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Applied plant virus research: an analysis, and a scheme of organization

L. BOS

Institute of Phytopathological Research (IPO), Wageningen

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Abstract

Everywhere there is a rapidly growing awareness of the impact of plant viruses on crop production and an increasing interest in their study and control.

Applied research on plant viruses completely differs from that on pathogenic organisms because of the exceptional nature of viruses. Cornerstone of methods of control and of all investigations is *identification* of the viruses, i.e. characterization and recognition and final diagnosis of the diseases observed in the field. Because of all the complicated techniques and of the resulting frequent discovery of new viruses, both aspects fall in the domain of the research laboratory. Virus identification as well as *ecology* and *control* require the close collaboration of specialists. This division of labour is essential because of the rapid development in research technology and the continuous increase in scientific information.

Besides the growers, many public and government agencies are involved in indirectly controlling virus diseases. Research to improve control and to provide continuous support to an ever changing crop husbandry is a public task.

Organizational structure of applied virus research has to guarantee a continuous virological assistance of crop cultivation in view of the incessant threat of international spread of viruses and the continuous agro-ecological changes. As a consequence of research specialization, per country or area a unit of applied plant virus research is needed. Within such units specialists have to collaborate. The tasks of such centres are described. Emphasis should be on the implementation of disease control in crops.

Introduction

Plant pests and pathogens are major factors limiting crop yield quantitatively and qualitatively. Viruses play an intricate part in plant disease because of their unique nature and behaviour, often still shrouded in mystery.

The economic effect of plant viruses can be illustrated by curly top virus nearly ruining sugarbeet cultivation in Western USA early this century. Another example is swollen shoot virus of cacao in West Africa, which killed millions of trees in Ghana during the 1930s and forced clearance there of several millions more between 1945 and 1957 to prevent further spreading. At present, most cassava in West Africa is affected by cassava mosaic, and reported losses are 20–90 %. Citrus tristeza (decline) is another devastating virus disease causing losses up to several millions of dollars each year in South America, California, the Mediterranean and elsewhere.

In contrast, several 'latent' virus infections are known, hardly producing overt symptoms, if at all. However, the viruses concerned may still unspecifically reduce vigour and longevity, and reduce yields by up to 10 or 15 %. They may escape notice, unless yields are carefully determined, but may still be of direct economic importance. Moreover, they may easily spread from symptomless crops to other crops, that are more sensitive and may become seriously affected. Hence, their mere presence may already lead to export restrictions.

Present efforts to improve crop production, notably in less advanced parts of the world, include the introduction of new crops and of genetically more uniform cultivars, improvement of cultural practices with fertilizers, irrigation, and control of pests and pathogens. Such efforts disturb the natural ecological equilibria and narrow the agro-ecological systems. Potentially more productive crops are often more vulnerable, and pests and diseases already endemic may become epidemic. New pests and pathogens are likely to be introduced, and especially viruses may easily do so unnoticed.

Agriculturists are now increasingly aware of the rôle of plant viruses. But information on plant viruses is still incomplete and much further research is needed. In this respect plant viruses pose many problems that are completely different from those of other pathogens and other harmful factors. This paper analyses the various aspects of modern applied research on plant viruses and describes the organizational consequences. In a following publication (Bos, 1976b) inferences will be made for developing countries.

Analysis of applied research on plant viruses

The various disciplines and specialisms involved in applied plant virology are enumerated in Table 1. Applied research on plant viruses has to start with observations on the diseases in the field, on how viruses turn up in crops. Hence, applied research projects have to deal with *virus diseases* of crops (left column). This work is plant pathology, with emphasis on the *crops* and their reactions. Thorough knowledge of the crops and their culture is essential. The main goal is to devise procedures for *control* of the diseases in the field (centre column, item C). However, first of all, the causative *viruses* have to be identified (item A), and their ecology (item B) studied, before effective control measures can be devised.

Let it be understood from the start that research and control of viruses is more complicated than of pests and other agents of disease or pathogens. Viruses basically differ from higher organisms and even from microbes (fungi, bacteria, mycoplasmas), which all have a metabolism of their own and most can be cultured for research. Microbes can usually be propagated on artificial media and can easily be examined, at least with a light microscope (Fig. 1). Several can be seen with the naked eye on diseased tissues, for instance when they form characteristic fruiting bodies, mycelium or colonies. Because their metabolism differs from the host's, microbes can often be killed or repelled with chemicals, innocuous to the host. Viruses, however, greatly resemble host nucleoproteins and 'live a borrowed life', completely depending on the metabolism of their host. Man's lack of knowledge of viruses is clearly illustrated by the recent discoveries of submicroscopic organisms, such as mycoplasmas and rickettsias as possible incitants of systemic diseases long attributed to viruses, and by the discovery of viroids, which are nucleic acids that seem too small even to code for one protein.

