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Decision Support Systems: Quenching the Thirst

A large number of Decision Support Systems (DSS) have been developed to assist extension agents, consultants, growers, and other agricultural clientele in the management of plant diseases. A search of the internet reveals many examples of operational DSSs with plant disease modules, including WISDOM for potatoes (University of Wisconsin), RADAR for apples (University of Maine), PAWS for several crops (Washington State University), and a DSS used for a variety of crops on the West Coast (Fieldwise.com).

The tools that can be used as part of a DSS are also well described in the literature. For example, Campbell and Madden (5) list over 70 models that have been developed for disease forecasting. However, an important question is, "How many DSSs are currently being used by growers on a day-to-day basis?" It is our observation that a large number of simple DSS tools are not widely used because they address only specific disease problems, whereas agricultural producers must manage the whole pest and disease complex within their production system. Nevertheless, narrowness of application is not the only reason for restricted usage, since many of the more complex DSSs have not been implemented. Travis and Latin (25) listed 11 DSSs (expert systems), of which only three have been implemented or commercialized. However, this problem is not limited to plant protection and is mirrored by the performance of DSSs in other industries (1). For every DSS success story, many others have failed or are struggling commercially. Many expert systems end up "dead on arrival" (never work),

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A Decision Support System (DSS) integrates and organizes all types of information required for production decisions (19). It can be as simple as a tool for processing data or as complex as a computerized expert system. Figure 1 is a conceptual diagram of a DSS for disease or pest management. Each component can be thought of as a method with a set of associated tools. For example, the data component is associated with the collection method, which has several tools including automated weather stations and site-specific weather products. DSS tools vary in complexity. Examples include rules, schedules of management, equations, combinations of decision aids (23), and expert systems (25). The type of DSS is determined by the cooperative efforts of a multi-disciplinary team of knowledge specialists, the technical and financial resources available, the degree of industry organization and support, and the expectations of end users (25). The selection of an appropriate DSS for a given cropping situation often depends upon the pathogen-pest complex as it interacts with crop and grower preference factors.

Fig. 1. An idealized Decision Support System for plant disease management showing components (red font), methodology (black font), and tools (blue font). Modified from Petersen et al. 1993 (19).

Fig. 2. A municipal water supply system as an analogy for barriers and solutions for Decision Support System (DSS) delivery.

among the ranks of the unemployed (never used), or serving a life sentence in research and development (never finished) (6).

The problems faced by DSS developers can be illustrated by an analogy with a municipal water supply system. After introducing the main problems and solutions through the analogy, we present case studies of our experience in the northeastern United States and Australia. Finally, we present our vision for the future development of DSSs. This paper is not intended as a review, but rather as a framework for DSS delivery or in our water supply analogy: quenching the thirst.

Water Supply System Analogy: Components and Problems

In the water supply system analogy of a DSS, water is the information that must reach the user in an appropriate manner to enable effective decision-making (or quench a thirst). The main components in the analogy are a reservoir for storage, a distribution network, quality control, a marketing system, and a readily accessible faucet (outlet) at the user's site. Problems arise in the supply system when components fail, are poorly designed, or are misinterpreted by users (Fig. 2). The first component is a "reservoir," which collects rain and stores the water until required by the

Fig. 3. A comparison of delivery mechanisms for Decision Support Systems (18).

system. In the same way, a DSS requires a reservoir of knowledge and data. Modern computer systems can easily store considerable quantities of data, but capturing the data can be problematic. Many DSSs have failed or "run dry" because they do not

provide an easy means to capture and store environmental or biological data. For example, some early DSSs relied upon manual collection and entry of weather data, while others made growers collect copious quantities of scouting data.

The next component of the supply system is a treatment plant to guarantee *water quality*. In the same way, DSSs require thorough evaluation to avoid poor-quality products that we call “junk data.” The junk data problem has developed because it has become so easy to deliver information electronically. Sometimes models are pushed into service before they have been sufficiently refined. For example, some models developed in controlled environment growth chambers are not ready for real-world input. Another important quality problem is the “sham trial and firing squad” syndrome whereby a good product can be rejected because of an improper evaluation. The quality assurance process should involve the refinement of DSS products by continual interaction between developers and users. However, when there is poor communication between the DSS developers and users, there is no opportunity to resolve why a certain product fails. In many cases, failure may result from a misunderstanding of the system’s inputs or outputs rather than failure of the system itself. After hasty judgment in the “sham trial,” the “firing squad” mentality takes over and the product is rejected as worthless and is discarded. A second aspect of quality control is the appropriate application and integration of models within the pest management system. For example, a model to forecast ascospore maturity can be inappropriately used to forecast the risk of infection, which may be dependent upon additional host and/or weather-related factors.

Beyond the treatment plant, water supplies have a “distribution network” of pipes that reach into the community of consumers. Instead of pipes, an agricultural DSS can use a variety of distribution networks such as: word-of-mouth, newsletters, recorded phone messages, facsimile (fax), electronic mail (e-mail), and web sites. Delivery systems have been classified as either “Push,” “Pull,” or “Plug” (21). Push and Pull systems provide DSS information from a remote source (Fig. 3). Push systems deliver information to the user, while Pull systems require the user to request the information. Push systems work best for supplying daily information, updates, and other types of dynamic information. Pull systems work best for allowing users to access specific databases or resources. Plug systems provide DSS information built into an on-site device, for example a disease predictor (14). They allow users to maintain hands-on contact with the data source. Push is analogous to turning on a faucet (tap), Pull is drawing water from the reservoir with a pump, and Plug is like installing bottled water.

