# 60 Decision support systems in integrated nematode management: The need for a holistic approach

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Farmers' decisions regarding the best approach to take in managing a nematode problem are often made just before the planting season begins and then at different stages in crop growth (Sikora and Roberts, 2018). This decision is usually determined by a combination of past experience, anticipated market prices and recommendations from both public and private extension services. In many cases an integrated nematode management (INM) system with multiple components is not considered due to lack of knowledge of the severity of the nematode problem, or the absence of an acceptable management tool such as a suitable resistant or tolerant cultivar, an appropriate non-host rotation crop or a suitable biocide for the situation.

Seldom, if ever, are data on nematode population densities and distribution patterns across a field taken into consideration in the decision-making process. This haphazard approach to INM is comparable to what could be called a 'take a chance' or 'shot in the dark' tactic which often results from the absence of effective decision support tools (DST) or decision support systems (DSS).

The development of INM strategies is knowledge intensive, bringing together host status, crop sensitivity, damage thresholds, nematode density and distribution, with known effectiveness of individual management measures. The vast majority of DSS were developed in countries with modern agricultural structures by scientists working at universities, extension services or agricultural base companies. In some cases, government agencies have played a major role in developing or suggesting management programmes where invasive pests are concerned.

In this chapter, we attempt to present presently available information on different forms of DST and DSS and discuss developments that are required to streamline and improve INM. Obviously, we will not be able to discuss all DST and DSS that have been developed over time, therefore, this chapter is not all inclusive.

## Governmental databases

Databases for quarantine nematodes have been developed in many countries. For example, that of the European Plant Protection Organization (https://gd.eppo.int/, accessed 20 October 2020) as well as by other national plant protection organizations around the world. These DST are aimed at preventing the introduction and spread of important nematode quarantine pests both between and within countries. They are

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also designed in some cases to limit nematode spread on export/import planting material. Their focus is clearly on diagnosis and regulation.

## Knowledge databases of universities and extension services

These databases are basically knowledge banks containing quality information on nematodes and INM approaches. They are open-access links that can be used to find and select management options across a wide range of nematode/crop interactions. There are a large number of websites and databases developed by universities and extension services around the world. This is especially true for the US where most university extension services have a website that covers nematodes and their management in their state (Table 60.1). These websites can be accessed not only locally, but also by growers on a global scale for information on nematode diagnostics, symptomology and methods of INM. These sites vary in size and detail depending on the importance of nematodes to agriculture in the region as well as by the number of extension specialists available to focus on nematode issues at that location. They are in most cases updated regularly by experts of the organizations involved and are therefore important as a first-line DST in obtaining information on INM. Due to the number of websites available we have limited the list to a few examples that cover a broad array of crops and nematode problems (Table 60.1).

We want to highlight the DST Nemaplex site (http://nemaplex.ucdavis.edu/Uppermnus/topmnu.htm, accessed 15 October 2020) of UC Davis University in the USA which offers an extensive amount of information to students, farmers, advisers and applied nematologists. The topics range from teaching nematology to supplying nematode management options.

Two well-developed commercial knowledge banks with extensive and up-to-date information on the most important plant parasitic nematodes on a global scale are marketed by CAB International in the UK:

- CABI Crop Protection Compendium (https://www.cabi.org/cpc, accessed 10 November 2020; and
- CABI Plantwise knowledge bank (https://www.plantwise.org/knowledgebank/, accessed 10 November 2020).

## Decision support tools

Decision support tools are important building blocks in support systems used for INM. They generate information on specific abiotic factors that influence nematode behaviour in the field and can be utilized to improve INM.

### Soil sensors

One of the most important DST available to nematologists are temperature and moisture monitors. They have been used in different forms for many years to measure abiotic effects on crop growth and nematode and disease behaviour. They are now more accurate and convenient for use in research and for INM. These monitors supply the user with automatic real-time monitoring of temperature and moisture levels in the soil that influence nematode population development over short and long periods of time. They generate data that can be used in the development of INM programmes designed to time the use of treatment options such as: post-plant nematicide treatments, application of biocontrol agents in standing crops, estimating population development, as well as for timely destruction of trap crops before egg laying begins. These types of monitors, coupled with advanced models for nematode population development over cropping sequences, could be used to improve INM in many crops.

Two of these monitors are discussed below.