For a better understanding of the complications involved, the three main aspects listed in Table 1 (A-C) will now be discussed.

Table 1. Aspects of applied research on plant viruses.

Crops-oriented virus research	Research aspects	Technically specialized virus research	Closely related fields
	A. Identification		
Virus diseases of crop A	1 virus isolation and purification		
	biology		
	- differential hosts		
	- differential transmission		
	- single lesions		
	- differential persistence of infectivity		
Virus diseases of crop B	physico-chemistry	virus biophysics and biochemistry	
	- precipitation		
	- ultracentrifuging		
	- chromatography		
	- electrophoresis		
	- ultrafiltration		
Virus diseases of crops C + D	2 virus description or characterization (for details Table 2)		
	biology		
	- host range and symptoms		
	- mode of transmission		
	- persistence of infectivity in sap		
Virus diseases of crop E	physico-chemistry	virus biophysics and biochemistry	
	electron-microscopy in vitro and in situ	electron microscopy	
	serology	serology	
	3 virus classification and nomenclature		
etc.	4 virus storage	taxonomy	
	5 diagnosis of virus diseases (also C1)		
	B. Ecology		
	1 host relationships		
	- internal translocation		
	- relationships to special tissues e.g. seed and pollen, xylem, phloem, and apical meristems		
	2 alternative plant hosts (e.g. weeds)		weed research
	3 virus transmission		
	- by contact and on equipment		
	- in soil		
	by nematodes		nematology
	by fungi		mycology
	- by insects and mites		entomology
	- in seed and pollen		
	C. Disease control		
	1 diagnosis (also A5; Table 3)		
	2 crop hygiene		
	- measures to be taken by the farmers		
	- to avoid sources of infection		
	- to prevent virus spread		
	- to increase crop resistance		
	- quarantine to avoid introduction of alien viruses		plant quarantine
	- production and distribution of virus-free propagating material		
	- removal of infected plants		
	- selection of virus-free mother plants	heat therapy	
	- freeing from virus	meristem tip-culture	
	- seed certification		seed certification
	3 selection and breeding for resistance		genetics and breeding
	- exposure of cultivars and populations		
	- to natural infection		
	- to artificial infection		

Tabel 1. Aspecten van toegepast plantevirusonderzoek.

Fig. 1. Plant cell with viruses and some pathogenic organisms drawn to scale: 1 μm = 1000 nm = 0.001 mm; limit of visibility with light microscope ca 300 nm. (Reproduced with permission from Agrios: Plant Pathology, Acad. Press, New York and London, 1969).

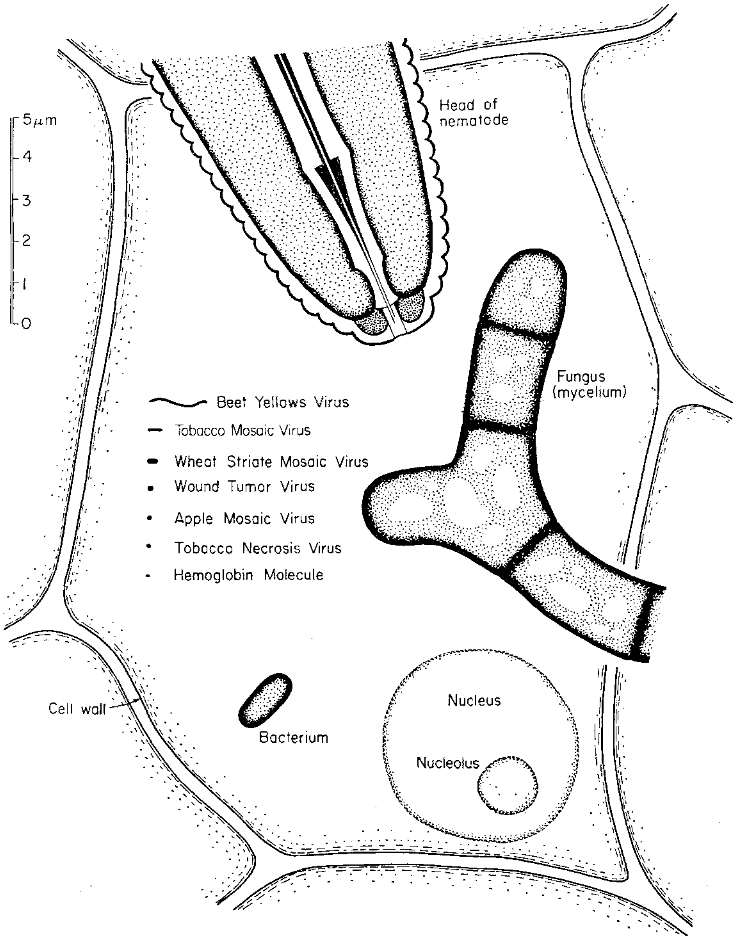

Fig. 1. Plantecel met virussen en enkele ziekteverwekkende organismen, op schaal getekend: 1 μm = 1000 nm = 0.001 mm; grens van zichtbaarheid met lichtmicroscoop ca. 300 nm. (Gereproduceerd met toestemming uit Agrios, 1969).