Some of the distribution systems can work in more than one way. For example, faxes can be used in both push and pull modes. One distribution problem in the pull mode is that users can easily become

discouraged as they search for desired information among poor-quality sources (*isolation*). A successful distribution system should be easy to use, reliable, cheap, and updated frequently. It should be able to carry both text and graphical information. For example, faxes have an advantage over many electronic techniques, in that paper is quick and easy to use (9,10).

A water supply system requires a marketing strategy to reach new customers and to raise the funds to build and maintain the system. Unfortunately, the developers of a DSS often fail to recognize the importance of a marketing strategy that will sustain the DSS after its initial release. The *cost* (retail price) of the DSS is a major factor in determining the number of users. This cost includes supporting infrastructure such as automated weather stations, computers, and internet connections. Another marketing consideration is user awareness. Users may be aware of the need for a DSS but not know how to use one, or they may use it incorrectly (*misuse*). Some users do not know where to access DSS information or may have *wrong expectations* about a DSS product and become disillusioned when these expectations are not met. In other instances, DSSs are poorly marketed and dumped on users with little explanation of how these systems work.

Unlike earlier decision tools, such as rules and tables, which use simple generic inputs, modern DSS software and electronic distribution networks are expensive to develop and *maintain*. The construction of a DSS often requires enormous time and financial investment (7), and when this responsibility falls on a single individual or small group, there is often little energy or resources left for the delivery phase. It is well known that complex products delivered without technical support or regular updates may quickly vanish from the marketplace.

Another major problem is poor design of DSS output. In the water supply analogy (Fig. 2), there is delivery to "Swampy Estates," where no houses will ever be built. No users wish to purchase the product despite the vision of the DSS development team. Sometimes a DSS is built to solve problems that do not concern real world users, or they are too simple and fail to address the most important management questions. This shortcoming may fall under the ivory tower syndrome. For example, a DSS addresses the question of saving an individual spray, but real world users may be more concerned with maintaining quality standards or meeting regulations. Part of this problem stems from the fact that while researchers often concentrate on a single pathogen, growers must deal with all aspects of farm management, including labor, equipment, finances, cultural practices, and management of an entire complex of several microbial and arthropod pests.

In a water supply system it is important to have a *practical faucet* (tap) that is easy to turn on, responds quickly and reliably, and has a consistent, appropriate flow. Unfortunately, many agricultural DSSs do not have a user-friendly interface. Unnecessary DSS *complexity* may produce a *hydrant blast* of information that users cannot absorb. For example, the output may be a confusing array of numbers even when disease pressure is low. Like a clogged faucet, other DSSs take too long to use because of delays in data processing or tedious input requirements. The *time* demand on the user can be the single most important factor in the success or failure of a DSS (27). When grape growers in Pennsylvania were asked what was the single most important limitation to their use of DSSs, their response was time. The time growers are prepared to spend using a DSS is, in their words, “as long as it takes me to drink a cup of coffee.” This time factor is proposed as the “cup-of-coffee” rule by one of the authors (JWT). If a DSS is too slow, users will interact with it less frequently.

Once water has been delivered, it is important to allow the user to choose how it will be consumed (*choice*). Many users prefer to drink water straight, while others will use the water to make other beverages. The same need for choice is true for the delivery of a DSS. Unfortunately, many DSS tools use only one method in the information flow (Fig. 1), with the result that some users find the information too complex, while others find the information does not allow them to choose among sev-

eral management options. Having outlined the barriers to DSS delivery and acceptance, we will now focus on some of the key solutions.

Solutions to Important DSS Problems

The essential knowledge base (reservoir) for developing and implementing a DSS can be achieved by seeking contributions from a diverse group of experts. Although we have no recipe for facilitating successful collaboration, we recommend that ownership of the DSS intellectual property must be appropriately recognized, and royalties should be shared between the contributing institutions. Lead personnel in DSS development should be cognizant and forthright in presenting the minimal likelihood that anyone will get rich from development of a DSS, and that contributors will more likely be paid in “coin of the realm” (i.e., in authorship on the DSS and related publications). Importantly, knowledge needs to be stored in a form that is easy for all contributors to understand, rather than as computer code known to only a few programmers. In developing a DSS, we have had most success when knowledge is stored in the form of dependency networks (25,26). A dependency network is a decision tree that uses Boolean logic (AND/OR diagrams).

The “cup-of-coffee” rule gives us clear guidelines about the time users are prepared to commit to DSS operation. A solution to the time barrier is to automate every method in the DSS information flow (Fig. 1). This means that there must be little or

no user input of data. Furthermore, data processing should be done swiftly, automatically, and preferably prior to user acquisition. For example, weather data should be automatically downloaded from a weather station or automatically delivered via an electronic service. In another example, a “lite” expert system could automate some of the decision making instead of having the user spend considerable time running a full DSS. The use of automated features in a DSS is discussed in more detail in the Case Study and Outlook sections.

DSSs vary in complexity, with production guides at the simple end of the spectrum and a full-expert system at the complex end (Fig. 4). What was previously shown as a circular process (Fig. 1) can also be represented in a linear format to show increasing complexity. The advantages of a simple DSS include: low cost, low technology, generic application, ease of delivery in multiple ways, and limited time requirements for learning and use of the DSS. In contrast, a more sophisticated DSS can provide greater integration of knowledge and allow growers to choose management tools and their associated risks. Growers who use the highest level of DSSs do not want to be led through the decision making process only to be given one possible action for a given disease scenario. They want to be able to evaluate several possible responses for a disease scenario and to choose for themselves (choice) the response and the relative risks associated with the action.

