Accountability, Philosophy and Plant Physiology

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Plant physiologists have two responsibilities to the public whose money supports them. One is to make profound discoveries. The other is to make useful ones. Current research is predominantly directed at exploring the behaviour of molecules and of whole plants and communities, with all forms of behaviour in between being somewhat neglected. It is argued that this imbalance diminishes both the profundity and the usefulness of physiological research.

It is commonplace to remark that funds for research are shrinking and that the use of what funds there are is coming under closer public scrutiny. Scientists are exhorted to make their work more `relevant' and to recognize that they are 'accountable' to the public; whose money supports them. Such sentiments are, in many ways, admirable, and the attempts made by many scientists to comply with them are equally admirable. But so far as the bulk of plant physiology is concerned, I believe that attempts to be directly useful are futile, and that the physiologist's responsibility to the public is much more subtle, though no less profound, than that which is normally implied by the term `accountability'. The argument that follows is concerned with exploring what I believe to be the plant physiologist's responsibility. It starts with a visual parable, proceeds to discuss the organisation of biological systems, and tries on the basis of that discussion to draw some conclusions about the sort of problems that plant physiologists should tackle. For convenience, the term `plant physiology' is used to describe the study of any aspect of plant behaviour, from metabolism through to the yield of crops or the primary productivity of ecosystems.

A visual parable

Figure 1 shows an array of dots. If we were asked to make a study of these dots, we would probably start by looking for pattern in them. We would note that their centres form a square array whose rows are at 45° to the horizontal, that most of the dots are circular, that there is a bimodal distribution of their size, and that dots of a given size tend to be clustered together. We might note that some of the dots appear to be malformed, and if we have tenured appointments we might have time to reflect that by using such a pejorative word as `malformed' we have already developed expectations about our observations, that is, that we have started to make theory - dots should be circular, and if they are not, it is an error.

It is clear then that there is plenty of pattern here. But is there significant pattern? What does `significant' mean? Have we been making the right observations? Could the large and small dots be a two-letter alphabet similar to that of the Morse code, so that we should be looking for lineal rather than areal pattern? There seems to be no way to find out.

But if we look at an extended field of the dots as shown in Figure 2, and if we blur our eyes to the extent that the dots almost disappear, they suddenly gain significance, and do

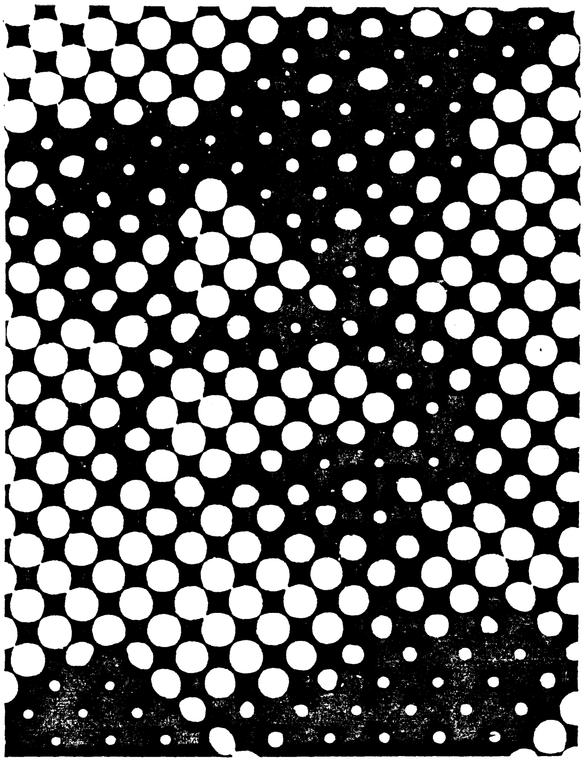

FIGURE 1
An array of dots.

disappear. We are no longer looking at dots. We are now looking at the face of a man who is smoking a pipe. Figure 1 is now seen to be a picture of his eyes, nose and mouth, and almost all our previous discussion on arrays, and rows, and size, and shape, is now seen to be irrelevant. All that matters is the gross distribution of the different-sized dots to give the illusion of light and shade. The significance of the dots can be seen only by abandoning almost all the detailed information we have about them, and only by changing the language that we use to describe them. We cannot discuss their significance by restricting ourselves to words like size, and *shape,* and array. We have to use words like light, and *shade,* and *nose,* and mouth.