Virus identification

Identification of a virus (characterization or description, and recognition and diagnosis of the disease) is the cornerstone of all further work on viruses and ultimately of control of virus diseases. However, viruses cannot be simply grown on artificial media, isolated in pure culture, and then studied and described. They require very special techniques of study. I have recently discussed the various aspects of virus identification (Bos, 1976a) and Tables 2 and 3 summarizing virus description and disease diagnosis, respectively, are from that paper.

Table 2. Properties used for virus description or characterization (after Bos, 1976a).

Biological properties

1 host range

2 symptoms (sometimes in special test or indicator plants)

3 (cross protection)

4 manner of transmission
- with sap and through contact
- in seed and pollen
- in soil (by nematodes or fungi)
- by insects and mites
- through grafting (and by dodder)

5 persistence of infectivity in expressed sap after
- storage in vitro
- dilution
- heating for 10 minutes

Intrinsic properties

1 physico-chemical properties
- particle size
- components (multipartite viruses)
- sedimentation coefficient
- molecular weight
- electrophoretic mobility
- electric charge and iso-electric point
- protein coat: structure and amino acid composition
- nucleic acid: content, nature and nucleotide composition

2 electron microscopic properties
- particle morphology
- particle sizes

3 serological specificity

Tabel 2. Eigenschappen gebruikt voor virusbeschrijving of -karakterisering (naar Bos, 1976a).

Virus description. For a long time it was only possible to characterize plant viruses by their biological properties (Table 2), employing infectivity as a workable character. Quite a number of viruses (especially 'persistent' insect-transmitted ones) are still exclusively known by their biological properties. However, biological properties can only be studied by employing test plants and vectors, which all vary widely with conditions and between individuals. Hence, the identity of a virus cannot be well established in this way, even if conditions of research be standardized (Bos, 1967) to allow comparison of results between laboratories. Moreover, the recent detection of mycoplasmas and rickettsias as agents of virus-like diseases shows the chances of misinterpreting them if only biological properties are known.

Through the advent of modern biochemical and biophysical techniques and rapid progress in molecular biology, an increasing number of viruses have now been isolated from their host cells or directly observed in host sap or tissues and characterized by their intrinsic properties (Table 2). In many parts of the world considerable information has thus been gathered in recent years on the viruses themselves. This has already allowed tentative classification of plant viruses, greatly facilitating the grouping and retrieval of information, and the recognition of viruses. *There is a semblence of order emerging from the chaos of the some 500 plant viruses* (Martyn, 1968, 1971) *more or less described so far.* Classification and nomenclature of the viruses help also to improve the ordering of and communication on information about plant viruses, including how to control them. Finally, it is essential to maintain described type mamaterial, preferably in a 'dry-collection', for further characterization as new techniques become available and for future reference.

However, the research techniques are complicated and require well equipped and well staffed laboratories employing biochemists, biophysicists, serologists and electron microscopists, who have to be specialists because of the sophisticated techniques they use, and because they have to keep abreast of developments in their fields. Thus, modern virus description usually is a matter of team work. Various specialisms are indicated in Table 1 (column 3).

Diagnosis of virus diseases. To outsiders diagnosis may now seem simply a matter of using a key to the known viruses, but till now there is no generally accepted classification of plant viruses. There still are many gaps in our knowledge, and viruses are so variable in themselves.

Nevertheless, several virus diseases can already be diagnosed with reasonable certainty. Table 3 lists 'ten commandments' for diagnosing a disease presumed to be

Table 3. Steps in diagnosing plant virus diseases (after Bos, 1976a).