A major disadvantage of the more complex DSSs is the high cost associated with their development. Eight years ago, an expert system was estimated to cost as much as \$52,000 to \$300,000 to develop and validate (7). However, the main disadvantage is the leap of faith required for growers to move from using a routine spray program to a computer-based DSS that requires weather information and regular pest scouting inputs. Delivering simple and complex DSSs provides a “pathway of learning” for growers to progress from one level of complexity to the next. As they do so, they learn how to integrate and interpret background information, and to make better management decisions. In our experience, growers introduced to an effective DSS at the simple end of the spectrum soon realized the need for a more complex DSS. A DSS should allow growers to select the level of complexity with which they feel most comfortable.

A solution we see to the marketing problem is to build university-commerce-user partnerships. By reference to universities, we also include other agencies, such as government institutions, that have R and D and/or extension responsibilities. The main strength of universities is that they have the personnel and information resources to build knowledge bases that lead to the

Fig. 4. A spectrum of tools for decision support showing components (red font), methodology (black font), and tools (blue font).

construction of DSSs. University extension personnel have established links to commodity and user groups and are independent of commercial bias. These people have the talent and knowledge to help acquire funding for development, research, and construction of DSSs through support of commodity groups. However, without firm support from commodity groups, research funds do not usually last long into the delivery phase. In addition, some R&D agencies are not geared to the provision of goods and services. R&D agency staff are often under pressure to begin new projects, and the maintenance of DSSs is not a high priority. This is where the linkage with private industry can assist in providing the resources for long-term stewardship of the DSS delivery and upgrades. Industry is better equipped to commercialize the delivery of DSSs. Commercialization can provide financial resources for the sustainability of the system. The downside of this linkage is that the nonindustry developers may feel loss of control of the DSS that they have created. In addition, some companies may not survive in the marketplace, and university developers may lose the time they have invested in product development. While commercialization provides a mechanism to promote DSS sustainability, user evaluation is critical for ensuring that DSSs are of high quality.

The solution to the water quality problem of the "sham trial and firing squad" is a systematic approach to evaluation where DSS products are refined by continual feedback from user groups (20). The developers of a DSS must work closely with growers in all phases of the product development from initial ideas to delivery and implementation. Feedback from growers can help determine what information is important and how it should be presented. An important consideration is that products should be as complete as possible before asking growers to provide an evaluation. For example, a computer-based DSS that crashes frequently will be considered ineffective regardless of the quality of information delivered.

Another important consideration in DSS development is that all steps of the information flow require evaluation. For example, site-specific weather data may require interpretation depending on the source. In Pennsylvania (28,29), it was observed that although temperature and relative humidity data from different brands of automated weather stations were similar, leaf wetness and precipitation were variable among instruments. Unfortunately, because there is no standard for the measurement of leaf surface wetness (2), all measurements require interpretation with respect to how the data were collected and what type of sensor was used. If it is known that a particular sensor design overestimates surface wetness, for example, this can be compensated for by the DSS.

As well as input, DSS output requires user evaluation. A solution to the hydrant blast of information is to package the DSS to meet growers needs. Historically, many DSSs have presented their outputs in quantitative terms, which growers find difficult to interpret. Often simple symbols can be used to indicate levels of risk, which can be associated with a management consequence. Another packaging consideration is the time interval growers use to make decisions. For example, apple growers normally consider half-day intervals (9). They will make decisions for this morning, this afternoon, or tomorrow morning. Although hourly data are best for estimating disease risk, this often provides too much information for a grower to process at the output stage.

In the next section, the problems and solutions are discussed using two case studies. The first is a DSS for apples in the northeastern United States, and the second is a DSS for grapes in Australia. In both studies, a comprehensive expert system was developed and initially seen as the final solution to the DSS needs of growers. In each case, the adoption of the expert system has been limited and the developers were forced to use alternative methods to get the decision support information to growers.

The Penn State Apple Orchard Consultant

This project was a collaborative effort by 30 apple growers, two universities (The Pennsylvania State University [Penn State], and Cornell University), and a commercial provider of agricultural information (SkyBit, Inc.). Our case study begins in 1990 with the commercial release of the Penn State Apple Orchard Consultant (PSAOC), a computer-based, holistic

expert system (Fig. 5). The PSAOC combined multiple orchard parameters, manual weather inputs, insect and disease status, and chemical databases with management logic to provide growers with highly specific recommendations for managing pests in individual orchards (26). The system was available for DOS or Macintosh computers. Before release, PSAOC was tested for several seasons by grower user-groups that helped refine its operation and user interface (4). Although the system sold several hundred copies in Pennsylvania and the New England region, it has not attained the widespread adoption by apple growers that had been anticipated by the developers.

A study of usage patterns found that 8% of the growers did not use the system at all and 54% used it less than twice per month (20). Few growers were prepared to use a complex computer program for making day-to-day decisions. Growers encountered difficulty with the collection and manual input of hourly weather data (28) and in keeping up with the weekly pest scouting required by the PSAOC system. Although processing the PSAOC recommendation itself took only a few minutes, the data input process required hours of labor. Most growers were simply not willing to invest that much time (cup-of-coffee rule).

By the mid-1980s, automated weather stations (AWSs) were becoming more frequently used as an alternative to manual weather data collection. Although a great improvement on the manual process, many AWSs were expensive (a cost barrier), some required considerable maintenance (a time barrier), and there were problems associated with the calibration and standardization of sensors (a quality barrier). Additionally, some AWSs were too complex to operate and download (28). Al-

Fig. 5. The Penn State Apple Orchard Consultant project. A, Graphical user interface of expert system. B, Grower user. C, Automated weather station. D, Apple orchard in bloom.

though originally seen as a solution to manual data input, it became clear that an AWS was less than a perfect answer.