#### *Nematool*

This DST was developed by BayerCropScience (https://nematool.com, accessed 12 November 2020) in close collaboration with nematologists in Spain to determine the progression of root-knot nematode development in the field under a host crop, and thereby determine the optimum time for application of the biopesticide Bioact in an established crop. The system collects temperature data in the field and sends information

**Table 60.1.** A partial listing of websites available from universities, extension services and government agencies offering integrated nematode management information on a wide array of nematodes and crops worldwide.

| Institution | Website[a] | Information coverage |
|---|---|---|
| Sociedade Brasileira de Nematologia/Brazilian Society of Nematology | https://nematologia.com.br/ (in Portuguese) | General nematology, diagnostics and management of nematodes on amongst others: soybean, cotton, maize, potato, rice, wheat, sugarcane, coffee, vegetables and fruit crops |
| NemaDecide, Wageningen University | http://www.nemadecide.com/ | Gives real-time results of soil sampling for specific nematodes on potato along with GPS coordinates to aid in site specific management. Mainly potato cyst nematodes but also lesion and root-knot |
| University of Florida Cooperative extension | https://sfyl.ifas.ufl.edu/search-result/?q=nematodes | Covers all major fruits, vegetables and field crops grown in Florida. Gives pertinent information on nematodes, symptoms, control tools and management recommendations. Updated regularly by Florida nematologists |
| University of Florida Entomology and Nematology Department | https://edis.ifas.ufl.edu/department_entomology_and_nematology | Provides in-depth profiles of insects, nematodes, arachnids and other organisms and integrated management tools |
| Nemaplex, University of California Davis | http://nemaplex.ucdavis.edu/Uppermnus/topmnu.htm# | Extensive information on diagnostics, management, methods, ecology, including spreadsheet tools for INM and making economic threshold decisions |
| University of California Agricultural & Natural Resources - IPM | https://www2.ipm.ucanr.edu/agriculture/ | Pest management information on 44 crops or groups of crops including nematodes. Chapters updated every 3–5 years by faculty members |
| Australia Department of Primary Industries and Regions | https://pir.sa.gov.au/search?collection=PIRSA-web&query=nematodes | Used in Western and South Australia to determine the presence and levels of *Pratylenchus thornei, P. neglectus, P. penetrans* and *P. quasitereoides* |
| UK, Agriculture and Horticulture Development Board | https://ahdb.org.uk/(A('xTcrINcvSX))/Search?q=nematodes | Covers management of a number of nematode problems including migratory, cyst and leaf nematodes on a number of crops in the UK |
| Indian Agricultural Research Institute Nematology ICAR | https://iari.res.in/index.php?option=com_content&view=article&id=72&Itemid=161 | All India coordinated research project on plant parasitic nematodes with integrated approach for their control |
| Louisiana State University Cooperative Extension | https://www.lsuagcenter.com/portals/our_offices/departments/plant-pathology-crop-physiology/nematode-advisory-service | Coverage of nematodes on cotton, turf, vegetables, soybean and others |
| University of Georgia | https://plantpath.caes.uga.edu/search.html?q=nematodes&cx=008984291200700708817%3Abqxfpp1iz4w&searchScope=siteOnly | Disease clinic provides diagnostic analysis or pests and diseases including nematodes and recommends appropriate management strategies |

*Continued*

**Table 60.1.** Continued.

| Institution | Website[a] | Information coverage |
|---|---|---|
| Lucid, Australia | https://keys.lucidcentral.org/keys/v3/crop_rotation_plant_parasitic_nematodes/ | Crop to be used in rotations and their resistance to plant parasitic nematodes |
| Best4Soil | https://www.best4soil.eu/ | A network of practitioners, for sharing knowledge on prevention and reduction of soil-borne diseases in 22 European languages. Offers a tool to develop unique crop rotation sequences to take into account nematodes and soil-borne diseases |

[a]Websites accessed 1–15 November 2020.

on degree days, along with information on application timing directly to the grower's computer or smart phone in real time.

### *LoRa Soil sensor*

The practical application of this sensor was co-developed by Valenco and Syngenta. It gathers information on both soil moisture and temperature. It generates data that can be used to correctly estimate the stage of nematode development using degree days. Wireless data transmission also allows real-time availability of information (Fig. 60.1).

