THE FIRST SEVEN YEARS OF THE REMOTE SENSING BASED RAGWEED MONITORING AND CONTROL SYSTEM

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ABSTRACT

The Institute of Geodesy, Cartography and Remote Sensing (FÖMI) provides services to the Ministry of Agriculture and Rural Development. FÖMI has a 30 years' experience in the applications of remote sensing. The programmes carried out in this period served as a basis to ragweed control.

The allergy induced by ragweed pollen has become an important issue in Hungary: some 60-100 million Euros per year are spent for medication and medical visits and tests because of the allergenic effect of ragweed. In Hungary, some 500 000 – 700 000 hectares are estimated to be infected by ragweed. About 80% of this area can be pinpointed by remote sensing techniques concentrating on arable land. To ensure the efficiency of this priority programme, the government amended the plant protection law in 2005.

FÖMI has supported the nationwide Ragweed Control Programme by its proprietary remote sensing and GIS methodology to monitor and map significant ragweed infected areas. This development basically relied on the knowledge and experience gained in FÖMI's previous Crop Monitoring and Production Forecast Programme (CROPMON, 1997-2003). The development of remote sensing (RS) and GIS methods plus the GPS technology makes the tasks of reconnaissance and field control more efficient. This system increases the success of preventing ragweed development. The system is a model for a range of integrated applications of remote sensing.

This article presents the main results of the programme until 2011. The seven years' operational experience in Hungary provides a realistic basis for adaptation in other areas.

INTRODUCTION – WHY THE SPECIAL RAGWEED CONTROL PROGRAMME IN HUNGARY?

The Remote Sensing Centre (RSC) of the Institute of Geodesy, Cartography and Remote Sensing (FÖMI) provided many services in the past 30 years to the Ministry of Agriculture and Rural Development (MARD) and the Ministry of Environment and Water. FÖMI has also accumulated operational experience in the applications of remote sensing (1,2,3). The unique methodology of the operational Crop Monitoring and Production Forecast Programme (CROPMON, 1997-2003) provided an excellent methodology basis for further application development (4,5). One of the operationally proven programmes is the support to ragweed control in Hungary (6,7,8).

During the execution of CROPMON, the accuracy of identification of the sporadic or dense ragweed cover was studied (2002-2004). A dedicated ragweed recognition methodology has been developed and validated. Based on the promising results, an ambitious national programme, called Operational Ragweed Control Programme, has been designed, and it has been carried out in Hungary since 2005. This is based on the integration of high-tech components: remote sensing, global positioning system (GPS), geographical information system (GIS) and web (WWW) interface.

The identification of ragweed infection by remote sensing was also an important issue of Association Francaise d'Etude des Ambroises (AFEDA), France. First they used only one high resolution satellite image for the detection of ragweed infection (9), but then they recognized the advantage of using multitemporal images for this purpose (10).

The main pillars of the control programme and its results are the methodology of production of ragweed risk map and the services of the Central Ragweed Server. These pillars will be explained in detail in the next two sections.

THE DERIVATION OF RAGWEED RISK MAPS WITH REMOTE SENSING

Ragweed recognition by remote sensing is much more difficult than crop identification. The evolution of weeds is not so regular in space and time as that of cultivated crops. As far as spatial irregularity is concerned, weeds usually do not cover the whole agricultural parcel; they are sporadic and heterogeneous in crop fields. Temporal irregularity means that the development of cultivated crops is usually determined, but ragweed can appear at any time within the vegetation period of a year.

A method has been developed that is based on the temporal profile of spectral characteristics of vegetation. This method has a fundamental importance in the proper detection of ragweed spots. It is vital to preclude the pollen spreading in order to effectively fight against the allergenic effect of ragweed. This can be reached only by timely recognition of the phenological stages of ragweed. The details of processing chain followed in FÖMI will be introduced in the following. Technically, it consists of the following steps:

- Preliminary ground truth (reference) data collection
- The derivation of primary ragweed map
- In-the-field validation of primary ragweed map
- The derivation and submission of final ragweed map

Figure 1 illustrates the steps of processing chain.

