ENDURE

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Report on crop x pest systems and specification for technical and organisational requirements for construction and test of operational DSSs that integer some 'best parts' of existing DSS

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RE Restricted to a group specified by the consortium (including the Commission Services)	
CO Confidential, only for members of the consortium (including the Commission Services)	

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1 Summary

1.1 Objectives

The objectives of this deliverable is to specify technical and organisational requirements for construction and test of operational DSS that integrate selected bests parts, as identified previously in a report with results from analyses of 70 European DSS (DI 2.3 / DI 2.4).

These ‘technical’ requirements’ include specifications regarding biology, agronomy, definition and composition of selected model components and possible ways of implementation, while the ‘organizational requirements’ include specifications of needs for organizing of the work to build and test such DSS.

The specifications should provide a basis for constructing DSS-prototypes, which are suitable for conceptual evaluation among end-users and for agronomical validation and/or field test.

1.2 Rationale

In a survey for identification of existing DSS for crop protection in Europe for, a total of 70 DSS were found. For subsequent analyses, these DSS were divided into 4 groups according to the crop x pest systems included in the DSS:

- 18 DSS for diseases in horticultural crops
- 37 DSS for diseases in arable crops
- 18 DSS for pests
- 9 DSS for weeds

and ‘best parts’ in a context of potentials for reducing use of pesticides were identified en each of these four groups.

Subsequently, 3 teams among the participants in ENDURE IA2.4 have been formed to to autonomic design unified DSS on a European level for 3 selected crop x pest systems:

- DSS for potato late blight
  AU (lead) and WUR
- DSS for codling moth in pome fruit
  UdL (lead), AGROS and INRA
- DSS for weeds in maize
  AU (lead), INRA and CNR

These teams have been collaborating with:

- the ENDURE Information Centre (SA4), which provided input on ‘end-user requirements’ for future DSS for crop protection
- the ENDURE Technical Task Force (IA4), which provided information on options for using and installing DSS components on a server provide by ENDURE

2 Design of unified, European DSS

2.1 DSS for potato late blight

In **Appendix 1**, documentation of an operational 'test platform' for DSS for potato late blight is provided. This test platform shall be used to test different DSS, in order to identify DSS or components of these which are suitable for a unified, European DSS for potato late blight.

Appendix 1 also includes provisional specifications for a unified, European DSS for potato late blight.

This DSS also integrate principles of Integrated Pest Management (IPM).

2.2 DSS for codling moth in pome fruit

On a workshop conducted on the ENDURE annual meeting in Wageningen in October 2009, representatives of the team, working on DSS for codling moth, presented status on activities.

According to plans, activities should have been conducted to validate a model, which can predict the timing of 1st flight of codling moth, which is the only output, originally planned in terms of designing a unified European DSS.

On the workshop in Wageningen, it was revealed, however, that no additional activities had been conducted in year 2009 regarding validation of models that can predict the timing of 1st flight of codling moth.

Results from comparisons of predictions and observations of time of 1st flights of codling moths had indicated that substantial, additional work is also required to design models that can predict these flights on a level of robustness, which is required by professional growers of pomefruit.

Consequently, the original idea of constructing also DSS, which could contribute to reduce dependency and/or use of insecticides in this production line, is obviously too immature in the context of ENDURE, why activities regarding DSS for codling moth were not included in the 4th JPA of IA2.4, so no unified DSS will be produced for codling moth in pomefruit.

2.3 DSS for weeds in maize

In **Appendix 2**, specifications for a unified, European DSS for weeds are provided. This DSS integrate identified 'best parts' of 3 existing DSS, and has been designed in a generic structure, which allow customization for arbitrary combinations of region, crop, weed species, control measures and 'conditions'.

This DSS also integrate principles of Integrated Pest Management (IPM).

DI2.7
Appendix 1

Documentation of a test platform for existing DSS and specifications for a unified, European DSS for potato late blight

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Content

1 Introduction

In a survey, which included 70 European DSS for crop protection, 15 DSS included diseases in potato. Some of these 15 DSS included different diseases on potato, however, initial focus was made on one particular disease: ‘potato late blight’, which is causing relative high losses of yield and which requires relatively high input of fungicides.

Details may be studied in a report ENDURE NETWORK - DSS: helping farmers make smart decisions / All the news / About ENDURE, which include also a detailed report (128 pp).

This document provide a summary of ‘best parts’ of existing DSS for potato late blight in terms of reducing use of fungicides.

2 ‘Best parts’ in existing DSS

The majority of the identified DSS for potato late blight utilise meteorological data to calculate infection periods and subsequent risk of epidemic progress. These calculations are used as a basis for recommendation for the timing of the first fungicide application and often also to predict subsequent needs for fungicide application. Some DSS make recommendations on specific dates of the first fungicide treatment and subsequent risk throughout the season.

In France, two DSS use ‘Guntz Divoux’ and ’Milsol’ models to calculate spray date and recommends compound and rate. These DSS also forecasts future sprays including spray date and recommendations on fungicide compounds and dose rates.

In Denmark, a DSS based on the ‘NegFry’ model, supports decisions such as timing of first- and subsequent fungicide applications, including fungicide compound and dose rate. This DSS is used in Denmark, the Baltic States and Poland.

‘Best parts’ in terms of potentials for reducing input of fungicides where not specifically identified, however, the following components of the analysed DSS were considered to be of particular interest for future developments:

- identification of high and low risk situations of disease attack
- identification of critical weather periods
- recommendations of timing, compound and dose rates of first fungicide application
- prediction of speed of fungicide degradation
- intervals of subsequent fungicide applications

In order to test robustness and potential of different components, connections must be made to databases with different weather datasets, and recommendations should be validated against data showing corresponding levels of attack of diseases and yield.

More basic information, descriptions etc. on existing DSS can be found on the ‘Euroblight’ web site (www.euroblight.net/EuroBlight.asp)

3 Test platform

3.1 Installations

In order to facilitate comparison of the performance of different DSS, a joint IT test platform has been installed on the Euroblight platform (http://www.euroblight.net/EuroBlight.asp). This test platform is targeted primarily for researchers and advisors, who have special interest in development of new tools and new concepts to improve management of potato late blight.

On this platform, different DSS can be uploaded and installed, and the test platform also includes a database, where different weather datasets can be uploaded and stored.

At present, 7 different DSS have been installed on the test platform, and weather data sets originating from many locations in Europe in the period of 2006-2009 have been entered in the weather database.

Selected DSS can be run on selected weather datasets, and responses from the DSS's can be evaluated and related to connected information, e.g. on timing and severity of attacks. An output parameter of particular interest is 'blight favourable weather', which may be verified against data/information on real infestations.

A DSS for fungicide degradation was also uploaded and installed. This DSS can predict, how long time a fungicide application will maintain satisfactorily levels of efficacy.

3.2 Tests

DSS that predict infection pressure has been analysed by use of weather datasets from different regions. Preliminary results from analysis show good correlations between selected weather parameters and calculated periods with 'high' and 'low' risk for infection during a growing season.

A conclusion from these preliminary tests has been that a next step will be to compare calculated risk periods with observed first appearance of field attack in different countries.

3.3 Plans for additional installations

For the remaining period of the ENDURE network, the following additional installations will be made on the test platform for DSS on potato late blight:

- at present, weather datasets include data on relative humidity and temperature as hourly values. A next step will be to include also data on precipitation and leaf wetness as hourly values. Furthermore, mean temperature and precipitation will be included as daily values. Collaborating suppliers of weather data in Valthermoden and Lelystad have already agreed to submit this additional weather data, and contacts in Belgium, Spain, Argentina, Brazil, Cyprus, Italy and Poland will be asked to supply similar data
- calculation with two selected DSS, 'ProPhy' and 'Plant Plus' will be conducted on selected weather datasets from Denmark, The Netherlands and United Kingdom

- different DSS components will equipped with version numbers, so that separate test runs can be made on different versions of the DSS components
- a disclamer will be included. This will inform that the content is only for research purpose and can only be used after permission from the owner, for which there will be also a hyper-link
- facilities will be designed and installed, where existing ‘best practice’ recommendations can be uploaded and installed. After proper testing this information will be publicly available
- a sub-model, which can predict leaf wetness, will be installed

3.4 Plans for additional tests

In the remaining period of the ENDURE network, the following additional tests will be made:

- selected DSS and selected weather datasets will be run to simulate control strategies and evaluate these against existing ‘best practice’ strategies.
- field data on timing and severity of first attack and subsequent development of attacks will be evaluated against model output.
- control strategies will be simulated by running selected DSS with selected weather datasets. The performance of different DSS in different regions and in different conditions of weather will be evaluated.

4 Unified, European DSS for potato late blight

Opportunities for identification of a concept for a unified, European DSS for potato late blight was analysed in the survey, but no single DSS were recommended as ‘best parts’ in terms of potentials for reducing use of fungicides.

Instead, as an initial step, it was recommended to analyse and test different DSS and sub-components of these in more detail. Progress on this work is presented in section 3.

4.1 Objectives

Based on attributes and preliminary test results of 7 DSS, which have been installed on the test platform, objectives have been set up for the design of a unified, European DSS for potato late blight. Such new DSS should include:

- recommendations for timing, selection of fungicide compounds and dose rates, so the total number of applications and the total input of fungicides (cost or TFI) is minimized
- provisions that ensure that environmental risk is minimized
- integration of principles of integrated Pest Management (IPM)

Robustness and potentials of recommendations produced by different DSS components shall be evaluated against existing ‘best practices’, according to a report produced in the ENDURE potato case-study.

4.2 Design

Based on results from tests of different DSS, which have been installed on the test platform, a conceptual framework for a for a DSS for potato late blight, unified on a European level, will be established.

This DSS shall include (at least) the following main components:

1. a monitoring network for early attacks of potato late blight
2. a toolbox of potato late blight risk indices
3. an interactive toolbox with basic control strategies which integrate principles of IPM

In the remaining period of the ENDURE network, only an overall design of this DSS will be produced. In the design process, opportunities for constructing generic components, which may also be adopted by different crop x pest systems, which involve similar biological mechanisms and weather data, will be evaluated. Additional diseases in potato and Downy mildew in grape and will initially be considered.

DI2.7
Appendix 2

Specifications for design of a unified, European, generic DSS for weed control

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Contents

1 Introduction

This document constitute Appendix 2 to the deliverable DI2.7 in the ENDURE network, which was planned to contain 'Technical and organisational specifications for construction and validation of unified DSS on a European level'. This document also constitute specifications for a 'modelling platform', which is one original idea behind the Virtual Laboratory in ENDURE.

In a survey which included 70 European DSS, 'best parts' with respect to potentials for reducing use of pesticides were identified. A summary of results from analyses have been compiled in ENDURE NETWORK - DSS: helping farmers make smart decisions / All the news / About ENDURE, which include also a detailed report (128 pp).

The present document includes:

- specification of 'best parts' on a level of detail, which support construction of operational DSSs
- specifications for exchange of information between 'best parts'
- specification of a generic frame, which enable customization of DSS for arbitrary combinations of languages, regions, crops, weed species, control measures, etc.
- specifications for integration also of 'simple algorithms' and 'best practice' recommendations, which can replace 'best part' components when customizing the DSS for selected combinations of regions, crops and conditions

In the autumn of 2009, the European Commission launched Directive 2009/128/EC, which provides requirements for the implementation of Integrated Pest Management (IPM) in EU member states before 2014. As this directive and the identified 'best parts' of DSS have much common content and outlook, it was found most relevant to integrate principles of IPM in this document, too. It will probably take decades, however, to design and implement the principles of IPM in all crops and all regions of Europe. Consequently, and as indicted in Directive 128/2009/EC and in this document too, design and implementation of DSS may be perceived as long-lasting strives for improvements.