## Remote sensing

Remote sensing is a rapidly developing DST for nematode detection, visualizing field clustering and estimating crop damage (see Chapter 59 in this volume). The Normalized Difference Vegetation Index (NDVI) is one of the most widely used indices in remote sensing for vegetation observations. NDVI can reveal where vegetation is thriving and where it is under stress, for example due to pest and disease damage (Oerke *et al.*, 2010). Remote sensing with NDVI can be used to estimate relative yield and supply an end of season plant assessment, as well as nematode distribution in the field during the cropping season. For example, remote sensing has been used to correlate sugar beet damage with *Heterodera schachtii* pre-plant densities (Hillnhütter *et al.*, 2011). It has also been used to measure tolerance to *H. schachtii* (Joalland *et al.*, 2018). Noling and Cody (2014) and Noling *et al.* (2015) used quantitative descriptions of canopy dimension to select integrated nematode management practices, describe yield impacts as well as treatment performance on horticultural crops on an industry-wide basis (see Chapter 26 in this volume). Hyperspectral sensors using NDVI can be

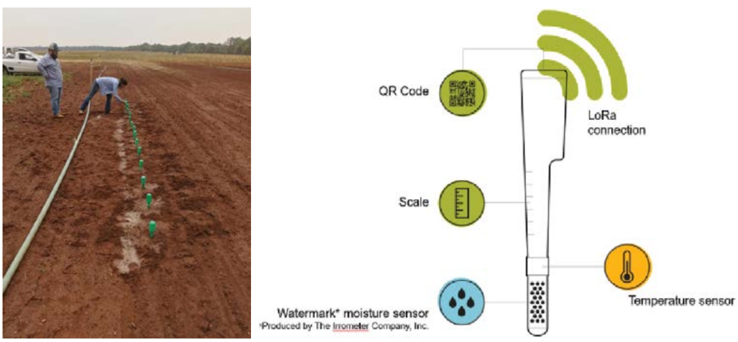



**Fig. 60.1.** Soil sensors (Valenco GmbH, Switzerland) for monitoring temperature and moisture relationships on nematode population development in microplots. Figure courtesy of M. Goll, Syngenta, Switzerland.


**Fig. 60.2.** AISA hyperspectral false colour infrared picture at GS 31 and digital map of *Heterodera schachtii* damage clustering. **(A)** Infrared photograph; **(B)** digitalized computer map with colours correlated with final nematode (*Pf*) densities (Hillnhütter *et al.*, 2011). Author's own figure.

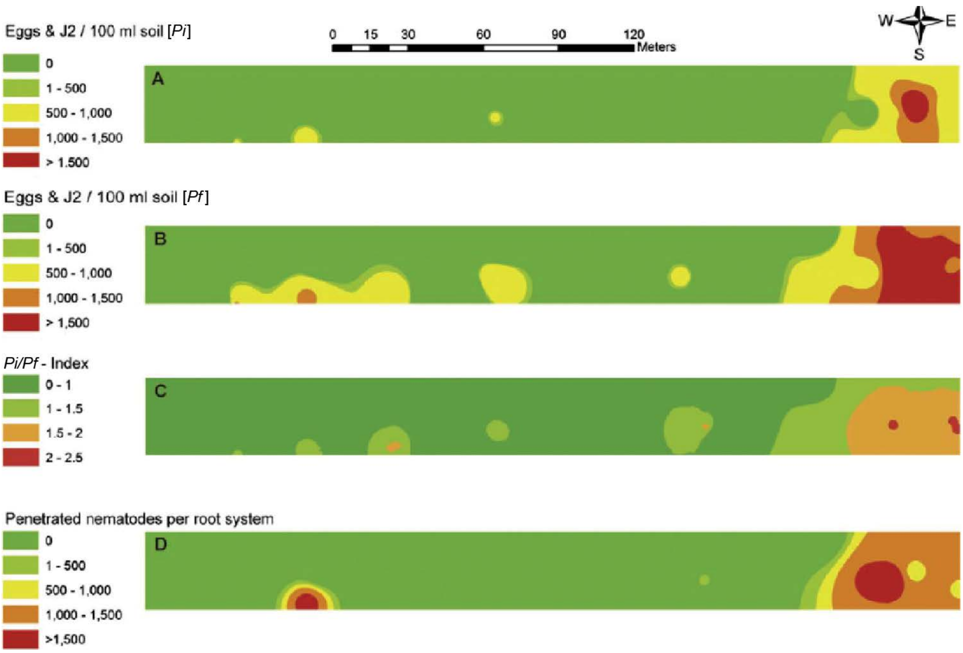



**Fig. 60.3.** Spectral angle mapper classification of *Heterodera schachtii Pi* and *Pf*, the *Pf*/*Pi* index and nematode penetration/root generated from the AISA infrared picture in Fig. 60.2. Author's own figure.

used to detect clustered distribution by measuring nematode-induced changes in crop canopy chlorophyll reflection (Fig. 60.2), which can then be related to ground truth data in specific clustered areas in a field (Fig. 60.3).

