	3.79	1.31	3.01	2.57	1.17	2.75	2.57	1.07
St. dev.			0.68			2.12			0.38

my method is evident; as an average my 1937 method reduced "real" error by 32%. The same paper shows, that all methods take advantage of the correlation between nearby plots; error is function of the correlation between plots of the same block, line, column, etc. But such advantage is maximum with my method. Moreover classical methods complicate the design, obliging to omit, or innecessarily increase, the number of treatments.

5. GAPS AND ABNORMAL PLOTS

Adjustment obliges to determine the productivity of each plot (deviation from treatment average) and gives a picture of soil heterogeneity. And application of the method so many years, to hundreds of experiments each year, has shown, that there are "gaps" (sudden changes of productivity); f. i. see fig. 1, yield increases abruptly from 63 in plot B4 to 105 in plot B5. There are also "abnormal" plots, whose productivity differs enormously from both neighbours and their average; f. i. see fig. 1, the yield of Cll is 91, when its neighbours yielded 151 and 160; it is a uniformity trial.

Naturally when two plots are separated by a gap, it is erroneous to adjust the yield of whatever of them on the basis of the other; and abnormal plots should not be taken in consideration. This is the method I have proposed (Papadakis 1970); it reduces appredíably error.

But naturally gaps and abnormal plots should be determined objectively; only few, approximately 10% of the plots can be eliminated; see paragraph 9.

6. ADJUSTMENT BASED ON EDAPHIC AND OTHER CRITERIA

Soil heterogeneity is due to several causes, chiefly edaphic, that could be estimated with soil analysis, etc. Pizarro, Braun and Touza (1969) have shown, that there is correlation between field capacity and yield in certain cases. We can therefore adjust yields, and determine gaps and abnormal plots on this basis.

I tried this method (Papadakis 1970), and the square of error has been reduced 40%. Naturally numerous analysis are necessary; but modern technology reduced considerably costs. In my opinion this method will be extensively used in the future. Moreover it can be combined with that of adjacent plots, using coefficients of multiple covariation.

7. REITERATION OF ADJUSTMENT

Effectiveness of adjustment depends naturally on the precision, with which average treatments yields have been determined; and since such accuracy increases with adjustment, it is advisable to repeat it. We may consider b as equal to 1 in all adjustments except the final one. Seldom is useful to adjust more than 3 times; see 9.

As table 2 shows, there is correlation between treatments mean yields given by successive adjustments, although the experiment is hypothetical. This fact shows, that adjustment cannot totally eliminate the errors due to distribution, which should be as good as possible; see 9; but it shows also, that it is not too drastic. Adjustment shown by table 2 includes elimination of gaps and abnormal plots.

I introduced reiteration with my "Agricultural Research" (1970).

8. CALCULATION OF THE ERROR, SIMULATION METHOD

We may say, that error is the difference between the yield, the analysis attributes to each treatment, and the yield the treatment would yield, if applied in all plots of the field. The distribution of d(deviations of plot yields from their respective treatments averages) gives a picture of soil heterogeneity; and the way these d compensate one another, shows "experimentally", how repetition reduces error; and using d, we could simulate this process. Naturally we cannot sum d of the same treatment, because their sum is equal to O; as far as possible the d summed should belong each one to a different treatment, but their distribution in the field should simulate, as well as possible, that of the plots of each treatment. This is the method I have proposed in my paper of 1940, and improved in the mean time. Elimination of gaps and abnormal plots improves simulation because it increases correlation between d of adjacent plots; see 9, where the results given by the method are shown; see also table 1.

9. EXAMPLE OF DESIGN AND ANALYSIS

Fig. 1 shows an hypothetical experiment designed on the uniformity trial of Lander et al (1938); for reasons of brevity we use only 65 of the 195 plots of the trial.

Attention should be paid, to distribute as well as possible the repetitions of each treatment in all the field; minimum distance between two repetitions should be maximized. Number of repetitions may vary, if convenient or necessary, from treatment to treatment. It is desirable for the plots adjacent to those of a treatment, to belong each one to a different treatment; but when comparison of two treatments is especially important, it is desirable to have them always in adjacent plots. Each plot is adjusted on the basis of **d** (average of the two d of adjacent plots; but when the difference d-**d** exceeds the gap limit, adjustment is done on the basis of d of one only adjacent plot, from which is not separated by a gap; and the same is done in the case of plots at the end of a file; when this is not possible, the plot is not taken in consideration, it is abnormal.