1	Determine plant species and cultivar infected	
2	Study symptoms	
3	Assess conditions, distribution, and incidence of the disease	clinical observation
4	Study infectivity by - sap inoculation - transmission by insects, mites, or nematodes - grafting (and use of dodder)	
5	Inoculate or graft a series of test plants and back-inoculate onto parallel ranges of test plants - to check possible multiple infection - to separate virus(es) concerned - to determine host range and symptoms	
6	Determine persistence of infectivity in expressed sap after - storage in vitro - dilution - heating for 10 minutes	
7	Examine with electron microscope	
8	Apply serology	
9	Isolate and purify, thereafter determine physico-chemical properties, and prepare a specific antiserum	aetiology
10	Inoculate a healthy specimen of the plant species or cultivar under investigation to fulfil Koch's postulates	

Tabel 3. Stappen bij de diagnostiek van plantevirusziekten (naar Bos, 1976a).

caused by a virus. According to the virus involved, the equipment at hand and the specialist's skill and experience, some aspects may be passed over or their order altered. The list begins with data on the 'patient'. The later items concern the agent of disease itself. Thus, emphasis in diagnosis shifts from *clinical observation to aetiology.* The latter, as is clear from what has been said on virus description, is inapplicable to viruses that have not yet of cannot yet be studied outside their hosts. Modern techniques like serology and electron microscopy have proved extremely helpful. Diagnosis of a virus disease is never unequivocal unless the virus has been isolated, studied outside its host and shown to incite the disease under controlled conditions after inoculation of a healthy specimen of the host species or cultivar (Koch's postulates; Table 3, item 10).

Virus description and diagnosis are inseparable. Following these lines, the researcher often finds that the virus under investigation deviates a little from known viruses or is completely new. Consequently, diagnosis of a virus disease often results in the description of a new virus or strain. This may especially hold for parts of the world, not yet thoroughly surveyed for viruses. Description and diagnosis are two inseparable aspects of virus identification. *That is why virus identification is the task of a research laboratory*, but it paves the road to diagnosis, making it easier and more reliable.

Virus ecology

Once a virus has been identified with one described earlier, the validity of information on its ecology obtained elsewhere can be easily checked or directly used for devising ways of control. However, even strains of a virus may differ ecologically, and then the ecology of the virus will have to be carefully studied (see also Table 1).

Relationships of the virus to its host may have an important bearing on ecology and determine whether virus-free mother stock can be obtained by heat therapy and meristem culture (see Control).

Alternative plant hosts are common with plant viruses. Restriction to a single plant species is exceptional. With more intensive research in recent years, most plant viruses have turned out to have much wider ranges of hosts, among them many weeds, than long assumed. For understanding of the ecology of viruses, knowledge of their natural host ranges and of the biology of alternative hosts is essential.

Transmission of viruses from plant to plant, as by contact and on equipment, by insects and mites, by nematodes or fungi in soil, and with seed and pollen, concern the true epidemiology of the virus diseases. Virus spread with seeds is turning out to be more prevalent than supposed (Phatak, 1974) and to be of special importance in international distribution by man himself. The study of virus transmission often requires knowledge of a vector's life cycle and the mechanism of crop infection, and demands assistance from an entomologist, nematologist or mycologist, or a plant virologist with a good background in those disciplines.

Control

Since virus diseases in crops cannot be cured directly by chemical or other means, virus diseases can only be controlled indirectly by preventing crops from becoming infected. This can be achieved by hygiene (phytosanitary measures), interfering in one way or another with the ecology of the virus.

Disease diagnosis. Reliable *diagnosis* is prerequisite. The subject has already been dealt with when discussing virus identification, of which it is part. For control there are already some techniques in routine use to index for certain viruses (for various examples see Bos, 1976a). However, such techniques are used only in the production of certified seed of a limited number of technically advanced crops like potato, chrysanthemum and carnation, grown under special conditions, and for finding virus-free mother plants to start such cultures. Under such rather controlled conditions, only a few well-characterized viruses are supposed to occur.

Crop hygiene includes precautions taken by the farmers themselves, such as use of virus-free seed and planting stock, control of weeds, selfsown plants and insects to avoid sources of infection and spread of viruses. Other important aspects of hygiene outside the farmers' control are: (1) preventing introduction of alien viruses into the country by quarantine and other import regulations; (2) preventing spread through the country and introduction into individual crops at their start with the planting stock by certification.

Serious efforts are being made to restrict international distribution of plant pests and disease incitants. As a consequence of the International Plant Protection Convention, approved at the 6th FAO Conference in Rome (1951), regional plant protection organizations were formed. Certain countries, like the USA and Kenya try to prevent or retard the introduction of alien pests and diseases through rigid quarantine regulations. From certain high-risk parts of the world, there is complete prohibition of import of certain crop material. For other crops, entry is restricted: they are permitted to enter from certain low-risk countries only with health certificates from the exporting countries and after inspection at the port of entry. Others are allowed to enter only in small amounts through intermediate or post-entry quarantine or introduction stations. A special problem is posed by the present intensive international exchanges of germ plasm for crop diversification and breeding programs.

