Computer aids for plant protection, historical perspective and future developments*

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Initiatives such as Videotext and forecasting models resulted in a relatively fast introduction of computer technology on to farms at the end of the 1980s. In several countries there were developments to create models for supervised control and data exchange became digital. Most models were developed for diseases that could expand very rapidly, or diseases that should be controlled regularly. In the 1990s, development of weather-related Decision Support Systems (DSSs) began. It is important to use the optimal way to disseminate information to the target group; which can differ between or even within countries. The use of DSSs results in a lower risk of crop damage by diseases and pests, and a lower input of active substances, from the use of adjusted dosages. Future developments may include the possibility of implementing a number of DSS-models into a Geographical Information System, which will support precision agriculture by providing adjusted spraying advice based on plot-specific characteristics. The success of DSSs is despite its development occurring independently in a number of countries. The speed of development of these systems would have been substantially faster had there been real cooperation between countries or groups of researchers. In order to withstand funding reductions, it is necessary for the development of new DSSs that collaboration between researchers and research groups internationally increases significantly in the near future.

Introduction

Since the middle of the 1980s there have been great developments in computer programs that could be used on farms as an aid to support farmers in taking farm management decisions about timings, dosages and optimal types of plant protection products. EPIPRE (Epidemic Prediction) (Daamen, 1991) was one of the first computerized advisory systems for supervised integrated control in Europe. Soon after the introduction of personal computers and modems on farms, government-funded programmes in several countries stimulated the introduction of this new information technology, the use of personal computers on farms and also the development of models and other possibilities for exchanging information (Meijer & Kamp, 1991). In addition, some EU-funded concerted actions (EU.NET.DSS) and EU-cost actions stimulated the development and introduction of this new information technology as a common initiative (Secher, 1993a).

History

Over the last 20 years the developments have been similar in a number of countries within Europe.

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Videotext

At the end of the 1980s there were developments in videotext advisory systems for farmers, e.g. in Germany, Belgium, Ireland, the Netherlands and Switzerland (Carletti & Claustriaux, 1991; Dunne, 1991; Forrer *et al*., 1991). Through these systems, transfers of information about the weather, varieties, plant protection products and how to use this information took place from advisors to farmers. These initiatives resulted in a relatively rapid introduction to farms of computer technology, but advice from these systems was general rather than being tailored to individual farmers or field-specific.

More customized to the needs of farmers were developments at the Norwegian Bulletin Board (Magnus *et al*., 1991). Farmers could ring into a system and download daily updated specific pest and disease warnings, together with the weather forecasts.

Advisory models, the first step to Decision Support Systems (DSSs)

Since the middle of the 1980s, there have been developments in a number of countries to create models for supervised control, e.g. in Norway, Denmark, Spain, the United Kingdom, Germany, the Netherlands, Italy, France and Sweden. Most models were developed for diseases that could expand very rapidly, or for diseases that should be controlled regularly, e.g. potato late blight, apple scab, cereal leaf diseases and grape downy mildew. Most of these advisory models compared observations and measurements of the disease severity and/or incidence taken by the advisor/farmer with a set of economic threshold values for the respective developmental stage of the host plants to calculate whether an application could be advised. This was the first step in the development of computer-aided support systems to help farmers decide whether a spray application was necessary. Information exchange with the central host (mainframe) computer in the early years was by mail; the time between an observation and the advice being approximately one week. Later on the data exchange took place digitally.

Initial improvements allowing farmers to run these advisory models on their home computers failed, because farmers no longer received other benefits gained from contact with the extension officers. Furthermore, the models were poorly adapted to the questions and needs of farmers. Farmers quickly learned the calculation rules of the models and used the rules in practice without using the models (Daamen, 1991).

Advisory systems used on stand alone computers in farms, the next step to Decision Support Systems

In the meantime, the development of a new generation of DSSs began, the weather-related DSSs (Bouma, 1993). These systems had a more integrated approach. Besides the weather data, other factors important for the duration of the protection were taken into account such as, the development of new leaves, dose of fungicide, wash-off by the rain and irrigation, susceptibility of the cultivars and disease pressure in surrounding fields. Furthermore, new, more powerful, personal computers were introduced at farms, and on-farm weather stations were developed. Data from these weather stations, together with the weather forecast were used as inputs for the weather-related models in the DSSs. From this moment on, these systems had extra value: the advice was adapted to the current situation regarding disease pressure (actual and forecasted), fungicide covering and weather characteristics.