The DSS system architecture, which is presented in this document, intends to constitute a general, structural frame, which may be at central point of reference for customization of DSS for weed control in arbitrary combinations of crop, region and conditions.

Considering IT structures, the present document do not intend to provide specific recommendations, as such tasks may more conveniently be transferred to IT-developers, who may have specific preferences regarding selection of IT tools, structuring of data, functions, algorithms, integration, etc. Due to the basic idea of enabling customizing of the DSS on different levels, a high-level source-code with embedded databases holding all components required for customizing may immediately seem as a convenient, basic structure.

The present document also includes recommendations for specific adjustments of EU regulation on pesticides and for organisational structures to support design and implementation of operational DSS, which are founded on the identified 'best parts' and requirements in Directive 2009/128/EC.

It has been a challenging task to reach consensus among the authors on details of this document. Issues of discussion have been included in separate sections.

2 ‘Best parts’ from existing DSS

Based on a survey, which included 70 existing European DSS, and in a context of reducing the use of pesticides, ‘best parts’ were identified. This survey included 9 DSS for weed control, of which the following ‘best parts’ were identified:

- CPOWeeds, Denmark
  - Continuous dose-response functions, which quantify differences in activity of single herbicides
  - Additive Dose Model (ADM), which can optimize herbicide tank-mixtures

- DECIDHerb, France
  - Phenological model to predict time of emergence of crops and weeds
  - Fuzzy logic scoring system to define the needs for weed control
  - Generation of weed control strategies based on the combination of individual weed control operations at different crop growth stage
  - Multi-criteria assessment of alternative strategies (=treatment options)

- Phytochoix, France
  - No specific best parts

- GestInf, Italy
  - Yield-loss functions
  - Economic net-return of alternative treatment options

- MLHD, The Netherlands
  - Quick assessment of the expected efficacy after a herbicide application

- OptHerbClim, France
  - Identification of optimum weather conditions for pre-selected treatment options

- IPMIDSS, Poland
  - (structural identical with CPOWeeds)

- DoseKey, Sweden
  - No specific best parts

- WM, UK
  - Mechanistic biological model to simulate crop growth
  - Weed dynamics in crop rotations

Opportunities for integration of selected best parts were analysed, and consensus were reached among to authors, to characterize identified ‘best parts’ in terms of ‘building blocks’, where original integrities are maintained.

Considering well-known biological mechanisms, idealistically a DSS for rational weed management should be designed from a relatively complex, mechanistic model. In a strive for demonstrating opportunities for reducing the use of pesticides within some reasonable span of time, however, probably an initial strategy of focussing on models of less complexity, may be promising. This rationale implies that the DSS shall initially search for mechanisms, which are relatively robust, relatively simple to design, and which are expected to contain relatively large potentials. In this context, a new DSS should strive for

‘picking lower hanging fruits first’.

If some success of initial versions is demonstrated, interest may probably arise for designing also more complex DSS, and a number of iterations of design and test may be foreseen.

One rationale behind such a strategy may be that even relatively simple models, and even if parameterized by rather conservative approaches, DSS which are satisfactorily robust and which demonstrate significant potentials as compared to existing 'best practices' may be designed and implemented.

Attributes of dose-response functions, which are generally used to estimate efficacy of herbicides, indicate that even quite simple DSS may have very significant potentials in weed control. According to these attributes, a reduction of target efficacy level from e.g. 99% to 90%, which is satisfying for most agronomic conditions, will reduce the required input of herbicides by 60%-95%, depending on the herbicide compound.

Another domain with a huge potential is differences in the susceptibility of different weeds to different herbicides. While some weed species require the registered dose of a herbicide, to achieve an agronomically satisfactory level of control, other weed species may be controlled satisfactorily by down to 5-10% of the registered dose rate.

Consequently, even a relatively simple DSS, which may integrate just the 2 ideas:

1. total kill may not be required
2. some weeds are more susceptible that others

may offer a significant potential for reducing the use of herbicides, while agronomic requirements for weed management are still considered. Another factor, which has a great impact on potentials, is the spatial resolution of decision making and application of herbicides. Farmers are generally capable and willing to differentiate herbicide applications on a field level, while 'best practice' recommendations are often designed, so that these are expected to perform satisfactorily for a relatively wide range of conditions, which may commonly occur on a regional level.

In a context of DSS for weed control and within the frames of ENDURE, the ambition will be to design only simple structures, which integrate identified 'best parts' to a level, where validation of functional integrity of the included components has been conducted. Within these limitations, initial focus will be on the following identified 'best parts', which originate from three selected DSS:

- DECIDHerb
    - Phenological model to predict time of emergence of crops and weeds
    - Fuzzy logic scoring system to define the needs for weed control
    - Multi-criteria assessment of alternative strategies (=treatment options)

- GestInf
    - Yield loss functions based on crop-weed competition
    - Estimated economic net return

- CPOWeeds
    - Dose-response functions of single herbicides
    - The Additive Dose Model (ADM)

In the following sections, these identified 'best parts' will also be referred to as 'building blocks'.

3 EU-directive on Integrated Pest Management

According to Directive 2009/128/EC, the principles of 'integrated pest management' (IPM) must be implemented in all EU member states by 1st January 2014. As this directive will be a framework for future activities on a farm and field level regarding crop protection, the new unified DSS for weed control, will be designed to comply also with specific requirements of this directive. In table 4.1 specific requirements in this directive are listed and related to the identified 'best parts' in CPOWeeds, DECIDHerb and GestInf.

Whilst herbicides are generally supplied on national or regional levels, alternative control measures, which in some cases require special equipment, may not be equally available and thereby constitute a new consideration in a context of designing DSS. For example, a DSS may invite end-users to select between alternative 'IPM-levels', which may consist as a gradient of the level of integration of specific non-chemical control measures. Alternatively, the DSS may initially ask end-users, which control measures that are available, e.g. 'field sprayer', 'seed-bed harrow', 'row-cultivator', etc., which may form a basis for more precise strategies on a farm and crop level.

According to the directive, national 'guidelines' must be designed and implemented on a crop level, may also provide more specific references in this domain.

In the subsequent descriptions, the new DSS will be referred to as the 'IPM-DSS'.

Table 4.1
Extractions from Directive 2009/128/EC of requirements regarding use of control measures for crop protection

Extractions from Directive 2009/128/EC	**Similar structuring included in 'best parts of DSS?**	**Comments**
Par 18: 'Crop x sector-specific guidelines' must be developed and implemented, following the principle of subsidiarity	Yes	Subsidiarity mean that guidelines shall be designed on a local level, where possible.
Art 4: Much competence regarding implementation of IPM is allocated to 'national action plans'.	Maybe	Structuring of 'IPM-guidelines' must be known, before DSS can be structured
Art 12: Ensure that use of pesticides is minimized	Yes	Input of herbicides will be minimized to achieve specific levels of efficacy for specific infestations of weeds
Art 14: Non-chemical methods shall be prioritized where possible.	No	New structures must be designed
Art 14: Member states shall ensure that professional users have at their disposal information and tools for pest monitoring and decision making	Yes	Specific instructions on monitoring and decision making will be made on a field level
ANNEX 3, Par 3: Sound threshold values are essential	Yes	The threshold concept is not directly applicable to weed management. Target level of control will be differentiated according to the severity of infestations, with a specific expert system to label this severity.

		Weed infestations which are considered inferior will be ignored (in future versions of IPM-DSS probably also to cropping system).
ANNEX 3, Par 4: Non-chemical methods must be preferred ... if they provide satisfactory control	No	New structures must be designed. The directive leaves open a discussion on how to combine different control measures.
ANNEX 3, Par 5: Pesticides applied shall be as specific as possible for the target	Yes	Herbicide treatments will be composed to achieve specific levels of control for infestations of weeds on a field level
ANNEX 3, Par 7: Anti-resistance strategies shall be applied	Yes and no	For tactical decisions (in an actual field) weed biotypes with known resistance to selected herbicide compounds, will be controlled with alternative measures. To prevent development of resistance (long-term management), new features must be designed

Discussion

In summary, the selected 'best parts'/'building blocks' from 3 existing DSS contain much of the information and structuring, which are also required by Directive 2009/128/EC.

For example, the amount of detail information required to evaluate threshold values and to recommend herbicide applications, which are specific for the target, i.e. different for different scenarios of region x crop x weed species x 'conditions', new IPM-guidelines are likely to be designed on basis of the same original data and much of the structuring, which are already included in the selected building blocks of the 3 DSS.

In order to evaluate field conditions to such considerable amounts of data, use of modern information technology for data processing and for communication seems to offer great advantages, which are also considered in the DSS.

Directive 2009/128/EC specify that much detail for implementation of this directive, shall be specified in actions plans on a national level. In case such action plans require use of specific preventive or eradicative measures in specific crops, decisions on actual 'levels' of IPM may be transferred from end-users to the IPM-DSS.

4 Timing of tasks on a field level

According to Directive 2009/128/EC, control measures shall be applied according to threshold values and targeted. Consequently, some structures will be required to ensure that attacks of different weeds, pests and diseases are properly and timely predicted, monitored or measured, before threshold values are evaluated, and before a targeted control measure can be selected. Presently, weeds can be determined on a field level only by field scouting.

These requirements in the directive have specific implications for the logistics of communications between the IPM-DSS and the end-users. As different weeds emerge differently in time and space, some instructions from the IPM-DSS regarding timing of field inspections, which connect with suitable and available control options, will be required.

These rationales also imply that in case a previously recommended control measure has not been executed as planned, or did not perform as expected, new monitoring and new decisions will be required to restore proper control. For example, if weather conditions postpone a recommended control measure, new scouting and new decisions may be required, to ensure that control measures are still targeted for the purpose.

These rationales should be applied irrespectively of the control measures that are considered, as both chemical and non-chemical control measures should be applied in rational ways. Consequently, the requirements for application of control measures according to thresholds and specific for the target imply that separate decisions must be taken for separate applications of control measures. Existing 'best practice' recommendations often include treatment programmes, which may include several treatments and pre-fixed times of applications.

Occasionally, unexpected and unfortunate conditions may cause that an applied control measure will not perform as expected. For example, a shower of rain a few hours after application of a foliar-uptaken herbicide may cause significant run-off and significant reduction of efficacy, why specific measures may be required to restore the situation. Such situations is also reflected in the Directive by an instruction saying that field inspections must be conducted to evaluate the success of previously applied control measures.

A model for the logistics between field monitoring, decision making and application of control measures is illustrated in Figure 5.1.

Consequently, the IPM-DSS must also include a 'Time plan', which provide instructions on how to prepare an approaching growing season, and when and how to conduct field inspections during a growing season. Such a plan should be specific on a region x crop level and include different flushes of seeded weeds, perennial weeds and maybe also to support decisions on pre-emergence-, pre-harvest and post-harvest control measures.

By nature, different control measures: are differently available, must be applied at different points of time, have different efficacy, are differently robust, have different costs, etc. Consequently, 'Time plans' shall integrate considerations of pros and cons of different control measures, and different stakeholder may have interest in designing these plans. Furthermore, to account for changes in supply of control measures, changes in costs, efficacy (change in resistance), etc. over time, 'Time plans' must be adjusted accordingly.