The production of virus-free or at least virus-tested seed or planting stock and the certification of such stock is important in the prevention of attack by certain viruses. However, it works only when farmers can and will pay the higher price, when sole use of certified material can be enforced and checked by government agencies, and when the virus-free material is not readily reinfected from other nearby sources. The production of such valuable planting stock requires skill and knowledge from farmers, inspectors and others concerned in testing and certifying the material for absence of viruses. Essential are facilities for detecting and recognizing the viruses occurring. It should be realized that a certificate never means that the material is absolutely free of virus.

Often, crops or special cultivars, especially those vegetatively propagated, are completely infected with virus(es). Then, virus-free mother plants must be found by *selection* with help of a thorough system of indexing, if possible to guarantee absolute freedom of virus. If no virus-free plants can be found, a few plants of certain crops can often be freed from certain viruses by *heat therapy* or *meristem tip culture*. The first technique uses the principle that viruses may be destroyed at temperatures just sub-lethal to the host. With the technique many viruses were eliminated from fruit trees. The second method, sometimes together with heat treatment, uses the principle that minute meristem tips, taken from virus-infected plants and grown aseptically on artificial media, produce plants free from certain viruses. The method has proved helpful in ridding potato, strawberry, carnation, chrysanthemum and some other vegetatively propagated crops of certain viruses. Both techniques require special skill and experience, and specialists. The techniques may have use too in helping genetically valuable but virus-infected plant material through quarantine. In all instances it is essential to test treated material thoroughly for virus.

Breeding for resistance is an important way of avoiding damage by viruses when sources of infection are hard to avoid and virus spread is difficult to prevent. In countries lacking knowledge and organizations to advise of enforce plant hygiene, use of resistant crops may be the simplest way of avoiding damage. But the more productive, genetically more homogeneous cultivars are often less resistant, especially to alien pathogens. Resistance may even not be available in the cultivars grown there or even in other parts of the world, or it may occur in cultivars unacceptable for other reasons. Breeding for resistance may then be the sole solution. There again, knowledge of the virus(es) and their strains is essential. A line or cultivar resistant in a certain area may not be so in another area or country, where other viruses or strains are prevalent. Often, resistance can best be tested under experimental conditions with artificial inoculation. Information on the inoculum to be used and the best way of testing are then indispensable. This breeding is sometimes considered the task of the crop virologist (Table 1, column 1), but is more often done by specialized breeders assisted by virologists (column 4).

Organization of research

To answer the question where and by whom or by which organization the research needed must be done, let us first explore where the research findings will finally be applied and who needs the information and thus will be mainly interested and responsible. Let us also analyse the main lines of research required. Then, the research itself can be briefly rediscussed.

Agencies concerned with control of virus diseases of plants

The only way of control of virus diseases in crops is protection of crops from infection (or from damage if infection cannot be prevented). In summary from what has been said earlier on the subject, their control can be achieved by: (1) avoiding sources of infection, (2) preventing virus spread, and (3) increasing crop resistance. In other words: control of virus diseases means interference with virus ecology and choice of resistant crops of breeding for resistance.

Since the complicated ecology of virus diseases includes such factors as remote sources of infection and long-distance transport of viruses by insects and other vectors, inclusive man himself, many of the measures of crop protection against viruses have to be taken outside the farms where the crops are grown. In addition, these crops may threaten other crops nearby or even remote. Consequently, public interests are at stake. Moreover, in areas and times of food scarcity, agricultural productivity is of even wider and direct public interest. Therefore, *measures against plant viruses are the concern of several government and other public agencies,* such as plant protection and

Table 4. Applied plant virus research.

A. TASK

Design of ways to and assistance in implementing control of virus diseases in crops

Note that plant virus diseases can only be controlled indirectly by
1 avoiding sources of infection
2 preventing or reducing virus spread
3 increasing crop resistance

B. RESEARCH ASPECTS	C. AGENCIES NEEDING INFORMATION
1 Survey of crops for viruses, identification of the viruses and their strains, development of reliable diagnostic methods inclusive routine tests	Agricultural Advisory Services Crop Protection Services Seed Certification Services Plant Quarantine Stations
2 Study of ecology of economically important viruses, including natural and artificial transmission	
3 Assistance to increase resistance of cultivars to viruses by:	
a testing of new cultivars submitted for registration	Cultivar Registers
b support to breeding for resistance to viruses by	
- development of test methods - provision of reliable inoculum - identification of complicating new viruses and virus strains	Private plant breeders and breeding companies Plant Breeding Institutes

Tabel 4. Toegepast plantevirusonderzoek: taak (A), onderzoeksaspecten (B) en instellingen welke behoefte hebben aan informatie (C).

agricultural advisory services, and training (education) institutions. Private breeders, seed growers and companies and seed certification services are also involved. Because of the public interest, the search of background information must be funded or supported by government or public agencies.