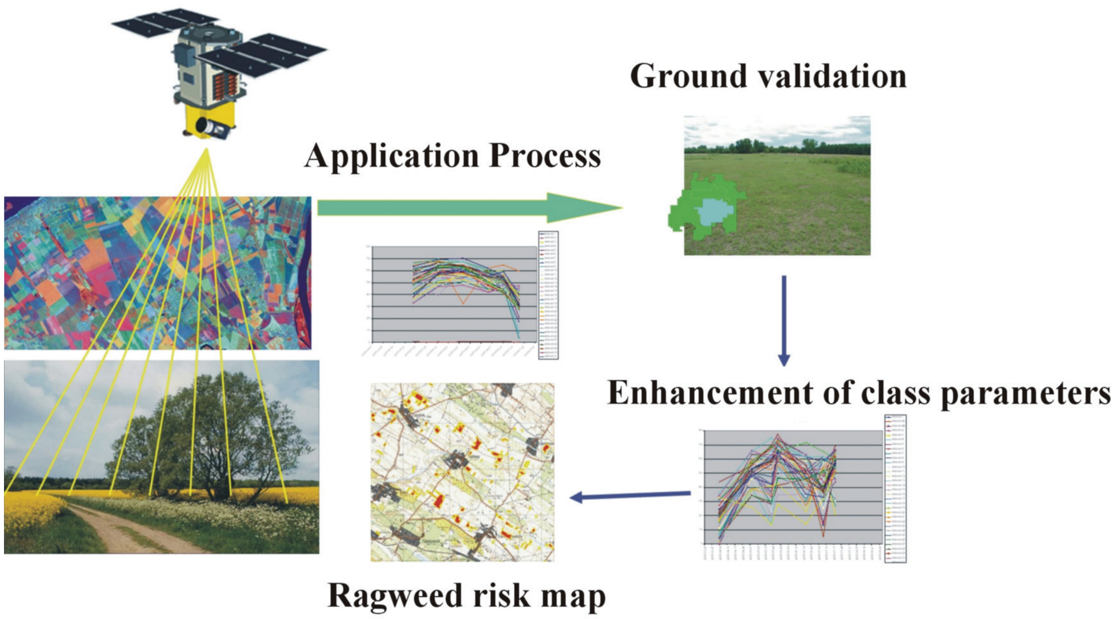

Figure 1: The scheme of ragweed risk map production.

The methodology of ragweed detection with remote sensing

The ragweed recognition model, based on the temporal profile of band values and certain vegetation indices extracted from high resolution satellite data series, performs very well. The method is general but the specific application developed by FÖMI is tuned to the ragweed occurrence parameters in Hungary. Although ragweed appears sporadically at numerous places within settlements, the majority of pollen strain comes from large ragweed stands on plough-lands: from contiguous ragweed spots on cereal stubbles and within sunflower parcels. Remote sensing control mainly aims at picking up areas bigger than 0.8 hectares. Due to the above-mentioned spatial characteristics and size distribution of ragweed spots, this trade-off does not mean serious limitation.

Ragweed spots falling into this size range can be efficiently detected with the application of the widespread multi-spectral satellite images having pixel size between 20 and 60 metres. During the monitoring process, medium resolution (IRS AWiFS) and high resolution (HR; Landsat 5 TM/7 ETM+, IRS 1C/1D/P6 LISS-III, SPOT 2/4/5 XS and Xi) satellite images were used simultaneously.

The analysis of remote sensing images is preceded by *the collection of* a small amount of *reference data* in the field. This provides a sample of both agricultural crops (or non-cultivated arable areas) and ragweed spots in a given region and time period, and supports visual and automatic interpretation.