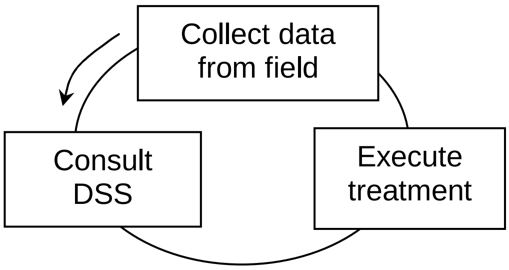

Figure 5.1
Procedure for communication between end-users and IPM-DSS

General instructions on timing may relate to growth stages of the crop (BBCH-scale), as this is a general point of entrance to time management in crop production. More precise instructions on timing may more efficiently refer to growth stages of weeds, temperature regimes or other techniques, which are relevant to ensure that thresholds can be evaluated properly and that control measures can be used targeted.

Table 5.1
Example of an IPM-DSS time plan for weed control in maize, where non-chemical measures include a 'seed-bed harrow' and a 'row cultivator'

BBCH	Activity
3 – 8	Inspect field and consult DSS In case needs for control are indentified, a mechanical treatment is recommended
10-11	Inspect field and consult DSS, when weeds have 1 true leaf In case needs for control are identified, herbicide treatments will be optimized
12-14	Inspect field and consult DSS, when new flush of weeds have 1 true leaf In case needs for control are identified, herbicide treatments will be optimized
15-18	Inspect field, when new flush of weed have 1 true leaf or max 2 weeks after previous treatment In case needs for control are identified, herbicide treatments will be optimized. In case only a few weed that have escaped previous treatments are present, treatment with a row cultivator is recommended
>18	No additional activities regarding weed control in this season.

In table 5.1 a simple design of an IPM-DSS 'Time plan' is proposed. Alternatively, a graphical design including illustrations of selected crop growth stages may be constructed.

In many cases, however, farmers prefer to purchase suitable assortments of pesticides in good time before a growing season.

To get a basic idea of which weed species and which weed densities that may be expected, data on weed infestations in previous years may be used as basis for consultation of the DSS before a growing season to order suitable assortments and quantities of control measures in adequate time before a growing season. To comply with Directive 2009/128/EC, however, tactical decisions must be made on topical data on crops and weeds.

Often, the same weed species appear in the same fields year after year, so this approach should be robust in most fields. Of course, new infestations will occasionally occur, and weed infestations may also change substantially with changes of the cropping system.

The procedure for interaction between the IPM-DSS and the user, as illustrated in Figure 5.1 implies that the IPM-DSS will always try to restore the weed management situation on a field level, irrespectively of more or less appropriate incidents in the past – of course within limitations of availability and suitability of control measures. For example, the IPM-DSS may recommend herbicide treatments ranging from 10% of a single herbicide (TFI=0,1) up to mixtures of 3 herbicides, each in the registered dose rate (TFI=3,0). In this way the intensity may be varied by a factor=30, why proper control may be achieved in very simple and very complicated weed infestations.

Tool to support correct timing of field inspections

To support correct timing of field inspections, the IPM-DSS will offer opportunities to include a tool that can predict the expected time of emergence of crop and weeds and subsequent growth stages.

This tool is based on algorithms originating from DSS 'DecidHerb', which relate time of emergence of the crop and the weeds to the time of sowing and actual weather conditions.

Time is managed in ’10-Day Periods’ (10-DP) or alternative time periods, e.g. weeks. The end-user submits information on time (date) of crop sowing. The crop is supposed to emerge in the 10-DP immediately following the 10-DP of sowing. Parameters are stored in a database.

For each weed species, the database includes information on periods of the year, when the species is able to emerge and whether a species is likely to have a protracted (long) period emergence or to have mainly one cohort (flush) in a given crop.

This database is adapted for the regional weather conditions. For a given species, the first flush of weeds (cohort) emerges in the first 10-DP following the 10-DP of sowing with possible emergence according to the database. For species with protracted (long) period of emergence, a second cohort is supposed to emerge 4 10-DP later (if still in the period of possible emergence) or in the first subsequent 10-DP with possible emergence. Additional cohorts are eventually emerging according to the same principle.

For each species (either crop or weed) and each possible emergence time, the database also includes the phenological stage at each ’10-DP’ following the emergence until maturity. Therefore, the prediction of the growth stage of a given cohort at a given time is only a selection in the database as a function of both the species and the date of emergence.

In Figure 5.2 a graphical design of output for the expected time of growth stages (11 step scale) for 4 cohorts of 1 weed species (black-grass).

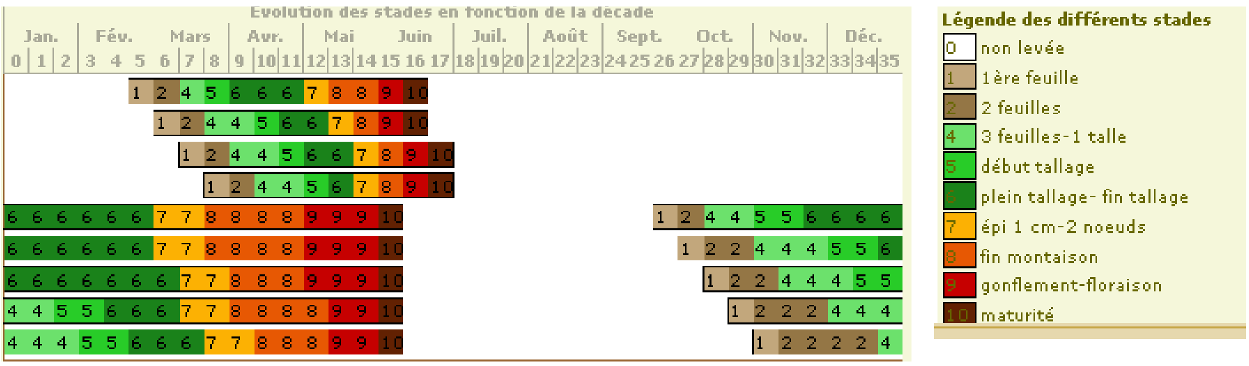

Figure 5.2
Display of expected timing of phenological stages for 4 cohorts (flushes) of black-grass (screendump from DECID’Herb)

Discussion

Time strategy
Prediction of weed emergence and of crop development will be valuable to target the timing of field inspections. Principles of algorithms have been derived from DECIDHerb.

DECIDHerb can recommend different ‘strategies’, which are specific combinations of ‘timing’ and possible accompanying spray programmes (time of herbicide application, herbicide names and doses). Such strategies have different consequences to overall cost, overall efficacy, multi-criteria assessment, etc.

In order to comply with the idea of applying herbicides according to threshold values and targeted for the purpose, the IPM-DSS can be customized to make separate decisions for separate treatments throughout a growing season. The IPM-DSS may alternatively be customized to recommend a series of future treatments, based on a present field report. Such customizing allows integration of the concept for multicriteria assessment.

A general disadvantage of planning future applications is that any previously planned treatment may be less targeted as compared to a treatment planned according to current field conditions.

Integration of IPM-principles
*A*ccording to Directive 2009/128/EC, non-chemical control measures should be preferred when sufficiently effective. Therefore, some considerations for timing and use mechanical treatments have been included in the 'Time plan'.

Pre-emergence versus post-emergence herbicide applications
In order to meet the requirement of a targeted use of herbicides, pre-emergence herbicide applications should be restricted to situations, where alternative control measures are significantly less effective or significantly more expensive.

Measures to meet requirements for robustness
In conventional farming, pesticides are often considered as relatively cheap and very robust control measures. Consequently, farmers may expect that recommendations from a IPM-DSS shall demonstrate similar levels of robustness. Furthermore, human advisors may be forgiven for failures that they will occasionally make, but similar failures made by IT-based DSSs, which include algorithms and equations, which are not immediately transparent to end-users, may not be so easy to forgive. Therefore, recommendations from the IPM-DSS shall be able to match the level of robustness of alternative recommendations.

The principle of consultation of the IPM-DSS before each single action in the field (Figure 5) will also ensure that recommendations are always relevant for actual conditions on a field level, irrespectively of the success of previous activities. Occasionally, recommendations from the IPM-DSS may not be correctly implemented, or subsequent unforeseen weather conditions (e.g. heavy rainfall) may influence the performance, why some counteracting measures may be required to restore the situation. The IPM-DSS will recommend control measures, which are always optimal for actual conditions, if possible. In very unfortunate circumstances, however, (e.g. very late growth stages of crop or weeds) the IPM-DSS may not be able to make recommendations. The procedure that is illustrated in Figure 5, will also contribute to ward off negative consequences originating from errors made in the design phase of the IPM-DSS (e.g. wrong estimation of model parameters) and errors made when consulting the IPM-DSS (e.g. wrong identification of weeds), as such errors will be accounted for in subsequent inspections of fields and consultations of the IPM-DSS. Reporting of errors to 'web-master' will of course also be used as inspiration for correcting specific estimates of model parameters and maybe for redesign of 'Time plans' or other components of the IPM-DSS.

Field inspections
Field inspections should be as simple as possible, considering the subsequent transformations and interpretations made by the IPM-DSS. Therefore, qualitative inputs should be preferred to precise quantitative description of the field infestations, as such are probably simpler and quicker to conduct by farmers. Furthermore, requirements for precision in input data should be adjusted to the precisions in subsequent calculations by the DSS.

5 Chemical control

5.1 Main model

Based on a field report and preferences regarding multi-criteria assessment submitted by the end-user, the IPM-DSS 'main model' will run through <u>3 main steps</u> which are compulsory, and a number of sub-steps, which may be installed as alternatives and/or which may be customized on different levels. This is explained in more details in the following sections.

The 3 main steps and sub-steps are as follows:

1. **Evaluate needs for control**

   1.1. **WPT (originating from DSS DecidHerb)**
   Quantify the Weed Potential Threat (WPT). Convert WPT into efficacy targets in percent

   1.2. **Target by simple algorithms**
   Use simple algorithms to identify efficacy targets in percent

2. **Identify herbicides (single and mixes), doses rates and adjuvants that meet needs for weed control, as identified in step 1**

   2.1. **Dose-response functions and ADM** (originating from DSS CPOWeeds).
   Identify herbicides and doses rates, specific for the target by use of dose-response functions and ADM

   2.2. **'Best practice' recommendations**
   identify herbicide and dose rates as in 'best practise' recommendations originating from handbooks or similar on regional levels

3. **Present and rank alternative treatment options according to attributes**

   3.1. Cost

   3.2. Expected efficacy

   3.3. Treatment Frequency Index

   3.4. Ipest Index (originating from DSS DecidHerb)

   3.5. Expected economic net return (originating from DSS Gestinf)

   3.6. Multi-criteria analyses (originating from DSS DecidHerb)

The user-interface language of IPM-DSS may be customized for conditions on a regional level.

For a selected crop x region crop, the IPM-DSS may customized for arbitrary combinations of 'sub-steps' within the main steps 1-3. In step 1 and 2, the presented sub-steps are alternatives, where only one can be selected for each customization.

In main step 3, however, at least one but also more alternatives, may be selected. This structure ensures that the DSS can be customized for different levels of complexity, as probably required in different cropping systems, in different regions, in different stages of development of the IPM-DSS, etc. Communication (=exchange of data) between building blocks have been enabled by minor adjustments of the structuring of original 'building blocks'.

Some of the listed components originate from DSS, which are protected by intellectual property rights:

- principles for calculation of WPT, prediction of emergence of weeds and multicriteria assessment, which was originally designed for DecidHerb
- principles for calculations by use of dose-response functions and ADM, which was originally designed for CPOWeeds
- principles for calculation of expected economic net return, which was originally designed for GestInf

Legal conditions for integration of these components in the IPM-DSS have not yet been clarified.