It is this transition from one language to another that epitomises the way our minds deal with layered systems. And it is by perceiving the world as being organised into conceptual layers that we manage to make sense of it; the use of such terms as `molecular level', `cellular level', and `whole plant level', attests to that. Much attention has been given to this propensity of ours during the last decade (e.g. Koestler and Smythies, 1969; Whyte et al., 1969; Pattee, 1973; Williams, 1975). What follows is a description of the main properties of layered systems, or hierarchically organised systems as they are sometimes called. The account is based on that of Mesarovic and Macko (1969).

Properties of layered systems

1. Each level has its own language, concepts, and principles. In our discussion of Figure 2 we used words belonging to three different levels: `array' and `dot' belong to the lowest (i.e. least organised) level; `light' and `shade' belong to the middle level, and summarise the important features of the organisation of the dots; `nose' and `mouth' belong to the highest level, and summarise important features

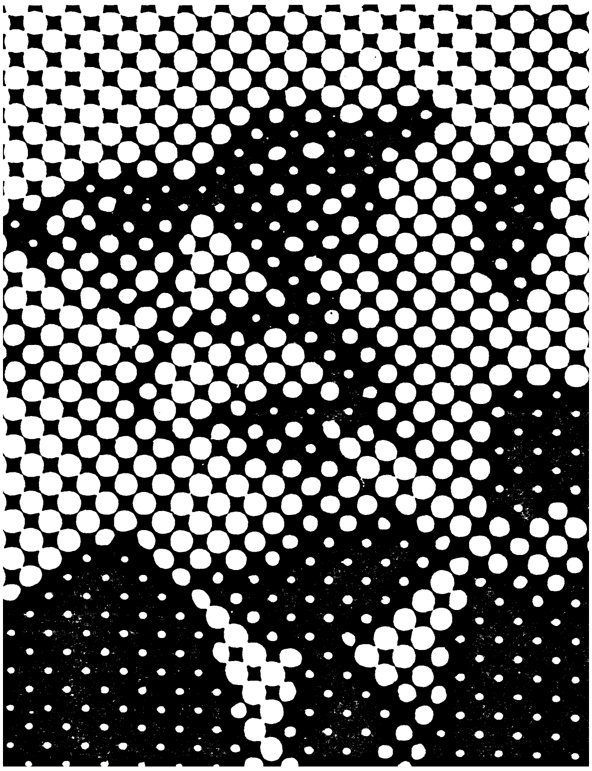

FIGURE 1
An array of dots?

of the organisation of light and shade. Our understanding of a layered system is, in part, measured by our ability to inter-translate the languages of adjacent layers. Translating to a lower layer provides us with explanations, translating to a higher layer provides us with the significance, of the phenomenon we are studying.

2. Discovery at a given level is stimulated by thinking of adjacent levels. We have seen that to discover a face while concentrating on the dots of Figure 2 is virtually impossible. Yet had we been told that the organisation of the dots represents light and shade, our discovery of the face would probably have been facilitated as we blurred the figure for the first time. Similarly, our appreciation of the significance of the dots in terms of light and shade might concentrate our attention on an important feature that we have not previously considered, namely the spatial frequency. If the array of dots were on a finer grid, we would be able to see more detail in the picture.

3. Interaction between levels is not symmetric: a higher level requires all lower levels in order to operate effectively, but not vice versa. If we transformed Figure 2 by cutting it up into several pieces and rearranging them, we would still have an array of dots, even though they formed a meaningless pattern. But if we transformed the dots by, say, squashing them so that they formed thin overlapping lines instead of discrete areas, we would have neither dots nor picture.

4.Higher levels result from constraints being imposed on lower levels. Randomly arranged dots would give no picture.' It is only after the dots have been constrained to form groups that a picture can arise. A group of large dots gives a patch of light; a group of small ones, a patch of shade.

5. A constraint is expressed in the language of the higher level. Dots are grouped (constrained) to form a patch. One _-could express the grouping in terms of the size and position of individual dots, but such a description would be tedious and befuddling and would give no clue to the significance of the constraint.

The organisation of biological systems

We normally think of biological systems as being layered: molecules, membranes, organelles, cells, tissues, organs, organisms, and communities. Figure 3 lists several plant physiological phenomena chosen to represent various levels of organisation, together with aspects of their significance and explanation. The status of a given phenomenon changes as we move up or down the organisational scale. Any given phenomenon may be the centre of our attention (level N), or may be viewed as explanation of a higher phenomenon (level N-1), or as the significance of a lower phenomenon (level N+1). The following chain illustrates the point: loading and unloading of sieve tubes - Munch flow - translocation - balanced growth - survival of plant; translocation is at once significance for the bottom triplet and explanation for the top one.

