### Name of the DSS

PLANT-Plus

### Who owns the DSS, Principal author’s, address,...

Dacom PLANT-Service BV, Waanderweg 68, PO Box 2243, 7801 CE Emmen, the Netherlands

### What is it for, what questions does it address?

Helping farmers to decide in their day to day operation on fungicide treatments, insect control and irrigation management.

**Disease control:** does the farmer have to spray and if so, what type of chemical should he best apply.

**Insect control:** monitoring of insect population to decide on timing of chemicals. **Irrigation management:** continuous monitoring of soil moisture to determine refill point, best water gift and timing.

### What input is required?

The system requires the availability of local weather data, either from synoptic or on-farm weather stations.

### Who is it for, who are the intended users?

- Growers: to ease the day to day decisions
- Consultants: to assist in recommending farmers what to do
- Processors: to justify inputs

### What are the advantages over conventional methods (whatever those may be)

Increased crop health and quality and lower inputs whenever the conditions allow to extend intervals.

### How frequently should the DSS be used or its values be updated?

Effective use of the system requires daily communication with the databank to update the weather data and run the model calculations.

### What scientific / technical enhancements would be desirable?

The models have proven to work in different countries and different climates.
11. PLANT-Plus: Turn-key solution for disease forecasting and irrigation management

P. Raatjes, J. Hadders, D. Martin and H. Hinds

PLANT-Plus was developed initially by Dacom as a DSS for management of *Phytophthora infestans*. It has been used on-farm since 1994. The system has been extended with a model for *Alternaria solani* and models for irrigation management based on ET data and soil moisture sensors. This way it offers a turn-key solution for the potato grower. The PLANT-Plus platform enables communication of data between farmer, consultant, processor and other accredited users in the food chain. The user can choose the most appropriate interface, such as Windows software (PC based) and Internet Server application and can configure a variety of output types such as SMS text messaging, Fax and Email warnings. PLANT-Plus offers an integrated five day weather forecast which provides a predictive risk assessment for the coming days. The disease models require the availability of on-farm, automatic, weather data. All PLANT-Plus disease models are developed in cooperation with experts from several areas and countries, such as Dr. L.J. Turkensteen, Dr. H.T.A.M. Schepers, Dr. W.G. Flier and Phd. J.E. van der Waals. In contrast to most of the other available models, PLANT-Plus uses a biological model that is based on the lifecycle of the fungus and combines infection events with the unprotected part of the crop. The model will recommend when to apply a new spray and what type of chemical to use: contact, translaminar or systemic.

The benefits of the models are clearly demonstrated in field trials and commercial evaluations all over the world: PLANT-Plus is sound technology that provides safe spraying programmes with the lowest possible use of chemicals for the control of Late & Early Blight.

The models for irrigation management are based on $ET_0/ET_c$ calculations of the soil water balance and/or direct monitoring through the use of soil moisture sensors. The ability to set the levels for field capacity and refill point, combined with the graphical outputs, allow the user to define when to irrigate and the most appropriate amount of water to apply.

**Introduction**

Dacom PLANT-Service BV is a commercial company from Emmen (NL) that has developed and operates the PLANT-Plus integrated system for crop management. Plantsystems Ltd is a UK based crop consultancy that has implemented the PLANT-Plus system across the UK, France and Portugal.
The development of the PLANT-Plus system was initiated in the early 90’s by Dacom as a crop recording system. It was already then envisaged to provide a platform to be able to exchange data and information between various partners in the agribusiness. On top of this platform a disease model was developed to optimise the control of *P. infestans* in potatoes. Given the state of technology at that moment it was possible to build a biological model based on fuzzy-logic principles and the use of hourly weather data, both retrospective and forecast. The PLANT-Plus databank uses a climate data interface that can import and distribute data of different types of on-farm weather stations, like Adcon, Skye, Metos, Campbell and Hardi Metpole. Holland Weather Services from Soest (NL, a WNI member) provides Dacom with a high-quality, local weather forecast for the coming 5 days for any desired location in the world.

