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Integrating Crop and Pest Management : the need for comprehensive management of yield constraints in cropping systems

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Abstract: Pests continue to cause significant crop losses in many cropping systems in spite of available technology for their control. Because crop management and pest management have too often been viewed as separate activities, little true integration has occurred. The IPM concept is not being widely applied even though there exists much knowledge on crop loss assessment, systems analysis, systems modelling, individual pest sciences and pest management. A systems analysis framework is described to identify areas for integrating crop and pest subsytems, and for integrating biological knowledge, management knowledge and social/environmental considerations. This framework will facilitate the design of integrated crop-pest management programs, leading to a rational allocation of resources in the activities of knowledge generation (research), dissemination (extension), modification and reception.

Keywords: Integrated Crop-Pest Management, IPM, Systems Approach.

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INTRODUCTION

Next to the physical environment, pests are the most important constraints to increased crop yields in many parts of the world. The common techniques to deal with yield losses caused by pests have been genetical (host plant resistance), chemical, biological and cultural. A common scenario is often to use host plant resistance as a first line of defence where possible, followed by the use of chemicals (Robinson, 1976). For example, the major impact of the international agricultural center system sponsored by the Consultative Group on International Agricultural Research (CGIAR), on plant protection, has been the incorporation of pest resistance into improved genotypes (Technical Advisory Committee, 1979). Biological and cultural methods, though appealing have been limited in their use worldwide.

The conceptual basis for much of the agricultural pest control in the developed world has been Integrated Pest Management (IPM) since the late 1960's. The IPM concept grew out of a need to respond to developing public concern about indiscriminate pesticide use in the 1960's (Huffaker and Smith, 1980), and the resultant development of resistance in pest populations to chemicals. The major application of the concept was initially limited to reduction in pesticide use and a deployment of alternate control techniques, although the IPM concept itself proposes an ideal - of rational use of control inputs to maintain or increase yields at minimal risk to the environment and society, yet giving a profit to the farmer (FAO, 1984a). The rational use of multiple control techniques is strongly advocated in

writings dealing with the concept, yet recently, Tschirley (1984) has questioned whether integration has been successfully achieved.

At the same time that the IPM concept was winning wide acceptance worldwide, several other conceptual approaches were being developed that affected IPM. These were the concepts of on-farm production constraints research as pioneered by the International Rice Research Institute (de Datta, 1978; IRRI, 1979), and the Farming Systems Research approach to solving problems in developing nations, actively promoted by the US Agency for International Development. Both of these approaches highlight an increasing awareness among agricultural scientists that real world problems are not compartmentalized into scientific disciplines (Spedding, 1979; Dent, 1978; Russell et al., 1982), and that institutional barriers are very evident when attempting to solve development problems in the third world. Concurrently, there has been increased appreciation of the limited role that technology can play to narrow the "yield gap" in some cropping systems; that technology and research are only two of the many essential ingredients in improving crop productivity (Norton, 1982b; Norton and Mumford, 1983a). Further, the IPM experience has sensitized the scientific community to the delicate nature of agricultural ecosystems, and to the need to anticipate how changes affecting one aspect of an agricultural system has repurcussions on other aspects as well as on total system behaviour (Teng, 1982; Ruesink, 1976). The scientific community is at the same time being forced into thinking more about interdisciplinary research

(Oldenstadt et al., 1982; Russell et al., 1982). The forces behind this resemble many of the concepts inherent in the "Systems Approach" (Dent, 1978). Farming Systems Research and the IPM concept both have similarities to the systems approach. It is the major premise of this paper that the conceptual framework for solving complex agricultural problems in general, and crop-pest problems in specific, is the approach commonly called the **"systems approach"**.