However, in order to achieve a high level of flexibility in terms of combining and customizing different 'best parts' for different crops and regions, also simple components, which are free to use, have been implemented in each of the 3 main steps.

Discussion

In this context, the term 'region' has been used for sub-division of probably large countries, where growing practices, growing conditions, weed flora, supply of control measures etc. may differ to an extent, which should be reflected by the IPM-DSS.

Example 1
Customization for grain maize in region 'Northern Italy'

- User interface language: Italian, user may switch to English
- selection for main step 1: simple algorithms
- selection for main step 2: dose-response functions and ADM
- selection for main step 3: user can select ranking for:
    - expected economic net return
    - cost
    - TFI

This example illustrate a customisation, where simple algorithms are used to quantify the needs for weed control while 'best parts' are used to identify control options and attributes of these.

Example 2
Customization for winter wheat in region 'Central France'

- User interface language: French, user may switch to English
- selection for main step 1: WPT
- selection for main step 2: dose-response functions and ADM
- selection for main step 3: user select ranking for:
    - cost
    - multicriteria assessment
    - Ipest index

This example illustrates a customisation, where 'best parts' are used to quantify the needs for weed control and to identify control options and attributes of these.

Example 3
Customization for Onions in Germany

- user interface language: German (only)
- selection for main step 1: simple algorithms
- selection for main step 2: 'best practice' recommendations
- selection for main step 3: ranking for cost (only)

This example illustrates a customization, where no 'best parts' are involved.

5.2 Evaluation of needs for control

5.2.1 Weed Potential Threat

The Weed Potential Threat (WPT) express the potential threat from specific weed species in a specific crop. The original WPT-concept includes 2 contributions with independent integrity: one regarding threats to the current crop (WPT-short term) and another regarding threats to the crop rotation. In context of the IPM-DSS, however, only the WPT-short term contribution will be considered (Figure 6.1).

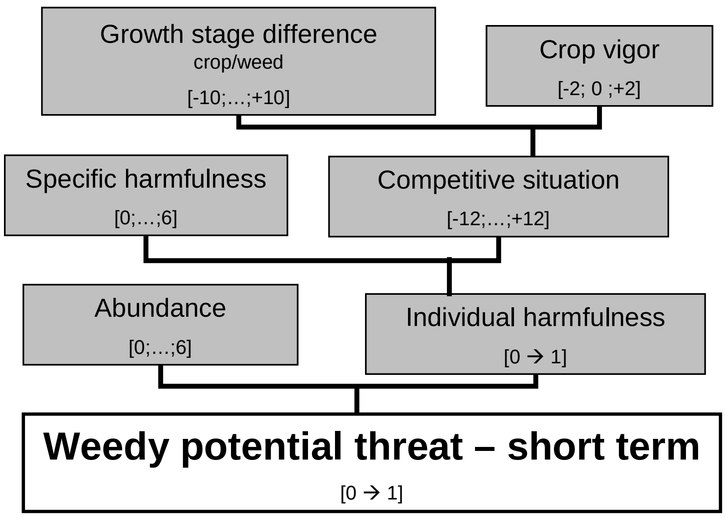

Figure 6.1
Aggregation of the various variables for the assessment of the WPT-short term index

The WPT-short term (ranging [0-1]) derives from the aggregation of (i) the density and (ii) the harmfulness of individual weed plants:

- the harmfulness of individual weed plants (ranging [0-1]) derives from the aggregation of (i) the specific harmfulness and (ii) the competitive situation
- the competitive situation (ranging [-12;…;+12]) derives from the sum of (i) the difference between the crop growth stage (class from 0 to 10) and the weed growth stage (class from 0 to 10), and (ii) a variable indicating the quality of the crop canopy, that takes 3 values:

  - +2 for a crop canopy homogeneous, dense and vigorous
  - 0 for an intermediate crop canopy
  - -2 for a crop canopy weak and/or heterogeneous

All the elementary variables aggregated are either inputs or data may be stored in a database. For each weed species, the database includes information for the following variables:

- specific harmfulness for each possible crop: 7 classes, from 0 when the weed is never observed in the crop to 6 for the most harmful species

- typical impact of crop competition on weed growth and seed production, assessed for each crop: qualitative classes from (1) for crops with little suppressive effects to (6) for crops with very strong suppressive effect

Principles for calculation of WPT-short term index

The user will enter a field report with the following information:

- crop name
- crop vigour
- crop growth stage
- corresponding information on:
    - weed name
    - weed density (density class)
    - weed growth stage

At each aggregation node, principles of fuzzy logic are used:

- for each aggregated variable, defining the threshold delimiting the range of values 'very favourable' (for weed management), the range of values 'very unfavourable', and thus the range of values intermediate between 'very favourable' and 'very unfavourable'. The very favourable and very unfavourable values are always restricted to the extreme values of the variable range. For calculating the WPT-short term index, 'density 0' is considered as the only fully 'very favourable' value for density, and 'density 6' is considered as the only fully 'very unfavourable' value

- for all values in between the 'very favourable' and 'very unfavourable' ranges, defining the shape of the membership functions describing the degree of membership to both the 'very favourable' and 'very unfavourable' fuzzy sets. For example a medium value for a given variable could typically correspond to a 50% membership to the 'very favourable' fuzzy set and a 50% membership to the 'very unfavourable' fuzzy set. These membership functions make it possible to give membership values to both fuzzy set for any value in between the extreme values. The membership functions typically have sigmoidal shapes, but they can have any shape to account for the knowledge available

- defining output values (estimated by experts) for the output variable for all combinations of fully 'very favourable'/'very unfavourable' aggregated variables. For example, for calculating the WPT-short term index, the output table is as following:

Density	Harmfulness of individual weed plants	WPT-short term (output value)
Very favourable	Very favourable	0
Very favourable	Very unfavourable	0
Very unfavourable	Very favourable	0.1
Very unfavourable	Very unfavourable	1

This output table indicates that the yield loss of a very harmful species is negligible if the species is not present, and that even a very strong density of a very small and weak species (such as Arabidopsis thaliana) induces only very little yield loss. For a given set of input variables, calculating the output using the Sugeno's inference method: the output is calculated as the weighted mean of the four output values for the four combinations of 'very favourable'/'very unfavourable' situations, where the weights are the four likelihoods of the combination. The likelihood of a combination is defined as the minimum of the two membership values of the combination.

For example, for an density of 5 (close to the maximum 6) of a species with a harmfulness of individual plants of 0.9 (close to the maximum 1), the likelihood table will be:

Density (membership)	harmfulness of individual weed plants (membership)	WPT-short term output value and (likehood)
Very favourable (0.25) Very favourable (0.25) Very unfavourable (0.75) Very unfavourable (0.75)	Very favourable (0.15) Very unfavourable (0.85) Very favourable (0.15) Very unfavourable (0.85)	0 (0.15) 0 (0.25) 0.1 (0.15) 1 (0.75)

In this case the output value of the WPT-short term will be:

$$\text{WPT-short term} = \frac{0 \times 0.15 + 0 \times 0.25 + 0.1 \times 0.15 + 1 \times 0.75}{0.15 + 0.25 + 0.15 + 0.75} = 0.59$$

Structuring of calculation of WPT-short term index

According to the structure and flow of data as illustrated in Figure 1, the following basic structuring of data in tables may be feasible:

WPT-table 1
Definition of values regarding growth stages

CropID (1 … n)	**Value**	**Description**
	0	Not emerged
	1	Emergence
	2	1-2 leaves
	3	2-3 leaves
	4	3 leaves – 1 tiller
	5	1 tiller – full tillering
	6	Full tillering – end of tillering
	7	End of tillering – ear 1 cm
	8	Beginning of stem lengthening
	9	End of stem lengthening
	10	Heading-maturity

Notes:
Values are used for aggregation in the 'Competitive situation'
Values and descriptions have been selected by experts
CropID has been included in order to enable use of different scales in different crops
Data examples of winter wheat

WPT-table 2
Definition of values for aggregation regarding growth stage of weeds

Value	Description
0	Not emerged
1	Cotyledons
2	Seedling 1-2 leaves
3	3-4 leaves
4	5-7 leaves
6	8 leaves and more
8	Flowering
10	Seed setting and maturity

Notes:
Common scale for all crops and all weeds
Values are used for aggregation in the 'Competitive situation'
Values and descriptions have been selected by experts

WPT-table 3
Definition of values for aggregation regarding crop vigour

CropID (1 … n)	Description	Value (effect on competitive situation)
	Weak, heterogeneous	-2
	Medium	0
	Strong, even canopy	+2

Notes:
Values are used for aggregation in the 'Competitive situation'
Values and descriptions have been selected by experts
CropID has been encluded to enable use of specific values in specific crops
Data example from winter wheat

The competitive situation is calculated by this formula:

Value of 'Competitive situation' =
Value of 'crop growth stage' - Value of 'weed growth stage' + Value of 'crop vigour'

WPT-table 4
Definition of values of 'competitive situation'
and membership to fuzzy sets (with data examples, skewed S-shaped function)

		Level of membership	
CropID (1 … n)	**Value**	**Very low competition against weeds**	**Very high competition against weeds**
	-12	1	0
	-11	0,9975	0,0025
	-10	0,995	0,005
	-9	0,99	0,01
	-8	0,989	0,011
	-7	0,988	0,012
	-6	0,985	0,015
	-5	0,98	0,02
	-4	0,97	0,03
	-3	0,96	0,04
	-2	0,95	0,05
	-1	0,925	0,075
	0	0,9	0,1
	1	0,85	0,15
	2	0,8	0,2
	3	0,6	0,4
	4	0,4	0,6
	5	0,25	0,75
	6	0,175	0,825
	7	0,125	0,875
	8	0,075	0,925
	9	0,05	0,95
	10	0,025	0,975
	11	0,02	0,98
	12	0	1

Notes:
CropID has been include to allow different membership functions in different crops
Data examples from winter wheat (skewed S-shaped function)

WPT-table 5
Definition of values of 'specific harmfulness' in terms of potential effect on yield loss
and membership to fuzzy sets

			Level of membership	
WeedID (1 … n)	**Value**	**Description**	**Very low**	**Very high**
	1	Negligible potential yield loss	1	0
	2	Very weak potential yield loss	0.98	0.02
	3	Weak potential yield loss	0.93	0.07
	4	Medium potential yield loss	0.5	0.5
	5	High potential yield loss	0.05	0.95
	6	Very high potential yield loss	0	1

Notes:
Support for estimation may be achieved from 'Cousens-functions'
Data examples from winter wheat in France

WPT-table 6
Definition of values of weed density (weed density classes) and membership to fuzzy sets

		Level of membership	
Value	**Description**	**Very low**	**Very high**
0	Absent	1	0
1	D< 0.1 pl/m²	0,99	0,01
2	0.1<D< 1 pl/m²	0,95	0,05
3	1<D< 3 pl/m²	0,9	0,1
4	3<D< 20 pl/m²	0,6	0,4
5	20<D< 50 pl/m²	0,25	0,75
6	D> 50 pl/m²	0	1

Notes:
The shape of the function of membership to the 'density' fuzzy sets approximately follows the shape of Cousens' equation of yield loss
Data example from winter wheat in France

The user will submit information (enter field report) with the following information:

- crop name
- crop vigour
- crop growth stage
- corresponding information on:
    - weed name
    - weed density (density class)
    - weed growth stage

WPT-table 7
Definition of output values 'individual harmfulness' (of individual weed species) from the 4 high/low-combinations possible of 'Specific harmfulness' and 'Competitive situation'

WeedID (1 … n)	'Specific harmfulness'	'Competitive situation'	'Individual harmfulness' (Output values)
	Very low	Very high competition	0,0
	Very low	Very low competition	SHH&CSL
	Very high	Very high competition	SHL&CSH
	Very high	Very low competition	1,0

Notes:
The 'Individual harmfulness' (output values) of a combination is defined in this way:
- Very low 'Specific harmfulness' x Very low 'Competing situation' is always = 0
- Very high 'Specific harmfulness' x Very high 'Competing situation' is always = 1
- Output of other combinations (SHH&CSL and SHL&CSH) are estimated by experts

The likelihood of specific output values of the 'Individual harmfulness' of a specific weed species is calculated from membership values of 'Specific harmfulness' and 'Competitive situation'.