The use of a databank platform also allows for the use of different user interfaces like old-fashioned PC-based MS-DOS applications, sophisticated PC-based MS-Windows applications and simple Internet Server Applications. The system can also deliver specific additional outputs like SMS text messages, E-mail and fax. The platform was subsequently extended with more regional applications: telephone-based, like ALPHI (Bouwman & Raatjes, 2000) and ALERT (Hadders, 2002) or like the web-based Syngenta Blight Forecaster (Hinds, 2003). The combination of crop records, weather data and treatment recommendations provides an excellent tool for crop assurance schemes.

### Disease forecasting models & principles

The PLANT-Plus disease forecasting models have been developed in close cooperation and harmony with experts on plant diseases, like Dr. Turkensteen (NL), Dr. Schepers (NL), Dr. Flier (NL) and PhD. Van der Waals (SA). For potatoes the model for Late Blight (*Phytophthora infestans*) was started in 1994 (Hadders, 1997) and the model for Early Blight (*Alternaria solani*) was started in 1999 (Smith, 2000).

All model inputs and outputs are evaluated and calculated hourly or three-hourly for the forecast data. This implies the need for high quality continuous weather monitoring stations and regularly updated weather forecasts.

In contrast to most other systems the PLANT-Plus model is a biological model, that evaluates the complete life cycle of the fungus. Additionally, any infection events are related to the degree of protection of the crop by chemicals and to new growth of leaves. The model can be divided into the following sub-models:

1. Unprotected part of the crop
   a. Growth of new leaves
   b. Degradation and wear off of chemicals
2. Infection events of the disease
   a. Formation of spores on each infected leaf
   b. Ejection and dispersal of spores into the air
   c. Germination of spores and penetration into unprotected leaves
3. Combination of unprotected leaf area and infection events into treatment recommendations
**Sub-model 1a:** Unprotected crop by growth of new leaves  
This factor is the most underestimated one in standard crop spraying regimes. Rapid growth in early season can cause crops to be vulnerable to infection from 3 days after fungicide treatment onward (Flier, unpublished). The assessment of growth of new leaves is dependant on field-scout reports, which means the farmer or his consultant will have to go out into the field regularly and score the development of new leaves compared to the last measurement (Hadders, 1997).

**Sub-model 1b:** Unprotected crop by degradation and wear-off of chemicals  
PLANT-Plus includes information about chemicals as part of the base of the system. This information includes active ingredients, recommended dose rates, a.i. efficacy against the disease and factors for wear-off influenced by precipitation and solar radiation. The background data is mainly derived from independent trials that were recently carried out by Schepers and his colleagues at Plant Research in the Netherlands (1996-2002) and from the agrochemical companies.

**Sub-model 1:** Unprotected part of the crop  
The results of sub models 1a and 1b together represent the unprotected leaf area. Basically it is of no concern if the crop is unprotected, as long as the there are no possibilities for the fungus to infect the crop. Trials have demonstrated that the spray interval can be stretched to 2-3 weeks without any problems under such circumstances (De Visser & Meijer, 2000; Raatjes et al., 2001; Kessel et al., 2003).

**Sub-model 2:** Infection events of the disease  
This sub-model replays the life cycle of the pathogen in hourly steps. The development of ‘new blight’ with sexual reproduction and more aggressive strains of *P. infestans* (Flier et al., 2002) is integrated into the system. The epidemiological soundness and accuracy of the Dacom models for *Phytophthora* and *Alternaria* have been successfully evaluated in numerous field trials (Smith, 2000; Denner & MacLeod, 1998; Marquinez, 1999; De Visser & Meijer, 2000; Wander & Spits, 2001). Whenever necessary the models will be updated to implement the most recent scientific background. The relation between a general fungus life cycle and the PLANT-Plus sub-models is presented in Figure 1.

**Sub-model 2a:** Formation of spores on each infected leaf  
Sub-model 2a calculates the number of viable spores on an imaginary lesion using temperature and relative humidity ranges to simulate growing and dying. In effect it can be compared to the size of the grey ring of sporangiophores present around a developing *P. infestans* lesion. The source of the lesion can either be from infected seed, resulting in a primary infected shoot or from secondary leaf infections. For *Alternaria* it can also come from infected debris.