The classification methodology developed makes use of the spectral and temporal characteristics of satellite images. Top-of-atmosphere reflectance values are calculated from visible and near infrared bands, which is the basis of vegetation index calculation, and ensures the uniform interpretation of different satellite images. Temporal profiles of vegetation indices – primarily NDVI and NDWI – are analysed: they indicate the growth of crops and weeds. First, the properties of those agricultural parcels are characterised where ragweed can appear with high probability in the given time period. (Generally, the stubbles of cereal parcels are targeted in July, while sunflower parcels in August.) Second, the difference in development of regular crops and weeds (mainly ragweed) is explored. Based on the parameters extracted from reference parcels and the decisions of human expert a membership function is created, which indicates the presence of ragweed depending on the date and the vegetation index values extracted from the area in question.

While examining the temporal profiles of parcels, it has been taken into account that satellite images of different dates may be available at different areas (of course, cloud coverage further restricts the usability of an image in some areas). The model developed is general in the sense that it is not bound to specific dates, but evidently its accuracy depends on the availability of images taken at proper dates.

The above mentioned membership function is applied pixel by pixel, but after the classification contiguous components of pixels marked as infected with ragweed are handled together. To overcome local classification errors, small components of infected pixels are filtered out. The resulting thematic map is called *primary ragweed map,* which is analysed and refined in subsequent steps.

Using different instruments: the extensibility of model

Although the method developed and used operationally at FÖMI is fitted to use the image types described above, similar remote sensing models can be developed that utilise quite different kinds of remote sensing data – satellite images of different spatial, temporal resolution and spectral properties, or even aerial photographs. This increases versatility.

In 2007, in the framework of the SPOT OASIS project, FÖMI evaluated the efficiency of SPOT 5 satellite data on two selected test areas. Beyond the multispectral data with 10 m spatial resolution, the panchromatic, 2.5 m resolution SPOT Supermode product was used. The main challenge was to demonstrate the efficiency of newly developed methodology in identifying ragweed-infected parcels and the examination of accuracy in the function of parcel size (11). As a result the usefulness of SPOT 5 data in ragweed detection was clearly proven. It provided very valuable information for the ground reference data collection about the localisation of ragweed spots. Due to the higher spatial resolution and favourable spectral properties, SPOT 5 data were much more effective in detecting ragweed infection than using Landsat TM or IRS-P6 AWiFS data, especially on small fields (about 1 ha).

In the *recognition* of ragweed a necessarily dense time series plays a crucial role, as ragweed must be recognized and exempted before pollen scattering in order to successfully block pollen spread. This emphasises the importance of temporal dimension of remote sensing data. However, if we focus on the *measurement* and documentation of ragweed, spatial dimension comes to the foreground. Measures against ragweed are restricted by the available resources of classical field inspection. It is crucial to shift the burden from ground control to remote sensing. One of the solutions is to increase the role of remote sensing in documentation, that is, the delimitation of ragweed spots. It has been proven during the control programme carried out in past years that the effectiveness of the follow-up field inspection highly depends on the accuracy of spots delineated with remote sensing.

In 2009, the experimental introduction of Very High Resolution (VHR) images brought in new quality in the measurement and documentation of ragweed spots. It is now seen that the introduction of VHR images highly increases spatial accuracy of ragweed risk maps submitted by FÖMI and thus the effectiveness of monitoring, and would give stronger support to on-the-spot checks. The procedure built on HR and VHR images has been used with proven efficiency for several years in the control of EU agricultural subsidies, and more specifically, in the detection of weeds and other unwanted vegetation. This is a very promising method in ragweed reconnaissance. Beside the operational ragweed control programme, in the frame of a research project the opportunities of using VHR images in ragweed recognition are being assessed. In 2010, the processing of VHR images was further improved with the introduction of segment-based classification.

The ground validation and the improvement of primary ragweed map

It is not possible in practice to derive an exact regional ragweed map. The ragweed risk maps provide a spatial guidance that point to the probable location of stands. Although primary ragweed map introduced above pinpoints many actual ragweed spots, but experience shows that it is worth supervising before submitting it to other institutes participating in the ragweed exemption programme in order to avoid false positive findings. Therefore, before submitting results, *primary ragweed risk maps are validated* on an about 10% sample *on the ground.* The necessary tuning of the classifier, the refinement of class parameters is based on this validation.

