A procedure for collecting and interpreting data from field experiments with nematicides

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SUMMARY

In the first part of the paper the main criteria necessary to study the nematicidal properties of different chemical compounds are discussed. A procedure to record qualitative variables (plant vigour, gall index) is also discussed.

In the second part a statistical approach, liable to increase the power of the techniques as compared with conventional procedures, is treated. This allows reference to the entire nematode population including all species present, to demonstrate similarities of and differences between the pesticides studied and to utilize qualitative and quantitative data simultaneously.

Techniques involved belong to the non parametric and newly developed multivariate statistical methods such as : factor analysis, discrimant analysis, Friedman's variance analysis and rank correlations.

RÉSUMÉ

Une méthode pour collecter et interpréter les données fournies par des essais de nématicides au champ

Dans une première partie, les principaux critères expérimentaux nécessaires à l'évaluation des propriétés nématicides de différents composés chimiques sont discutés ainsi qu'un procédé particulier de notation des variables qualitatives (vigueur de la plante, index de galles). La valeur et la représentativité des données sont également discutées.

Dans la deuxième partie sont représentées quelques techniques statistiques susceptibles d'élargir le jugement par rapport aux techniques conventionnelles. Elles permettent d'évaluer globalement l'activité nématicide des produits sur la totalité des espèces de nématodes sans se limiter aux seuls ravageurs. Elles permettent également d'établir des liens de ressemblance entre les divers pesticides eu égard à leur action sur les différentes espèces de parasites et de traiter simultanément les données qualitatives et quantitatives.

Les méthodes utilisées font appel aux analyses statistiques multivariates et non paramétriques : analyse factorielle des correspondances, analyse factorielle discriminante, analyse de variance de Friedman et corrélation de rang.

Methods are described to evaluate compounds with nematicidal properties, using experimental designs developed by Good, Sasser and Miller (1963), Good and Raukin (1964), McBeth (1969), Ritter, Scotto la Massese and Cuany (1970), Kämpfe (1971) and Bunt (1975). Using randomized blocks or Latin squares designs, experiments were made using *Meloidgyne* spp. as test animals and tomato as a host.

Tomato was chosen as a host because of its easily measurable reactions to *Meloidogyne* infection, marked yield decreases and obvious root symptoms (galling). After reviewing the main experimental criteria, the extent to which experimental results are representative of the treatments given, and statistical techniques adapted to interpret data in this specific problem are discussed. Other methods may be applied when experimental conditions so demand and a few of these techniques are cited.

Selection and notation of data

To measure the efficacy of a nematicide, its action on plants at different physiological stages and on parasitic and non-parasitic soil nematodes should be recorded.

At the beginning of the experiment, ranked ratings were assigned for plant vigour in plots within each block. Thus, the rating 1 is given to the plot showing the weakest growth and 2, 3, ..., n (n is the number of plots per block) are assigned according to increased vigour. Where growth was equal, average rank was given to the plots concerned. Thus in a block of 6 plots where ranks 1, 2, and 3 can be assigned without ambiguity and the remaining plots have the same plant vigour, all three can be given the rank : $\frac{4+5+6}{3} = 5$. The data thus obtained may be analyzed by particular techniques (analysis of Friedmann, 1937). This type of analysis is also suitable for the treatment of gall indices. The efficacy of a product to control *Meloidogyne* spp. is expressed by the degree of root galling as follows : 0 : no galls; 1 : few galls of 1 to 2 mm in diameter; 2 : numerous galls of 2 mm; 3 : few galls of 5 to 8 mm; 4 : numerous galls up to 1 cm in diameter; and 5 : coalescent galls. The mean of the indices of all plants within blocks makes it possible to rank the data within each block in the same way as was done for plant vigour. Another type of analysis for independent data (pot trials) is the analysis of Kruskal and Wallis (1952).

Fruits were harvested as they matured (three to five harvests depending on cultivars). Number and weight of fruits can be treated by analysis of variance of canonic correlation (Tomassone, 1974). Identification of other nematode species present gives additional information and supplement data based on symptoms and damage, thus allowing evaluation of the specific effect of the compounds and their influence on biocoenosis. In fact, if a relation exists between root reaction and penetration of larvae of *Meloidogyne*, it does not measure their development within roots. Thus, the root-knot index does not allow measurement of the systemic effects of chemicals, especially if the treatment is made after roots have been invaded.

In addition to the parasites intended to be controlled, other species should also be considered. The general concept of phytosanitary trials is often in contradiction with this scientific point of view. Although it is realized that the parasite constitutes a production problem, it is part of a complex with a real biological cohesion between components. Subject to pressure by the other components, the parasite cannot constitute the central element any more, and its elimination should not represent the only standard for judging a nematicide. Unfortunately, the results of analyses are not always very clear. Certain particular characters of nematodes (contagious distribution, sometimes rapid recolonization by certain species) make it necessary to ascertain the validity of nematological analysis : previous study of their distribution, transformation of data (Merny & Déjardin, 1970). Elliot (1977) has developed a number of techniques for the bentic fauna which can be applied to soil nematodes. Taking the entire population into account, more general techniques (multivariate analysis) can be used, as will be discussed below.