To begin 2nd adjustment we determine the deviation of not adjusted yield of each plot from the treatment average after first adjustment; and the operation continues in the same way.

To begin 3rd adjustment we determine the deviation of not adjusted yield of each plot from treatment average after 2nd adjustment; and the operation continues in the same way. But if this adjustment is the final one, we calculate b, the coefficient of covariation of d on **d**, and instead of substracting **d**, we substract b**d**.

Table 2 gives the mean yields of the 13 treatments before and after the first, second and third adjustment. It gives also the square of the "real" error of these average yields; it has been progressively reduced from 131 to 84, 66 and 64, that is by 51%; for the 7 treatments with 5 repetitions — no abnormal plot has been eliminated — the reduction is from 124 to 67, 76 and 41; for the 6 treatments with 4 repetitions — 1 abnormal plot has been eliminated — the reduction is from 138 to 82, 84 and 91.

To calculate the error with simulation method we begin by computing the deviations of the yield of each plot after 3rd adjustment from the corresponding treatment average. Then we planify (see table 3) what adjacent plot will replace each plot of each treatment; each plot is replaced with one no abnormal plot adjacent to it and from which it is not separated by a gap; 1 and if necessary more than 1 plot of each treatment is not replaced; the plots that are summed in each case should belong, if possible, each one to a different treatment. We sum algebrically the deviations corresponding to each treatment, we divide by the number of repetitions, which differs from treatment to treatment because of abnormal plots; we square; we sum; we divide by the number of treatments; and we have the calculated square of error, irrespective of the number of repetitions. If we desire to have separate estimations of the error, according to the number of repetitions, we sum separately the squares of treatments with 4 and 5 repetitions, and we calculate the corresponding averages; naturally the number of treatments of each category should not be too low.

As the comparison of tables 2 and 3 shows, there is very good agreement between computed and real error. Here are the figures (squares):.

	Computed	Real
General	61	64
4 repetitions	82	92
5 repetitions	42	41

With classical methods the difference between computed and real error is enormous, see table 1. This is because, for reasons we cannot forsee, each distribution, while all at random, results in a different compensation, more or less effective, of soil productivities, simulation method gives the error of the distribution we have applied.

Pc	Tr	y	A d	d	Tr	y	B d	d	Tr	y	C d	d	Tr	y	D d	d	Tr	y	E d	d
1	13	83	−44	–	7	88	−13	–	2	88	−22	–	8	63	−63	–	6	132	+17	–
2	2	85	−25	−38	6	113	−2	−4	8	110	−16	−12	10	102	−43	−25	11	113	+10	+16
														gap						
3	11	72	−31	−45	2	116	+6	~~−32~~	4	121	−3	−28	5	132	+13	~~−25~~	1	129	+14	+5
		gap				gap				gap										
4	9	66	−65	−40	8	63	−63	~~−17~~	3	77	−41 Abn	~~−5~~	12	105	−7	+4	2	110	0	+20
										gap										
5	4	74	−50	−46	10	105	−40	−52	7	94	−7	−20	11	99	−4	−17	12	138	+26	+18
6	12	85	−27	−33	9	91	−40	−32	6	116	+1	+16	7	74	−27	~~+27~~	7	138	+37	+18
										gap				gap						
7	6	99	−16	−30	1	91	−24	−27	11	143	+40	+24	4	182	+58	~~+12~~	10	154	+9	+39
8	1	83	−32	−22	5	105	−14	−41	12	158	+46	~~+3~~	13	179	+52	+50	5	160	+41	+24
						gap				gap										
9	3	91	−27	−23	4	66	−58 Abn	~~−14~~	13	94	−33 Abn	~~+41~~	2	151	+41	+30	13	165	+38	+56
						gap				gap				gap						
10	5	105	−14	−8	11	88	−15	−48	1	151	+36 Abn	~~−30~~	9	138	+7	+24	9	201	+70	+51
										gap										
11	7	113	+12	0	12	74	−38	−14	5	91	−28 Abn	~~+32~~	1	121	+6	+10	3	182	+64	~~+98~~
										gap									gap	
12	8	140	+14	+4	13	113	−14	−24	9	160	+29	+25	3	132	+14	+2	8	253	+127 Abn	~~+60~~
										gap									gap	
13	10	140	−5	–	3	107	−11	–	10	223	+78 Abn	–	6	113	−2	–	4	179	+55 Abn	–

TABLE 2.