By the mid-1990s, university cooperators and SkyBit Inc. began the evaluation of site-specific weather data in the form of simulated observations and forecasts (17,21). Simulated observations are generated by spatial interpolation procedures using data from weather observations made by local, state, or national weather station networks or services. High-resolution atmospheric models are used to create site-specific forecasts. SkyBit produced the site-specific weather data as part of its "E-Weather Service." Growers, as monthly subscribers, could receive data products on a daily basis by either fax or e-mail (21,24). For example, the SkyBit E-Weather Forecast product provides estimates of weather variables every 3 h for a 48-h forecast and daily estimates out to 10 days. No on-site weather measurement was required, thus freeing the user from the constraints of collecting data. The PSAOC

system was modified so that SkyBit data could be automatically downloaded from e-mail. The apple DSS project assisted growers by providing initial financial subsidies during periods of product testing and development. During the 3-year project (1996 to 1998), the cost of SkyBit products was subsidized completely in the first year, partially in the second year, and not at all in the third year. Given the history of earlier DSSs, it was quite surprising that most (28 out of 30) growers opted to remain with the program through the third year.

At this stage, the project took an interesting twist. Rather than being used as input into the PSAOC, growers were using the weather data as a simple DSS. For example, the wind speed and direction forecasts helped users to make decisions about the best time to apply (or not apply) pesticides. Although the PSAOC could deliver far more detailed decision-making information, growers were using the weather data as a DSS tool. This was mainly because the weather data (usually

in fax form) only required a few seconds to read compared with many more minutes required to access the PSAOC *even with* the automatically input weather data.

From this crucial shift in simplifying the approach to DSS delivery, the rest of the project unfolded along an easier path, paved by our interaction with the growers. It was a simple next step for the grower group to suggest that "It would be nice to have some disease warnings attached to the weather forecasts." This need resulted in the creation of an Apple IPM disease product (Fig. 6). The IPM Apple Disease is part of SkyBit's "AgWeather" line of products, which are offered to the agricultural community through its commercial E-Weather Service. Its format is fairly representative of "single-sheet" products that are being offered by weather companies in the United States. The IPM Apple Disease product displayed in Figure 6 is for a rural site in central Pennsylvania; it is delivered daily by e-mail or facsimile to growers on a subscription basis. The product columns are divided among "weather" and the diseases of "apple scab, fire blight, and sooty blotch and flyspeck." The product rows contain data "based on observations" and "based on forecasts." In one quick glance, growers can see the past weather simulated for their location and a 10-day forecast. The weather variables being tracked include daily maximum temperature (TMX), minimum temperature (TMN), precipitation total (PREC), average relative humidity (ARH), and leaf wetness hours (LW). Individual models for each disease simulate and predict day-by-day the accumulated wetness (AW) and temperature (TW) of a potential disease event and a pest "window" (PW). The models are initiated with a grower-provided biofix date, which is displayed as the year, month, and day (YYMMDD) under the disease name. The pest window (PW), through the use of symbols, informs a grower of days when a disease is expected to be either not active (-), active but not infectious (+), or active and infectious (++). It is important to note that the pest models in the IPM disease products only determine if weather conditions at a particular site are conducive for disease development. If conditions are favorable, onsite scouting must still be carried out to determine the presence and pressure of a simulated disease. At this level in the DSS spectrum, environmental data were processed through models/rules and the results displayed as a daily risk for each disease.

The IPM Apple product line presents individual daily risk assessments for three diseases and eight insects (8) and could be seen as an end point for DSS development. However, within the first season of use, growers were requesting the integration of these daily risk values. Unfortunately, the integration of individual risks requires knowledge of individual orchard factors.