Another important factor in the success of DSSs was the governmental policy of most European countries to render agriculture more sustainable by reducing the number of applications of active substances and the dependency of farmers on plant protection products. One possibility for reaching this aim was the use of DSSs. Together with the establishment of the main DSSs, a number of models were developed to reduce the impact of the plant protection products in the environment, e.g. the creation of PIEC (Predicted Initial Environment Concentration) (Gyldenkerne & Secher, 1996) in Denmark.

Important national developments of Decision Support Systems

Norway

In Norway, a bulletin board system was set up at the beginning of the 1990s and some years later a voice board system called TELEVIS was introduced. The bulletin and voice boards gave the results of the disease and pest monitoring in wheat and barley fields together with the results of NORPRE (a warning system for diseases and pests in barley and wheat), the two- and five-day weather forecasts and the recorded weather data (Magnus *et al*., 1991, 1993). In 1995, the system was expanded to have models for cereals, potato, top fruit and vegetables (Magnus, 1995). In 2001, a new web-based warning system was developed, called VIPS. VIPS calculates warnings for several pests in top fruit, vegetables and cereals. The warnings are site-specific and the extension service validates the biological data (Folkedal & Brevig, 2003).

Finland

At the end of the 1980s, Geographical Information Systems (GISs) for monitoring and predicting potato crop production began to be used (Merkkiniemi & Kaukoranta, 1991) in Finland. With a GIS it was possible to use maps to have an overview of the distribution of potato cyst nematodes and to predict their development. The data could be analyzed alongside climatic data, the type of soil and other biotic factors. Besides the GIS, some expert systems for the use of herbicides, fungicide and insecticides were also used (Rantanen *et al*., 1993). Later on a GIS was used for forecasting and monitoring pests, e.g. the carrot fly (Tiilikkala *et al*., 1996).

Denmark

An advisory system for crop protection (PC-Plant protection) was developed in the early 1990s (Secher, 1993b). PC-Plant protection could be divided in two parts, for pests and for weeds. In the weed control part, an expert model decides whether weeds should be controlled. The system selects the optimal herbicidal mixture and calculates the adjusted dose. This approach aims to reduce herbicide use to a minimum (Rydahl, 1993).

The pest control part of the system calculates adjusted dosages of fungicides and insecticides with the use of weather-related cereal pest and disease models. In addition, a decision support system for the control of potato late blight NEGFRY has been developed (Hansen, 1993). In 1996, NEGFRY was integrated into PC-Plant protection (Murali & Hansen, 1996).

Since the start of the 1990s the quality of these systems has been improved as research results have been incorporated into them. The Danish systems are also used in many other countries, including in Sweden, Finland, the Baltic countries and Poland. Crop Protection Online, a new web-based system was developed in 2001 (HagelskÆr & Nistrup Jørgensen, 2003; Rydahl, 2003). The system architecture has been designed with an emphasis on a high level of flexibility for future adjustments resulting from agronomic and legal requirements. The DSS models have been linked to a pest identification module and to a comprehensive database on plant protection product label information.

The Netherlands

Since the mid-1980s, Dutch farmers have been using DSSs as an aid in the control of pests and diseases. This began with

EPIPRE and, later on, weather-related potato late blight warning systems were developed (Prophy and Plant-Plus). In the 1990s many weather-based DSSs were developed, e.g. systems for the control of onion leaf spots; Mycos, a model for the control of ring spot in cabbage; models for the control of blight fire in flower bulbs; models for the control of scab in apples and pears (DLV-Welte en RIMpro); a model for Cercospora leaf spot in sugar beet and a system for the control of fungal diseases in winter wheat and barley (CerDis) (Bouma, 2003). More recent developments include a model for control of Botrytis in strawberry, downy mildew in lettuce, and a system for the guided control of nematodes (Nemadicide). In addition, a decision support system was developed to predict and evaluate the effect of meteorological conditions on the effectiveness of the application time of pesticides (GEWIS) (Bouma, 2003).