Not adjusted (No), after first adjustment (1st), after second adjustment (2nd), and after third (3rd) adjustment yields of the experiment given as example· R = square of the "real" error of treatment mean yields.

Tr	No	1st	2nd	3rd	
1	115	114	117	116	
2	110	111	118	114	
3	118	119	112	114	
4	124	133	128	120	
5	119	134	134	135	
6	115	115	121	118	
7	101	103	104	106	
8	126	117	110	106	
9	131	126	126	127	
10	145	131	130	127	
11	103	117	117	120	
12	112	109	117	118	
13	127	121	124	126	
R	131	84	66	64	General
R	124	67	76	31	5 repetitions
R	138	82	84	91	4 repetitions

Fig. 1. Plan of an hypothetical experiment on Lander et al (1938) uniformity trial. See 9, and tables 2 and 3;5 blocks, A, B, C, D, E; 13 plots pel block; tr = treatment; y = yield. **First adjustment**: d = deviation from treatment mean yield; **d** = average d of the two contiguous plots; limit of adjustment = standard deviation of the difference of d between adjacent plots > 33 and < 34; when the difference between adjacent plots, positive or negative, is ⩾ 34, we consider, that there is a gap between them. The yield of each plot is adjusted substracting **d**, but when the difference d-**d**, positive or negative, is ⩾ 34, the adjistment i sdone substracting d of the contiguous plot, from which it is not separated with a gap; and in the same way we adjust the plots that begin or end a file; when that also is impossible, because of gaps, the plot is considered as abnormal, and it is not taken in consideration. *N. B.* For typing reasons underlined d of the plan is written **d** in the text and this legend.

T A B L E 3.

The table shows, for each treatment, the plots, whose deviations, d, are summed; f. i. 6/7 in line 1 of block A means plot A 7 of treatment 6, with d + 12; as the table shows the d summed belong each one to a different treatment and to plots contiguous to those of the treatment, whose sum is calculated. The table shows also, how these d are averaged, squared, summed, and averaged, to have error square. See plots in fig. 1; but adjustments have changed abnormal plots.

Tr	Block A Tr/Pl d	Block B Tr/Pl d	Block C Tr/Pl d	Block D Tr/Pl d	Block E Tr/Pl d	Mean	Squ.
1	6/ 7 +12	5/ 8 +12	abn.	9/10 — 6	1/ 3 +19	+37/4 = + 9	81
2	11/ 3 — 4	2/ 3 +29	8/ 2 +21	13/ 8 +11	12/ 5 + 8	+65/5 = —13	169
3	5/10 —24	3/13 + 3	4/ 3 +18	6/13 —24	9/10 +21	— 6/5 = — 1	1
4	9/ 4 —13	11/10 +17	3/ 4 —29	7/ 6 —15	abn.	—40/4 = —10	100
5	3/ 9 + 7	1/ 7 + 5	abn.	12/ 4 — 3	13/ 9 — 9	0/4 = 0	0
6	1/ 8 —12	7/ 1 —10	6/ 6 —10	3/12 +20	11/ 2 — 8	—20/5 = — 4	16
7	8/12 +24	6/ 2 + 4	7/ 5 + 7	4/ 7 +10	10/ 7 — 1	+44/5 = + 9	81
8	7/11 + 7	8/ 4 —30	2/ 1 —26	10/ 2 — 2	abn.	—51/4 = +13	169
9	4/ 5 — 2	10/ 5 +17	9/12 + 9	1/11 —10	3/11 — 3	+11/5 = + 2	4
10	10/13 —15	9/ 6 —11	abn.	8/ 1 —16	7/ 6 +11	—31/4 = — 8	64
11	2/ 2 +12	4/ 9 —26	12/ 8 +15	11/ 5 — 1	6/ 1 +18	+18/5 = + 4	16
12	12/ 6 + 3	13/12 +10	11/ 7 + 6	5/ 3 +16	2/ 4 —19	+16/5 = + 3	9
13	13/ 1 —12	12/11 —25	abn.	2/ 9 + 5	5/ 8 — 5	—37/4 = — 9	81
Sum							791

791/13 = 61 = error square of treatments mean yields after 3rd adjust.
According to nimber of repetitions:
4 repetitions: (81+100+0+169+64+81)/6 = 82
5 repetitions: (169+1+16+81+4+16+9)/7 = 42

Distribution should be efficient. To obtain that we distribute as well as possible the repetitions of each treatment in all the field; minimum distance between two repetitions of the same treatment should be as great as possible; when possible the plots adjacent to those of each treatment should belong each one to a different treatment; that improves adjustment and facilitates application of simulation method; but if we are interested in a particular treatment comparison, the repetition of these treatments should be always contiguous (split plot technique). However the analysis proposed in this communication can be applied to experiments with classical or other design. Number of repetitions may vary from treatment to treatment, according to its importance, available seed, etc. Division of the field in blocks facilitates the design, but they are not rigidly respected; they should correspond to different levels of productivity, but that naturally is rarely possible.