WeedID (1 … n)	‘Specific harmfulness’ (SH)		‘Competitive situation’ (CS)		‘Individual harmfulness’ (Likelihood) [3)]
		Membership value [1)]		Membership value [2)]	
	Very low (L)	SHL	Very low (L)	CSL	Min(SHL, CSL)
	Very high (H)	SHH	Very low (L)	CSL	Min(SHH, CSL)
	Very low (L)	SHL	Very high (H)	CSH	Min(SHL, CSH)
	Very high (H)	SHH	Very high (H)	CSH	Min(SHH, CSH)

Notes:
[1)] Lookup in WPT-table 5
SHL = very low membership value of ‘specific harmfulness’ of a reported weed species
SHH= very high membership value of ‘specific harmfulness’ of a reported weed species
[2)] Lookup in WPT-table 4
CSL= very low membership value of ‘competitive situation’ of a reported weed species
CSH= very high membership value of ‘competitive situation’ of a reported weed species
[3)] The likelihood of a combination is defined as the minimum of the two membership values of the combination

The individual harmfullness of one weed species can be calculated from the following equation:

$$\underline{\textbf{\textit{Individual harmfulness}} = \frac{\sum_{4combinations} Outputvalue * likehood}{\sum likehood}}$$

or:

Individual harmfullness, high$_{WeedID}$ (IHH) =

$$\frac{0 * \mathrm{Min(SHL;CSL)} + \mathrm{SHH\&CSL} * \mathrm{Min(SHH;CSL)} + \mathrm{SHL\&CSH} * \mathrm{Min(SHL;CSH)} + 1 * \mathrm{Min(SHH;CSH)}}{\mathrm{Min(SHL;CSL)} + \mathrm{Min(SHH;CSL)} + \mathrm{Min(SHL;CSH)} + \mathrm{Min(SHH;CSH)}}$$

Values of ‘Individual harmfulness’ represent the highest competitive abilities of a specific weed species. Accordingly, the low-end individual harmfulness of a particular weed species can be calculated from the following equation:

Individual harmfullness, low$_{WeedID}$ (IHL) = 1,0 - IHH

The potential short term threat (WPT-short term), which is interpreted as the potential yield loss within a growing season of a specific weed species, has been defined a function of the aggregation of ‘Density’ and ‘Individual harmfulness’.

WPT-table 8
Definition of output values 'WPT-short term' (of individual weed species) from the 4 high/low-combinations possible of 'Specific harmfulness' and 'Competitive situation'

WeedID (1 … n)	'Density' (AB) [1]	'Individual harmfullness' (IH)	'WPT-short term' (Output values) [2]
	Very low (L) Very low (L) Very high (H) Very high (H)	Very low (L) Very high (H) Very low (L) Very high (H)	0,0 ABL&IHH ABH&IHL 1,0

Notes:
[1] Valued are based on user input and lookup of membership values in DB Table 6
[2] The 'WPT-short term' (output values) of a combination is defined in this way:
- Very low 'Density' x Very low 'Individual harmfulness' is always = 0,0
- Very high 'Density' x Very high 'Individual harmfulness' is always = 1,0
- Output of other combinations (ABL&IHH and ABH&IHL) are estimated by experts

The likelihood of specific output values of the 'WPT-short term' for different weed species shall be calculated from membership values of 'Density' and of 'Individual harmfulness'

WeedID (1 … n)	'Density' (AB)		'Individual harmfulness' (IH)		'WPT-short term' (Likelihood) [3]
		Membership value [1]		Membership value [2]	
	Very low (L) Very high (H) Very low (L) Very high (H)	ABL ABH ABL ABH	Very low (L) Very low (L) Very high (H) Very high (H)	IHL IHL IHH IHH	Min(ABL, IHL) Min(ABH, IHL) Min(ABL, IHH) Min(ABH, IHH)

The WPT-short term index shall be calculated by the following equation:

WPT-short term =

$$\frac{0 \text{ x } \mathrm{Min}(ABL;IHL) + ABH\&IHL \text{ x } \mathrm{Min}(ABH;IHL) + ABL\&IHH \text{ x } \mathrm{Min}(ABL;IHH) + 1 \text{ x } \mathrm{Min}(ABH;IHH)}{\mathrm{Min}(ABL;IHL) + \mathrm{Min}(ABH;IHL) + \mathrm{Min}(ABL;IHH) + \mathrm{Min}(ABH;IHH)}$$

Example of calculation of WPT-short term values

Input from end user on crop

Crop name	Wheat
Crop vigor and quality of crop emergence	Good
Crop growth stage	3

Input from end user on weeds

Weed name	Density class	Growth stage class
Capsella bursa pastoris	3	2
Galium aparine	2	1

Lookup in WPT-table 5:

WeedID	Specific harmfulness against wheat
Capsella bursa pastoris	2 (very weak)
Galium aparine	5 (high)

Calculation of the 'competitive situation' by aggregation of contributions (values) from: Value of 'crop growth stage' - Value of 'weed growth stage' + Value of 'crop vigour'

Species	Competitive situation
Capsella bursa pastoris	= 3 – 2 + 2 = +3
Galium aparine	= 3 – 1 + 2 = +4

Calculation of the 'individual harmfulness' (Index of harmfulness of individual weed plants)

	Specific harmfulness (level of membership)		Competitive situation (level of membership)		'individual harmfulness'	
					Output value	likelihood
Capsella bursa pastoris	Very low	0.98	Very low competition	0,6	0	0.6
	Very high	0.02	Very low competition	0,6	0.3	0.02
	Very low	0.98	Very high competition	0,4	0.3	0.4
	Very high	0.02	Very high competition	0,4	1	0.02
Galium aparine	Very low	0.05	Very low competition	0,4	0	0.05
	Very high	0.95	Very low competition	0,4	0.3	0.4
	Very low	0.05	Very high competition	0,6	0.3	0.05
	Very high	0.95	Very high competition	0,6	1	0.6

Hence:

Individual harmfulness (Capsella) = $\frac{0 \times 0.6 + 0.3 \times 0.02 + 0.3 \times 0.4 + 1 \times 0.02}{0.6 + 0.02 + 0.4 + 0.02}$ =0.14

Individual harmfulness (Galium) = $\frac{0 \times 0.05 + 0.3 \times 0.4 + 0.3 \times 0.05 + 1 \times 0.6}{0.05 + 0.4 + 0.05 + 0.6}$ =0.67

Those values of individual harmfulness are in accordance with the far highest competitive ability of Galium aparine as compared to Capsella bursa-pastoris, which is not compensated by the slightly smaller growth stage of Galium aparine.

Calculation of the WPT-short term as a function of the aggregation of density and individual harmfulness:

	Density (level of membership)		harmfulness of individual weed plants (membership)		WPT-short term	
					Output value	likelihood
Capsella bursa pastoris (Density = 3)	Very low	0.9	Very low	0.86	0	0.86
	Very low	0.9	Very high	0.14	0	0.14
	Very high	0.1	Very low	0.86	0.1	0.1
	Very high	0.1	Very high	0.14	1	0.1
Galium aparine (Density = 2)	Very low	0.95	Very low	0.33	0	0.33
	Very low	0.95	Very high	0.67	0	0.67
	Very high	0.05	Very low	0.33	0.1	0.05
	Very high	0.05	Very high	0.67	1	0.05

Hence:

WPT-short term (Capsella bursa-p.) $= \frac{0\times0.86+0\times0.14+0.1\times0.1+1\times0.1}{0.86+0.14+0.1+0.1}$ =0.09

WPT-short term (Galium aparine) $= \frac{0\times0.33+0\times0.67+0.1\times0.05+1\times0.05}{0.33+0.67+0.05+0.05}$ =0.05

In this case, both Capsella bursa-pastoris and Galium aparine are expected to be only a little threat for yield loss, because of the low competitive ability of Capsella bursa-pastoris and of the low density of Galium aparine.

Principles of parameterization

All parameters shall be estimated from expert knowledge supported by literature.

Discussion

In the initial version of IPM-DSS, the WPT-long term index has not been prioritized for integration, because the integrated parameters are very difficult to estimate and validate. Instead, requirements regarding long term weed control, which is of course important in a DSS for practical use, will be accounted for in validation tests of different versions of the IPM-DSS, where progressive versions of the WPT-short term values, which will be transformed into ‘Target efficacy values’, have been integrated. Subsequent assessment of residual weed infestation and weed seed production in field plots treated according to different versions of IPM-DSS will contribute to select a version that demonstrate as suitable balance between treatment intensity and also long term weed management. Measurements of the amount residual weeds late in the growing season may give indications on relative contributions to the weed seed bank.

WPT-short term values will be estimated at the species level, however, weed control decision on a field level is taken as a function of the whole community, where different ideas may exist on how different weed species should be represented and weighed. In the IPM-DSS, identified needs for control must be met on a species level. This means that combinations of weed species present in a field and accompanying target efficacy values and efficacy of herbicides on a species level, will define the minimum dose rates of single herbicides.

If, alternatively, WPT-short term values were calculated on community levels, some weeds species, which may appear in very ‘unfavourable’ combinations of e.g. ‘Density’ and ‘Harmfulness’, may occasionally not be controlled to satisfactory levels. This may violate (jeopardize) requirements for robustness of the IPM-DSS as a whole.

It may be argued that some farmers may be satisfied with control measures, which is slightly less efficient against some weeds and slightly more efficient against other weeds as compared to alternative control measures. This argument favours decisions taken as a function of an overall efficacy on the whole community, of course giving a high weight on species with a high WPT-value.

These arguments, however, also illustrate the complexity involved when striving for a balance between target efficacy level and the intensity of control measures. Assuming that most farmers have a joint understanding of such balances, the task of identifying such balances may conveniently be allocated to the DSS rather that the end-users.

20 years experience with dissemination of CPOWeeds, show that recommendations produced by this DSS shall probably be more robust than recommendations made by humans. Just a few serious mistakes made by a probably not so transparent DSS, may cause a sudden and definite termination of confidence with recommendations made by the DSS, why actions should be taken by the constructors behind DSS to ensure that such incidents do not occur. Hands-on test of DSS user-interfaces and field test of recommendations from DSS should therefore be conduced before release of a new DSS.

In conclusion, even occasional but systematic risks of unsatisfactory efficacy of recommendations produced by an IPM-DSS should be minimized. Therefore, WPT-short term values/Target efficacy levels shall be estimated with best possible care, so that recommendations that comply with these are expected to match requirements for robustness on a farm level. Luckily, this rather conservative approach will not destroy potentials for very significant reductions of herbicide input as compared to alternative 'best practice' strategies, as the IPM-DSS will benefit from mainly 2 aspects: 1) the presence of weeds differ strongly between fields and 2) some weeds can be controlled with high efficacy from even small proportions of registered herbicide dose rates.