**Sub-model 2b:** Ejection and dispersal of spores into the air  
After formation, the spores can be dispersed into the air. This can be caused by either climatic conditions like a (sudden) drop in the relative humidity, wind, or rain. But the
Lesion itself also purges out spores, a process called leakage (Turkensteen, 1995, unpublished). The inputs for this model are the output from sub-model 2a and the presence of the disease in the vicinity of the field, provided by field-scouts (Hinds, 2000) or a disease mapping system (Hendriks, 1999; Hadders, 2002). This sub-model has been evaluated with spore traps. The graph in Figure 2 compares the PLANT-Plus output with spore trap readings near a trial carried out by Schlenzig from TU München-Weihenstephan. Note that the absolute spore counts cannot be compared with the PLANT-Plus output as it calculates a fictitious figure, but the trends match closely. The information about the presence of the disease is vital for an accurate calculation. The model will, nonetheless, calculate spore flights based on a very low (standard) presence, but not at accurate levels. Recent research has revealed the effect that different sources of infection can have on Late Blight epidemics, like infected mother tubers, dumps, (excessive) distant sources and volunteers (Flier et al., 2002; Raatjes & Kessel, 2003; Van Baarlen & Raatjes, 2001). For example, in the Netherlands in 1999 one field with a severe infection caused secondary infections in other fields up to 30 km away. In 2000 and 2001 the effect of infected seed was clearly demonstrated and in 2002 early volunteers had great effect on primary inoculum levels. Sub-model 2b results in a fictitious concentration of airborne spores to be deposited on the foliage of the potato field.

Ad sub-model 2c: Germination and penetration of spores into unprotected leaves
The next step in the life cycle is to calculate the germination and infection of the spores on a leaf and it completes the infection event. This part is based on temperature, leaf
wetness and variety resistance. Leaf wetness enables the spores to germinate. PLANT-Plus has a specific model that calculates the leaf wetness of the crop, based on climatic conditions and the latest observation for crop density. Temperature and variety resistance influence the speed of germination, penetration and incubation. Sub-model 2c results in the fictitious number of spores that can infect an unprotected leaf. The accuracy of this sub-model is demonstrated in the correspondence with outbreaks in the fields (Van Baarlen & Raatjes, 2002). Based on surveys of Late Blight, age and size of lesions are associated with the timing of the infection events according to the model.

In a broader range the infection events for *P. infestans* were compared to the number of outbreaks reported to the disease mapping system in the Netherlands. The graph in Figure 3 shows the timing of the infection events compared to actual reported outbreaks of Late Blight. The arrows depict the delay in onset, caused by the incubation of the disease.

Raatjes & Kessel (2003) have also demonstrated that the accumulated PLANT-Plus infection index over the seasons reflects the accumulated number of outbreaks. The outputs of models 1 and 2 are combined into one simple graph (Figure 4) that reveals all the necessary information. The model run always starts with the date of crop emergence or the most recent chemical treatment (left of the graph) and uses retrospective weather station data until the present (purple line) and continues with five days of forecast data.

Sub-model 3: Combination of unprotected leaf area and infection events into advice
Sub-model 3 interprets the unprotected leaf area and the infection event and provides a recommendation whether to use a chemical and what type (contact, translaminar or systemic) to use (Figure 5). The choice of the chemical is left up to the grower or his advisor. Within the recommendation, the system also specifies the relative need for a
treatment: not needed, to be considered or necessary. The following recommendations for chemical types are feasible:

- no treatment needed
- treatment with contact fungicide to be considered / necessary
- treatment with translaminar fungicide to be considered / necessary

Figure 3. Relation between timing of PLANT-Plus infection events and reported outbreaks.

Figure 4. Example of PLANT-Plus disease model output.
• Treatment with systemic fungicide to be considered / necessary

This recommendation is influenced by the timing of the infection event related to the current point of time. An infection in the previous 12 or next 24 hours will have to be treated with a contact fungicide. Depending on timing, temperature and variety resistance an ‘older’ infection event will have to be ‘cured’ with either a translaminar or a systemic fungicide. The last three days of the forecast are not converted into an advice, but the user can view it in the graphical output.

Trials and projects have demonstrated that PLANT-Plus strategies rely heavily on contact fungicides as recommendations are often triggered before or during the infection event (Bouwman & Raatjes, 2000; Kleinhenz & Jorg, 2000, 2001). Continuous, daily consultation of the system will however be necessary to achieve this.