Implications for research

The preceding discussion implies that our understanding of a biological phenomenon is incomplete unless we can relate it to (or translate it into) phenomena in the adjoining levels of the organisational scale. If we cannot relate it to a higher level, the phenomenon may be trivial, and studying it could be analagous to studying the shapes of the dots in Figure 1. If we cannot relate it to a lower level, our knowledge of it is merely descriptive, and our work on it is likely to be called superficial and even unscientific.

Unfortunately, much plant physiological research seems to suffer from one or other of these defects. The mores of academic plant physiology are such that any phenomenon is deemed to be worth studying, providing only that it is `interesting'. This often means only that it has been studied, somewhat unsuccessfully, by an influential person; or preferably by two or more influential people whose opinions differ. Translocation in phloem is one of the best examples. The controversy that has raged for many years over what is the mechanism of translocation has resulted in there being comparatively little work done on phenomena associated with the function of translocation, namely, the ordered movement of metabolites around the plant.

	WHOLE PLANT	ORGAN	CELL	MEMBRANE
SIGNIFICANCE (Level N+1)	SURVIVAL OF PLANT	BALANCED GROWTH	CONTROL OF WATER USE	CONCENTRATE CHLOROPHYLL
DESCRIPTION (Level N)	BALANCED GROWTH	TRANSLOCATION	STOMATAL MOVEMENT	CHLOROPLAST MEMBRANE
EXPLANATION (Level N-1)	TRANSLOCATION	'MÜNCH' FLOW	TURGOR CHANGES	AMPHIPATHIC MOLECULES

Figure 3.

Schematic representation of phenomena at various levels of organisation in a plant and the relations between them.

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This is particularly unfortunate, because the bulk of what evidence there is suggests that longitudinal movement in the phloem is rarely likely to limit the movement of metabolites around the plant. Thus, studying the mechanism of this movement has some analogy with studying the shapes of the dots in Figure 1. If the main thrust of the voluminous and often ingenious research on the phloem had been concerned with the loading and unloading of the sieve tubes rather than with longitudinal movement along them, our understanding of the system would, I believe, be much more advanced than it is.

In the context of Figure 3, then, academic plant physiology is prone to concern itself only with levels N and N-l, with the consequent danger of over emphasising unimportant problems. Applied plant physiology, on the other hand - at least in the extreme form in which it is concerned with producing immediately useful results - is prone to concentrate on levels N and N+1. That is, it is often concerned with discovering significant phenomena, without worrying about their explanation. Most agronomic field trials provide good examples of this. The danger of working without an adequate theoretical (i.e. explanatory) framework is that our imaginations are likely to become barren, so that we spend our time playing minor variations on an old theme. If we were asked to improve the resolution of Figure 2, for example, we might be at a loss if we did not know that the patches of light and shade arise from the grouping of different-sized dots; this knowledge suggests immediately that we should try to increase the spatial frequency of the dots.

The emphasis placed by academic plant physiologists on levels N and N-l, and by applied plant physiologists on levels N and N+l, may be a partial explanation for the curious distribution of research effort shown in Figure 4. The search for explanation, if not balanced by a concern for significance, tends to drive one's research farther and farther down the organisational scale. The search for significant description, if not balanced by a concern for theory, tends to drive one's research farther and farther up the organisational scale. No doubt there are many other factors contributing to the shape of Figure 4. The increasing proportion of `soft' funds for research, for example, accentuates both ends of the spectrum. Funds given for applied work encourage the empirical study of whole plants and communities in the hope that a quick practical pay-off will keep the money rolling in. Funds given for fundamental work encourage the study of

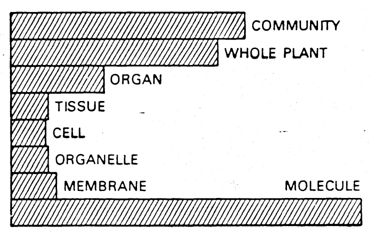

FIGURE 4
Relative frequency of references to work concerned with the behaviour of plants at different levels of organization in *Current Advances in Plant Science, Vol. 8,* nos. 1 and 4 (1976), and Vol. 9, nos. 1 and 4 (1977). Every tenth reference in these numbers was assessed, on the basis of title only. If the title did not give a reasonably clear idea of what level of organisation the particular piece of work was concerned with, the reference was excluded from the classification. References to work not concerned with behaviour (e.g. taxonomy, phytochemistry) were also excluded. The pattern of relative frequency was the same in all four numbers.

phenomena having small time scales: experiments that can be done in hours are more likely to lead to quick papers than experiments that take days or weeks. Quick papers lead to the renewal of grants; quick experiments lead to the study of molecular events.