10. WARNING: COMPETITION BETWEEN ADJACENT PLOTS, NEGATIVE CORRELATION BETWEEN THEM

When two plants grow at a little distance from one another, they compete; the yield of one increases, while that of the other decreases; when for whatever reason one plant grows better than its neighbour, it reduces its neighbour growth, and may cause its death. In the case of crops, as wheat, that are sown densely, only a small percentage of the plants that germinate arrive at maturity, the great majority die in the mean time; but if you sow the seeds at a great distance from one another, and you control carefully weeds, the majority of the seeds gives ripen plants with several dozens of ears each one. Neighbour rows of adjacent plots compete to one another, and this fact invalidates many experiments, because it distorts relative yields. the object of the experiment. The fact is long ago known and has been called interference; to reduce it border lines are eliminated, but that often results in operational errors. To reduce this systematic error, I was using, in wheat experiments, plots not narrower than 2 meters; plots were separated with 50cm corridors, sown with Triticum monococcum; plots were sown by hand in rows perpendicular to their length, and attention was paid, to have one at least plant at the two ends of these short lines; naturally all that was increasing costs. In the case of pocket experiments, one plant per pocket, the distance between wheat pockets was 50cm; such distance should be naturally considerably increased in the case of bigger plants, as maize. Tree experiments are often useless, because the distance between trees in insufficient to exclude competition, and there is sometimes negative correlation between adjacent plots. In tree experiments it is difficut to avoid competition, unless ditches, sufficiently deep are open to impede passage of roots from one plot to another.

Competition reduces correlation between adjacent plots, and may make it negative; adjustment on the basis of adjacent plots becomes less advantageous; but more important than that, relative treatment yields are distorted, and the experiment is useless. Since plants compete chiefly by their roots (Pickering 1917, Papadakis 1938, 1941, 1954, 1971, 1977, 1981) a study of the extension of border lines roots is useful.

11. RECUPERATION OF INFORMATION FROM EXPERIMENTS CARRIED OUT WITH OTHER METHODS

As pointed out in paragraph 9, we reduce error with adequate distribution; but experiments designed with other methods can be analysed with my method; treatment yields are improved, error is reduced, and formerly insignificant differences become significant, permitting conclusions.

12. EXPERIMENTS IN POCKETS, TREE EXPERIMENTS

Due to the mechanism of plant competition there is antagonism between productivity and aggressivity. As a result when genetically different individuals are grown together, the less productive are advantaged and selected; to discover and select the most productive it is necessary to exclude competition. That is why I have introduced experiments in pots, 1 plant per pot, and field experiments in distanciated pockets (50cm in the case of wheat), 1 plant per pocket (Papadakis 1935, 1937, 1938). In these experiments the yield of each pocket is adjusted on the basis of 4 adjacent pockets. In tree experiments 1 pocket contains 1 tree; but trees should be separated by ditches sufficiently deep to impede root passage; otherwise the surface exploited by each tree differs considerably from the presumed one, and relative treatment yields are distorted.

13. FACTORIAL EXPERIMENT

In the Institute of Thessaloniki I did many experiments with many levels of each factor. They conduced me to adopt a new method (Papadakis

1954); the number of levels is increased, but each level is repeated only once, except some "cardinal" levels, as level 0 in fertilizer experiments; deviations are calculated, supposing that between 3 neighbour levels yields increase or decrease lineally; that permits to use my method.

14. GENERAL OBSERVATION

For a long time the analysis of field experiments has been faced as an exclusively mathematical problem, ignoring the peculiarities of field heterogeneity, etc. The mathematical aspect is certainly fundamental, but to apply mathematics to a problem, it is also useful to know well the problem studied. And we can hope, that following this way we can arrive to important advances.

On the other hand for a long time methods of analysis of field experiments have been too rigid. A certain elasticity may be useful.