Finally, records should be made if treatments exert an influence on plants and other members of the biota (weeds, fungi, insects, molluscs, worms), whether they are useful or harmful. By recording certain variables using a special notation, a skeletal framework can be established for complementary studies. Values of 0 or 1 are allotted to the variables. In judging leaf colour related to virus attack, for example, a row of four figures may represent the aspect of the leaves, the first representing virus symptoms, the second yellow leaf colour, the third light green and the fourth dark green. Thus 1100 represents presence of virus and yellow foliage, 1010 virus infection and light green foliage etc. These « presence-absence tables » can be studied by factorial analyses or by non parametric techniques (Cochran, 1950).

Data interpretation

Complexity of interpretation

Evaluation of a nematicide is based on the determination of the number and the species of nematodes surviving the treatment and secondly on the improvement of yields. Final judgement is based on these two criteria which

not necessarily need to coincide. Therefore, statistical analyses applied separately to each of these criteria sometimes result in different interpretations.

Many examples are known of phytotoxic products which, by interfering with root development, simultaneously decrease nematode reproduction and yields. Sometimes final populations in nontreated plots, decrease considerably compared to treated plots if development of nematodes in controls is inhibited by the presence of other organisms. *(Pyrenochaeta lycopersici, Colletotrichum coccodes)*. Under such conditions populations in nontreated plots tend to be lower than in those where polyvalent products were applied. The same phenomenon may occur when a high population of a nematode species suppresses the population of the species under study. By studying data separately the ignorance of pathogenecity of many nematodes persists.

Other factors, such as inbalance between leaves and fruit production, effects on earliness, modifications interfering with the nitrogen cycle and other ecological aspects should also not be neglected. Often changes caused by soil treatment exert a favourable influence on the metabolism of plants and justify such treatment independent of phytosanitary considerations. Because of « stimulatory effects », it is advised not to rely on a single experiment. In fact, the effect often becomes less obvious after repeated treatments (Cuany, Lavergne & Mars, 1977). Therefore, it is better to separate the action of nematodes from other factors influencing yields (Scotto la Massese, 1971); such a separation is difficult to achieve under field condition. Concerning the criteria necessary for making decisions, too much emphasis is placed on quantitative variables (weight etc.), qualitative criteria (fruit shape and colour) are also valuable characters. Classification of quantitative variables is also a mean for studying nonlinear relationships.

On the other hand, the significance levels usually fixed at 0.01 and 0.05 are sometimes too low and sometimes too high. To predict yield improvements of a low priced crop with a risk of 5 % of making a wrong decision may not be logical, whereas in a valuable crop it may be worthwhile to treat even if, in 70 % of the cases, no improvements should be expected.

Recent developments in agriculture necessitate not only studying the disappearance of a parasite following treatment but to consider economical and ecological factors (pollution) as well. Some examples of multivariate factorial analysis and non parametric methods are presented to become familiar with these techniques. For the first category of techniques it is necessary to have access to a computer, FORTRAN programmes for these tests have been developed (Lebart & Fenelon, 1978). As far as non parametric techniques are concerned, their easy application will be demonstrated.

Multifactorial analyses

Data analysis comprises a set of more or less related techniques, intended to obtain a synthesis and classification of results obtained. Two methods suitable for nematology are presented here :

factor analysis

discriminant analysis.

In the example presented these techniques are applied to the results of a routine analysis (Tabl. 1).

Factor Analysis (F.A.)

This technique is adapted to the study of positive data organised in matrices with two indices : rows and columns and especially for « contingency tables ». In Table 1, the rows represent the samples, each sample being a replication of a certain treatment, and the columns different species of nematodes. Each row is characterized by its « profile », i.e. by the percentage of the total population for each species, and its « weight », i.e. the total of the row. Two samples can be considered identical if the relative abundance of all species is the same in both samples.

In the Factor Analysis, each sample is represented by a point in a space with as many dimensions as species or each species by a point in a space with as many dimensions as samples. In both cases, a set of points is obtained. Both representations are linked and species-representing and sample-representing points can be drawn on the same diagram. In each space defined either by species or by samples,

the computer defines orthogonal axes (factors) which are the lowest inertia axes of both sets of points. In Figure 1, variables (nematode groups) and samples (treatments) are represented simultaneously on a plane defined by the two first factors.

In the present example, the numbers of nematodes belonging to ten different groups (A, B, C, ...J) have been counted in samples of soils having received one of thirteen treatments. Each treatment is designed by a two- or three-figure number. The last figure represents the replication and the first ones the treatment. Thus, number 12 means first treatment and second replication whereas number 134 means treatment 13 and fourth replication.

The reading of the diagram, in Figure 1, is different from that of a classical cartesian diagram. Three important points must be considered.

The notion of contribution. In F.A., each element (in the present case species or samples) plays a more or less leading part in the definition of a factor. The *absolute contribution* of an element in a factor is the part played by this element in the variation explained by the factor. The proportion of the variation of an element explained by a factor is the *relative contribution* of this factor to this element.