Some of the basic ideas in the systems approach are the hierarchical nature of systems (e.g. crop-pest ecosystem), their division into subsystems (e.g. crop, pest), the interrelatedness between the subsystems, and how addressing only part of the system (e.g. pest or crop) will not lead to a complete understanding of the system for its management (Teng, 1985). In agriculture, we see crop scientists or agronomists emphasize the crop, pest scientists emphasize the pest, and so on. The IPM concept was an early attempt to recognize the interrelatedness between the different pest, parasite and predator populations that make up agricultural ecosystems, and a systems approach to IPM has been advocated (Ruesink, 1976). The argument presented here is that, because of "disciplinary myopia", in both the developed and developing countries, no real holism or integration has occurred in treating the crop and its associated biological populations as equal subsystems. This latter treatment is necessary for a strong integration, and a move must be made to get away from the situation where an IPM person emphasizes the pest subsystems while the agronomist emphasizes the crop subsystem.

There is an urgent need to integrate both crop management and pest management, to treat these as equally important activities, and to synthesize both conceptually into an activity of **integrated crop-pest management.**

The remainder of this paper will be used to review the knowledge base available for implementing the concept and to discuss the design of integrated crop-pest management programs using the concept.

THE KNOWLEDGE BASE FOR IMPLEMENTING INTEGRATED CROP-PEST MANAGEMENT

Systems Analysis

The systems approach is a scientific philosophy that proposes a holistic view on agricultural systems (Spedding, 1979). In practice, the philosophy is actioned using a set of methodologic tools, commonly referred to as "systems research" (Dent and Blackie, 1979). This in turn comprises "systems analysis" and "systems synthesis" (Teng, 1982). Conducting a systems analysis of any management or biological system starts with a conceptual analysis of the system, the physical components of the system structure, the components of its operating environment, the inter-relationships between structural and environmental components, rules governing system behaviour and system output (Teng, 1985). Systems analysis does not require more than pencil, paper and a knowledge of how to conduct the analysis. A tangible product of this mental exercise is a conceptual model of the system being studied, its major components and their relationships to each other and to the environment. Following these activities, and

using the conceptual model as a framework, a literature review or interaction with scientists knowledgeable about the system will lead to identifying knowledge gaps about the system (Heong et al., 1984; Kranz and Hau, 1980). This relatively informal approach to analysis has proved to be a very educational tool in designing management programs for specific pests or crops (Giese et al., 1975; FAO, 1984b; Norton, 1982a), for identifying research/extension needs for IPM (Johnson et al., 1985b), and for evaluating payoffs to development projects (National Research Council, 1982). The systems analysis procedure described above has also been called a "soft systems approach", in contrast with computer modeling, which is a "hard systems approach" (Bawden et al., 1984).

The systems analysis of any farming system will also define the spatial and temporal hierarchy of the system. For example, a potato farming system may consist of many distinct potato production systems, each occurring on a separate production area (Johnson et al., 1985b). Further, the analysis extends not only to the ecosystem and management system, but also to the flow of information within it. This information flow occurs from those who generate information for improving the system (the researchers), to those who synthesize the information (managers, modelers), to those who disseminate the information (extension personnel), till finally to the information receptor (farmer) (Norton, 1982a). A systems analysis can therefore lead to identifying which aspect of the information flow (research, synthesis, extension, reception) needs to be improved in order that

infrastructural constraints to increased crop productivity be reduced. The technique is well documented in scientific literature (Dent & Anderson, 1971; Kranz and Hau, 1980; Teng, 1982, 1985; Zadoks, 1971).

A rigorous systems analysis is necessary before any knowledge is generated for an integrated crop-pest management system.

Systems Modeling

In many developed countries, it has become fashionable to build complex and detailed computer models of crops, pests and farms. These models attempt to synthesize multiple hypotheses and data sets from different laboratories, in order that the behaviour of the system be simulated (Dent and Blackie, 1979). Although systems analysis is an essential step in the process of building a system simulation model, many scientists have recognized that the process of systems analysis may be as beneficial if not more, than the final model itself (Giese et al., 1975; Teng, 1985). In the context of third world agriculture, systems models may have a role in testing strategies for system improvement, especially if models already exist in the developed countries and only environmental data are required from elsewhere to run the models. Examples are the physiological crop growth models for wheat, sorghum, corn, etc. (Loomis et al, 1979), which may be used to identify physiological constraints on yield in developing countries. The knowledge base and technology needed to develop these models makes it very inefficient for developing country scientists to attempt building their own models.