The PLANT-Plus model is not ‘blocked’ on short intervals or long intervals. This means that a new recommendation to treat can be given after 2-3 days, when conditions are dangerous and the crop is growing rapidly. On the other end recommendations not to spray can continue to be given for 3-4 weeks under dry conditions. As McGrath (2000) reports: farmers would normally never dare to wait that long.

All recommendations include an outlook for the spraying conditions for the next five days, based on expected rainfall and wind speed. This provides the user with a tool for advanced planning.

Figure 5. Example recommendation output of Dacom disease forecasting model.
Principles for irrigation scheduling

The PLANT-Plus platform has been extended with models for irrigation management. The system offers two options to optimise the crop water usage:

Direct sensing based on soil moisture sensors. The climate data interface has the option to read data from two types of soil moisture sensors: suction and volumetric. The suction type sensors such as Gypsum block, Watermark and Tensiometer provide data in pF and hPa. The C-Probe, Profile Probe and Virrib are volumetric sensors and those provide the relative soil water volume in %. The system has simple graphs to present, view and interpret the readings. Users can define custom settings for re-fill points and field capacity.

Calculation of Soil Moisture Water Balance based on ET$_0$.
The ET model in PLANT-Plus is based on the measurements of the weather stations combined with crop observations such as crop stage and crop growth. First the ET$_0$ is calculated according to the official FAO guidelines (Allen et al., 1998). The outcome is modified into the ET$_c$, based on the recorded crop information. Using the date of planting the crop as the starting point, the continuous soil moisture water balance is calculated, while adding rain or irrigation and deducting the ET$_c$. In practice the models are not only used to increase yield and reduce water usage, but also to prevent defects such as potato common scab.

Quality of weather forecasts

One of the key advantages in PLANT-Plus is the delivery of a local five-day weather forecast anywhere in the world. This implies a strong dependency on the forecast that must, therefore, be of high quality. Dacom is continuously evaluating the accuracy of the forecast data by comparison to the on-farm meteorological stations.

In 1997 a study was done in the Southern part of the Netherlands (Maastricht area) to evaluate the results of PLANT-Plus (Geelen, 1997). Relative humidity is a crucial factor in the epidemiology of fungal diseases. In the comparison the forecast underestimated the readings for the humidity by approx. 13%, which meant that the realised humidity was always higher. Raatjes et al. (2001) have made the same comparison for Egypt and find more or less the same results, but this has not resulted in (more) curative sprays or missed infection events. This means that for critical conditions the forecast will indicate the infection event in time, although the details of the forecast may not always be fully correct. The conclusion is supported by the large share of contact fungicides that PLANT-Plus users generally apply.
Experiences and results

The experiences and results with PLANT-Plus can be split into two parts: field trials and commercial evaluations amongst growers and grower groups.

Field trials with P. infestans model

Many field trials around the world have been carried out to demonstrate the benefits of the PLANT-Plus *P. infestans* model. Some of the trials will be discussed here and the results are summarised in Table 1. The trials represent different climatic conditions: from dry, arid to wet, maritime climates. The density of potato crops in the area also differs from trial to trial.

In the Netherlands evaluation trials were conducted at research station ‘t Kompas in Valthermond over the years 1995 to 2001 where the PLANT-Plus model was compared with standard field practice. Using the PLANT-Plus model resulted in an average reduction of 28% in the number of applications, while disease control remained adequate.

In South Africa a trial was conducted in 1998 to compare different disease forecasting models with standard practices (Denner & MacLeod, 1998). This trial resulted in failure of the Winstel and Ullrich-Schrodter models to control *P. infestans* effectively under these high pressure conditions. The PLANT-Plus model managed to control the disease as well as the standard field spray programme, but reduced the number of sprays applied. It should be mentioned that most of the field trials do not represent ‘normal’ field conditions, but are under extreme pressure from the untreated, infected controls.

A trial in the UK at Harper Adams University College with the variety Cara in 1998 (Jenkinson, 1999) resulted in a very robust PLANT-Plus programme that was very cost effective, despite the fact that more sprays were applied compared with standard practice.