Another reason for the emphasis on molecular events is that the molecular biological chauvinists of the last 20 years (e.g. Crick, 1966) have convinced large numbers of researchers that the only really worthwhile explanation of biological phenomenon is at the molecular level. That this proposition is nonsense is, I hope, evident from the previous discussion on layered systems. But if the reader is not convinced he could perhaps set himself the task of explaining the *expression* on the face in Figure 2 in terms of the arrangement of the dots.

No matter what the reasons for the shape of Figure 4 are, it implies to me that plant physiology is unhealthy. In understanding the behaviour of a plant, no level of organisation is more important than any other, so that when the research effort at some levels is up to an order of magnitude greater than that at other levels, it must greatly increase the chances of choosing problems that are either trivial or too difficult. How, for example, is one to judge the significance of a molecular phenomenon if the appropriate behaviour of membranes and organelles is not well understood? How is one to explain the behaviour of whole plants if the behaviour of tissues and organs is not well understood? Figure 4 is, of course, a slice in time, and the peaks at either end may not be chronic but may represent an attempt to catch up with well-researched fields in the middle of the scale. This is hard to assess, but I doubt it. It may have been partly true of the vigorous research into metabolic pathways during the 1960s, but the momentum of that research seems to have advanced it well beyond our knowledge at most other levels.

Accountability.

Whether one sees Figure 4 as a symptom of illness or not, it remains true that much plant physiological research is concerned either with seeking the explanation for a phenomenon without worrying about its significance, or with seeking a significant phenomenon without worrying about its explanation. Both approaches are inefficient, and, since they rely for their support on public money, both approaches are therefore irresponsible. It seems to me that plant physiologists (collectively) have two, somewhat linked, responsibilities. One is to make profound discoveries about the behaviour of plants; the other is to make useful ones. The chances of making a profound discovery are greatly increased by searching for the explanations of significant phenomena. It is therefore important to think at three levels simultaneously, along the lines implied in Figure 3. One way of -encouraging thought at level N+l is to ask how the phenomenon at level N could be improved. To ask such a question does not necessarily imply that there is any chance of effecting an improvement, or even that one's work is, in spirit, applied. It is merely a device for 'focusing thought on the function of the phenomenon, and should help prevent the physiological equivalent of studying the shapes of the dots in Figure 1. With one general exception, the chances of making a directly useful discovery at levels below* that of the whole plant, or perhaps the organ, are very small, and we fool ourselves if, in the name of accountability, we try to do so; all the examples discussed by Evans (1977) of physiological research that has proven directly useful are concerned with research on the whole plant or the organ.

The general exception referred to is that of sabotage. One of the properties of layered systems, discussed earlier, is that higher levels rely on the proper functioning of all lower levels if they themselves are to function properly. An effective herbicide could therefore be discovered as a direct result of work on, say, the metabolic pathways of photosynthesis.

Tissue culture and other manipulative techniques, such as those covered by the term `genetic engineering', may also prove to be of great worth, but their practical contribution seems likely to be almost always indirect, in that they are concerned with implementing useful discoveries made at higher levels. - But although people working on the lower levels of organisation are unlikely to discover anything that is immediately useful; it does not mean that they are not accountable to anyone. They are: not directly to the public, but to their colleagues who are working at the higher levels of organisation of the plant.

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References

CRICK, F. (1966) *Of Molecules and Men.* University of Washington Press, Seattle.

Evans, L. T. (1977) 'The plant physiologist as midwife'. *Search* 8262-268.

KOESTLER, A. and SMYTHIES, J. R. (eds.) (1969) *Beyond Reductionism.* Hutchinson, London.

MESAROV1C, M. D. and MACKO, D. (1969) 'Foundations for a scientific theory of hierarchical systems,' in *Hierarchical Structures* (L. L. Whyte, A. G. Wilson and Donna Wilson, eds.). American Elsevier, New York. pp. 29-50.

PATTEE, H. H. (ed.) (1973) *Hierarchy theory: The challenge of complex systems.* George Braziller, New York.

WHYTE, L. L., WILSON, A. G. and WILSON, DONNA (eds.) *(1969) Hierarchical Structures.* American Elsevier, New York.

WILLIAMS, R. F.. (1975) 'The shoot apex, leaf growth and crop production'. *J. Aust. Inst Aqric. Sci. 41 18-26.*