Apart from detailed crop physiological models, simpler models exist for predicting crop yield (Johnson et al. 1985a; Fishman et al., 1984), pest population growth (Teng, 1985), crop yield losses due to pests (Teng and Shane, 1984) and for decision-making in pest control (Teng and Rouse, 1984). All these require some form of computer technology, the minimum of which is a microcomputer, a piece of equipment by no means impossible to obtain in many developing countries.

The procedures for building computer-based simulation models of crops and pests are now fairly well-established (Ruesink, 1976; Loomis and Adams, 1983; Teng, 1985). These models have shown themselves useful research tools - to test hypotheses, to synthesize information and to explore management strategies. There has however only been limited success in the use of computer models for on-farm crop-pest management, although there is much activity underway in many developed countries (Teng and Rouse, 1984). Simple mathematical models with relatively few equations have been used for yield and loss prediction in the developed countries, and these may be the type of models with quick payoff for the developing countries, rather than the detailed computer-based models (Seem and Russo, 1984).

Systems analysis (the "soft" systems approach) and systems modeling (the "hard" systems approach) have demonstrated their usefulness for developing practical methods to guide farmer decision-making. In plant pathology, use of economic decision-aids such as those for soybean disease control (Stuckey et al., 1984) exemplify a "soft"

approach. In this soybean decision-aid, knowledge on the system is synthesized into numerical values, so-called "points", e.g. in the Illinois system, if rainfall is below normal, the point value equals 0, if rainfall is normal, the point value equals 2 and if rainfall is above normal, the point value equals 4. Points are assigned for different states of cropping history, cultivar type, etc. and a total of 15 or more is used to trigger a spray action in grain fields. Similarly, systems analysis was used to identify questions with numerical answers (0 or 1), which together with simple damage functions are used in the BEANRUST (Meronuck and Teng, 1984) and RUSTMAN (Teng and Montgomery, 1982) programs to time spraying for rust in beans and sweet corn respectively. Chiarappa (1974) developed a flow chart of questions to help determine if any pathosystem would be amenable to the use of supervised disease control techniques, in particular, quantitative predictive models. The use of a "soft" systems approach is adequate in many situations for integrating known control measures for single or multiple pests and should be used before any effort to develop complex models.

Crop Loss Assessment

Crop loss assessment has become a scientific theme which encompasses many techniques (Zadoks, 1985). It may be viewed as a problem definition discipline, providing the necessary information for assessing and evaluating system performance. With respect to crop and pest management, crop loss information allows decision-making on the economics of pest control in individual farms, while at a farming

system level, crop loss information provides a basis for decisions on the impact of new crop production/pest control technology, e.g. pesticides (Teng and Shane, 1984).

Crop loss technology is useful for quantifying the magnitude of production constraints due to similar pest (insect, disease, weed) groups or to interacting pest populations (Walker, 1983). There are many successful applications of the technology for gathering data that can then be used to set research or extension priorities for reducing the effect of production constraints (Pinstrup-Andersen et al., 1976; Stynes, 1980; Wiese, 1982) . Essential components of applying crop loss assessment for improving crop yields are the estimation of attainable yield in the absence of pests, and the estimation of the actual yield, when pests are present. There have been significant advances made in the practical estimation of both these yield levels, especially through the use of simple crop yield models (Johnson et al., 1985; Fishman et al., 1984) and soil moisture level measurements (Brown et al., 1981). A project in Montana, U.S.A. used sample-surveys to demonstrate to farmers the difference between wheat yields, with and without pest-induced losses under water-stressed conditions, and could calculate for each farm a biological production efficiency (Nissen and Juhnke, 1984).