The refined membership function is used to derive an enhanced risk map. Validation ensures the optimisation of ragweed stand identification accuracy. This means the aim of finding as much ragweed stands as possible (reduction of omission error) while keeping the false positive cases (commission error) at low level. The major factor in the efficiency of the control programme is the high reconnaissance performance and accuracy (which may reach or exceed 90%) of spots, independently from the terrain, location and environment. Beside validation, traditional ground measurement steps can be built into the system to complement the results of remote sensing survey.

The "product": the usage and evaluation of final ragweed map

Countrywide ragweed risk maps are produced focusing to the most heavily infected croplands. The most important areas where there is a high probability of ragweed occurrence are *non-cultivated arable spots* and the *stubble-fields of cereals,* but *sunflower* is also a target of survey. These maps can be considered as the "product" of remote sensing ragweed detection. *The final ragweed risk maps* are submitted to the experts of local Land Offices. Relying on them, more rigorous ground recording can be done very efficiently by the local Land Offices experts.

These activities include the detection, measurement and recording of contaminated areas during the on-the-spot check procedure of Land Offices' experts. They plan and optimise the route of their checks based on ragweed risk maps.

The institutions participating in the exemption programme – mainly Land Offices – send back their feedbacks through the Central Ragweed Server about the control of risky areas. These feedbacks are built in the method as ground truth (reference) data, and are used for making the subsequent ragweed risk map more precise. Beyond the on-the-spot validation carried out by FÖMI's field inspectors, this feedback can be considered a very important means of accuracy assessment.

Unfortunately, it is hard to tell the real accuracy of ragweed risk maps. The ideal situation would be to immediately start field check for every ragweed spots when a risk map is submitted, but due to the limited capacity of field inspectors, this cannot be accomplished in practice. Several days, often 1-2 weeks may elapse until a spot of risk map is examined in the field. It happens that during this time farmers remove ragweed from the area, often by disking. This is, of course, correct from the viewpoint of defence against ragweed, but highly decreases the accuracy of remote sensing exploration, as these cases are not registered as positive hit: one cannot unambiguously state that the area was infected by ragweed before disking.

Therefore, limited data on exploration accuracy is available. In 2008, the real accuracy and the potential of ragweed risk maps were cooperatively assessed in two test areas. Collective on-the-spot checks were carried out in ten days after the ragweed risk map production. The assessment was managed by the experts of MARD, FÖMI and Land Offices. As a result, it turned out that the accuracy of remote sensing survey was 90%. Based on the risk maps, Land Office experts recorded some 300 hectares of areas that were actually infected with ragweed, in two days! These collective checks have proven that the risk maps are so efficient that the total area of ragweed spots that can be recorded and documented in situ is 50-100 times larger if remote sensing based risk maps are applied properly.

THE ESTABLISHMENT OF CENTRAL RAGWEED SERVER

The countrywide ragweed probability map, described above, delineates the possible locations of ragweed infected spots. This map is utilised by the organisations that participate in the prevention programme. It helps in the planning of on-the-spot control, in the optimisation of visiting ragweed spots.

These organisations are the following: Land Office Network (LON), Plant Protection and Soil Conservation Directorate of Central Agricultural Office (CAO PPSCD), Agricultural and Rural Development Agency (ARDA) and FÖMI.

In 2005 FÖMI started to develop the *Ragweed Information System*, which consists of the Central Ragweed Server (containing a database and a server application) and the clients. The database stores information about infected spots. The central server ensures fast data exchange among authorities: it synchronises and facilitates the work of 400-500 officials of the organisations from July to September, during the most critical ragweed-growing period.

These activities include the detection, measurement and recording of contaminated areas during the on-the-spot check procedure of Land Offices' experts. They plan and optimise the route of their on-the-spot checks based on ragweed risk maps of FÖMI. They measure the infected area, determine the involved cadastral parcels and based on the data in cadastral database, they find out the responsible land owner and land user.