Only elements with high relative contribution are taken into consideration in reading the graph. The results identify only variables A and F on factor 1 and variable D on Factor 2 (Tabl. 2).

The notion of proximity. The proximity of two points indicates a close link of these points when both have a high relative contribution from the factors under consideration (as in the case of points 14 and F, 102 and A on factor 1 and points 31 and D on factor 2), whereas a large distance between them indicates opposition (variables F and A on factor 1 for instance).

Table 1

Effect of 13 different nematicides on numbers of various non phytophagous and plant parasitic nematodes found in 100 g of soil (averages of five replications).

Treatments	Nematodes									
	non phytophagous nematodes	*Dorylaimida*	*Mononchidae*	*Tylenchus* spp.	*Aphelenchus avenae*	*Meloidogyne arenaria*	*Macroposthonia* spp.	*Rotylenchus laurentinus*	*Tylenchorhynchus ventrosignatus*	*Pratylenchus thornei*
1	186	99	3	210	27	850	11	410	2	12
2	45	21	2	94	5	38	10	80	0	6
3	107	40	0	142	8	13	21	112	2	0
4	182	43	0	136	13	232	5	171	0	2
5	184	74	0	126	19	371	8	196	0	0
6	226	16	0	67	13	8	11	96	0	11
7	154	3	0	58	21	226	2	99	0	0
8	87	5	0	21	16	0	3	10	0	0
9	299	38	3	170	24	160	13	360	0	18
10	445	20	0	74	19	13	3	128	0	13
11	269	35	0	138	19	133	21	219	0	13
12	109	2	0	5	6	1	3	3	0	8
13	95	4	0	20	29	46	3	38	0	2

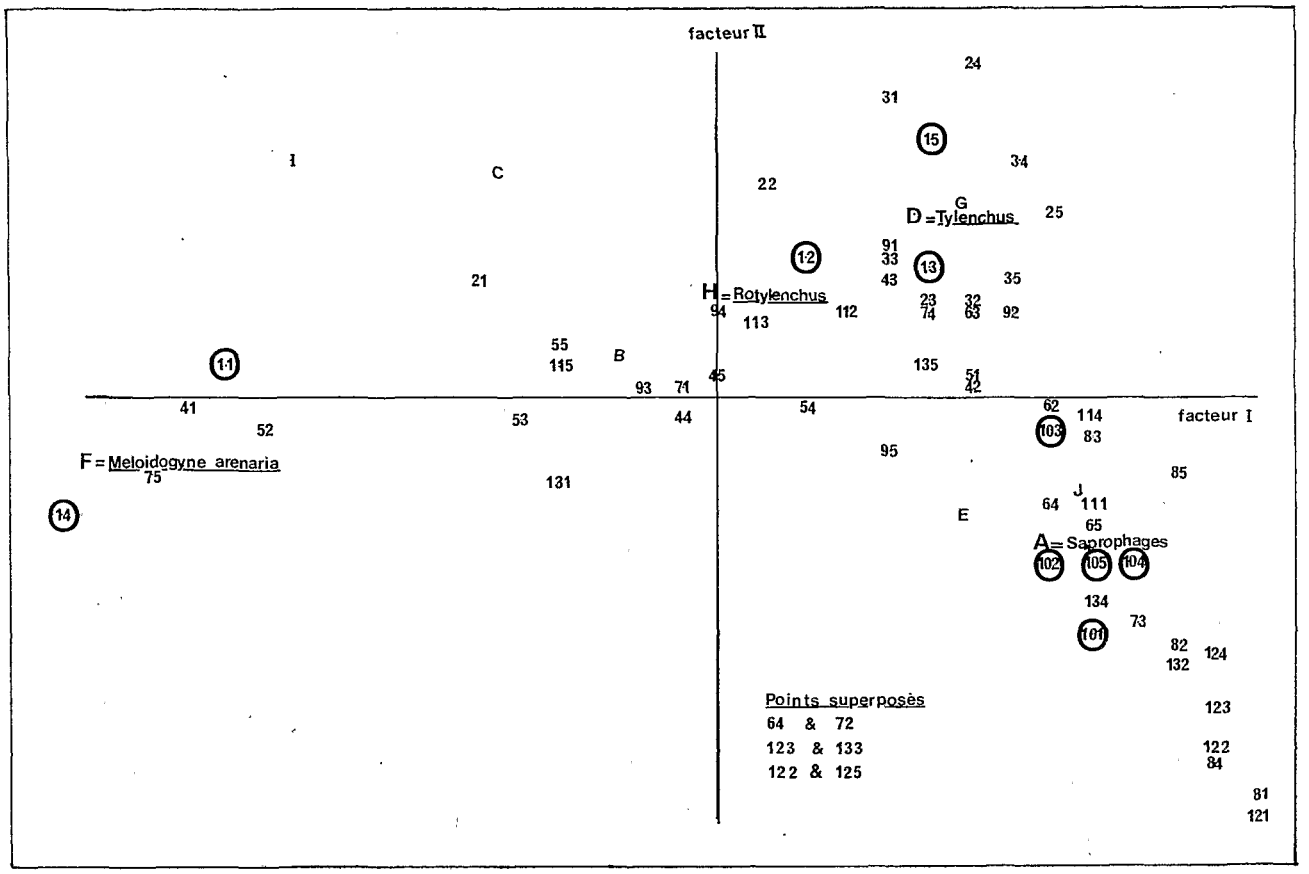

Fig. 1. Representation of nematode species (letters) and treatments (figures) on a plane defined by the two first factors (F.A.).