As a scientific theme, crop loss assessment includes techniques for the measurement of pest populations, pest abundance and pest injury, sampling methods for estimating pest intensities in farmers' fields, survey methods and on-farm pest-loss experiments (Teng and Shane,

1984). These techniques are applicable under both high technology and low technology situations. In the developed countries, various computer-based techniques - database management systems, information delivery systems and economic decision aids for pest control - are now commonplace (Teng and Rouse, 1984). As yet these have limited use in improving farming practices in many developing countries. However, computer technology has a definite role in increasing the productivity of individual scientists and the efficiency of data analysis in both developing and developed countries, especially through the use of small microcomputers (Rouse and Teng, 1984) .

Crop loss assessment offers a means for obtaining the information whereby the importance of different pests on crop productivity can be determined. Crop loss information in many countries will lead to rational decisions on the allocation of scarce resources (James and Teng, 1979). It is therefore an essential component of integrated crop-pest management, whether the unit to be managed is a single field or an agricultural system with many fields.

Pest Science

The component sciences in pest control have traditionally been entomology, plant pathology and weed science (Allen and Bath, 1980). Accompanying the development of these sciences has been a visible strengthening of disciplinary departments in many research and educational institutions worldwide. While a valid argument can be made for the need to have strong disciplinary departments in order to further each science, an adverse effect has been that pest

management, which requires an interdisciplinary approach, has suffered because of disciplinary barriers in institutions (Russell et al., 1982). In the developed countries, much of the pest biologic knowledge is available, although distinct gaps have been identified even on crops that have been well-researched. For example, with potatoes, a recent study (Johnson et al., 1985b) demonstrated the lack of information on the following aspects of many pests: disease epidemiology, pest dispersal, pest survival, predictive systems, quantitative pest effects on yield, management thresholds, models for explaining multiple pest-crop interactions, pest assessment methods, pest sampling procedures and the regional distribution of pests. In the developing countries, knowledge on the above and on more fundamental pest biology such as life-cycles may even be incomplete. The same study (Johnson et al., 1985b) showed that knowledge on pest biology at the levels of organization of the individual, population and community are more relevant for pest management than knowledge at the levels of the cell or organelle. Another study on rice pest management supports this conclusion (Norton, 1982a). A systems analysis, done to identify what aspects of pest biology are required to address specific management problems, will facilitate the deployment of scarce research resources.

Pest Management Science

Pest management systems may be divided into the technical, biological system (supported by knowledge generated in the pest sciences) and the management system (supported by knowledge from pest management

science) (Norton and Mumford, 1983a,b). Too often, biologic knowledge has been generated without due consideration for the decision-making process of the farmer, his managerial skills and options, and the technology to implement the knowledge. Concurrent with research on pest biology must be research on aspects such as the integration of two or more management tactics for single or multiple pests, the management of resistance genes in the crop population to pests and in the pest population to chemicals, crop-pest ecosystem design, the socio-economics of IPM implementation, the determination and modification of current farmer practices (Matteson et al., 1984), the design of macro-level (regional) crop-pest management strategies and the decision process of the farmer (Johnson et al., 1985b). Furthermore, little has been done to research the management aspects of the crop - pest system (a bioeconomic system) or the economics of management (Mumford and Norton, 1984), when compared to what is known on the management of industrial systems. This is especially true in the use of quantitative management tools, such as those known collectively as "Operations Research". For example, the use of matrices to describe knowledge gaps on different components of the crop-pest system (see section on System Description, below) is an application of both the 'PERT' and 'critical path' methods commonly used in R & D planning and management in the private sector (Ackoff and Sasieni, 1968).

Pest management science is a relatively new endeavour even in the developed countries (Brader, 1979) with innumerable problems in its

application, foremost of which are the strong disciplinary boundaries at universities, research institutions and extension agencies. It may well be that the developing countries, with a shorter history of scientific institutionalization, are more amenable to adopting the systems approaches required for effective implementation of integrated crop-pest management.