A trial by the Bundesamt für Forschung und Landwirtschaft in Austria resulted in no reduction in chemical use, but significantly improved disease control. In Spain in 1998 the summer was very dry and PLANT-Plus managed to keep fields virtually blight free with only 2 contact sprays, compared to 2 systemics and 2 contacts in normal practice (Marquinez, 2000). In Tulelake valley in the USA a trial was conducted in 1998 by UC Davis that resulted in improved control of the disease and a small reduction in the application of fungicides.

In the Netherlands a broader testing programme was started in 1999 to compare different advice models with standard field practice. The PLANT-Plus model resulted in a fair reduction in chemical costs of 60 Euros per hectare while maintaining appropriate disease control (Kessel *et al.*, 2003). Wander & Spits (2001) concluded after the first year that PLANT-Plus uses relatively few curative products and starts relatively late with the first spray, compared to other models, like ProPhy and NegFry. Kleinhenz & Jorg (2001 & 2002) concluded the same for trials in other countries such as Belgium, Switzerland, Ireland, and Germany. Generally the PLANT-Plus model performed well in the trials that were carried out within the framework of the EUNET project (Hansen,
**Table 1. Results of field trials with PLANT-Plus P. infestans model** This table compares number of sprays per season, chemical costs in Euros per hectare, foliage infection at the end of the season, tuber blight after harvest and yield in tonnes/ha for two strategies: STD (common practice in the area) and PP (PLANT-Plus).

<table>
<thead>
<tr>
<th>Trials</th>
<th>Sprays (no.)</th>
<th>Costs (Euros/ha)</th>
<th>Foliar Blight (%)</th>
<th>Tuber blight (%)</th>
<th>Yield (tonnes/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Std</td>
<td>PP</td>
<td>Std</td>
<td>PP</td>
<td>Std</td>
</tr>
<tr>
<td>Netherlands, Kompas 1995-01, unpublished</td>
<td>14,3</td>
<td>10,6</td>
<td>267</td>
<td>212</td>
<td>-</td>
</tr>
<tr>
<td>South Africa, 1998, Roodeplaat, Denner &amp; MacLeod, 1998</td>
<td>7,0</td>
<td>5,0</td>
<td>-</td>
<td>-</td>
<td>76,5</td>
</tr>
<tr>
<td>Austria Trials at BFL 1998; unpublished</td>
<td>7,0</td>
<td>7,0</td>
<td>-</td>
<td>-</td>
<td>69,0</td>
</tr>
<tr>
<td>Spain, Trial in 1998; Marquinez, 2000</td>
<td>4,0</td>
<td>2,0</td>
<td>-</td>
<td>-</td>
<td>0,00</td>
</tr>
<tr>
<td>United States, 1998 Tulelake valley, U.C. Davis; unpublished</td>
<td>4,0</td>
<td>3,0</td>
<td>-</td>
<td>-</td>
<td>10,0</td>
</tr>
<tr>
<td>UK, BPC, 1998; Jenkinson, 1999</td>
<td>12,0</td>
<td>15,0</td>
<td>252</td>
<td>295</td>
<td>1,50</td>
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<tr>
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<td>14,9</td>
<td>11,8</td>
<td>290</td>
<td>229</td>
<td>0,04</td>
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<tr>
<td>Sweden, 3 trials 1999-2001; Wiik, 2002</td>
<td>10,9</td>
<td>9,5</td>
<td>-</td>
<td>-</td>
<td>0,02</td>
</tr>
<tr>
<td>Belgium, Gembloux, Hansen et al., 2001</td>
<td>11,0</td>
<td>7,0</td>
<td>-</td>
<td>-</td>
<td>3,5</td>
</tr>
<tr>
<td>Ireland, Oakpark (Hansen et al., 2001)</td>
<td>13,0</td>
<td>11,0</td>
<td>-</td>
<td>-</td>
<td>50,0</td>
</tr>
<tr>
<td>Germany, 2001 &amp; 2002; LWK Viersen, unpublished</td>
<td>10,5</td>
<td>11,0</td>
<td>430</td>
<td>437</td>
<td>59,0</td>
</tr>
<tr>
<td>USA, Tappen, 2002; Syngenta/NDSU; unpublished</td>
<td>10,0</td>
<td>7,0</td>
<td>-</td>
<td>-</td>
<td>0,0</td>
</tr>
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</table>