However, the position of a particular point on the graph, in relation to one of the factors, does not necessarily indicate a simple gradient. So, the placement of point 14 opposite variable A does not mean that the number of nematodes A, counted in sample 14, is smaller than the number in sample 102. It means that the variable F plays a leading role in situating point 14. We can thus study population « profiles » taking into account all interspecific relationships.

The notion of variability. Even if the phenomenon is well explained by the plane defined by factors 1 and 2, a certain variability remains unexplained. In the present example, seven species are not characterized by the two first factors (they all have a low relative contribution value). They can be characterized by a third or a fourth factor perpendicular to the plane of the first two ones. In this experiment nematode H has a high relative contribution from the third factor (Tab. 2). The proximity of two points on the plane does not necessarily mean a corresponding spatial proximity and so, before coming to conclusions about the similarity of their behaviour, we have to consider the relative contribution of the other factors. In fact, in the present example, only 72.69 % of the information is explained by the first two factors (Tab. 2 « cumul » column). More than a quarter of the information is explained by the other factors.

Discussion. Reading the graph on Figure 1 is complex and can only be interpreted using the elements given in Table 2, allowing consideration of the notions cited above.

Table 2

Contributions values

	Factor I		Factor 2		Factor 3	
	Relative Contributions (RC)	*Absolute Contributions (AC)*	*RC*	*AC*	*RC*	*AC*
1 — Variable points						
A	*676*	259	304	369	3	7
B	15	1	38	8	56	24
C	12	0	43	3	44	7
D	273	60	*474*	329	209	307
E	148	15	61	20	25	17
F	*967*	646	24	51	6	29
G	98	8	128	32	1	1
H	0	0	406	180	*547*	513
I	26	0	24	1	42	5
J	102	11	17	6	121	91
2 — Observation points						
101	*434*	23	391	65	43	15
102	*523*	11	282	18	106	14
103	*842*	13	18	1	31	3
104	*664*	23	215	23	8	2
105	*599*	32	242	41	0	0
31	93	4	*547*	84	54	17
11	*880*	119	12	5	49	45
12	79	2	*493*	30	81	10
13	*463*	10	*432*	29	29	4
14	*892*	246	72	63	18	34
15	125	6	*464*	72	260	85

Variability explained by the factors

		% of variability	Cumul
Factor 1	0.3793	55.298	55.29
Factor 3	0.1119	17.392	**72.69**
Factor 3	0.0563	8.214	80.90
Factor 10			100

If we consider the distinction between the control plots, coded 11-12-13-14 and 15, and the plots treated with DB 185 (92,5 % ethylene dibromide applied at 58 kg active ingredient per ha), coded 101-102-103-104 and 105, it is evident that these two sets of points differ in the way nematodes are controlled. The DB 185 points are located opposite the F and D species, *M. arenaria* and *Tylenchus* spp., which are well controlled. In this case only non-phytophagous nematofauna (A) survive. At the same time all the check points remain close to the points of the phytophagous species in spite of a certain dispersion resulting from the natural heterogeneity. On the other hand, points representing treatments 4 and 5 are close to the control points, indicating that their effect on nematofauna is very weak. Each treatment should be considered in the same way. Consideration of the third factor or axis in which the variable H *(Rotylenchus laurentinus)* has a high relative contribution would give us additional information about the effect of various treatments on this nematode.