In most cases the models were developed by private organizations (Opticrop and Dacom) in close cooperation with pure or applied research organizations. Most models use the Internet for weather data exchange or transferring of updated parts of the models.

United Kingdom

Since 1990 a number of models have been used by farmers and advisors concerning diseases and pests in arable crops due to the developments within ADAS (the British extension service) and the Meteorological Office (Hims, 1991). Subsequently, a joint research and development programme began to develop a computer-based DSS to produce on-going forecasts of risks posed by main pests and diseases in cereals and rape, IDR (integrated disease risk) and IPR (integrated pest risk) (Walters & Hims, 1993). Furthermore PEST-MAN, a computerized forecasting tool for pests in apple and pear was developed (Morgan & Solomon, 1993).

Potato late blight DSSs were first introduced to the UK in the form of Beaumont periods (Beaumont, 1947) in the 1950s, which has subsequently been replaced by the Smith period (Smith, 1956), first implemented in 1975. Since the introduction of the ‘Fight against Blight’ campaign, two web sites, Blight Alert and Blight Watch, provide information on late blight using weather-based forecasting systems (Bradshaw *et al*., 2004). In 1998 Plant_Plus (a Dutch Late Blight DSS) was introduced to the UK (Hinds, 1998) to produce farm-specific advice.

The Morph/HRI group developed and introduced a software framework containing computer models called MORPH (Methods Of Research Practice in Horticulture). The results of MORPH models can take the form of tables, spreadsheets or graphs for interpretation by growers and consultant agronomists. The models can be divided into three groups: Top Fruit models (apple scab, powdery mildew, Nectaria fruit, fireblight, codling moth, tortrix moth and pear psyllid), vegetable/cabbage diseases (Alternaria, ring spot and white blister) and vegetable/cabbage pests (cabbage root fly, carrot fly, pollen beetle and narcissus fly).

DESSAC (Decision Support Systems for Arable Crops) combine a set of databases and three DSS modules: a wheat disease manager, a system for decision support for oilseed rape pests; a system for weed management and a model for the simulation of nitrogen in arable land (Audsley *et al*., 2005).

Germany

In Germany many weather related pest and disease models have been developed, but not in a structured way. The same developments took place simultaneously in different universities because there was no federal responsibility for crop protection advice in Germany. Important developments were Pro_Plant, the Bavarian and IPS approach, the models of the German Meteorological Service and models from the former GDR.

In 1993 the PASO-project started, in which 13 plant protection services from 11 Bundesländer participated. Ten agricultural and horticultural models were validated and used by the advisory services (Kleinhenz *et al*., 1996). To ensure the continuation of this work on DSS and the elaboration of new systems, an institution (ZEPP) was founded. Seven out of 10 tested DSSs proved to be useful for crop protection extension work and, in addition, some new models were developed during the test phase and incorporated into the ZEPP work (Kleinhenz & Rossberg, 2000). In 2000, ZEPP began to elaborate an Internet-based warning system for the main arable crops. This system is based on weather-based DSSs, comprehensive up-to-date monitoring in farmers’ fields, and specific advice from extension officers (Röhrig & Kleinhenz, 2002).

Pro_Plant (Frahm *et al*., 1991; Frahm & Volk, 1993) was developed to reduce the input of plant protection products to a minimum. In 1995, Pro_Plant covered cereal diseases, growth regulators in cereals, sugar beet diseases, rape pests and weeds in maize (Frahm *et al*., 1996). In 2001, the system was redeveloped as an Internet version. The Internet version (proPlant Expert) gives online assistance for making field-specific decisions on a range of problems, e.g. fungicide application in sugar beet, cereals and potatoes, application of growth regulators in rape and cereals and insecticide application in rape. On the other hand the ‘old’ CD-ROM version can also be used (proPlant Classic) (Newe *et al*., 2003). With help of the system it is also possible to generate maps (of Germany) of the possible infection of Phoma in oil seed rape (Volk & Alpmann, 2006).