Together with this, an official procedure starts against the owner or user of the area and the ragweed eradication is executed on the contaminated spots. Each such case is officially recorded by CAO PPSCD.

ARDA is also informed in connection with the payment of EU subsidies. This is because the presence of ragweed in an agricultural parcel is considered the serious violation of the so-called Good Agricultural and Environmental Conditions (GAEC), which are related to area-based agricultural subsidies.

All these information are stored in four geographical layers of the Central Ragweed Server. They contain ragweed infected areas

- identified by remote sensing,
- registered by the experts of LON,
- reported by civil people (public announcements),
- found by PPSCD experts.

These layers are displayed in the client software connected to ragweed server individually or all at once. Every layer contains different descriptive data for the ragweed spots. The records of these layers can be loaded to the GPS for ground control carried out by LON's experts. These records are stored on the layer called "ragweed infected areas". The LON record contains, among others, a unique, automatically generated identifier, the extent and the severity of ragweed infection and its effect on cultivated plant. Photos taken during the field survey can also be attached.

Beyond the "forward" data flow from the detection of ragweed to the information on fine paid by responsible land owner or user, Central Ragweed Server is also used by participating institutions to provide quality feedback to each other about the data they received – for example, on the accuracy of ragweed spots found by remote sensing, as explained above.

Due to the nature of ragweed contamination and the legal rules of exemption, several institutes and people are involved in the process, as seen above. It is inevitable to provide timely information exchange among the participants in order to efficiently fight against ragweed. Central database, properly defined contact points and interfaces between the server and clients, hardware components and field survey instruments used help in the efficient implementation of the process of exemption programme.

Beside the risk maps provided to Land Offices, certain generalised spatial information on ragweed infection is made publicly available. It must be emphasised that the redesigned Ragweed Control Programme primarily builds on the co-operation of land users. To persuade the activity of inhabitants, spatial statistics of ragweed infection are available for people in the form of electronic maps. Statistics are calculated from the ragweed risk maps derived from satellite data and summarised at settlement level, serving as a general measure of ragweed infection. These maps are available via the websites of FÖMI and MARD. Figure 2 shows examples of the maps for the past operational years of the programme.