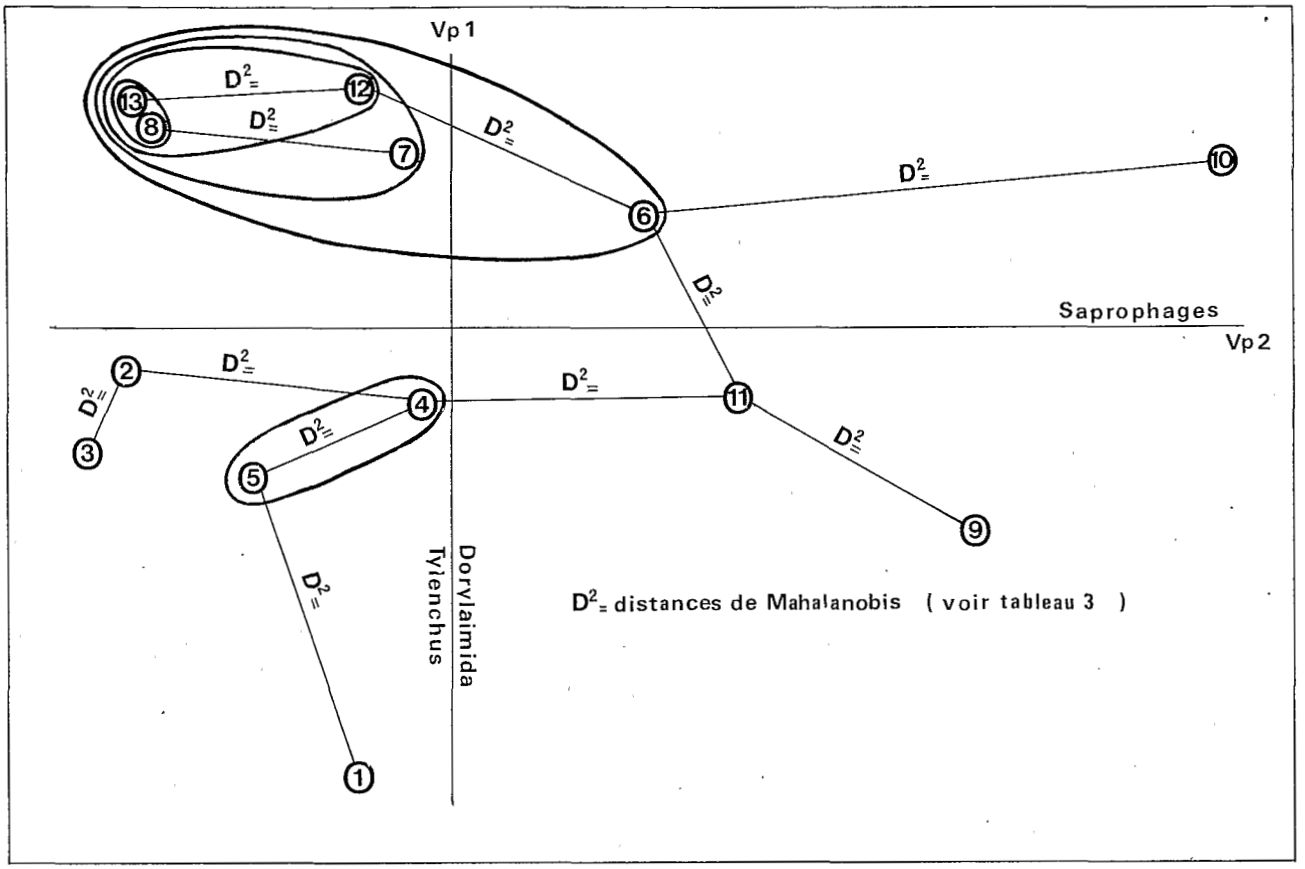

Fig. 2. Discrimination of the different treatments on a plane defined by the two first factors (D.A) with indication of the shortest distances between treatments.

Discriminant Analysis (D.A.)

In this analysis, the observations are grouped in several populations, known prior to the experiment. In the present example, each population consists of the different replications of the same treatment. As in the F.A. each observation is represented by a point in space, whose dimension is the number of variables; this also allows graphical representations. The purpose now, is to discriminate between the populations in the best possible way, thence in computing the factors, the variability *within* populations and the variability *between* them is distinguished. Therefore the factors are not the same as those computed with the preceeding technique or with a principal components analysis. Moreover, a distance is introduced, called « Mahalanobis distance » which allows the comparison of treatments.

The discriminating or separating potential of each factor, or axis, is tested. In the present example, we have a two dimensional space defined by two axes : 1, horizontal and 2, vertical, whose discriminant potentials have been tested by a highly significant χ^2 (Fig. 2).

Axis 1 is negatively correlated to nematode species groups B and D, Dorylaimida and *Tylenchus* spp. respectively.

Axis 2 is positively correlated to species group 4 (non-phytophagous nematodes). These variables allow the best discrimination between treatments. Variables A and D were already important in determining the two main factors in the F.A.

Table 3

Mahalanobis distances (× 100).

N° of the treatments	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*
2	2.233											
3	2.142	662										
4	1.881	483	802									
5	1.439	682	716	233								
6	3.828	753	1.303	714	1.277							
7	4.382	1.068	2.034	885	1.580	478						
8	4.876	831	1.684	1.179	1.657	510	293					
9	1.462	1.404	1.881	1.165	1.471	482	2.413	2.893				
10	5.470	2.468	3.062	1.666	2.497	642	1.214	1.684	2.078			
11	2.213	820	851	470	761	424	1.202	1.483	696	1.177		
12	5.403	1.016	2.089	1.404	2.128	358	384	167	2.842	1.317	1.461	
13	5.063	1.123	2.026	1.508	1.944	735	356	**84**	3.078	1.916	1.733	348

Other variables are correlated with axes having a non-significant discriminant potential. Variable F *(Meloidogyne arenaria)* is correlated with the third factor and variable H *(Rotylenchus laurentinus)* with the fourth factor. These factors are not represented here.

As in the F.A., the proximity of two points on a plane does not necessarily mean that they are close to each other. The calculation of their Mahalanobis distance provides a better comparison between treatments (Tab. 3). They can be analysed by two methods : (1) a statistical test carried out on the distance between two treatments; for example a generalisation of the « least significant difference », (Gigout, Masson & Millier, 1976). (2) classification of treatments based on the Mahalanobis distances matrix (Tab. 3). A dendrogram built by successive aggregation (ascending algorithm) is shown in Figure 3 : the first group consists of the two closest populations, in the present example populations 8 and 13, with a distance value of only 0.84. Then, the next closest populations, 12 and 7 and so on are incorporated. If a maximum distance level is computed, as for an identity test adapted to two populations (3.58 in the present case) treatments 6, 7, 8, 12 and 13 are included in a first group and treatments 4 and 5 in a second, all other treatments are considered different.