Following this approach, the IPM-DSS is expected to demonstrate potentials for reducing herbicide as compared to existing 'best practice' strategies without compromising on requirements for robustness. In case some success regarding this IPM-DSS is achieved in ENDURE/PURE, a basis may be established for introduction of more sophisticated algorithms and calculation functions in future versions of the IPM-DSS.

Conversion of WPT-short term to target efficacy in percent

In order to enable communication between dose-response functions and WPT, WPT-short term values will be converted into optimal target efficacy (%) and minimum target efficacy (%) by use of the relation, which is illustrated in Figure 6.2. Equations that match this figure may be set up.

In case the maximum dose (N) of a herbicide cannot meet the optimal target efficacy level, calculations will be made to evaluate whether a 'minimum' level, which may be approximately 20 efficacy-percent units below the optimum level, can be achieved by N. In that case, N will be presented as a low-ranked recommendation and followed by a remark explaining that the maximum dose has low effect (but sometimes recommendable anyway, if alternatives are sparse).

Further differentiation may be considered for the following additional parameters:

- 'Season', in case different values are required in different seasons (e.g. 'autumn' and 'spring')
- 'Undersown crop", in case different values are required, when specific crops are 'undersown'
- 'Minimum efficacy', in case some lower level of efficacy shall be used in case the maximum dose of a single herbicide cannot meet target efficacy.

Facilities could be made to 'enable' or 'disable' these additional, agronomical parameters.

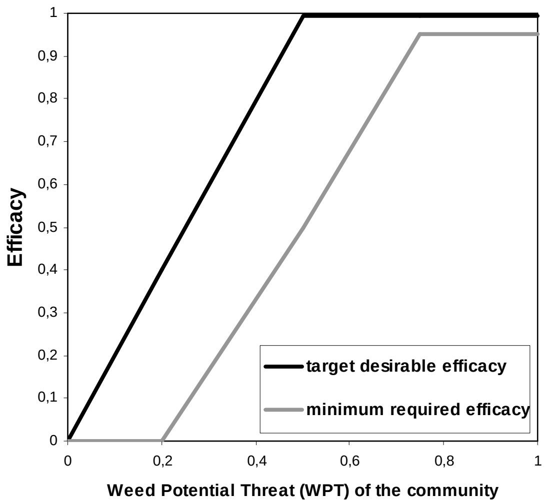

Figure 6.2
Example of efficacy function quantifying the need for weed control 'required' and 'desirable'

Discussion

Target efficacy levels in range 0,9-1,0 (equal to 90-100%) should be considered with great care, as marginal increases of efficacy result in very drastic increases in dose rates.

However, if the target efficacy values are considered to be real and not a threshold, the options with very high doses that approach the target could be eliminated after the multi-criteria analysis because they are too expensive, bad for the environment while providing only limited improvement of the efficiency as compared to strategies with lower doses. This argument is in favour of 'desirable target' coupled with multi-criteria analysis, and not for 'target as minimum threshold required efficiency'. This approach may be close to the way that farmers think.

Target efficacy levels in range 0,01-0,50 (equal to 1-50%) should probably be converted to 0 (cero), as corresponding dose rates will not give meaningful effects under field conditions anyway.

The parameters 'Season' and 'Undersown crop' and 'Minimum efficacy' are probably not relevant for the planned prototype in maize.

5.2.2 Simple algorithms

A database with the following structure (variables) may be designed:

- region
- crop
- crop growth stage interval (optional)
- expected yield (classes, optional)
- undersown crop (optional)
- season (optional, e.g. 'spring', 'autumn)'
- weed species (including resistant biotypes)
- weed density (classes)
- target efficacy (% reduction on biomass on a weed species level)

Weed experts will fill in combinations and estimates. Based on a field report submitted by the end-user, the DSS will look-up target efficacy levels on a weed species level.

Principles of parameterization

Expert algorithms are used to define target efficacy levels for different combinations of variables.

From a relative conservative starting point (high levels of target efficacy) actual levels have been achieved after typically 2-3 iterations of prototype adjustments and field tests, in which the following requirements were evaluated: a) no cases of yield loss as compared to existing 'best practices', b) max 10% total weed cover at harvest, c) no weeds observable from a distance during the growing season

Discussion

The structure as well as the content of this database will be based on expert knowledge, of course supported by existing literature.

A fundamental idea behind this structuring of data is that farmers will often have requirements regarding weed control, which go in different directions. Such requirements may include prevention of loss of quantity and quality of yield, prevention of propagation of weeds in the crop rotation, prevention of complications from weeds in harvesting and post-harvesting processes, and also cosmetic aspects are sometimes mentioned by farmers as being important.

In resent years, increasing problems with herbicide resistance require special strategies on weed biotypes, which are more or less resistant to specific compounds.

Consequently, a DSS that strives for general acceptance among farmers should also reflect such requirements.

Immediately it may seem impossible to integrate such quite different aspects in a single figure on a species level, but this is actually, what this expert-structure intends to do. Initially, target figures shall be defined from a relatively conservative starting point, of course by integration of conservative interpretations of results from available literature, e.g. from studies on effects on yield, 'competition indexes' and similar relevant material. Such an initial 'version' shall be expected to meet all the requested qualities of weed control on levels that are immediately acceptable in practice.

Subsequently, mechanistic reductions may be introduced and field tests of such various 'levels' may be conducted to get indication of how far such reductions can be taken, before some of the listed requirements are violated to levels which are unacceptable to farmers. The suggested working process will strive to identify target levels, which are balanced against different requirements.

The variable 'region' enables integration of separate target efficacy levels on a regional level.

The variable 'crop' (and combinations with undersown crop if enabled) allow specific target efficacies for different crops.

The variable 'crop growth stage interval' allows differentiation of target efficacy levels in different intervals of crop growth stage. In some crops, 'thresholds' increase and accompanying target efficacy levels decrease with increasing growth stages of the crop

The variable 'season' allows differentiation of target efficacy levels in different seasons (e.g. 'spring' and 'autumn). This variable is required as a supplement to 'crop growth stage intervals', as these variable cannot alone ensure unique determination, if an actual crop stage is actually in the autumn or the spring, which is important to know in order to select relevant control measures.

5.3 Identification of control options

5.3.1 Dose-response functions and the Additive Dose Model

Dose-response functions for single herbicides

Single herbicides and accompanying maximum dose rates (='registered doses', ='N-doses') that are available for a reported combination of crop x crop growth stage interval will be identified. Among these, dose-response functions are used to identify candidate herbicides and to calculate dose rates that meet target efficacy levels on individual weed species.

Biotypes of weed species that are resistant to specific herbicides (specific modes of action) will be included as separate biotopes (separate weed species).

For a reported weed community (e.g. on a field level), the highest calculated dose of each herbicide will be recommended as a treatment option. In case the N (maximum allowed) dose is exceeded, the herbicide is excluded for use alone, but such herbicides may enter calculations of herbicide tank-mixtures.

Dose-response functions will be parameterized for combinations of: crop x herbicide x weed species x weed growth stage. Optionally, temperature / Rh and water stress may also be integrated (Streibig et al, 1993)

$$E_{WeedID} = \frac{100}{1 + \exp(-2(A + B * \log(Dose / CF_{wgs})))}$$

where

E_{WeedID}	is the expected, relative efficacy in percent 4-6 weeks after a herbicide application
$Dose$	is the herbicide dose rate on a specific weed species
A	is a parameter expressing the horizontal displacement of a dose-response curve
B	is a parameter expressing the slope of a dose-response curve around ED50
CF_{wgs}	is the Correction Factor (relative potency) on herbicide doses for an alternative weed growth stage, i.e. a dose correction factor required to obtain a specific efficacy level for an alternative growth stage of weeds as compared to the growth stage of weed data used for estimation of *A* and *B*. In case temperature/Rh and/or water stress are also included, CF_{wgs} shall be multiplied with $CF_{temperature/Rh}$ and $CF_{water\ stress}$

Estimates of *B* may be obtained from tests in semi-field experiments, and *B* is considered as a constant on a herbicide compound level. Estimates of *A* can be varied for different combinations of crop, crop growth stages, herbicides and weed species. Estimates of CF_{wgs} can be differentiated for different combinations of crop, crop growth stages, herbicides, weed species and weed growth stages.

A database for storage may include the following variables:

- crop ID
- undersown crop ID (if enabled)
- crop growth stage interval (if enabled)
- season (if enabled)
- herbicide ID
- maximum dose rate of herbicide

- weed ID
- estimate of A (at well defined level of weed growth stage, temperature regime and level of water stress
- estimate of B (Often considered as constant on a herbicide compound level)
- estimate of CF_{wgs} (Relative to doses uptained by use of estimate of A)
- estimate of $CF_{temperature}$ (If enabled. Relative to doses calculated by use of estimate of A)
- estimate of $CF_{waterstress}$ (If enabled. Relative to doses calculated by use of estimate of A)

Principles of parameterization

B expresses the 'slope' of the function around $ED_{50.}$ This parameter can be estimated from efficacy tests of herbicides in field or semi-field conditions, where 5-8 doses provide efficacy >0% and <100%.

A expresses the horizontal displacement of the function. This parameter can be estimated from efficacy test of herbicides, where at least 3 doses have been tested on different weed species in field conditions.

By mathematical rearrangement, alternative estimates of 'A' may be transformed into 'adjustment factors' (or 'correction factors', CF) on the dose.

CF_{wgs} expresses the correction factor for weed growth stage relative to the dose expressed at the growthstage behind the estimate of A. Data can be produced in semi-field conditions.

$CF_{temperature}$ and $CF_{waterstress}$ work similar to CF_{wgs}. Data may conveniently be produced in climatic simulators.

Input from end-users

To the application named 'Solve weed problem', the user will submit the following input

- name of crop
- name of under-sown crop (if enabled)
- name of season ('Spring and summer' or 'Autumn', if enabled)
- crop growth stage (to comply with instructions on labels)
- list of weed name(s), weed growth stage (classes), weed density (classes)
- minimum and maximum temperature on day of herbicide application (if enabled)
- water stress (classes, if enabled)

Discussion

Biotypes of weed species, which are resistant to specific herbicides mode of actions, may be included as separate weed species, e.g. 'Stellaria media, SU-resistant' and dose-response calculations may be adjusted, so that the expected efficacy of the maximum dose against a resistant biotype is very low. In this way, herbicides with alternative modes of action will automatically be recommended by the IPM-DSS for tactical control.

For simplicity, and when considering resources available for DSS construction in ENDURE and possible new projects, the optional CF for temperature / Rh and water stress have been made optional, as quite many data are required to produces estimates of these parameters. A consequence of such decision is that the estimates of the

A parameter should be sufficiently robust to cover different regimes of these parameters, however specific comment may alternatively be inserted to provide guidance on probably extreme conditions, e.g.:

'Herbicide XX should not be used, if the temperature is <5 deg. C.'

In order to minimize the risk for development of herbicides resistance, strategies should be followed across the crop rotation to ensure that the herbicide mode of action is systematically changed over time. However, such facilities have not yet been designed for the IPM-DSS.

The Additive Dose Model for optimization of herbicide tank-mixtures

The Additive Dose Model (ADM) is used to identify relevant tank-mixes of herbicides. This model offers opportunity to optimize compositions of herbicides, so that specific efficacy targets for a mixed population of weed species are met under different conditions of weed species, weed growth stages and weather conditions (temperatures/Rh and water stress).

The ADM uses the methodology of 'linear optimization' to identify 2-4 component mixes (herbicides and accompanying dose rates), which are optimized for arbitrary constants relating to the doses of the herbicides, e.g. cost, TFI or alternative indexes that may be derived from compositions of herbicide products and accompanying dose rates.