Correlating NDVI remote sensing with soil temperature sensor data can be used to predict nematode population dynamics over time in crop rotations in different parts of a field. This information can then be used to develop computer models for decision making at the farm level (see Nemaplot below). Once this relationship is established INM can be optimized for various nematode–crop interactions.

## Predictive models

Predictive models could have a major impact on INM in the future. They will become important as climate volatility impacts INM decision making and alters nematode population dynamics from year to year, making decision making complex. Nemaplot is an example of a predictive model developed to predict yearly oscillations in *H. schachtii* population densities in rotations of varying lengths and crops (Schmidt *et al.*, 1993). Figure 60.4 shows how a population fluctuates over a 3-year period as influenced by crop cycle, ambient temperature and intercropping management. Decreases from initial pre-plant densities as influenced by non-host crops and the natural antagonistic potential is extrapolated from the literature and research data. Using the initial population density determined by sampling before sugar beet and this natural decline data, the *Pi* before the next sugar beet crop can be estimated by the model and used to support grower selection of management options. In Sweden, SBN-Watch offers comparable functionalities to control sugar beet nematodes (Omer *et al.*, 2019). This type of model could be expanded to other plant parasitic nematodes to improve INM decision making where ground truth data and past research data has been or will be generated in the future.

## Decision support systems

Advanced DSS are designed to aid growers in making real-time decisions on how to manage farms and in some cases nematode problems. These programs combine information on many different aspects of farm management.

There are many DSS available developed by industry and government agencies for agronomic aspects of farm management. However, none of these DSS have components that focus on INM. The systems discussed below have been developed for use in the EU and could be used to develop similar programs for other plant parasitic nematodes in appropriate cropping systems wordwide.

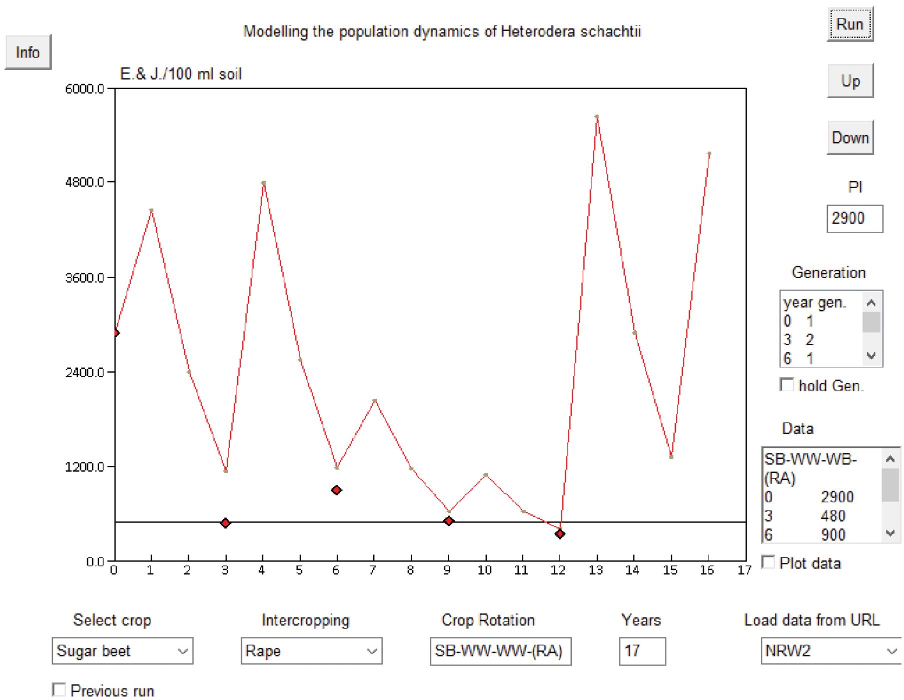



**Fig. 60.4.** Graphic representation of the population fluctuation of *Heterodera schachtii* in a 3- year rotation with intercropping in Germany as calculated by the Nemaplot program compared to long-time observations (red dots). Figure courtesy of K. Schmidt, Bonn, Germany.