In this example, the conclusions drawn by D.A. are in agreement with those of F.A. and the links between treatments are determined with a better precision in D.A.

The results obtained with multivariate analyses allow us to draw conclusions about differences and similarities in the behaviour of pesticides towards the whole nematofauna and to determine, among the different species of nematodes, which are best indicators of the effects of nematicides. They should not prevent consideration of the initial data (Tab. 1), especially for interpretation of treatments results like n° 1, 2, 3, 9, 10 and 11 which differ appreciably.

Univariate analyses

Univariate analyses can be applied to quantitative as well as qualitative data. In experiments with nematodes, they can be applied to population evaluations, crop weight, gall index, vigor index and so on.

Analysis of variance as a complement to multivariate analysis

After having homogenised the variances, an analysis of variance can be carried out between treatments with all nematode species or groups. The results from this analysis can be compared with those of the discriminant analysis.

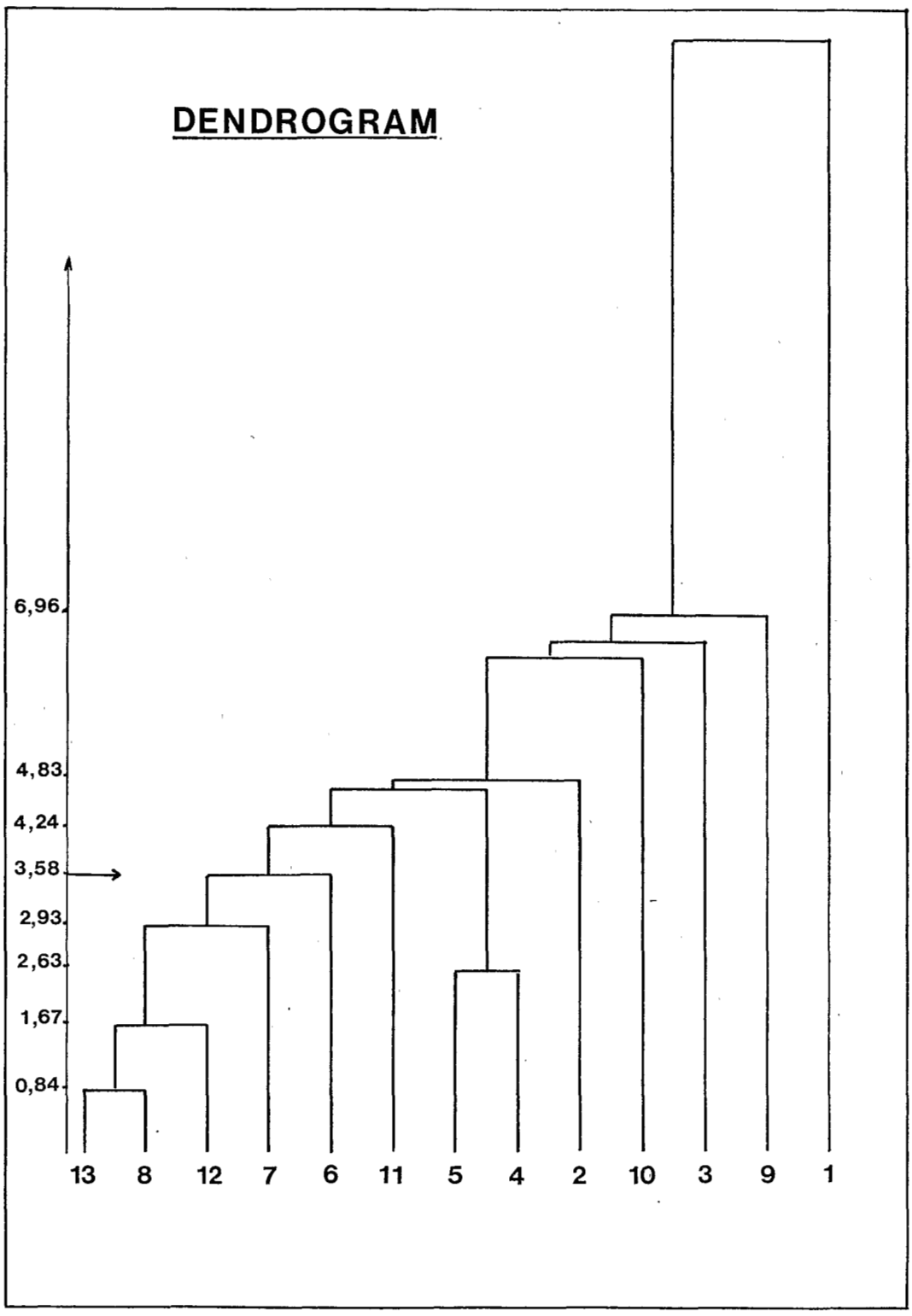

Fig. 3. Classification tree (dendrogram) of the thirteen treatments.