Table 4 summarizes the task of applied research on plant viruses (item A), the aspects involved (item B), and the agencies directly needing information (item C). The different aspects are interdependent (item B 1-3). Support to programs of breeding for resistance to viruses cannot be given without proper knowledge of aspects 1 and 2, both requiring specialized assistance as outlined before. The table also indicates how there is a constant feed-back to the specialism with problems resulting from the collaboration in breeding programs.

Structure of applied research

Before outlining the organization of applied research, two facts should be stressed. Firstly, situations of viruses in crops are never static, since so many biological factors are involved in their ecology. With changes in agricultural practices and increasing international trade and traffic, they may even be increasingly dynamic. Hence, crop husbandry requires *continuous virological* support. Research organization should guarantee such continuous assistance. Secondly, the techniques to study viruses and their control are so complicated that they cannot be studied and applied by individual persons. Plant virologists, working on their own, would be completely at a loss, unable to implement essential techniques of research and unable to cope with the rapid developments in plant virology.

As a result, research on plant viruses in most advanced countries has already differentiated considerably and now usually takes place in units where various specialists, as mentioned in Table 1, collaborate. Well organized groups include at least a number of crop-oriented virologists, each concentrating on a special crop or group of crops, a virus biochemist/biophysicist, a serologist, and, if possible, an electron microscopist (or at least a technician, well trained for the purpose). Cooperation of the technically oriented specialists with the various crop specialists and between crop virologists is the more important since various viruses may infect totally unrelated crops, and different crops often are infected by closely related viruses requiring similar techniques for identification and control. Collaboration with or at least advice from a nearby entomologist and a nematologist is usually ensured. An insect-proof greenhouse or series of greenhouses and a reasonably equipped laboratory with at least a preparative ultracentrifuge, an ultraviolet spectrophotometer and an electron microscope are essential facilities.

In larger units, further specialization along the lines of Table 1 may be feasible and helpful. In all specialized groups, the crop virologists are to study the problems in the field, to define the economic importance, and to 'feed' the unit with virus problems to work on. In view of their interest in pathology, they may also be the members of the team responsible for the biological identification of viruses with help of test plants, take responsibility for the ecological work, and collaborate with the breeders. It will be their responsibility to synthesize the results of the other workers in solving the practical problem. But all members of the group have to be aware that their work has to contribute to implementing control of virus diseases in the field.

Like between the various organelles within a living cell, within such virus units (Fig. 2) there should be an open communication between the various specialists with a constant circulation of information. Through such collaboration the specialists not only benefit from each other, they also contribute to each others programs; there is no exploitation but collaboration and interdependence through specialization.

The situation in the Netherlands may serve as a model. The more free and basic research on plant viruses is performed in the Universities of Wageningen, Amsterdam, Utrecht and Leyden, and is linked to teaching. Independently, most of the applied plant virus research for the whole country has been taken care of since 1949 by the Virus Department of the state sponsored Institute of Phytopathological Research at Wageningen (Bos and Roosje, 1974).

In the Department, six of the scientific staff of ten concentrate on virus diseases of cereal crops and grasses, potatoes, fruit trees and woody ornamentals, ornamentals grown in greenhouses, vegetable crops in greenhouses (especially tomatoes), and vegetables grown in the open, respectively. To ensure close contacts with growers' problems, the two scientists working on greenhouse ornamentals and vegetables are stationed at the experimental stations situated in areas where such crops are grown: at Aalsmeer and Naaldwijk. Besides these crop-oriented plant virologists, there are four more technically oriented specialists: for virus biophysics and biochemistry (purification), serology, meristem tip-culture, and soil transmission. A well trained technician is responsible for electron microscopy. For work with vectors there is a

Fig. 2. Collaboration between specialists in unit of applied plant virus research (e.g. as part of a research institute for plant protection) and some of the lines of communication with other departments, institutions, services, breeders and last but not least with growers.