## Akkerweb/FarmMaps

This is an open-access DSS providing information required for smart farming application, including weather data services, satellite crop images, soil maps, crop polygons and more (Van Evert *et al.*, 2018). The program also provides visualization tools, a DSS digital store, task map generator and an array of models. Examples include models for calculating water availability (Watbal model), potato crop growth (Tipstar model), late blight infection (Blight module) and nematode management (NemaDecide) for individual fields or within a field. Other models are available for variable-rate application of herbicides, fungicides, nitrogen top-dress application in potato and potato haulm killing. Akkerweb has over 30 apps. FarmMaps, released in 2021, is the new version of Akkerweb and has a new data repository and management system as well as a more intuitive dashboard design (Fig. 60.5).

## NemaDecide

NemaDecide is a DSS for the management of plant parasitic nematodes (Been *et al.*, 2005). It was developed for INM of nematodes in potato (*Globodera* spp., *Pratylenchus penetrans* and *Meloidogyne chitwoodi*). Models for population dynamics, yield reduction, partial resistance, soil sampling, chemical control, etc. are included in the system. It combines several data sources and models to enable strategic and operational decisions at the farm and field level. The quantitative information system provides growers with the possibility of estimating risks of yield loss, population development, probability of detection of foci by soil sampling, calculation of cost/benefit of control measures, as well as providing advice for farmers to optimize financial returns. Farmers can also compare cropping scenarios and ask ‘what if’ questions (Fig. 60.6).

This DSS offers the opportunity to compare different INM designs and can be used for general agricultural practices and certification schemes, as well as for educational purposes. Gaps in knowledge related to INM recommendations are pinpointed in cooperation with the agricultural sector, user groups and extension services. Thus, the most problematic questions receive priority in research programmes, which are now better focused on practical problems.

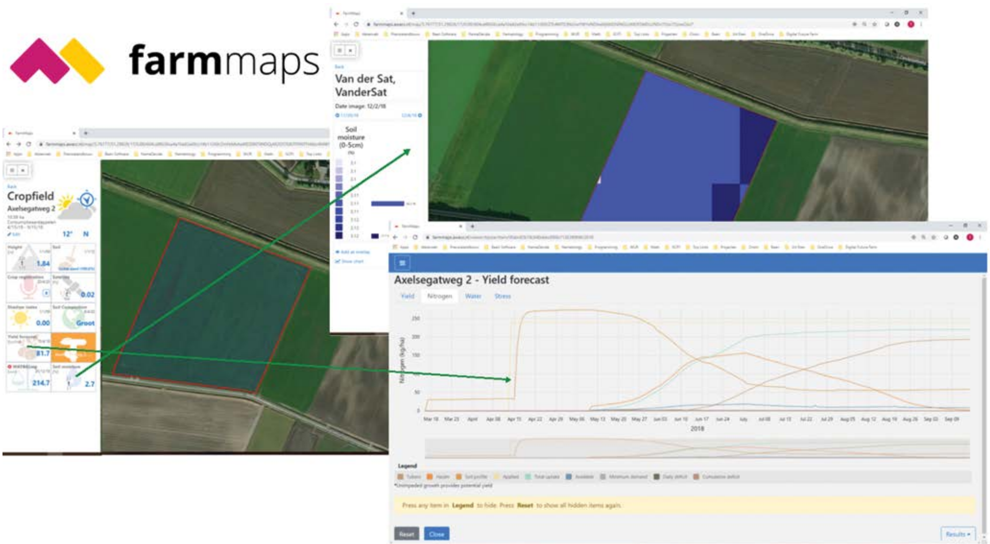
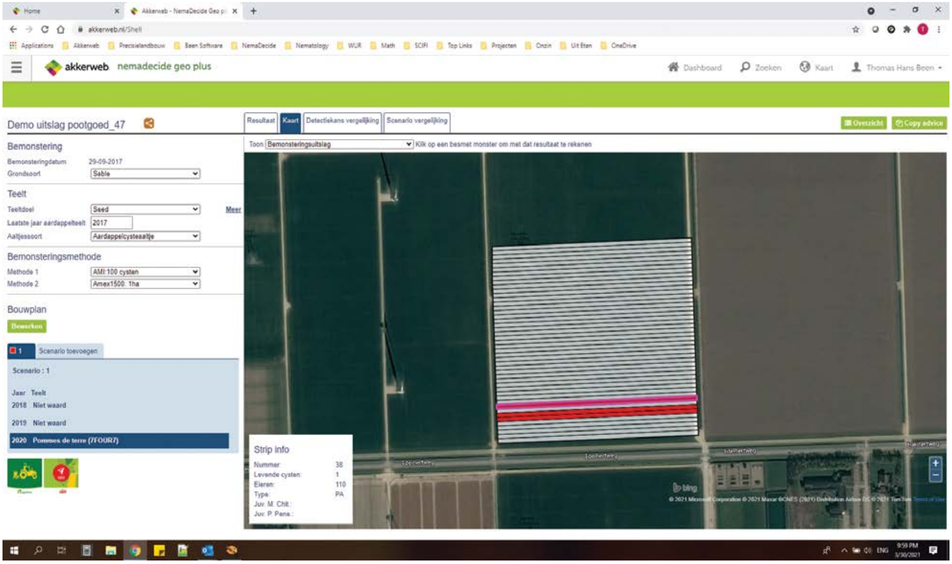