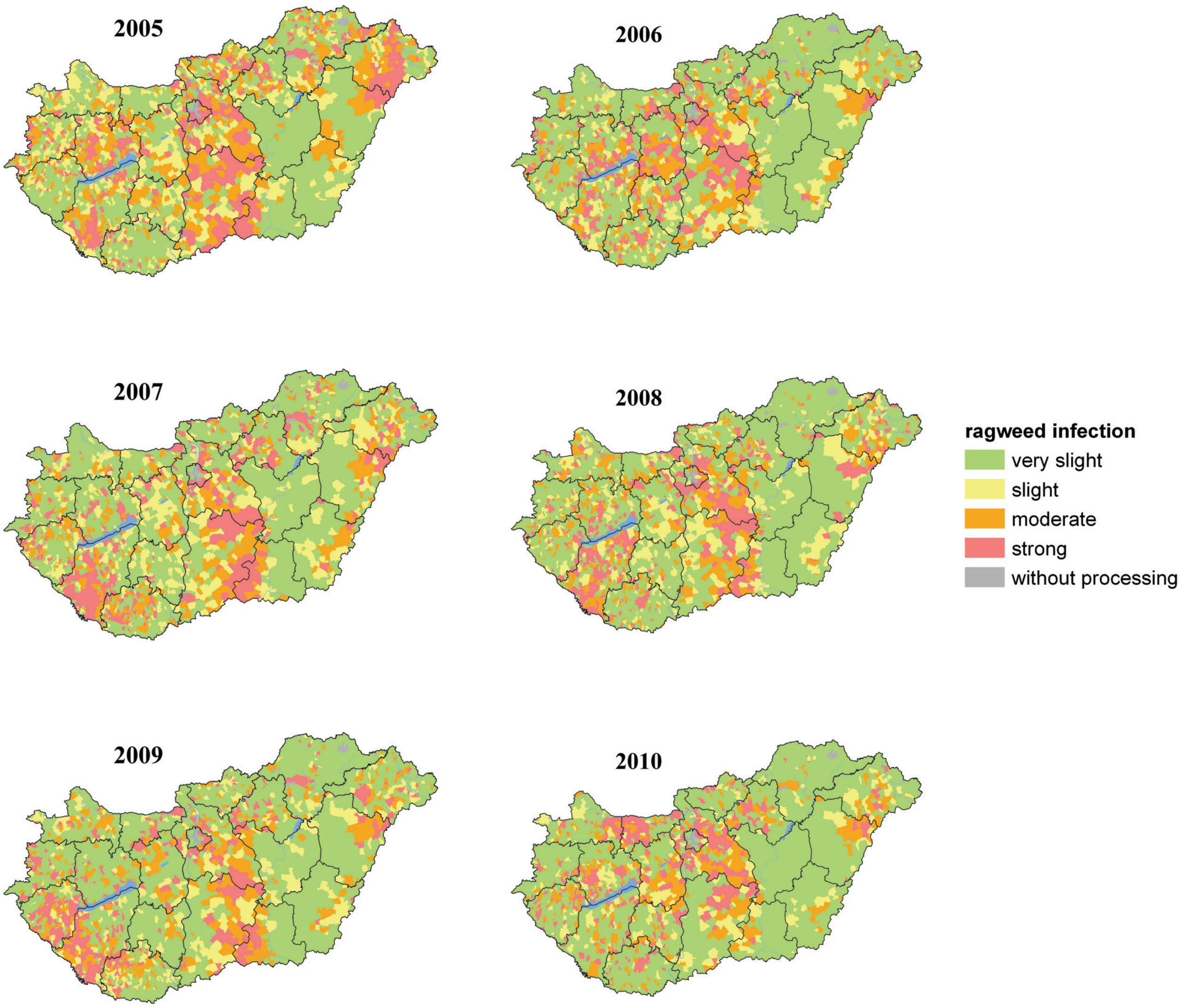

Figure 2: The spatial distribution of ragweed risk in settlements between 2005 and 2010.

HIGHLIGHTS OF THE RAGWEED CONTROL PROGRAMME BETWEEN 2005 AND 2011

In **2005** ragweed risk maps were produced several times. The first risk map was the result of a retrospective analysis of year 2004. Based on ground data from PPSCD and satellite images from the previous year, a substantial model validation has been carried out. It was concluded that about 10 times larger infected area (approximately 100 000 ha) could be detected using year 2004 images than the cases recorded by PPSCD in the field, restricting the comparison to ragweed stands reaching 0.8 ha. After this retrospective analysis, the operational ragweed monitoring started to examine the current (2005) status. The targets of remote sensing detection were non-cultivated arable spots and the stubble-fields of cereals. Some 20 000 spots covering 60 000 hectares were identified altogether in Hungary.

In **2006** a very limited ragweed monitoring programme was performed. The emphasis was put on the development of Central Ragweed Server (CRS). The remote sensing control brought up about 3 500 spots (18 601 hectares) of ragweed in the reduced target area. After developing the server and providing multi-day trainings for users, the Central Ragweed Server ensured a more efficient service in 2006. Since then, the server has undergone further major improvements, which were driven by the needs arising at different institutions participating in the programme.

In **2007,** the target of ragweed detection was extended again. FÖMI RSC identified high risk ragweed spots in several time periods on highly infected areas within the whole Hungarian territory. The number of spots was more than 4 000, covering about 10 000 hectares. Some new functions and modules for CRS have been developed to speed up the administration and documentation of the Ragweed Control Programme.