E-WEATHER SERVICE										AGWEATHER IPM APPLE DISEASE PRODUCT									
For: PA-CENTRE COUNTY-ROCKSPRING										Date: SUN May 20, 2001									
WEATHER										APPLE SCAB 010420				FIRE BLIGHT 010427				SOOTY BLOTCH 010510	
Date	TMX F	TMN F	PREC in	ARH %	LW hr	ASM %	AW hr	TW F	PW	ADH 65F hr	AW hr	TW F	PW	ALW hr					
=====	=====	=====	=====	=====	=====	=====	=====	=====	=====	=====	=====	=====	=====	=====	=====	=====	=====	=====	=====
BASED ON OBSERVATIONS																			
0501	84	44	0.00	47	0	2	0	-	+	225	0	-	-	-	-	-	-	-	-
0502	85	48	0.00	55	0	3	1	53	+	225	1	53	+	-	-	-	-	-	-
0503	88	52	0.00	56	2	4	2	57	+	225	2	57	+	-	-	-	-	-	-
0504	88	55	0.00	55	0	6	0	-	+	225	0	-	-	-	-	-	-	-	-
0505	71	49	0.00	51	0	8	0	-	+	225	0	-	-	-	-	-	-	-	-
0506	69	43	0.00	44	0	10	0	-	+	225	0	-	-	-	-	-	-	-	-
0507	69	41	0.00	45	0	13	0	-	+	225	0	-	-	-	-	-	-	-	-
0508	67	43	0.21	69	9	16	15	56	++	225	6	63	++	-	-	-	-	-	-
0509	75	49	0.00	67	10	21	19	57	++	225	19	57	+	-	-	-	-	-	-
0510	79	46	0.00	55	0	27	0	-	+	225	0	-	-	0	-	-	-	-	-
0511	83	47	0.02	58	2	35	2	75	+	225	2	75	++	0	-	-	-	-	-
0512	67	50	0.13	78	10	42	10	61	++	225	10	61	+	0	-	-	-	-	-
0513	66	42	0.00	47	0	48	0	-	+	225	0	-	-	0	-	-	-	-	-
0514	61	36	0.12	62	3	52	3	50	+	225	3	50	+	0	-	-	-	-	-
0515	69	36	0.00	55	7	58	7	44	+	225	7	44	+	0	-	-	-	-	-
0516	70	42	0.00	48	0	64	0	-	+	225	0	-	-	0	-	-	-	-	-
0517	56	47	0.07	81	14	69	9	56	++	225	9	56	+	0	-	-	-	-	-
0518	65	52	0.03	90	24	75	35	58	++	225	35	58	+	0	-	-	-	-	-
0519	77	57	0.03	60	9	81	38	58	++	225	38	58	+	0	-	-	-	-	-
BASED ON FORECASTS																			
0520	69	52	0.00	66	0	86	4	56	+	225	4	56	+	2	+	-	-	-	-
0521	58	56	1.91	85	22	89	28	57	++	225	28	57	+	26	+	-	-	-	-
0522	64	55	-----	85	24	91	52	57	++	225	52	57	+	50	+	-	-	-	-
0523	61	50	-----	83	24	93	76	56	++	225	76	56	+	74	+	-	-	-	-
0524	56	46	-----	83	24	94	100	55	++	225100	55	+	+	98	+	-	-	-	-
0525	58	43	-----	82	24	95	124	54	++	225124	54	+	+	122	+	-	-	-	-
0526	61	45	-----	76	24	96	148	54	++	225148	54	+	+	146	+	-	-	-	-
0527	66	46	-----	69	24	97	172	54	++	225172	54	+	+	170	+	-	-	-	-
0528	68	49	-----	68	24	98	196	55	++	225196	55	+	+	194	+	-	-	-	-
0529	70	51	-----	65	18	98	18	62	++	225	18	62	++	212	+	-	-	-	-
***** IMPORTANT: Check the dates at the top of each column. *****																			
Green Tip Date - is used for Apple Scab																			
Blossom Date - is used for Fire Blight																			
Petal Fall Date - is used for Sooty Blotch																			
ASM = Apple Scab Maturity Percentage																			
ADH = Accumulated degree-hours from blossom date up to a max of 225.																			
ALW = Accumulated leaf wetness hours from petal fall date.																			
AW = Accumulated wetness hours for the most severe event.																			
TW = Average temperature during the most severe event.																			
PW = Pest Wait/Watch/Warning:																			
- = not active																			
+ = active but no infection																			
++ = possible infection & damage																			
***** ATTENTION: Please report your biofix dates (1-800-454-2266) *****																			
Please call 1-800-454-2266 to report biofix dates for Green Tip, Blossum, and Petal Fall. Your product will NOT be correct unless these dates are reported accurately.																			
Thank you.																			

Fig. 6. The SkyBit AgWeather IPM Apple disease product on 20 May 2001 for a site in central Pennsylvania (22).

Orchard factors can be varied and complex, such as precipitation since the last fungicide application, type of fungicide last applied, current season inoculum potential, and host susceptibility factors such as growth stage and fruit versus leaf susceptibility. To achieve this integration, we needed a DSS with the capabilities of an expert system: the PSAOC. The project had now gone full circle as growers realized the need for the very same expert system that they had ignored for so long. Ideas for the development of the apple DSS are explored further in the Outlook section.

Australian Case Study – The AusVit DSS for Grapes

The Australian DSS project was a collaborative effort between several state departments of agriculture (or equivalent), universities (including Penn State and Cornell), grower organizations, private industry, and other R&D agencies. The project focused on the management of diseases and pests in commercial viticulture, mainly wine grape production (Fig. 7). In Australian viticulture, state departments of agriculture have one of the main extension roles, although universities, federal institutions, and industry groups are also important players. In particular, our discussion will focus on grape downy mildew (*Plasmopara viticola*), a sporadic but serious disease in Australia. One of the main problems in management of this disease has been the complex epidemiology of the pathogen. For this reason, we developed the simple “10:10:24” rule to determine if weather conditions have been suitable for primary infection (16). The 10:10:24 rule states that primary infection occurs with a minimum of 10-mm rainfall, when air temperatures are at least 10°C and when the soil surface remains wet for ≥24 h. A similar rule was developed for secondary infection. These rules were developed in the 1980s, and by the mid-1990s, they were incorporated into a variety of nontraditional extension techniques including songs (15) and cartoons. The rule-based system had the advantage of simplicity, was easily understood, and could be communicated through a variety of different media. The rules did not require any specialized weather monitoring equipment but instead were commonly used with daily weather summaries provided by the mass media or with simple weather instruments such as a rain gauge or max-min thermometer.

A disadvantage of the rule-based system was that its epidemiological over-simplifications and crude data inputs might lead to prediction errors. Since the pathogen is so potentially destructive and the crop value is high, a DSS that could predict downy mildew with greater confidence was required. Also, the rule-based system did not allow the estimation of incubation

periods or provide management recommendations. A prototype of DMODEL, a computerized empirical simulator of downy mildew (13), was completed in 1991, although validation and field-testing continued for several more years. Inputs to the DMODEL simulator include 10-min weather data, crop phenology, and vineyard observations of disease. The expert system within DMODEL gave users a choice of management recommendations and explanations on the likely risks associated with each choice. Since 1999, a modified form of DMODEL has been available to users in a low-cost automated weather station/disease predictor (Plug) (14). The predictor uses a simple display and red lights to indicate infection risk and time of lesion appearance.