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ΠΕΡΙΛΗΨΗ

Τὸ 1937 δημοσίευσα μιὰ μέθοδο ἀνάλυσης τῶν πειραμάτων στὸν ἀγρό, ἡ ὁποία αὐξάνει σημαντικὰ τὴν ἀκρίβεια τοῦ πειράματος. Ὕστερα ἀπὸ 30 χρόνια ἐγκατάλειψης τῆς μεθόδου, μετὰ τὸν τελευταῖο παγκόσμιο πόλεμο, ἡ μέθοδος τράβηξε τὰ τελευταῖα χρόνια τὴν προσοχή. Τουλάχιστον 9 μελέτες δημοσιεύθηκαν πάνω στὴ μέθοδό μου καὶ τὸ British Council διώρισε ἐπιστήμονες γιὰ νὰ μελετήσουν τὴ μέθοδο. Ἀλλὰ ὅλοι αὐτοὶ οἱ ἐπιστήμονες μελέτησαν μόνο τὶς 9 σελίδες τῆς ἐργασίας μου τοῦ 1937 ἢ τὴν ἐργασία τοῦ Bartlett (1938) πάνω στὴ μέθοδό μου. Δὲν διάβασαν τὶς μεταγενέστερες ἐργασίες μου (Papadakis 1940, 1954, 1970). Καὶ συνεπῶς ἀγνοοῦν μερικὲς τελειοποιήσεις, οἱ ὁποῖες αὐξάνουν πολὺ τὴν ἀκρίβειά της. Σκοπὸς τῆς σημερινῆς ἀνακοίνωσης εἶναι νὰ καταστήσω γνωστὲς αὐτὲς τὶς τελειοποιήσεις καὶ νὰ συζητήσω μερικὲς ἀπόψεις τοῦ θέματος ποὺ ἀγνοοῦνται. Μποροῦν νὰ συνοψισθοῦν στὰ ἑξῆς: 1) Σχεδιάζοντας ὑποθετικὰ πειράματα πάνω σὲ δοκιμὲς ὁμοιομορφίας (uniformity trials) μποροῦμε νὰ προσδιορίσομε τὸ «πραγματικὸ»