DESIGN OF AN INTEGRATED CROP-PEST MANAGEMENT SYSTEM

The "soft" systems approach to program design for integrated crop-pest mangement is represented in Fig. 1. An existing crop-pest management system may be viewed as receiving input (from system description and analysis), and providing output to enable system improvement via some defined objectives. The output from system description takes the form of problems which are identified and questions which are raised; both lead to the generation of a knowledge base via research or technology adaptation, from which implementation steps may be taken. The improved crop-pest management system is also viewed as having identifiable objectives which are suited for evaluation through a monitoring / surveillance system, thereby providing adequate feedback to determine if corrective action is needed.

System description

The first step in design is to describe the crop-pest system by detailing its biological system and its management system, using the systems analysis method sensu Norton (1982a,b) and Johnson et al.

(1985). This phase involves defining the components of the major biological subsystems, e.g. crop subsystem - species, cultivars ; pest subsystem - individual pests, parasites and predators. For each subsystem-subsystem combination (e.g. crop 1 - pest 1), a series of analysis matrices is created, to identify the effect of weather, the effect of pesticides, interactions between weather and pesticides, etc. (Fig. 2). For example, in the weather matrix, the columns would be different weather factors like temperature, relative humidity while the rows would be the life cycle stages of each pest. Each weather factor - life cycle stage "box" would then be filled in with a notation indicating the state of knowledge, vis-a-vis importance for pest management. Similarly, the change in state of the major components of the system is traced through a time profile matrix, which allows the identification of critical times for several states (Walker et al., 1978; Norton, 1982a; Johnson et al., 1985b). This kind of analysis also generates questions in the minds of the participating scientists as to how important various aspects of the crop-pest biological system are. The final product is a detailed description of the crop-pest system, and is really a conceptual model of the entire crop-pest ecosystem which can be used for guiding data collection and further research, leading if desired to the development of a detailed system simulation model.

The description of the management system includes analyzing the decision process of the farmer by using a decision-tree to structure all the decisions he/she encounters before, during and after each

"season" (Norton, 1982b; Norton and Mumford, 1983a). Each decision can then be evaluated relative to potential value for crop or pest management. A monetary value may also be assigned to each decision point and an enterprise budget created for estimating the cost-benefit of any management decision, its associated risk, etc. (Johnson et al., 1985b). A payoff matrix is also created from this analysis of farmer decisions, to help in estimating potential benefit from conducting research on any decision point. Crop loss information and damage functions are used at this point to enable judgements on the potential importance of a pest.

Apart from describing the crop-pest system, it is also necessary that the infrastructure for conducting research, for extension, for local training of trainers, etc. be described and analyzed for potential improvement.

Defining problems to be resolved

The system description step results in a determination of the major components of the system, their linkages and their role in the decision process of the farmer. It also defines how much is currently known on all aspects of the crop-pest system, and what the knowledge gaps are. Following the system description, it is necessary to determine how much of the current research, extension and teaching effort is addressing the knowledge gaps involved in the biology/management of the system. At the same time, an effort has to be made to involve the scientists in a common institution (e.g. within a province or a country), in a participatory process of

defining the constraints on system improvement and which of these constraints deserve priority for action. The final product of this step is to secure an agreement, through participation of all scientists, of what the major crop-pest biologic or management problems are, how they should be addressed, and what the action timetable is (Johnson et al., 1985b). Often, several iterations of opinion are necessary before agreement is possible on research problems and needs, and the 'Delphi Method' (Linstone and Turoff, 1975) is one procedure used for this process (Johnson et al., 1985b). All these should be done within the framework created in the system description step. As Ruttan (1982) noted, research resource allocation cannot be efficiently done by administrators, independent of the opinions of researchers. As with a computer modeling effort, the end users of the model need to be involved in the conceptualization and development of the model, if the model is to eventually have practical value (Dent and Blackie, 1979). Researchers of the crop - pest management system need to be actively involved in the definition of problems and the identifying of research needs and priorities. In this context, information on the occurrence of crop management problems, the magnitude and recurrence of pest problems, data on production constraints obtained through on-farm surveys or experiments, would all serve to help problem definition. A listing of priorities for research, extension, teaching, (and training in the case of developing countries) is one end product of the problem definition step.