For optimization of a 2-component mixture, the following equation is used:

$$1 = \frac{z_A}{Z_A} = \frac{z_B}{Z_B}$$

where

z_A and z_B	are the doses of herbicide A and B in a mixture producing the same biological response
Z_A and Z_B	are the doses of herbicide A and B, when applied singly, which produce a common level of efficacy e.g. 50% efficacy

For 3- and 4-component mixtures, the equation must be expanded accordingly.

Values of Z are obtained from calculation of actual doses to meet target efficacy levels for a specific combination of weed species, weed growth stag, temperature regime and water stress regime, as specified by the dose-response functions in the previous step.

In order to calculate optimized ADM-mixtures, specifications must be provided on which specific 2-, 3- and 4-component herbicide mixes (combinations of herbicide products) that shall be available for the ADM-calculations.

Limitations for the ADM-optimization:

- for legal reasons, calculated mixes, where N dose of some mixing partner is exceeded, must be excluded
- for practical reasons, mixes where the dose of some mixing partner is below some lower limit, e.g. <0,1 N shall be excluded

Relevant adjuvants for single herbicides and for mixes will be included. In specific tank-mixes, some mixing partners may contain sufficient amount of an adjuvant, which may be required by other mixing partners. To account for such conditions, adjuvants may be adjusted according to the concentration of specific herbicides in specific mixes.

Principles for parameterization

In order to obtain mixes of agronomical relevance, calculations will only be made on mixes, which have been defined in a model database.

Mixes that have antagonistic effects, which may be studied in semi-field experiments (or specified on product label) should be excluded. 3- and 4-way mixes may be allowed from studies/indications on 2-way mixes.

Special algorithms can be customized to administer specific adjuvants, depending on the components included in a mixture.

Discussion

In order to achieve robust calculations with the ADM, mixing partners should not have antagonistic effects on the efficacy. In case some mixing partners have synergistic effects on the efficacy, the observed efficacy is expected to be higher than the expected efficacy.

When dose-response functions for single herbicides have been parameterized, and relevant, possible 2-4 component ADM mixtures have be specified, the IPM-DSS can estimate efficacy of any composition of herbicides dose rates of the relevant mixes. In this way, ADM offer great opportunities to identify specific herbicide mixtures that match special compositions of weed species and conditions.

Parameterisation of the dose-response functions require data on the efficacy from several doses of single herbicides, where 3 doses is considered as an acceptable minimum. Such data are, however, not generally available. Efficacy data, which are submitted for registration of new herbicides, are generally confidential.

In return for production of such data, however, efficacy from any dose rate of the herbicides used alone or in mixes with other herbicides can be estimated automatically by the IPM-DSS.

The combination of dose-response functions and the ADM enable differentiation of herbicide input from 5-10% of a single herbicide (TFI=0,05-0,10) to a mixture consisting of 3-4 herbicides, each in the registered dose rate (TFI=3,00-4,00). In terms of TFI the input on a field level may be varied by a factor 4,00/0,05=80. This means that the DSS will be able to recommend 'targeted treatments' in fields with low and simple weed infestations, and also in fields with high and complicated weed infestations. The DSS will also be able to restore suitable control in many fields, where the weed management situation has got out of control.

If compared to the extent of traditional field experiments to identify 'best practice' strategies on a regional level, the total work load to parameterize the IPM-DSS can be significantly reduced.

5.3.2 'Best practice' recommendations

'Best practice' recommendations may be derived from existing handbooks and similar. To provide recommendations for single treatments, the following variables may be required:

- crop
- undersown crop (optional)
- growth stage interval
- season (optional)
- herbicide
- herbicide dose rate

- weed species
- weed growth stage (classes)
- expected efficacy level (classes)

As an alternative to a single treatment with a single herbicide, 'best practice' recommendations may also include 1) tank-mixtures of herbicide products and 2) programmes, which include multiple treatments, and combinations of these two components.

Such combinations are also referred to as 'treatment programmes', and such may be defined uniquely as connected information on timing, products and dose rate, and may conveniently be presented in the following layout (example):

Timing	***Product***	***Dose rate***
1. crop stage 10-12	*Herbicide A*	*1,0 l/ha*
	Herbicide B	*30 g/ha*
2. crop stage 13-14	*Herbicide A*	*2,0 kg/ha*
	Herbicide C	*2,0 tablets/ha*
	Adjuvant D	*0,15 l/ha*

Discussion

According to Directive 2009/128/EC, herbicides should be applied according to threshold values and specific for the target. Consequently, the a.m. example of a treatment programme that also include future applications, must be seen as a recommendation only for special situations, for example, where probably knowledge on thresholds is sparse or where the supply of suitable control measures are sparse.

5.4 Attributes of alternative control options

Based on the herbicide treatment options, which may be recommend for conditions in a specific field on a specific day, a total list of herbicide control options, will be produced.

For alternative herbicide control options, different attributes may be calculated.

5.4.1 Cost

Cost is calculated by multiplying dose rates of herbicides and adjuvants with a unit cost of different products. Total cost is calculated by summary.

5.4.2 Expected efficacy

By use of an approximate calculation routine, the expected efficacies from single herbicides or ADM-mixes of herbicides are calculated for different combinations of weed species, weed growth stages, temperatures/Rh and water stress.

5.4.3 Treatment Frequency Index

The Treatment Frequency Index (TFI) is calculated by summarizing actual dose rates proportional to TFI reference doses that define TFI=1,0 for different herbicides.

5.4.4 Ipest Index

The Ipest index expresses risk of leaching and run-off (Bockstaller et al.). All possible chemical control measures are classified and stored in a database with the following detail information:

- soil texture
- soil depth
- soil slope
- crop growth stage
- herbicide and dose interval
- values of Ipest environmental impact index (currently 9 levels) which corresponding to the nine theoretical combinations of:
    - risk for leaching, range 0-1.
      Currently, 3 classes is used: low (0) medium (0.5), high (1,0)
    - risk for herbicide run-off, range 0-1.
      Currently, 3 classes is used: low (0) medium (0.5), high (1,0)

The user will submit information on: soil texture, soil depth, soil slope. Previous steps in the IPM-DSS will submit information selected herbicides and actual growth stages
For a combination of herbicides, the Ipest index is calculated by this equation:

$$Ipest_{combination} = 1 - \prod_{i=1}^{k} (1 - Ipest_i)$$

where k is the number of herbicides, $Ipest_i$ is the value of the i[st] operation.

For a given combination of herbicide and dose, the Ipest value is calculated for the given field by interpolating in between the Ipest values stored for the 4 closest combinations of risks of leaching and run-off (mean of the 4 values weighted by the risk distance).

5.4.5 Expected economic net return

Knowing the infestation (type of weeds, stage and density), the program estimates the yield loss (Y_L) due to the competition of the weeds using the "Density equivalent" method (Berti and Zanin, 1994). The system is based on the estimation of the competitive effect of a mixed weed population. This estimation is performed through the transformation of the density of each weed species into "Density equivalent" (Deq), defined as the density of a reference species which determines a yield loss equal to that caused by the weed being examined at the density observed. The relationship between infestation density and crop yield loss is described with the widely used rectangular hyperbola (Cousens, 1985). This curve is defined by the two parameters *i* and *a*, which represent the initial slope of the curve and the asymptotic yield loss at high weed density, respectively.

Prediction of yield loss

A hypothetical species, characterized by parameters *i* and *a* both equal to 100 was adopted as reference. The yield loss of the crop in competition with the reference species can then be expressed as:

$$Y_L\% = \frac{100 \cdot D}{1 + D}$$

For species j which has the parameters i_j and a_j, the Deq_j is then:

$$\frac{100 \cdot Deqj}{1 + Deqj} = \frac{i_j D_j}{1 + \frac{i_j D_j}{a_j}}$$

and therefore:

$$Deqj = \frac{i_j D_j}{100 + i_j D_j \left(\frac{100}{a_j} - 1 \right)}$$

The Deq_j values can be summed to obtain a total density equivalent (Deq_t) and the total competitive effect of the mixed infestation can then be given by:

$$Y_L = \frac{100 \cdot Deqt}{1 + Deqt}$$

The calculated effect in percent of a herbicide application is assumed to reduce the weed density at a similar level.

Prediction of expected economic net return

Each weed control treatment is characterised by a cost (C), which includes the cost of the herbicide (Ch), distribution (Cd) and an added cost for herbicides in class one: the Italian trade-union regulations impose a half day of rest for each half day of work with highly toxic compounds (I toxicological class). For the farm this translates into an added cost (Cr):

$$C = Ch + Cd + Cr$$

The total cost of the treatment (Ct) is given by the following equation:

$$Ct = C + Vl_i$$

where Vl_i is the value of the loss caused by the weeds surviving the treatment "i" ($Vl_i = Y_{Li}\ P$)

The monetary loss caused by the weeds in the absence of control (Vl_O) is:

$$Vl_O = Y_{wf}\, Y_{Lo}\, P$$

where P is the grain price and Y_{wf} is the yield of a weed-free crop.

The net economic return (net margin) for the treatment "i" (Nm_i) is therefore:

$$Nm_i = Vl_O - Ct_i$$

The treatments can be ranked on the basis of their Nm_i.

Principles of parameterisation

The crop x weed competition model of single weed species include estimates of 2 parameters, *i* and *a* . *I* express the relative yield loss in a weed density of 1 weed per m^2, and *a* express the maximum relative yield loss of infinite high weed densities. Estimates may be obtained from local studies and/or from literature.

Each combination of herbicide treatment x weed species x weed growth stage is characterised by a specific efficacy of control (expressed as percentage of control). Estimates are obtained from experiments and from literature.

Input from end-users

- crop name
- expected weed free yield
- grain price
- cost of herbicides
- names on weed species
- density of weed species (presently integers, in future: classes)
- weed growth stage (2 classes)

5.4.6 Multi-criteria analyses

The multi-criteria analysis includes 4 criteria:

1. Expected overall efficiency
   (weighted mean of the efficiencies on each weed species, weights are the WPTs)
2. TFI
3. Ipest
4. Expected economic net return

The method used for the multi-criteria analysis is an interactive method based on the Tchebychev criterion (Gabrel & Vanderpooten, 2002). It is interactive because it is basically based on the distance, in the multi-dimensional space of the 5 criteria, between each possible strategy and an ‘expected ideal solution’ defined by the user. Actually, the user defines two components of this theoretical ideal solution, namely the expected cost and the expected environmental impact (i.e. expected value). The other features of the ideal solution are fixed in the system.

Once the ideal theoretical solution is defined, the Tchebychev distance to this ideal is calculated for each possible strategy by:

$$D_z = Max_{\;j=1,\dots,5} \left\{ \frac{1}{z*_j - z_{*j}} (z°_j - z_j) \right\}$$

where

Z_j is the value of the considered potential strategy z for the criteria j
$Z°_j$ is the value of the ideal strategy for the criteria j
$Z*_j$ is the maximum value for the criteria j across all strategies (zenith)
Z_{*j} is the minimum value for the criteria j across all strategies

The term $\frac{1}{z*_j - z_{*j}}$ makes it possible to normalise all the 4 criteria as a function of the range of values covered from the best to the worst across all potential strategies, including the theoretical optimal one.

The 'best' strategy is the one with the lowest D_z across all potential strategies (i.e. the one with the worst criteria being not so bad). The system ranks the potential strategies in ascending order according to D_z and displays the 20 or 50 'best' ones, according to the preferences of the user. When the efficiency for weed control of the best solution is too low, the user is asked to modify the values of the 'expected ideal solution' either by increasing the expected cost or by accepting an increase in the *Ipest index* , and run again the system.