In Bavaria, the warning service for plant protection runs a system of DSSs and forecasting models for several fungal pathogens (cereals and potatoes) and pests. A network of weather stations provides the weather data necessary for the DSSs (Tischner, 2000; Hausladen & Zinkernagel, 2002). Furthermore, models for the control of diseases in top fruit, grapes and vegetables have been developed (Hoppmann & Holst, 1996; Hindorf *et al*., 2000; Leinhos *et al*., 2002).

Switzerland

Decision support systems for winter wheat (EPIPRE) and winter barley (HORDEPROG) have been used in Switzerland since the mid-1980s. In the early 1990s, a DSS for late blight control (PhytoFAP) was developed (Forrer *et al*., 1991). PhytoFAP was the precursor of PhytoPRE, an information and decision support system for late blight in potatoes (Forrer *et al*., 1993). For the timing of the first spray, PhytoFAP used the 'Negativ-prognose'-model. Later this model was improved with help of the Main Infection and Sporulation Period (MISP) model. The MISP model indicates weather events that are crucial for the outbreak and development of late blight epidemics. Both models were transferred into PhytoPRE +2000 (Steenblock *et al*., 2000). In 2001, PhytPRE +2000 was replaced by an Internet version as a plot-specific potato late blight recommendation system (Steenblock *et al*., 2002).

Vitimeteo plasmopara is a warning model for downy mildew in grape and was developed between 2002 and 2003. The model calculates the possibility of sporulation and infection and incubation time. The model is used in the southern part of Germany and in Switzerland (Bleyer *et al*., 2006).

France

In France a number of forecast models were developed for diseases in cereals in the 1990s. Meteopro was developed as a model for decision support in vineyards against diseases and pests (downy mildew, grey mold, black rot and grape moth) (Maurin, 1991; Maurin & Fricot, 1993). Subsequently, a system of weather stations together with field observations was set up to run 28 forecasting models in top fruit (e.g. codling moth, apple scab, fire blight of apple, olive fruit fly), viticulture (e.g. downy mildew, grapevine moth), vegetable growing (e.g. *Septoria apiicola*), cereals (e.g. *Puccinia triticana*, *Mycosphaerella graminicola*), potatoes, oil seed rape and sunflowers (e.g. potato late blight, *Sclerotinia sclerotiorum*, brown stem canker of sunflowers *Diaporthe helianthi*) (Jacquin *et al*., 2003).

Italy

The developments of DSSs started at an early stage in Italy. In 1973, a project was launched starting with testing of IPM methods. In 1989, a computer network was installed to collect and process the data obtained from farms and to supply meteorological data to technicians. At that time there were also some developments in models for diseases in orchards and vineyards (Cravedi *et al*., 1990; Malavolta *et al*., 1991; Orlandini *et al*., 1993). In the Emilia-Romagna region there many DSS developments, e.g. a model for cereal diseases (Battilani *et al*., 1993). Subsequently, a number of models were developed, such as for the prediction of: tomato late blight, onion leaf diseases, botrytis in strawberry flowers and fruits, grape downy mildew, Cercospora in sugar beet and also some pest models. These disparate developments show the lack of a national programme. Both the approach to development and the management of the models and systems differ between the several regional warning services. The majority of the models were developed for the control of fungi and pests in: grapevine, apple, pear, peach, tomato, potato, onion, olive, sugar beet and wheat (Rossi *et al*., 2000). In recent years, more simulation models have been developed, e.g. for the simulation of ascospores of *Venturia inaequalis* on apple trees (Rossi *et al*., 2003a), for the risk of Fusarium head blight in wheat (Rossi *et al*., 2003b), and for estimating the potential development of *Diaporthe helianthi* epidemics (Battilani *et al*., 2003).

Collaboration between scientists and model developers

To a certain extent, there was an exchange of information during the development and validation of the different DSSs. In the 1990s some EU-funded projects began, such as the concerted actions EU.NET.DSS (European network for the development of Decision Support Systems) (Secher, 1993), EU.NET.ICP (European network for development of an integrated control strategy of potato late blight) and cost actions (Cost 611) to stimulate the development and introduction of computerized warning and decision support systems as a common initiative. The coordination of ongoing research in order to avoid duplication of efforts was another aim of these networks.