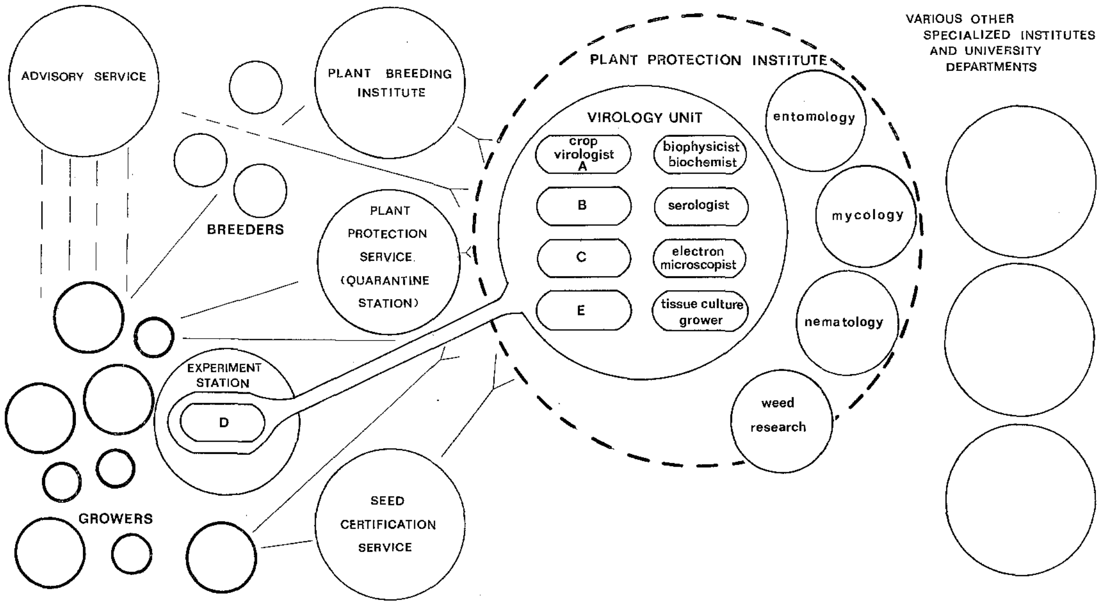

Fig. 2. Samenwerking tussen specialisten in onderzoekeenheid voor toegepaste plantenvirologie (bijv. als onderdeel van een onderzoeksinstituut voor gewasbescherming) en enkele van de communicatielijnen met andere afdelingen, instituten, diensten, veredelaars en niet in de laatste plaats met gewassentelers.

close collaboration with the Departments of Entomology and Nematology of the institute.

Research on flower bulb virus diseases is traditionally situated at the Flower Bulb Research Station at Lisse, and is now performed by three scientists.

Results of research finally reach practice through direct personal contacts between researchers (especially the crop-oriented specialists) and growers and breeders, but usually more indirectly via extension or advisory services and plant protection and seed certification services. Contacts with these are at a direct and personal level, and more indirect via publications on results of research, via papers presented at the annual meetings of the Netherlands Society of Plant Pathology, and via lectures during vocational training and occasional courses for officers employed by the organizations mentioned.

Up to and including world war II most agricultural scientific work in the Netherlands was taken care of by departments, notably of the Agricultural University at Wageningen. Since then, it was concentrated in separate research institutes. That in the Netherlands no direct and continuous exploitation of experience is gained from applied plant virus research for the training of students must be considered a disadvantage. However, often teaching staff is recruited from research institutes, and some collaborators of university laboratories pursue practical work themselves. In several countries, like the USA, there is a complete integration of research, teaching and advisory work.

Definition of tasks of plant virus research unit(s)

From the foregoing, the following major tasks and responsibilities of national or regional plant virus research units emerge.

1. Survey for viruses in crops of the area covered, and identification of the viruses found.
2. Establishment of a collection of the viruses and their strains (preferably in dry state for future reference and as a permanent source of inoculum for breeding programs if required.
3. Assessment of economic implications of the viruses concerned.
4. Study of the ecology of the economically important viruses and development of techniques of indirect disease control (hygienic) measures.
5. Assistance to plant protection services, plant quarantine stations and seed certification services in developing and monitoring routine diagnosis of virus diseases.
6. Support to breeding programs by
   a. providing information on the identity, incidence and distribution of economically important virus diseases and their strains;
   b. providing information on techniques for testing breeding populations, lines or collections of germ plasm for resistance, either by exposing these to natural infection in the field or by inoculating them mechanically or with help of vectors;
   c. providing reliable inoculum for artificial infection, or information on where best to expose trials to natural infection and how to enhance such natural infection.
7. Selection or preparation by meristem tip culture or heat treatment of virus-free planting stock from vegetatively propagated crops or cultivars totally infected with harmful viruses, and maintenance and distribution of such stock.
8. Assembly of information on plant viruses already found and possibly occurring in the geographic area to be covered, and distribution of such information to research workers, institutes and other authorities involved in controlling the virus diseases.

Final conclusions

It may be objected that the approach to applied plant virus research presented here is rather basic, employing fundamental specializations in plant virology. Admittedly, there is no sharp distinction between applied and fundamental or basic plant virology. The present outline depends on basic disciplines but is *directed* towards the optimal solution of practical problems.

In this respect even academic virus research, for instance that on the molecular biology of viruses, has facilitated virus isolation for identification and in future may well provide ways for direct control of plant virus diseases. Workers in applied virology are aware of these important developments, and through study of literature and contacts with their academic colleagues keep in touch with molecular biology.