λάθος καὶ νὰ συγκρίνομε «πειραματικῶς» διαφόρους μεθόδους. Μ' αὐτὸ τὸν τρόπο ἔδειξα ὅτι ἡ μέθοδός μου εἶναι ἀκριβέστερη ἀπὸ τὶς κλασσικὲς μεθόδους οἱ ὁποῖες εἶναι ἐπὶ πλέον ἀνακριβεῖς στὴν ἐκτίμηση τοῦ σφάλματος. 2) Στὸν ἀγρὸ ὑπάρχει συσχέτιση (correlation) μεταξὺ τῆς παραγωγικότητας κοντινῶν τεμαχίων καὶ ἡ ἀκρίβεια ὁποιασδήποτε μεθόδου ἐξαρτᾶται ἀπὸ τὸ κατὰ πόσον ἐπωφελεῖται αὐτῆς τῆς συσχέτισης. Ἡ συσχέτιση εἶναι μεγίστη μεταξὺ διπλανῶν τεμαχίων καὶ γι' αὐτὸ τὸ λόγο ἡ μέθοδός μου εἶναι ἡ ἀκριβέστερη. 3) Στὸν ἀγρὸ ὑπάρχουν χάσματα (gaps, ἀπότομες αὐξήσεις ἢ πτώσεις τῆς παραγωγικότητας) καὶ ἀνώμαλα (abnormal) τεμάχια, τῶν ὁποίων ἡ παραγωγικότητα διαφέρει πολὺ ἀπὸ τὰ δύο διπλανὰ τεμάχια καὶ ἀπὸ τὸ μέσο ὅρο τους. Προσδιορίζοντας ἀντικειμενικὰ αὐτὰ τὰ χάσματα καὶ ἀνώματα τεμάχια, καὶ μὴ λαμβάνοντάς τα ὑπ' ὄψιν, αὐξάνομε πολὺ τὴν ἀκρίβεια. 4) Ἡ διόρθωση μπορεῖ νὰ γίνει καὶ μὲ βάση ἄλλα κριτήρια. Ἡ μία διόρθωση δὲν ἀποκλείει τὴν ἄλλη, χρησιμοποιώντας συντελεστὴ πολλαπλῆς συσχέτισης (multiple covariation) ἡ μέθοδος αὐτὴ ὑπόσχεται πολλά. 5) Ἡ ἀκρίβεια ἐξαρτᾶται ἀπὸ τὸ κατὰ πόσον ἡ μέση παραγωγικότητα τῶν ἐπαναλήψεων κάθε μιᾶς ἀγωγῆς (treatment), διορθωμένη ἢ μή, διαφέρει ἀπὸ τὴ μέση παραγωγικότητα τοῦ ὅλου ἀγροῦ. Διάφορα σχέδια καταρτισθέντα μὲ τοὺς ἴδιους κανόνες, διαφέρουν πολὺ μεταξύ τους ἀπ' αὐτὴ τὴν ἄποψη. Γιὰ λόγους ποὺ δὲν μποροῦμε νὰ προβλέψομε, γιατὶ δὲν ξέρομε τὴν παραγωγικότητα κάθε τεμαχίου, μιὰ διανομὴ μπορεῖ νὰ εἶναι πολὺ καλύτερη ἀπὸ ἄλλη. Οἱ κλασσικὲς μέθοδοι δὲν λαμβάνουν ὑπ' ὄψη αὐτὲς τὶς διαφορές, καὶ γι' αὐτὸ τὸ λόγο ἡ διαφορὰ μεταξὺ «ὑπολογισμένου» καὶ «πραγματικοῦ» σφάλματος εἶναι ὑπερβολική, ὅπως ἀποδείξαμε «πειραματικῶς. Μὲ τὴν ἐργασία προτείνω μία μέθοδο «ἀπομίμησης» (simulation), ἡ ὁποία ἀπομιμεῖται τὸν τρόπο οἱ ἀποκλίσεις παραγωγικότητας μεταξὺ τεμαχίων τῆς ἴδιας ἀγωγῆς (treatment) ἀντισταθμίζουν ἡ μία τὴν ἄλλη καὶ περιορίζουν τὸ σφάλμα. Ἡ ἐργασία δείχνει «πειραματικῶς» ὅτι ἡ μέθοδος αὐτὴ περιορίζει στὸ ἐλάχιστο τὴ διαφορὰ μεταξὺ ὑπολογισμένου καὶ «πραγματικοῦ» σφάλματος. 6) Οἱ χαμηλὲς ἢ ἀρνητικὲς συσχετίσεις μεταξὺ διπλανῶν τεμαχίων ὀφείλονται σὲ ἀνταγωνισμὸ ἀκρινῶν γραμμῶν, ὁ ὁποῖος εἶναι ἀπὸ παλαιὰ γνωστὸς μὲ τὸν ὅρο «interference», διαστρεβλώνει τὶς σχετικὲς ἀποδόσεις τῶν ἀγωγῶν (treatment) καὶ κάνει τὸ πείραμα ἄχρηστο. Πρέπει νὰ λαμβάνονται μέτρα γιὰ νὰ ἀποφεύγεται αὐτὸς ὁ συναγωνισμός. Στὴν περίπτωση τῶν δένδρων εἶναι πολὺ συχνός, καὶ μποροῦμε νὰ τὸν ἀποφύγουμε χωρίζοντας τὰ πειραματικὰ τεμάχια μὲ χαντάκια ἀρκετὰ βαθιὰ γιὰ νὰ μὴ περνᾶνε οἱ ρίζες ἀπὸ τὸ ἕνα τεμάχιο στὸ ἄλλο. 7) Ἡ μέθοδος ἐφαρμόζεται σὲ πειράματα σχεδιασθέντα μὲ ἄλλες μεθόδους καὶ μπορεῖ νὰ χρησιμοποιηθεῖ γιὰ νὰ βγάλομε συμπληρωματικὰ συμπεράσματα ἀπὸ πειράματα ποὺ εἶχαν ἀναλυθεῖ μὲ ἄλλες μεθόδους. 8) Γιὰ πολλὰ χρόνια ἡ ἀνάλυση τῶν πειραμάτων στὸν ἀγρὸ βασίσθηκε σὲ καθαρὰ θεωρητικὲς ἀπόψεις. Ἀλλὰ καὶ ἡ μελέτη τῆς ἀνομοιομορφίας τοῦ ἀγροῦ ἔχει σπουδαιότητα. Καὶ ὁ συνδυασμὸς τῶν δύο ἀπόψεων μπορεῖ νὰ ὁδηγήσει σὲ μεγάλες προόδους.

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