Setting objectives and timetables for implementing and evaluating system improvement via research, extension and teaching.

In applying the systems approach to integrated crop-pest management, it is important that the objectives for distinct activities be clearly defined for known time periods. A periodic review is needed of these objectives, the success or otherwise in meeting them and their relationship to the overall goal of improving the crop-pest management system. Within the context of the preceeding steps, a framework can be created for linking traditional, basic and applied research approaches to the systems research process (Dent and Blackie, 1979). Again, this may take the form of qualitative or quantitative models (Fig. 2), either of which will contain the syntheses of information required for implementing a new production and protection system (FAO, 1984b).

This step generates much of the information for system improvement. Implicit in this is the generation of information through research, the synthesis of the information, its dissemination and an evaluation of the acceptibility of the "new" knowledge by farmers (Norton, 1982a). A continuing process of data gathering to provide feedback on system status or improvement would be very useful, using concepts and techniques for regional crop loss programs and large-area crop or pest surveillance programs (James and Teng, 1979; Heong, 1983; Teng, 1984; Welch, 1984). It is important that a regular review process be designed at the outset to examine the rate at which system objectives are being met, and where necessary to repeat the analysis step. This

latter was one of the key points made by consultants who designed two recent FAO projects, the Gambia Integrated Crop Management Project and the Sudan Cotton Integrated Pest Control Project (FAO, 1984b). However, it is difficult to expect the availability of an adequate database for evaluating system behaviour without implementing a large-area crop or pest surveillance system.

CONCLUDING REMARKS

Agricultural research worldwide is under serious resource constraints, which in recent years has led to a need for greater accountability in scientific effort. One by-product of this situation is the emphasis on solving "real-world" problems, many of which are short-term in nature and involve applied research. At the same time, these "real-world" problems commonly recognize no scientific, disciplinary boundaries and have required an interdisciplinary team approach for their solution (Russell et al, 1982). Many of the reasons that are fuelling the move towards team efforts at problem solving resemble ideas inherent in the systems approach (Dent, 1978; Dent and Anderson, 1971). It has therefore not been surprising to see increased application of systems methodology in many diverse fields of agricultural research. However, what has been less frequent, but which has potentially greater payoff, is use of the systems approach to analyse, plan and evaluate projects. In this paper, an effort has been made to show how the knowledge base for integrated crop-pest management projects could benefit by using an organizational framework derived with systems analysis.

Goodell (1984) recently posed a challenge : "Do we really want IPM to work?", and rightly concluded that farmers in developing countries often have technology thrust on them by scientists with little appreciation for the technology needs of farmers. Wherever they have been given the opportunity, farmers have been the only true integrators of scientific knowledge. Although often viewed by researchers as receipients of knowledge, farmers are by necessity, also implicit practitioners of the "systems approach". It is sad that the pest management scientific community, because of disciplinary and institutional barriers, has only recently risen to the twin challenges of firstly, interdisciplinary problem-solving and secondly, doing research that matches the needs of the farmer. Furthermore, disciplinary rivalries at many institutions often result in independent research on crop management and pest management. These issues are highlighted here because they have been major impediments to ensuring there is relevant crop-pest management research, and to the broad adoption of available knowledge on IPM. The view presented in this paper is that a systems approach will provide the basis to guide the research needed and to synthesize the knowledge generated, for integrated crop-pest management.