Inevitably, modern research on agriculture and modern agriculture itself, both being exponents of human culture, tend to drift away from the natural situation. This holds notably for specialized disciplines easily losing sight of the natural situation and its requirements. Hence, whatever structures for applied virus research be created, they should ensure optimum contacts with the field problems to be studied. This is of particular concern when dealing with applied plant virus research for developing countries, but these will be discussed in a separate paper (Bos, 1976b). Communication should guarantee that all actions aim at the implementation of control of virus infections in crops.

Samenvatting

Toegepast plantevirusonderzoek: een analyse en een organisatieschema

Overal ter wereld wordt men zich steeds meer bewust van de nadelige invloed van virussen op groei en opbrengst van gewassen en is er sprake van een toenemende belangstelling voor onderzoek over en bestrijding van plantevirussen en -virusziekten.

Het toegepaste onderzoek over virussen (Tabel 1) verschilt geheel van dat over pathogene organismen door de uitzonderlijke aard van virussen als ziekteverwekkers (Fig. 1). Hoeksteen van de bestrijding en van alle onderzoek is de *identificatie* van de onderhavige virussen, d.w.z. de onderscheiding of karakterisering (Tabel 2) en de herkenning van de virussen als basis van de diagnostiek van de virusziekten (Tabel 3). Vanwege de vele bij dit onderzoek betrokken gecompliceerde technieken, en het feit dat diagnostiek van virusziekten vaak leidt tot de onderkenning van nieuwe virussen, behoren beide onderzoeksaspecten tot het werkterrein van het wetenschappelijke laboratorium. Deze aspecten, evenals de studie van de virus-*oecologie* en van de methoden van *bestrijding*, vereisen de nauwe samenwerking van specialisten. Taakverdeling bij het onderzoek is ook gebiedende eis met het oog op de snelle ontwikkelingen bij het virusonderzoek en de enorme toename van de hoeveelheid informatie.

Virusziekten kunnen in de gewassen alleen indirect worden bestreden. Daar vele maatregelen hiertoe moeten worden genomen buiten het bedrijf van de betrokken teler zelf, zijn veel publieke, met name overheidsinstellingen erbij betrokken. Het doen van onderzoek gericht op de bestrijding is dan ook van algemeen belang en een taak van de overheid. De verschillende aspecten ervan hangen samen (Tabel 4).

De structuur van het onderzoeks'apparaat' dient dusdanig te zijn dat de teelt van gewassen voortdurend virologisch kan worden begeleid met het oog op de internationale verspreiding van virussen en de aanhoudende agro-oecologische veranderingen. Als gevolg van de bij het plantevirusonderzoek vereiste specialisatie is het nodig per land of gebied te beschikken over een centrum of eenheid voor plantevirusonderzoek waarbinnen een aantal specialisten (volgens Tabel 1, ook Fig. 2) samenwerkt. De situatie in Nederland, met een voor het hele land centrale functie van de Virusafdeling van het Instituut voor Plantenziektenkundig Onderzoek, wordt als voorbeeld gesteld.

Tenslotte worden de taken van dergelijke centra van toegepast plantevirusonderzoek nader omschreven. De organisatorische opbouw moet garanderen dat de ontwikkeling van bestrijdingsmethoden bij het onderzoek centraal staat.

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References

Bos, L., 1967. Methods of studying plants as virus hosts. In: Maramorosch, K. & Koprowski, H. (Eds), Methods in virology I. Acad. Press, New York and London: 129–162.

Bos, L., 1976a. Problems and prospects in plant virus identification. EPPO Bull. 6: in press.

Bos, L., 1976b. Research on plant virus diseases in developing countries; possible ways of improvement. In manuscript.

Bos, L. & Roosje, G. S., 1974. Van planteziektenbestrijding naar gewasbescherming, een bezinning naar aanleiding van 25 jaar IPO-onderzoek. (With English summary: From disease and pest control to crop protection; a reflexion on the occasion of 25 years IPO research). Meded. Inst. Plantenziektenk. Onderz. Wageningen. 666: 123 pp.

Martyn, E. B. (Ed.), 1968. Plant virus names; an annotated list of names and synonyms of plant viruses and virus diseases. CMI Phytopath. Pap. 9: 204 pp.

Martyn, E. B. (Ed.), 1971. Plant virus names. Supplement No. 1; Additions and corrections to Phytopathological Paper No. 9, 1968, and newly recorded plant virus names. CMI Phytopath. Pap. 9, Suppl. 1: 41 pp.

Phatak, H. C., 1974. Seed-borne plant viruses. Identification and diagnosis in seed health testing. Seed Sci. Technol. 2: 3–155.

Address

Instituut voor Plantenziektenkundig Onderzoek (IPO), Binnenhaven 12, P.O. Box 42, Wageningen the Netherlands.