The 'no action' strategy has an *Ipest* index = 0 and Cost = 0 Euro, but the efficacy against a given species is not nil as the efficacy takes the value of the variable 'crop suppression', a component of the WPT-long term, which results from an aggregation of the crop suppressive ability, the difference in crop/weed growth stage and the crop vigour. Therefore the 'no action' strategy might be the 'best' solution ranking number 1 if (i) the overall WPT is low, (ii) the other possible strategies are either very costly, with a very high environmental impact and/or a weak efficiency, and/or (iii) the crop suppression effect on the weeds present is high. The chance for the 'no action' strategy to rank number 1 is of course increased when the theoretical ideal solution is defined with a low cost and a low environmental impact.

Definition of the target desirable value for each criteria Z°

Criteria	target desirable value
Overall efficiency	=f(overall WPT of the community)
TFI	0
Ipest	0
Expected economic net return	Maximum values across all the alternative options

$$WPT_{overall.community} = 1 - \prod_{n.species} (1 - WPT_i)$$

Principles of parameterization

The running of the DECID'Herb system leads to a search in a database with many components, some of which requiring parameterisation as a function of the region of use:

- Periods of possible emergence for each weed species (mainly based on expert knowledge)
- Crop and weed phenology for each cohort according to the period of emergence (mainly based on expert knowledge)
- Crop suppressive ability against each weed species (mainly based on expert knowledge)
- Weed potential harmfulness for each crop/weed combination (mainly based on expert knowledge)

Other components of the database required might be less 'region-dependant' at least in a first step:

- expected efficacy for combinations of: herbicide x dose x weed species x weed growth stages
- weed potential seed production (qualitative ranking)
- depth of potential germination-emergence (qualitative ranking)
- weed cycle length (short vs long)
- seed bank persistence

6 Non-chemical control

As for the chemical control measures also non-chemical control measures, rather simple or more advanced routines may be used. At this initial stage of development of non-chemical control measures and accompanying strategies, however, only relatively simple technologies and only relatively simple decision algorithms will be considered.

Simple algorithms to recommend non-chemical control measures may be constructed as a hierarchic set of questions that can all be answered with a clear 'yes' or 'no'.

All combinations of questions and answers shall lead to some recommendation, for example: 'No need for control', 'Use harrowing' (specification of details).

Recommendations will be presented as combinations of text and illustrative graphics, pictures and video clips.

7 IT system architecture

A IT system architecture for the IPM-DSS may be designed as a generic frame, where all agronomic definitions, all estimates of parameters, all details of user interfaces including different languages, may be customized for conditions on a regional level.

In context of the ENDURE network, functional integrity will be demonstrated in simple diagrams, spreadsheets etc., and the functional integrity will be validated.

Based on this present document, however, processes to design and construct operational DSS may be initiated by different organisations in different countries, and additional customization to suit specific local requirements, may of course be considered, too.

In future activities, a generic IT system architecture, which reflect the content of this document, may be constructed. An immediate recommendation is to use high-level programming for applications, which may be consulted on-line. Opportunities for customization may conveniently be enabled by editing integrated databases.

The system architecture will be based on modules, so that the system will be easy to improve by adding new specificities. Since the beginning of the IPM-DSS development, different successive versions of the DSS will be planned, with the idea of developing first a simple version able to demonstrate the potential for assembling the best ‘building blocks’ of existing DSSs, and then improving it by introducing refinements to account for the whole complexity of decision making in weed management.

- The first simple version, purely 'tactical', will integrate’:
    - the WPT model to define target efficacies (minimum required)
    - dose/response functions and the ADM model to select a list of candidate options
    - a multi-criteria analysis to rank these tactical options

- The second version will introduce also 'strategic' aspects, thus including weed management programs accounting for the timing of weed control operations, which integrate:
    - a phenological model to predict weed growth stage at every crop growth stage
    - the WPT model to define target efficacies (desirable)
    - dose-response functions and the ADM model to assess efficacies of a large list of candidate 'treatments' (different herbicides, different doses, different stages, different mixtures), the list of candidates including also mechanical weeding 'treatments' and the 'do nothing' option
    - the generation of strategies (=programs) by combining all the individual candidates treatments, and estimating their efficacies, costs, IFT, Ipest, economic net return, and finally (v) ranking these strategies based on multi-criteria analysis

- The third refined version will also include more explicitly the cropping system context for defining target efficacies (for example by using a WPT-long term close to what is currently used in DECID'Herb)

8 Suggestions for organisation of work

As explained in previous sections, different tasks relating to the IPM-DSS may conveniently be executed on different levels and by different organisational units.

Some core structures originating from 'best parts' of existing DSS may conveniently be designed on a central level, e.g. core structuring of 'fuzzy logic', as originating from DSS 'DecidHerb' or calculation routines for optimization of herbicide tank-mixes, as originating from DSS 'CPOWeeds'.

Decisions relating to specific customization for specific combinations of region, crop, weed species, control measures, etc. will, however, require a detailed understanding of regional aspects of these components, why some regionally based organisations must take this responsibility.

Finally, tactical decisions on farm- and field levels must primarily be taken by farmers, as consultants are too few in number to overcome this task.

Tasks required to design and use of the IPM-DSS may be allocated like this:

- *European body*
  - structuring of 'building blocks'
  - construction of operational frame
  - collaboration with international research to identify new potent ideas
  - collaboration with regional bodies to prioritize development strategy
- *Regional bodies*
  - *s*election and customization (parameterization) of 'building blocks' for specific combinations of crop x region.
  - validation tests
  - close relations to applied regional research
  - close collaboration with other regional bodies:
    - exchange experiences from designing and testing DSS for different crops
    - exchange experimental data to support estimation of specific parameters
  - feed-back to European body
- *End-users*
  - supply farm- and field-specific information to IPM-DSS
  - feedback to regional bodies

9 Suggestions for adjustment of EC-regulation

Specific elements in Directive 2009/128/EC (the 'IPM-directive') and specific elements in indentified best parts of DSS for weed management have implications, which may benefit from specific changes in regulation on a European level.

Agrochemical companies that apply for registration of a new pesticide will submit comprehensive data, which document characteristics as required by the registering authority, e.g. toxicological, eco-toxicological and other characteristics of a pesticide. Data that document suitable tolerance of crops and suitable efficacy on pests must also be submitted.

Considering data on efficacy, documentation must basically be submitted for dose rates, which the pesticides are applied for. However, data must also be submitted to document the so-called ‘minimum effective dose’. Such data will also include results from test of dose-rates, which are lower than the registered dose rates.

In case of herbicides, however, which are often registered for a spectrum of weed species, data on reduced dose rates to document the ‘minimum effective dose’ must be submitted only for a few weeds.

According to present regulation, data submitted for registration of pesticides, is the property of the companies that submit applications, and by routine, applying companies require strict confidentiality on such data. From common, commercial point, companies that register and sell pesticides, have little interest in spreading data that document sufficient efficacy of dose-rates, which are much lower that the registered dose-rates. Consequently, in most European countries, little information is available to those who decide on pesticide applications on the efficacy of reduced pesticide dose rates.

In conclusion, the present regulation that enable agrochemical companies to keep confidentiality on data that document the efficacy of dose rates below registered doses rates, does not support the intentions in Directive 2009/128/EC in terms of using pesticides targeted for the purpose (in terms of dose rates), and in reduced doses, wherever possible.

Considering the identified ‘best parts’ of DSS, the component that integrate dose-response functions for specific combinations of herbicides and weeds, has a particular potential for recommending reduced dose rates of herbicides, while maintaining agronomic requirements for control. According to parameterisation of this dose-response function in 6 North-European countries, some weed species may be controlled to agronomically satisfactory levels by down to 5-10% of a registered herbicide dose rate. To parameterize this dose-response function, data from tests of systematically reduced dose rates are required.

Public funding is generally not available for systematic tests of the efficacy of pesticides in reduced doses, and farmers’ organisations across Europe have so far showed little interest in supporting such activities.

In conclusion, to support intensions in Directive 2009/128/EC and to support opportunities for design potent and robust DSS, which underpin the same intensions, the following recommendations regarding future regulation of pesticides are provided:

- future requirements for data, which are submitted for registration of pesticides, and which document efficacy of pesticides, must by routine contain results from systematically reduced doses. For pests that shall be listed on product labels, the efficacy of at least 1/1, 1/2, and 1/4 of the dose, which is applied for registration shall be documented

- efficacy data, which are submitted for registration of pesticides, shall be available to the public

Discussion

In the context of achieving a more targeted use of pesticides, where opportunities for reducing dose rates are also exploited, only the data that document efficacy against different weeds, pests and diseases, are actually required. As pesticides are subjects of much public concern in general, it is assumed that all information of inherent attributes of pesticides will be interesting to the public. Such changes in regulation may not, however, be supported by representatives of the agrochemical industry.

From isolated commercial standpoints, such changes in regulation may probably reduce the commercial interest in supplying pesticides for some markets, for example in crops with ‘minor use’. This is, however, a general problem, which is already approached in different ways. In some countries, grower organisations organize ‘off-label registrations’, and produce data required by registration authorities accordingly. Such ‘off-label registrations’ do not have legal implications for the companies, who sell pesticides for such uses.

Fear for development of pesticide resistance
In resent years, an increasing number of incidents have been reported, where specific weeds, pests and diseases species, which were formerly sufficiently susceptible to registered dose rates of specific pesticides, have become resistant to levels, where the pesticide can no longer be recommended for control. Resistant biotypes are a serious concern, as such biotypes will probably never regain the original level of susceptibility, and ‘resistance management’ is therefore an important and increasing challenge around the globe.

Suppliers of pesticides often argue that the use dose rates of pesticides, which are lower than registered dose rates, will probably promote development of resistance. Of course, a general reduction of the dose rate of a pesticide will inevitably reduce the efficacy. As little documentation is available to support counterarguments, these suppliers have had much support among farmers and advisors to general warnings against use of reduced dose rates of pesticides.

Authorities that register new pesticides will generally require that pests that shall be listed on product labels must be controlled at some minimum level of efficacy, for example 75-85%. Control strategies, which may be recommendable to sanity specific species or specific biotypes, may however require levels of efficacy, which are higher, that generally required for registration. Consequently, a registered dose rate of a herbicide may provide massive ‘overkill’ of very susceptible weed species, while the same dose rate may be insufficient against biotypes that needs special consideration to prevent or to sanity development of resistance. Consequently, the ‘full-dose strategy’, which is generally recommended by suppliers of pesticides is a rather weak strategy to prevent and to sanity herbicide resistance.

According to actual Danish parameterisation of the dose-response function presented in section 6.3, the weed species Stellaria media and Myosotis arvensis, can be controlled by 95% (which is a relatively high level suitable even for drastic sanity strategies), by application of 40% and 70% of the registered dose of the herbicide ‘Express ST’, (500 g/kg tribenuron-methyl, registered dose rate is 2,0 tablets/ha). This example illustrates that efficacy levels suitable for an anti-resistance strategies may be achieved by dose-rates much lower than the registered dose rate.

In conclusion, future strategies to prevent or to sanity problems with weed resistance may conveniently be initiated with identification on target efficacy levels, which are suitable to control different species and biotypes of weeds. Subsequently, different combinations of herbicides and dose rates may be selected to meet specific requirements for efficacy. Such a change of strategy requires, however, that data on the efficacy of different herbicides in different dose rates against different species and biotypes of weeds are available, to those who construct DSS for such purposes and to those who make decisions by other means on herbicide applications.