One subgroup within the concerted action EU.NET.ICP was for the development and validation of late blight DSSs (Hansen, 1996). One of the goals at the start of this project was to develop an European Integrated Control Strategy and a common DSS where all available knowledge was available. The first step was to describe the 10 main potato late blight models and submodels used in Europe (Bouma & Hansen, 1999). This original goal was one step too far. The potato late blight pressure and the aggressiveness of the fungus within Europe were not comparable from one region to another, the regional DSSs were not comparable (Andrivon, 1999; Hansen, 2000). The common interest in developing a good aid for the control of late blight resulted in an improvement of the quality of the different models, during a period in which disease pressure of potato late blight increased. In the same common approach a number of late blight DSSs were compared to each other under practical circumstances (field trials) over several years (Jörg & Kleinhenz, 1999; Kleinhenz & Jörg, 2000). During the validation trials of the DSSs, the fungicide input was reduced by 8–62% compared to routine treatments and the level of the disease was lower compared to routine treatments (Hansen *et al*., 2002).

Another example of collaborations were the comparison trials with cereal disease DSSs in Denmark, Germany and the Netherlands (Schepers *et al*., 1996; Johnen *et al*., 1998).

Integration and use of Decision Support Systems

The frequency of personal computers on farms in Western Europe varies between 30 and 70%, depending on the country, while access to the Internet varies between 50 and 90%.

Many options are available for disseminating information or advice to end users, including:

- output of the models being sent or directly used to the end users as an output of a PC program, or by fax

- weather-related DSSs being run on central computers using data collected from farm weather stations, together with the (three-day) weather forecast. The output of these models is sent to subscribed farmers. They receive a daily fax with the current disease calculations together with recommendation about whether to spray or not
- using an Internet version of these models, e.g. PhytoPRE +2000 or VIPS
- using a voice response database, voice alert or SMS messages
- using an advisor. In many countries and regions, extension officers or farm chemical advisors use DSSs to help them provide recommendations to farmers, with this advice disseminated in several ways. This advice should be fitted to the needs of end users.

It is important to use the most optimal way to disseminate information to the target group, which can differ between or even within countries. If the output of a DSS can be used as input for other systems, compatibility between them is very important. Syngenta and BASF provide information from their DSSs on their web sites which is a relatively new way to dissimulate this information.

Advantages of using DSSs

By using the best-suited plant protection product in dosages that are adapted to the actual conditions of disease pressure and meteorological conditions, the use of the DSSs can result in a lower risk of crop damage by diseases and pests and, in a lot of cases, in a lower input of active substances.

The results of a large number of trials with DSSs in many countries has shown that in most cases, DSSs provide good advice on applications of plant protection products and help to reduce the input of active substances and to lower dependency on agrochemicals. In using these systems, users will become more conscious of the relations between weather conditions and the efficacy of plant protection products. Meanwhile, the systems have been established as important tools for the achievement of more sustainable agricultural practices (Bouma, 2003).

Perspectives

In recent years there have been many new developments, of which the introduction of the PDA was one. A number of suppliers of DSSs also offer a ‘smaller’ system to run on a PDA. PDAs are equipped with GPS receivers and can carry geographical information such as soil maps, topographical maps and other environmental conditions. Together with weather data they facilitate site-specific applications of herbicides and pesticides. It is therefore a convenient tool whether used alone or in conjunction with a personal computer.

In several countries GIS-applications are being developed. In the (near) future there is a possibility of implementing a number of DSS models in a GIS environment in order to adjust spray advice according to characteristics of the plots. Recent developments in mobile communications technology and the Global Navigation Satellite System (GNSS) enables the development of precision farming and facilitates practical solutions for farmers.

Site-specific information collected by sensors mounted on tractors and agricultural machinery will provide important input in decision support systems. Weed detection systems using cameras and picture analysis offers great opportunities to improve selective spraying. Several studies have shown that the use of herbicides can be reduced significantly (by 35%–90%), when the product and dosages are applied in a fashion that is adjusted to weed species and sizes.

Conclusions and future developments

In recent years many weather-related pest and disease models have been developed. Similar developments have taken place in many European countries, from the early development of DSS to the recent provision of such programs on the Internet.