This table compares number of sprays per season, chemical costs in Euros per hectare, foliage infection at the end of the season, tuber blight after harvest and yield in tonnes/ha for two strategies: STD (common practice in the area) and PP (PLANT-Plus).
PLANT-Plus provides an excellent and robust combination of reducing the number of sprays, while controlling the disease. Trials by Wiik in the Southern part of Sweden (Skåne) from 1999 to 2001 have demonstrated that PLANT-Plus gives good control for starch varieties with nearly 30% reduction in the number of treatments. In the susceptible Bintje the model had some problems with recommendations in the first two years of the project in one of the trial locations.

In 2002 a trial using PLANT-Plus was carried out by the LandWirtschaftsKammer Vierssen in Germany. It was estimated that the use of PLANT-Plus resulted in a financial revenue of approx. 200 Euros per hectare when yield increase and chemical costs were taken into account.

**Commercial evaluation of P. infestans model**

Dacom has always closely monitored the performance of the P. infestans model in commercial fields, either through projects or study groups. At present over 1,000 farmers all over the world are using this model. Table 2 summarises the results of some evaluations.

The results of the system have been studied ever since the introduction of PLANT-Plus in the Netherlands. In the North Eastern part of the Netherlands the STER project for sustainable agriculture (Hadders, 1997) demonstrated that using the PLANT-Plus model resulted in substantial savings on blight control (Regeer, 1997). The same results were found in other projects in other parts of the Netherlands in the years 1995 to 1999. The costs of both blight control and crop protection are greatly affected by the weather conditions during the seasons: 1995 and 1996 were rather dry and 1997, 1998 and 1999 were rather wet. At present it is rather difficult to compare the results of PLANT-Plus users with non-users as all potato growers in the Netherlands are alerted by telephone when PLANT-Plus calculates an infection event in their area (Hadders, 2002).

In an inquiry amongst PLANT-Plus users in Flevoland, Netherlands it was found that the confidence of growers was rated at 3.9 on a 1-5 scale (Balk, 2000). PLANT-Plus users applied on average more sprays than common in the area, but spraying costs were lower. The costs strongly correlated with the confidence of the user in the system.

Hinds (2000) studied the use of the PLANT-Plus model compared with farmer’s normal practice in the UK and found a significant reduction in fungicide use, while there was no difference in blight control under moderate blight conditions.

In Egypt, winter conditions are relatively dry, but sometimes a devastating late blight epidemic can occur. Farmers tend to (over) spray with prophylactic sprays. The introduction of PLANT-Plus has resulted in approx. 50% reduction while keeping the crops disease-free. The fields of the project were under a centre pivot irrigation regime, but still the intervals could be stretched to over 3 weeks without any problem (Raatjes et al., 2001). The feasibility of the model was also tested under tropical conditions in Indonesia which is a region where previously farmers have been unable to keep the crops alive until tubers are full grown. Implementation of PLANT-Plus resulted in postponing
the onset of the disease while saving the use of chemicals by increasing chemical efficacy through improved timing of applications. Recent evaluations in Belgium, Canada and Latvia have confirmed the previous results.

Hinds (2001) investigated the practicalities that large farms run into when they want to apply the PLANT-Plus system on large areas of potato and found it possible to implement the system. Reaction time to spray warnings can be within 2 days, given good communication and adequate sprayer capacity. A Syngenta/Frito-Lay project using the variety Courlan (a sensitive variety) emphasised that Late Blight can be effectively

Table 2. Results of commercial evaluations of P. infestans model. This table compares number of sprays per season, chemical costs in Euros per hectare and control of foliar blight at the end of the season (+++ very good; ++ good; + acceptable; - bad; - - very bad) for two strategies: STD (common practice in the area) and PP (PLANT-Plus ).