While DMODEL was a good answer to the problem of predicting downy mildew, it did not assist with the management of other serious pest and disease problems. In 1991, this need was addressed by the development of AusVit, an expert system for grape management. The system was built in collaboration with more than 26 scientists from fields such as plant pathology, entomology, viticulture, plant physiology, and computer science (11). The AusVit system began as a grass roots collaborative effort, and researchers did much of the early knowledge engineering without official funding. Progress on the system was rapid, and within a few years (1993) an early prototype was taking shape. About this time, the Cooperative Centre for Viticulture (CRCV) adopted the project and provided the necessary funds to pay for the salary of the software developer. The CRCV is one of several ephemeral research institutions created by the Federal

Government of Australia. Inside AusVit, the DMODEL simulator functions as an infection risk model, and its output is integrated with recommendations for other diseases and pests (11).

By the late 1990s, the AusVit system was nearing completion and the CRCV began its commercialization phase. The AusVit project was recognized by many as a silver bullet to DSS needs in viticulture. Although AusVit ran smoothly and was successful in evaluation trials across Australia (P. Magarey, *unpublished data*), it was not widely adopted by the grape industry. The AusVit system required weather and scouting data, but the principal limiting factor may have been the perceived high cost of the software (~US\$500), which limited its use to major wineries and vineyards (11). The system was beyond the reach of independent growers, many of whom are part-time operators on small properties. Many of these growers did not have faxes, let alone computers. Most of these growers were located in three viticultural districts, the Riverland (near Loxton, South Australia), the Sunraysia (near Mildura, Victoria), and the Murrumbidgee Irrigation Area (near Griffith, New South Wales). This concentration of growers enabled a cooperative or community-based approach to DSS delivery and a solution to the AusVit delivery crises.

In 1992, the Victorian Department of Agriculture initiated a cooperative pest and disease information service for grape and citrus growers known as CropWatch. Six years later, a companion service, CropWatch SA, was started in South Australia's Riverland region (12). This service highlights the cooperation and synergy that may be achieved between different organi-

Fig. 7. Grape production in Australia. A, An overview of vineyards near Mildura, Vic. B, Model-T-MetStation, a weather station and disease predictor. C, Oilspots and sporulation of *Plasmopara viticola* (grapevine downy mildew). D, Screen dump of AusVit Decision Support System as used in Australian Viticulture.

zations. CropWatch SA is a joint venture between the Department of Primary Industries and Resources South Australian (PIRSA), the local grape and horticultural industries, and a private crop monitoring agency. CropWatch SA established an AWS network with 15 sites at strategic locations in vineyards around the Riverland district. AWS data are automatically downloaded via a mobile phone link each week or more often if necessary. Experienced commercial vineyard personnel check each AWS and survey the vineyard sites every 14 days during the growing season. They assess current levels of diseases and pests and relay that information to the CropWatch SA office.

Weather data and field surveys are used by the AusVit expert system to produce crop management recommendations. After deliberation, PIRSA staff compile a one-page statement on the risk of pests and best management practices. CropWatch disseminates this statement to growers in a number of ways. One is by fax (push), which provides ready access to up-to-date technical information each week to some 400 growers. Other methods include fax (pull), e-mail (push), and a recorded telephone message or "hotline" service (pull). Some growers find a telephone message is more user friendly and convenient.

Although CropWatch provides a mechanism to deliver outputs of AusVit to the masses, it is not the complete answer in itself. The future of the AusVit system is uncertain. Although the perceived success of the AusVit project was critical to the decision to extend the life of the Cooperative Centre for Viticulture (CRCV) by an extra 7 years, it was not included in the new strategic plan. The CRCV needed to find new research directions, so instead a commercial partner is being sought to take over the development and maintenance of the AusVit system. This illustrates the value of having a suitable commercial partner involved in the DSS development from the beginning. Nevertheless, the AusVit system remains a powerful DSS tool.

Outlook

One of the biggest changes influencing the future of agriculture is the continued demise of the small family farm and the rise of large-scale agribusiness. This will increase the need for DSSs. The trend is moving from growers making decisions for a single site toward consultants or managers requiring integrated information for multiple sites in diverse regions. Another change has been toward more complex technologically based agriculture with greater requirements by governments and processors for regulating and reporting the use of pesticides.

We feel the bottom line for the development of DSSs is that users do not want "nuts and bolts"; they just want answers,

i.e., a simple tool to do a complex task efficiently and effectively. For example, water consumers do not care about the size or complexity of the distribution pipes as long as the system provides the water they need. In addition, they do not want to assemble the water system each morning before the faucet can be turned on. Our vision for a twenty-first century DSS is a concept that will be a total management solution for growers, what we will term a "super consultant." Many parts of this system have already been developed, and now these components need to be integrated to produce a holistic system.

The first feature of a super consultant is that it will address all facets of crop management, not just pest and disease management. It will be designed to assist precision agriculture, irrigation, nutrition, regulatory reporting, ordering of supplies, and farm finances. Although the existing distribution networks of fax, e-mail, and phone will still be important, the super consultant will be delivered through a web site. This will allow for the elimination of software at the users' level and will provide a mechanism for a merging of push and pull approaches. Furthermore, it allows the DSS to be updated easily and continuously. Web delivery will also provide a mechanism for seamless communication among databases including weather and pesticide registration. Although web-based communication can be slow, this problem may become less important as communication networks are modernized.