Table 4

Yields of the tomatoes cultivation.

N° of the treatments	*Chemical and amount of active ingredient per ha*	*Weight of fruit harvested on 10 tomato plants (averages of 5 replications)*	*Duncan's test at* $\alpha = 0,05$
4	Dacamox or 3,3 Dimethyl-1-(methyltio)-2-butanone 0-[(methylamino) carbonyl] oxime, 8 kg	40.54	
1	Check	44.43	
8	Éthylène dibromide (injection), 173 kg/ha of DB 185	46.66	
5	Dacamox 10 kg	47.86	
7	Éthylène dibromide (spraying application), 173 kg/ha of DB 185	48.86	
2	Aldicarb, 10 kg	50.12	
12	Ethylene dibromide (injection), 300 l	50.36	
9	Ethylene dibromide (spraying application), 58 kg/ha of DB 185	53.04	
11	Ethylene dibromide (spraying application), 87 kg/ha of DB 185	53.74	
3	Aldicarb - Sulfone, 12,5 kg	54.02	
10	Ethylene dibromide (injection), 58 kg of DB 185	54.86	
6	Ethylene dibromide (injection), 87 kg of DB 185	57.64	
13	Dichloropropane - Dichloropropène, 400 l	57.88	

Treatments have a significant effect ($P \leqslant 0.01$) on nematode species or groups A (non phytophagous nematofauna), B (Dorylaimida), D *(Tylenchus* spp.*)* and H. *(Rotylenchus laurentinus)* and at $P \leqslant 0.05$ for F *(Meloidogyne arenaria)*. A multiple comparison test (Duncan's test) carried out on the average populations A, F and H (Tab. 1) concurs with discriminant analyses of results.

— In treatment 1 (control) *Meloidogyne arenaria* and *Rotylenchus laurentinus* are especially abundant.

— In treatments 9 and 11 *Rotylenchus laurentinus* is abundant.

— In treatment 10 non-phytophagous species are abundant.

— In treatment 2, the populations of non-phytophagous nematodes are very low.

For crop yields, analysis of variance and Duncan's test give the classification shown in Table 4. It would be interesting to determine a possible correlation between the structure of nematode populations and crop yields. In treatments 8 and 12, although nematode populations are low (Tab. 1) crop yields are poor (Tab. 4) due to their phytotoxic effects. If these treatments are deleted, the coincidence between nematode populations and crop yield is fairly good.

Non-phytophagous nematodes do not seem to have any effect on the yield : treatments 6 and 10, which do not kill them, as shown in Figure 2, lead to the same yields as treatments 3 and 13 which kill them.

Dorylaimida and *Tylenchus* spp. seem to have a better reference value in making distinctions between treatments : they are more abundant in treatments 1, 2, 4, 5, 9 and 11 which have low yields than in treatments 6, 10 and 13 which have high yields. However, it should not be concluded that crop yields are only affected by these two nematode groups. The treatment had a significant effect on *Meloidogyne arenaria* and *Rotylenchus laurentinus*. Crop yield is low in treatments 1, 4, 5 and 7, where the population levels of both species are high, and high in treatments 2, 6 and 13 where this level is relatively low.

Table 5

Vigour ratings.

Blocks	*Treatments*												
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*
1	4.5	4.5	8	12	12	12	8	2.5	8	2.5	8	1	8
2	3	3	7.5	7.5	12	7.5	12	3	12	7.5	7.5	1	7.5
3	2.5	10.5	6	6	10.5	10.5	6	1	6	6	10.5	2.5	13
4	2.5	5.5	5.5	9.5	9.5	5.5	9.5	2.5	5.5	9.5	12.5	1	12.5
5	2.5	6	12.5	6	6	12.5	10	6	2.5	10	6	1	10
Rj	15	29.5	39.5	41	50	48	45.5	15	34	35.5	44.5	6.5	51

In fact, the Dorylaimida considered in this analysis include unidentified and non-phytophagous species which can be more numerous than the phytophagous species whose direct effect on the yield can be hidden. For this reason, the study of trophic groups should not be mixed with that of separate species. Each should be studied separately.

Non parametric methods

Ranked qualitative data (symptoms and vigour ratings) and correlations between parasites and yields can be analyzed with non parametric methods. The principle of these methods as well as example are discussed by Dacunha-Castelle and Tomassone (1975).

In this article two statistics will be considered : plant vigour and gall index. In Table 5 vigour ratings are given from the experiment discussed before. Friedman's method for randomized blocks will be used to verify the null hypothesis H_0 : all treatments have the same influence on plant vigour.

Compute :

$$\chi_r^2 = \frac{12}{N K (K+1)} \left[\sum_{j=1}^{j=k} (Rj - \overline{R})^2 \right]$$

in which K = number of treatments (13)
N = number of blocks (5)
Rj = sum of ranks per column
$\overline{R}$ = mean of Rj = 35.