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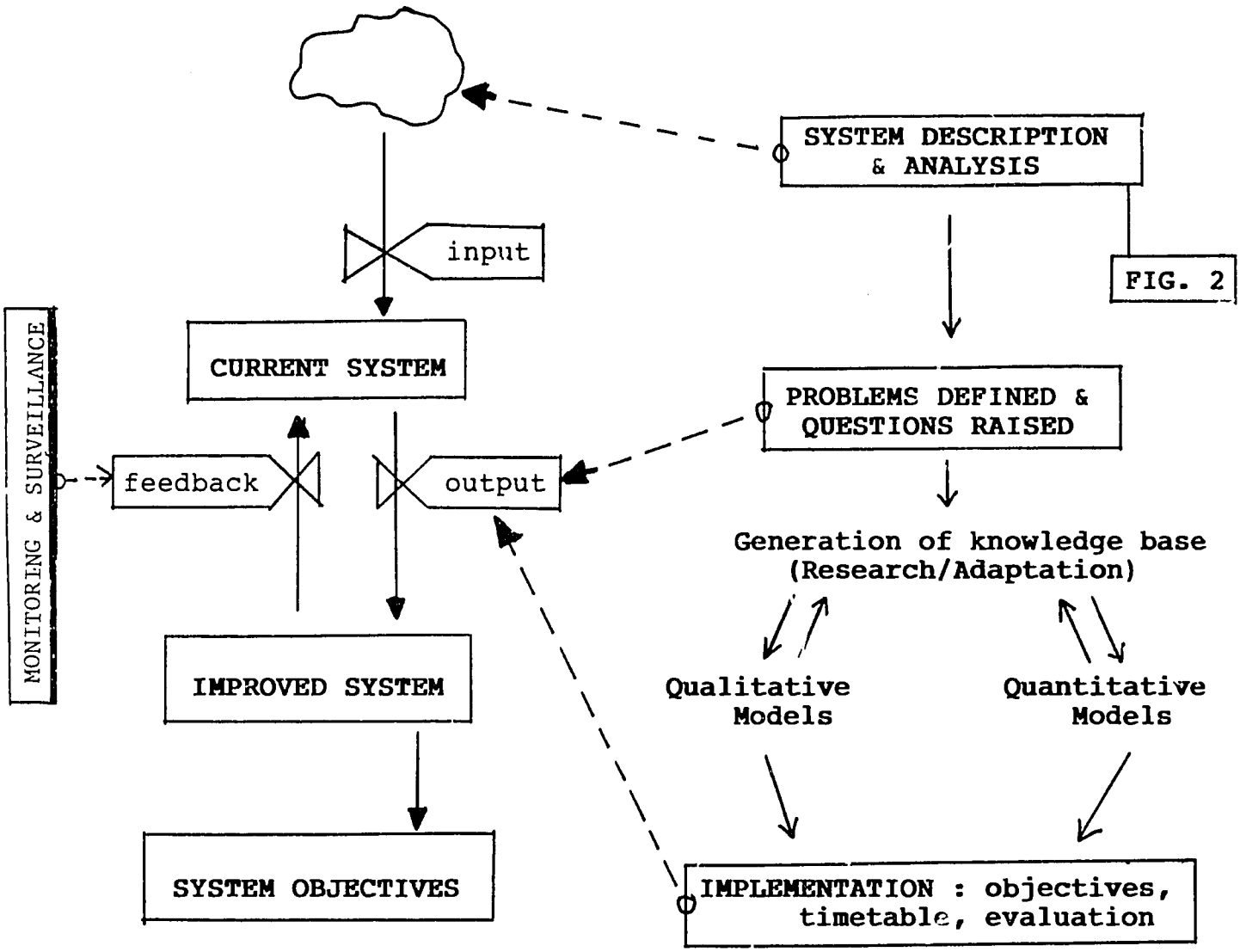

Fig. 1. Steps in the design of an Integrated Program for Crop - Pest Management using the Systems Approach.