Generally, the models supported improvements in the applications of plant protection products well, helping to reduce the amounts of active substances used, lower the frequency of use and reduce farmers’ dependency on agrochemicals. Furthermore, by using these systems users will be more conscious of the relations between weather conditions and the efficacy of plant protection products.

The weather-related decision support systems are an important tool to achieve more sustainable agricultural practices. The systems are not designed to make an absolute decision, but instead they collate and process relevant information, and interpret and communicate a range of suitable options to be considered in the decision making process. Successful DSSs were those in which the users were involved in the design from conception to delivery.

Although the development of DSSs has been successful, it is unfortunate that the development most Decision Support Systems took place separately and simultaneously in a number of countries. The speed of improvement would have been substantially more rapid if there had been real cooperation between countries or groups of researchers who were working on almost the same models for equivalent pests, diseases and weeds. It is a waste of funding and energy to develop the same models with the same target in countries within the same climatic zone. To withstand the reduction of funding sources and meet the requirements of the funding bodies in future, it is necessary for the developments of new DSSs that collaboration between researchers or research groups on an international level increases significantly in the near future.

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Outils informatiques pour la protection des plantes, historique et perspectives

Des outils tels que le Minitel et les modèles de prévision ont conduit à une introduction relativement rapide de la technologie informatique dans les exploitations agricoles à la fin des années 1980. Dans plusieurs pays les développements ont été plus importants, ce qui a permis de créer des modèles pour encadrer la lutte, et de dématérialiser les échanges de données. La plupart des modèles ont été développés pour des maladies qui pouvaient se disséminer très rapidement, ou des maladies contre lesquelles on devait lutter de façon récurrente. Le développement de systèmes d'aide à la décision (SAD) liés à la météo a été initié dans les années 1990. Il est important d'optimiser la dissémination de l'information au groupe cible, qui peut varier entre ou même au sein des pays. L'utilisation des SAD permet de réduire le risque de dégâts pour la culture par des maladies et des ravageurs, et l'apport de substances actives, grâce à l'ajustement des doses utilisées. Les développements à venir incluent la mise en œuvre d'un certain nombre de SAD au sein d'un Système d'Information Géographique, ce qui accompagnera l'agriculture de précision en conseillant des traitements ajustés basés sur des caractéristiques spécifiques de la culture. Les SAD se développent avec succès dans de nombreux pays, mais de façon indépendante. L'extension de ces systèmes aurait été considérablement augmentée s'il y avait eu une réelle coopération entre pays ou groupes de chercheurs. Afin de résister aux réductions budgétaires, il est nécessaire pour le développement de nouveaux SAD que la collaboration scientifique internationale augmente de façon importante dans un futur proche.

Компьютерная поддержка для защиты растений: историческая перспектива и предстоящие разработки

Развитие таких починаний, как Videotext и прогностические модели, привело к сравнительно быстрому внедрению компьютерной технологии на фермах в конце 80-х годов. В нескольких странах были проведены разработки по созданию моделей для контролируемой борьбы, а обмен данными стал цифровым. Большинство моделей были разработаны для быстро распространяющихся заболеваний или таких, с которыми следует регулярно бороться. В 90-е годы началась разработка систем, содействующих принятию решений (Decision Support Systems, DSS), основывающихся на погодных данных. Очень важно при этом использовать оптимальный способ передачи информации заинтересованной группе лиц, которая не всегда одинакова в различных странах и даже внутри стран. Использование результатов DSS приводит к снижению риска для сельскохозяйственных культур от заболеваний и вредителей, а также к понижению внесения действующих веществ за счет использования откорректированных дозировок. Будущие разработки могут включать возможность внедрения целого ряда моделей DSS в Географическую Информационную Систему, которая будет поддерживать прецизионное сельское хозяйство путем предоставления консультаций по скорректированным нормам опрыскиваний с учетом характеристик конкретного участка земли. Успех DSS очевиден, несмотря на то, что их разработка в целом ряде стран ведется независимо. Разработка таких систем могла бы происходить значительно быстрее, если бы существовало подлинное сотрудничество между странами или группами исследователей. Для разработки новых DSS в условиях сокращения финансирования необходимо, чтобы на международном уровне сотрудничество между исследователями и группами исследователей в ближайшем будущем существенно увеличилось.

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