<table>
<thead>
<tr>
<th>Area (Project area)</th>
<th>Year(s)</th>
<th>Sprays (no.)</th>
<th>Costs (Euros/ha)</th>
<th>Blight control</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Std PP</td>
<td>Std PP</td>
<td></td>
</tr>
<tr>
<td>Netherlands (Westerwolde area)</td>
<td>1995</td>
<td>12,6 10,1</td>
<td>188 142</td>
<td>++ ++</td>
</tr>
<tr>
<td>Netherlands (Study groups in STER-project; Regeer, 1997)</td>
<td>1996</td>
<td>10,4 9,0</td>
<td>154 136</td>
<td>++ ++</td>
</tr>
<tr>
<td>Netherlands (Project Brabant Province)</td>
<td>1997</td>
<td>16,3 15,5</td>
<td>315 304</td>
<td>+ +</td>
</tr>
<tr>
<td>Netherlands (Project Drente Province)</td>
<td>1996-1999</td>
<td>13,5 11,7</td>
<td>217 197</td>
<td>++ ++</td>
</tr>
<tr>
<td>Netherlands (Project Maastricht area)</td>
<td>1997-1998</td>
<td>14,8 13,1</td>
<td>305 253</td>
<td>+ +</td>
</tr>
<tr>
<td>United Kingdom (Commercial evaluation in the East Midlands; Hinds, 2000)</td>
<td>1999</td>
<td>12,2 10,0</td>
<td>243 176</td>
<td>+++ +++</td>
</tr>
<tr>
<td>Egypt (Feasibility study in Ismailia; Raatjes et al., 2001)</td>
<td>2000-2001</td>
<td>7,5 3,5</td>
<td>272 127</td>
<td>++ ++</td>
</tr>
<tr>
<td>Indonesia (Feasibility study on Sumatra)</td>
<td>2002</td>
<td>14,3 10,0</td>
<td>441 241</td>
<td>— ++</td>
</tr>
<tr>
<td>Canada (On Farm trial on PEI (Canada); Department of Agriculture)</td>
<td>2002</td>
<td>9,0 6,0</td>
<td>— —</td>
<td>+++ +++</td>
</tr>
<tr>
<td>Belgium (Farm Frites/ Syngenta project)</td>
<td>2002</td>
<td>13,5 11,3</td>
<td>295 219</td>
<td>+ ++</td>
</tr>
<tr>
<td>Latvia (Syngenta/ Latfood project)</td>
<td>2002</td>
<td>5,0 4,0</td>
<td>— —</td>
<td>+ ++</td>
</tr>
</tbody>
</table>
prevented by optimised timing of fungicide treatments according the PLANT-Plus model (Hinds, 2002), whereas the standard strategy might fail. One of the other advantages of the PLANT-Plus model is that it can produce retrospective reviews of the season that can be used to teach and train the farmers about how to improve their late blight management strategy. Mistakes can be pinpointed and alternative strategies preventing late blight epidemics are provided. From both the trials and commercial on-farm evaluations it can be concluded that PLANT-Plus is proven, sound technology that provides safe spraying programmes with the lowest possible use of chemicals for the control of Late Blight. Choice of fungicide planned to control *P. infestans* has, in some cases, resulted in increased problems with the control of Early Blight (*A. solani*). This might be due to poor control of Early Blight by some oomycete-specific fungicides.

**Field trials and commercial evaluations of the A. solani model**

The model for *Alternaria solani* was first used as a prototype in cooperation with the University of Pretoria, South Africa by PhD. J.E. Smith-van der Waals. The model was evaluated and calibrated in field trials in 1999 and 2000 and the calculation of infection events by PLANT-Plus matched the actual spore flights monitored using spore traps (Smith, 2000). Based on the results of the trials the model was modified to increase accuracy.

Hadders (2003) concluded that infection events for *Alternaria* often coincide with the infection events for *Phytophthora* and that the problems with *Alternaria* are therefore not recognized because of the (side-)effect that the *Phytophthora* treatments have on *Alternaria*. On several occasions, however, separate infection events are observed for *Alternaria*.

In a project in Egypt aiming to study the technical and economical feasibility of the PLANT-Plus models it was recognized that successfully reducing the applications against Late Blight increased the problems with Early Blight. In the second year of the project the Early Blight model was therefore included in the study. A comparison at Chipsy’s farm led to the conclusion that both standard and PLANT-Plus strategies provided adequate control of the disease, but PLANT-Plus applied six sprays, compared with eight in normal practice.