We obtain :

$$\chi_r^2 = \frac{12}{5 \times 13 \times 14} [(15-35)^2+(29.5-35)^2 .. .. +(51-35)^2=33,6]$$

Consulting this value in a χ^2 table, at K−1 degrees of freedom, H_0 is rejected because it is superior to 28.3, a value corresponding to a critical region of 0.005. Supposing a value inferior to 21.03 had been found, H_0 should have been accepted because the probability of making a wrong decision by accepting H_0 would have been more than 0.05.

To decide what treatments are significantly different from each other, different techniques are available. Taking into account whether the test includes a control or not, unilateral or bilateral tests can be used. In nematology, bilateral tests are preferred because controls sometimes are not representative. In the case of increasing dosages of a product, Page's test (1968) is preferred. On the other hand the « multiple comparison test » is suitable in most situations.

Referring to Table 5, the absolute value of the $78 \left(K \frac{(K-1)}{2} \right)$ differences which exist between different treatments, when they are compared, pair wise are calculated. (Example : for the difference between treatments 12 and 13 this value is | 51 − 6.5 | = 44.5. In Table 7 all values thus calculated are entered. Looking up in the table of differences reproduced partly in Table 6 for K = 13 and N (number of replications) = 5 one finds the value r = 40 at $\alpha = 0.049$ and r = 44 at $\alpha = 0.009$.

Table 6

Differences for some values of K and N.

N	K = 3 r (α, 3, n)	α	N	K = 4 r (α, 3, n)	α	N	K = 13 r (α, 3, n)	α
3	6*	028	2	6*	083	2	23	032
							24	006
4	7*	042	3	8*	049	3	30	038
	8*	005		9*	007		32	009
5	8*	039	4	10*	026	4	35	054
	9*	008		11*	005		36	033
							38	012
6	9*	029	5	11*	037	5	40	049
	10*	009		12*	013		41	033
							44	009
7	9*	051	6	12*	037	6	44	054
	10	023		13	018		46	027
	11*	008		14*	006		49	009

Table 7

Calculation of Spearman's rs.

Treatments	Repetitions N = 15	X crop yield	Xc rank	Y number of M. arenaria in one gram of roots	Yc rank	di = |Xc-Yc|	di²
	1	24.5	1	9,952	1	0	0
	2	53.7	10	8,847	3	7	49
1	3	52.7	9	7,624	5	4	16
	4	30.3	2	8,816	4	2	4
	5	41.5	4	9,182	2	2	4
	1	41.4	3	1,110	10	7	49
	2	45.7	5	939	15	10	100
2	3	47.8	6	1,173	9	3	9
	4	60.6	13	976	14	1	1
	5	51.1	7	1,187	8	1	1
	1	52.6	8	1,259	6	2	4
	2	58.3	12	1,066	12	0	0
13	3	54.4	11	1,227	7	4	16
	4	63.4	15	1,023	13	2	4
	5	60.7	14	1,093	11	3	9
Σ di²							266

Thus we find that treatments 12 and 13 differ significantly at a level of 0.009 whereas the difference between treatments 5 and 12 (43.5) is significant at the level 0.049 etc. This type of analysis can also be used for gall indexes.

Correlation methods

Only Spearman's rank correlation test will be treated here. It can be used to measure the degree of dependency between yields and nematode infestation. For the sake of simplicity, the case of only 3 treatments repeated 5 times will be discussed. In total 15 pairs of observations will be obtained (yield and nematode infestation). Yields are ranked by giving the lowest the rank 1 and the highest the rank 15. As one wishes to establish a relation between high yields and low nematode infestation, ranking of nematode infestation will be from 1 for the highest to 15 for the lowest level of infestation.

Spearmans correlation coeeficient is given by :

$$rs = \frac{1 - \Sigma\,(di)^2}{N^3 - N}$$

in which di is the absolute difference between the two ranks alotted to each plot. Calculating rs we find the value 0.525. In the case of ties the formula is different. If $N > 10$, $t = rs\sqrt{\frac{N-2}{1-rs^2}}$ in which t may be found in Student's table with N-2 degrees of freedom. In this case $t = 2.22$ (13 degrees of freedom) which corresponds to a probability of $0.025 > P > 0.01$. The correlation between the two variables mesured is significant and it may be concluded that a close relation exists between the presence of *M. arenaria* and reductions in yield. This test can also be used to demonstrate a relationship between quantitative and qualitative characters (e.g. weight of fruits and symptoms).

Conclusions

Results obtained by multavariate analyses correspond to a large extent to those obtained by analyses of variance. Both methods allow to group compounds with similar effects. Multivariate analysis however makes it possible to compare and analyze rapidly several sets of data (nematode species) at the same time.

The results presented as a graph allow an easy interpretation even for persons not familiar with these techniques. Contrary to classical methods, multivariate analyses can demonstrate the effect of nematicides not to one species only, but to the whole complex of species present in the soil samples, thus allowing evaluation of both specific and general effects of the treatment.

Univariate tests have a higher power, and therefore enable the experimenter to demonstrate significant differences when the results obtained from treatments and control differ little. Most of these tests require that certain assumptions should be met (homogeneity of variances, additivity, normality). Non parametric methods make it possible to analyze very different problems, especially those concerning qualitative characters, without necessitating these requirements to be met.

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