In **2008,** the focus was put on the remote sensing based production of risk maps. The aim was to derive maps for the most infected areas 3-5 times from mid-July. The thematic focus was put on cereal stubbles, which are usually strongly covered by weeds after harvest. IRS P6 LISS, AWiFS and SPOT XS/Xi satellite images were used during the remote sensing assessment. The difference in size of elementary mapping unit of field measurements and recording (1-5 m) and that of the remote sensing one (20-60 m) sometimes caused conflicts, together with the improper application and interpretation of the “risk map” notion. To overcome these conflicts, the joint assessment of usability of ragweed maps, carried out together with other institutions, also took place in 2008.

In **2009,** beyond the successful execution of operational programme using high resolution images, an attempt to introduce very high resolution images into the remote sensing survey took place. As mentioned above, this improvement can significantly increase the efficiency of measurements and documentation. Although currently VHR images are too expensive and difficult to acquire to cover the whole country in a campaign, they have been used several times since then in smaller sample areas.

In **2010,** further improvement of classification methodology took place. Beside the “classical” pixel-based classification used in the operational control programme, *segment-based* classification of VHR images was introduced. Therefore the spatial characteristics of ragweed spots could be examined in a much more sophisticated way than earlier (simple filtering of contiguous components based on their size). VHR images are very good in the detection of *textural changes* caused by the appearance of ragweed. The matching between results of segment-based and pixel-based processing is about 90%.

In **2011,** co-operating institutions has changed the organisation of field surveys. Beyond the ragweed risk maps, a new demand has arisen: the production of crop structure maps. These maps help authorities to find those crops in the field that are the most endangered by ragweed. Therefore another guide is provided to optimise field work. This way the methodology that was used in CROPMON is operationally used again, but it is certainly improved to reflect technological changes of past years.

CONCLUSIONS

The Ragweed Control Programme has been operational since 2005, with similar general technological and administrative background. The implementation of components and the extent of survey have been changed throughout these years to satisfy the needs arose. Based on the results we can conclude that the immense problems of ragweed and pollen allergy in Hungary could not be efficiently controlled without space technologies. The introduction of four high tech components (RS + GPS + GIS + WWW) was inevitable to basically improve the traditional ground-based ragweed control system in Hungary. The remote sensing assessment covers the whole arable land and helps in the optimisation of in situ measurements and their documentation. The time requirement of ground based components was dramatically decreased by a productive geo-informational provision (remote sensing), surrounded by GPS and GIS techniques, the data exchange and the new legal provisions of the Plant Protection Law. The administrative tasks have also been made much more effective.

This is apparently the only way to implement a system that is able to successfully fight against ragweed in Hungary. It is remote sensing that determines the effectiveness of survey, due to its large area coverage and the extensibility of statistical image analysis methods. The model can utilize a wide range of satellite images. The usage of higher resolution satellite data should be increased to find further infected areas and to radically decrease the amount of ragweed and its health impact.

At system level, it can influence the decrease of ragweed infected areas and pollen load. It is "spatially fair", helps to maximize the necessary counter actions in situ by any authorities or responsible institutions within their limited capacity. The system is also a model for a wide range of integrated thematic applications of remote sensing. The most determining and indispensable subsystem is the ragweed recognition by remote sensing. It is objective, accurate, reliable, and can be used in quite different ways by adjusting the spatial, temporal and spectral properties of image data set to be acquired to the regional or local needs and possibilities in the same methodology framework. Therefore, the system design is technologically high level and scalable. Actually, much less flexibility can be seen in the cost saving, institutional and political "dimensions". The system must be operated under hard circumstances: severe limitations and budget constraints affect the possibilities.

Certainly, the applied remote sensing surveillance can be used alone as well, for reliable information collection only, without a similar institutional framework and legal procedures. The seven years' operational experience in Hungary (~ 100 000 km^2 area) provide a sound basis for adaptation. However, it can be a model to be applied in other areas. All the subsystems can be tailored and adapted to a wide variety of special local and regional needs, terrain and environmental conditions and ragweed stands occurrence. Parts, components or the whole system can be operated in any European region where ragweed infection is an issue.

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