In addition, the web provides a tool for reducing the isolation of users. Scouting reports or spray programs at one property can be compared with others from neighboring properties to check for any anomalies or errors. Topical problems or issues can be rapidly communicated within a group of cooperating users who agree to share data. Users will not need to be in their office to access the super consultant. Instead, they will communicate with the DSS via personnel data assistants and web-active mobile phones. In the not-too-distant future, speech recognition and text-to-speech technology will free users from the inconvenience of the keyboard.

The super consultant will also have greater automation of interpretation than the current DSS. The interpretation and integration of disease and pest models will be based on static-site profiles and site-specific weather information. The static-site profile information includes factors about the site that do not change substantially during the growing season, such as cultivar, tree or vine age for perennial crops, and disease levels in previous seasons. Other information such as scouting reports can be relayed directly to the DSS. We have termed this limited interpretation and integration of information a lite-expert system. When the lite-expert system detects a potential problem or risk, a user

may choose to run the full-expert system to receive a greater choice of recommendations. As well as being part of a more complex computerized DSS, results from a lite-expert system can also be delivered to users by fax or e-mail.

The most important component of the super consultant is that it will handle all the required record keeping. This frees the user from a substantial time burden of bookkeeping. Site-specific weather data and the scouting reports also serve as accepted criteria for justifying (to regulatory authorities, wholesalers, or processors) the application of the pesticides. A super consultant is likely to have a much higher developmental cost than existing DSSs. For this reason, we believe it is most likely to be constructed as a joint venture of private industry, universities, and government agencies. This would require the pooling of resources by companies with complementary products to create the one-stop "supermarket," where subscribers will most likely be billed on a per-month and/or a per-hectare schedule.

An alternative vision to the super consultant is the "web portal" concept. A government, university, food processor, or grower cooperative would be the most likely host of such a portal. The web portals will be shopping malls of services from many sources available to growers. For example, regional or district scale information products may be provided free by extension services, whereas information for an individual farm may be provided by a consultant for a service fee. This will allow growers to choose among service providers. Although such choices do not exist in most industries, the ease of information delivery via the web will ensure competition at least in the major industries. Password access can restrict information from commercial services to the fee-paying users.

Another vision for future DSS development is what we might consider the "open source" concept, which is based upon free redistribution and integrity of the source code. The open source operating system, Linux, has now become so comprehensive that it is a serious competitor to rival commercial operating systems, but it is available free or commercially at a fraction of the cost. In an open-source environment, DSS components, such as models, are built by a community of developers and made available freely over the web. The difficulty with such an approach is that there has been little or no standardization, particularly in the case of plant protection models. There has been a diversity of both approaches to modeling and programming languages. However, modern programming techniques (common object models or COM) now allow models to become essentially interoperable (3). That is, by designing standard interfaces, models can be "plugged and played" from one DSS to

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Dr. Russo is president and senior research scientist at ZedX, Inc. and SkyBit, Inc. ZedX is an information technology company that specializes in custom weather databases and decision support algorithms for the agricultural and environmental industries. SkyBit specializes in the electronic delivery of site-specific weather data and weather-dependent products to

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Mr. P. Magarey received his B.Ag.Sc. (Hons) from the University of Adelaide in 1975 prior to working as a plant pathologist at Loxton Research Centre. His interest in delivering effective disease management information to grape growers led to the development of DMODEL, a simulator for grapevine downy mildew, and its subsequent incorporation into AusVit, an expert system for Australian viticulture. In 1991, he received a Churchill Fellowship which led to the development of the Model T MetStation, a low-cost weather station and disease predictor for managing grape downy mildew and other diseases. He has co-edited a manual on grape diseases and pests and a practical field guide to identifying diseases, pests, and disorders of grapevines.

another. Even models constructed in such archaic programming languages as FORTRAN can be “plugged” by the addition of a COM wrapping. One advantage of the interoperability concept is that a huge monolithic DSS can be broken down into component pieces by a layered architectural approach (3). It is unclear if interoperability will reduce construction costs to the point that relatively complex DSS can be built for minor crops or for developing countries.

Conclusion

In this article, we have used the analogy of a water supply system to describe the structure of a successful DSS. Like a water supply system, a DSS must have a reservoir for storage, a distribution network, quality control, a marketing system, and a practical faucet at the user's site. Our case studies have demonstrated that simply building a comprehensive DSS is not enough to ensure its adoption by users. User evaluation is critical to make sure that all of the components of a DSS perform well. Furthermore, a DSS must do more than just perform well; it must save the user time and money. The DSS must have a reliable source of revenue to ensure its long-term sustainability. In the future, we anticipate that DSSs will become more integrated, more complex, and more expensive to build. Distribution networks will make greater use of the web, and outputs will provide more information in graphic and map form. However, we still see a role for the simple DSSs, which can provide a stepping stone to the more complex systems.

The challenge remains for plant pathologists and other crop scientists to standardize their modeling techniques to create greater opportunities for interchange of models and DSS tools. Even among the authors of this paper, we find very different visions for how the future DSSs will be built. One thing is certain: despite the incredible advances in plant pathology of the twentieth century, the challenge of fighting plant diseases will continue in the twenty-first century. We anticipate that DSSs will be an important part of meeting this challenge.