In a Syngenta trial in Tappen, North-Dakota the *A. solani* model was tested by Dr. N. Gudmestad (North Dakota State University) in the 2002 season. PLANT-Plus suggested seven sprays compared with ten following the standard schedule and ten in a Blitecast strategy. The incidence of the disease under the PLANT-Plus strategy was somewhat higher than under the other two, but we argue that this was largely influenced by the plot layout and by the choice of fungicide. It was decided in advance to use only Bravo Zn to control *Alternaria*, whereas a strategy with a combination of other active ingredients probably would have been more effective.
Field trials and commercial evaluations of the irrigation management model

The ET model for irrigation management in PLANT-Plus was validated in a trial at Kompas, Valthermond, Netherlands in 1997 and it resulted in 78% crop cover at the end of season compared to 74% in the unirrigated control. The Valthermond area with typical sandy/peaty soils is not an area where irrigation is usually needed.

In Japan, a comparison was made in 2001 & 2002 for Calbee Potato between the C-Probe, Watermark and the ET model, based on 10 locations on Hokkaido. It was concluded that the calculations from the ET model matched the trends from the Watermark and C-Probe sensor readings (Figure 6) and can therefore be used as a tool for irrigation planning.

Murata (Calbee, 2002, unpublished) validated the readings from the C-probes by oven-drying soil samples to analyse their water content and found a good correlation between the readings and the actual water content.

![Figure 6. Comparison between summed C-Probe readings (red line) and calculated soil water balance (green line), based on FAO ET model.](image)

In Portugal the use of tensiometers clearly indicated a failure in irrigation practice. Not being alert resulted in soil conditions that were too dry for only two days at around tuber initiation and the effect was a significant incidence of potato common scab.

The use of Watermark sensors with PLANT-Plus in a cotton crop in Egypt resulted in a saving of 300 mm of water applied by sprinkler irrigation compared with traditional furrow irrigation (Banna, 2002, unpublished).

The interpretation of the irrigation management models can be compared to trend-watching and is therefore rather complex and takes a lot of learning. A number of mistakes, such as incorrect sensor installation or non-representative positioning in the field, can have a large influence on the success or otherwise of the system. Common sense combined with technical skill will therefore always be needed when applying sensor- or ET-based irrigation strategies.

Future developments and constraints
The previous results and experiences might lead to the conclusion that every farmer should be ready to use the PLANT-Plus system as there is a clear economic benefit. Yet, even in the Netherlands there is only a small, although steadily increasing, proportion of the ‘professional’ farmers using the models. Spanninga (1998) concluded in his market survey that farmers have different kinds of excuses why not to use the models. One of them is the complexity of the subject and the difficulties farmers find in understanding the recommendations. To change the farmer’s mind from an easy-going, prophylactic strategy to an alert approach, reactive to infection events has always been the toughest challenge. It is as a South-African vine grower said: “PLANT-Plus is like a cell-phone. First you don’t want it, but when you have it, you can’t be without it anymore.” Contradictory recommendations or even opposition from others who influence opinion, like chemical resellers or governmental bodies, is another threat to successful implementation.

Furthermore, the successful introduction of PLANT-Plus requires the availability of an effective range of fungicides for the control of the disease. In some countries like Sweden and the Netherlands there are only a few fungicides registered and this sometimes leaves the farmer with few options to choose products, especially translaminar and systemic fungicides. It should be a general concern that most of the registered chemicals are not fully efficacious against Alternaria

Another point of concern is the effort that farmers have to make to provide crop information. In essence this is a positive thing as farmers will have to go out into the field to observe their crops, but it is often considered to be too much trouble. Dacom is therefore seeking alternatives such as Remote Sensing images or automated snapshot cameras. Bakker (1999) has found that processing RS images into crop cover maps can provide accurate information. The PLANT-Plus feasibility study in Egypt (Raatjes et al., 2001) however, revealed significant problems with the availability of useful, cloud free images.

Dacom has extended the PLANT-Plus system with a large and successful range of disease models for other crops like vegetables, fruits and vines. Dacom is also developing additional models for insect management. Currently models for thrips, carrot fly and aphids are in the testing phase.

References