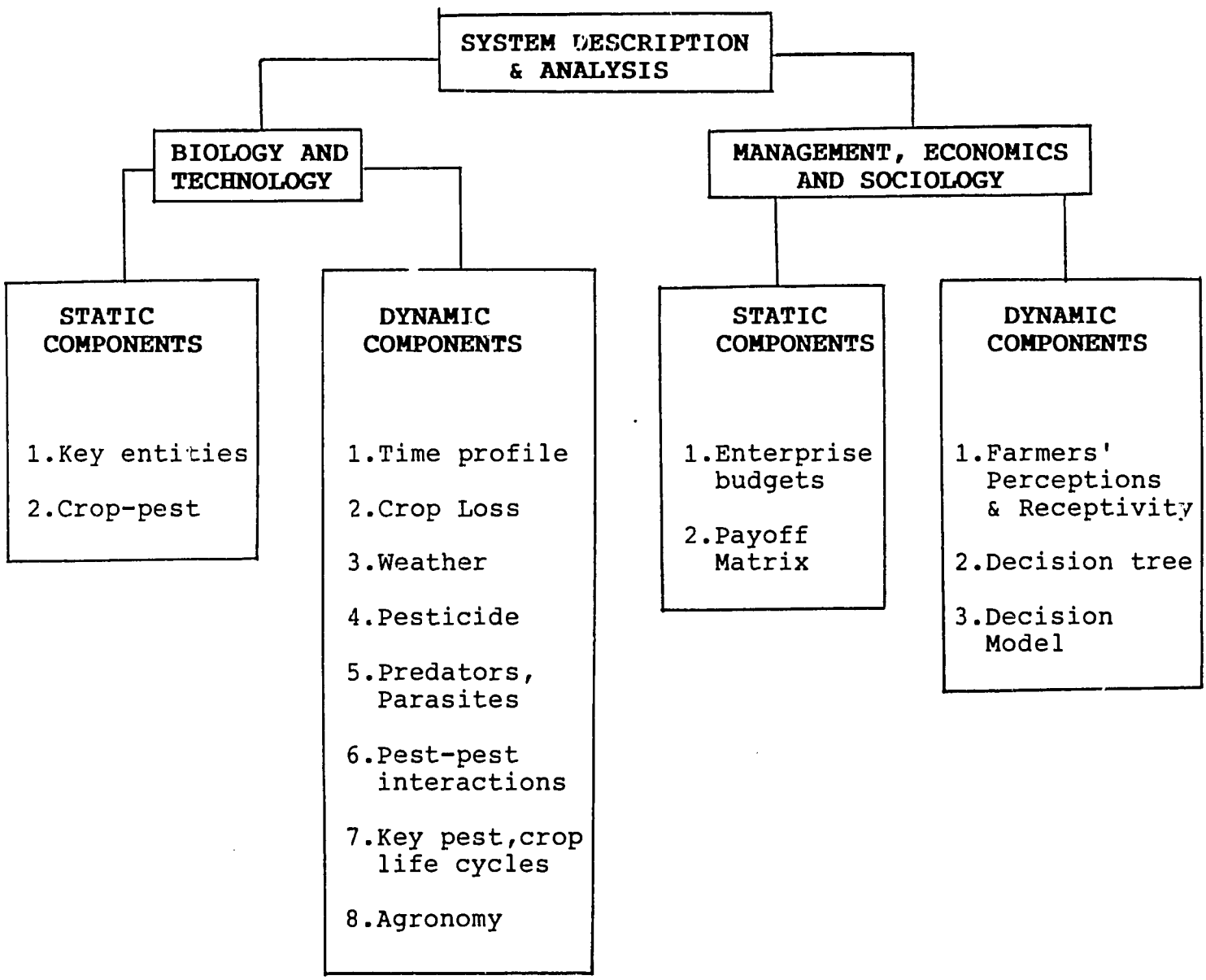

Fig.2 Components of a soft systems approach for crop-pest management system analysis. (After Norton, 1982)