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Literature Cited

- Adelman, L. 1992. Evaluating Decision Support and Expert Systems. John Wiley & Sons, New York.
- Anonymous. 1990. Conclusions and recommendations of the joint WMO/EPPO/NAPPO Symposium on Practical Applications of Agrometeorology in Plant Protection. EPPO Bull. 21:699-700.
- Bernard, L., and Kruger, T. 2000. Integration of GIS and spatio-temporal simulation models: Interoperable components for different simulation strategies. Trans. GIS. 4:197-215.
- Bowser, T. A. 1992. Adoption of an expert system by apple growers: Test of a new model. M.S. thesis. Pennsylvania State University, University Park.
- Campbell, C. L., and Madden, L. V. 1990. Introduction to Plant Disease Epidemiology. John Wiley & Sons, New York.
- Casey, J. 1989. Picking the right expert system application. Artif. Intell. Expert Sys. 49:44-47.
- Crassweller, R. M., Travis, J. W., Heinemann, P. H., and Rajotte, E. G. 1993. The actual and potential future use of expert system in horticulture. Hortic. Technol. 3:203-205.
- Felland, C. M., Travis, J. W., Russo, J. M., Kleiner, W. C., and Rajotte, E. G. 1997. Validation of site-specific weather data for insect phenology and disease development in Pennsylvania apple orchards. PA Fruit News 77:10-17.
- Felland, C. M., Travis, J. W., Russo, J. M., Kleiner, W. C., and Rajotte, E. G. 1997. Response of Pennsylvania apple growers to site-specific weather data. PA Fruit News 77:45-49.
- Gershengfeld, N. A. 1999. When Things Start to Think. Henry Holt, New York.
- Magarey, P. A., Emmett, R. W., Herrmann, N. I., Wachtel, M. F., and Travis, J. W. 1997. Development of AusVit, a computerized decision support system for integrated management of diseases, pests and other production factors in Australian viticulture. Vitic. Enol. Sci. 52:175-179.
- Magarey, P. A., and Wachtel, M. F. 2000. CropWatch SA: A mildew management service for Riverland grapegrowers. Page 31 in: Proc. Int. Workshop Grapevine Downy Powdery Mildew. 3rd. SARDI Research Report Series No. 50.
- Magarey, P. A., Wachtel, M. F., Weir, P. C., and Seem, R. C. 1991. A computer-based simulator for rationale management of grapevine downy mildew *Plasmopara viticola*. Plant Prot. Q. 6:29-33.
- Magarey, P. A., and Western, M. D. 1999. The Model T MetStation®: A weather station/disease predictor. Page 312 in: Proc. Bienn. Australas. Plant Pathol. Conf. 12th.
- Magarey, R. D., and Magarey, P. A. 1993. “Pirates of Powdery” and “Black Spot Blues” - new songs for disease warnings. Aust. Grapegrow. 357:64.
- Magarey, R. D., Magarey, P. A., Emmett, R. W., Wachtel, M. F., and Biggins, L. T. 1993. The mildews - some rules of thumb. Aust. Grapegrow. 357:23-24.
- Magarey, R. D., Seem, R. C., Russo, J. M., Zack, J. W., Waight, K. T., Travis, J. W., and Oudemans, P. V. 2001. Site-specific weather information without on-site sensors. Plant Dis. 85:1216-1226.
- Magarey, R. D., Seem, R. C., Travis, J. W., Russo, J. M., and Magarey, P. A. Decision support systems: Delivery barriers and solutions. In: Plant Disease Forecast: Information Technology in Plant Pathology. Y. H. Kim and E. W. Park, eds. Korean Society of Plant Pathology, Seoul, Korea. In press.
- Petersen, G. W., Day, R. L., Anthony, C. T., Pollack, J., and Russo, J. M. 1993. Importance of spatial variability in agricultural decision support systems. Pages 167-169 in: Proc. Soil Specific Crop Management. P. C. Robert, R. H. Rust, and W. E. Larson, eds. American Society of Agronomy, Madison, WI.
- Rajotte, E. G., Bowser, T., Travis, J. W., Crassweller, R. M., Musser, W., Laughland, D., and Sachs, C. 1992. Implementation and adoption of an agricultural expert system: The Penn State Apple Orchard Consultant (PSAOC). Acta Hortic. 313:227-231.
- Russo, J. M. 2000. Weather forecasting for IPM. Pages 453-473 in: Emerging Technologies for Integrated Pest Management: Concepts, Research, and Implementation. G. G. Kennedy and T. B. Sutton, eds. American Phytopathological Society, St. Paul, MN.
- Russo, J. M., and Zack, J. W. Commercialization of Plant Disease Forecasting in the United States. In: Plant Disease Forecasting. E. Park, ed. Korean Society of Plant Pathology, Seoul, Korea. In press.
- Seem, R. C., and Russo, J. M. 1984. Simple decision aids for practical control of pests. Plant Dis. 68:656-660.
- Travis, J. W., Felland, C. E., Truxall, D., Hickey, K. D., and Russo, J. 1999. Automated weather and fire blight model delivery to growers. Acta Hortic. 489:531-537.
- Travis, J. W., and Latin, R. X. 1991. Development, implementation and adoption of expert systems. Annu. Rev. Phytopathol. 29:343-360.
- Travis, J. W., Rajotte, E., Bankert, R., Hickey, K. D., Hull, L. A., Eby, V., Heinemann, P. H., Crassweller, R., McClure, J., Bowser, T., and Laughland, D. 1992. A working description of the Penn State apple orchard consultant, an expert system. Plant Dis. 76:545-554.
- Travis, J. W., and Rajotte, E. G. 1996. Implementing IPM through new technology and the non-agricultural community. J. Agric. Entomol. 12:219-227.
- Truxall, D. L. 1995. An environmentally driven model for grape black rot scouting and the impact of environmental data differences on disease control decision making. Ph.D. diss. Pennsylvania State University, University Park.
- Truxall, D. L., and Travis, J. W. 1994. Analysis of the accuracy of predicted weather data on the impact of apple disease management. (Abstr.) Phytopathology 84:1125.