**Fig. 60.5.** An impression of the dashboard of FarmMaps. All information of a field can be reached via the widgets. In this figure soil moisture and the yield forecast of potato are highlighted. Figure courtesy of Wageningen University & Research, Field Crops.

(A)




(B)

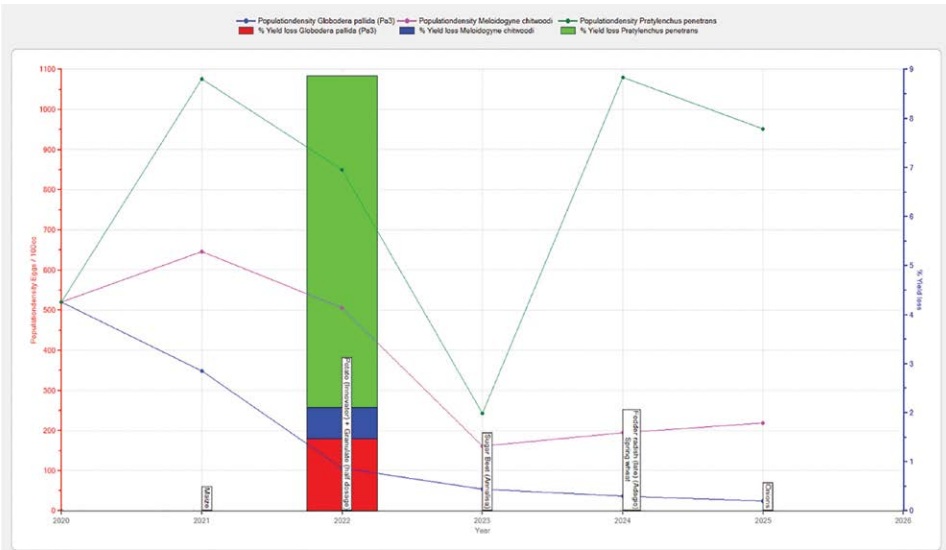



**Fig. 60.6. (A)** Screenshot of NEMADECIDE GEO application on Akkerweb, with on the right a map of the field with the sampled strips and the red strips in which a nematode infestation has been detected. The data from the infested sample strips (red) can be uploaded via the nematicide button and the comparison of scenarios can start. **(B)** The lines show the population dynamics of *Globodera pallida, Pratylenchus penetrans and Meloidogyne chitwoodi.* The bar expresses the percentage yield loss in potato (innovator + granular nematicide half dosage) caused by each species. Figure courtesy of Wageningen University & Research, Field Crops.

### Best4Soil

This is a European network DSS developed in co-operation with practitioners for sharing knowledge on prevention and reduction of nematodes and soil-borne diseases. The program provides an INM system by developing what we term 'clever crop rotations' (www.best4soil.eu/database, accessed 15 February 2021). The approach and design is based on the Dutch program www.aaltjesschema.nl (accessed 15 February 2021) which has its origin in 1968

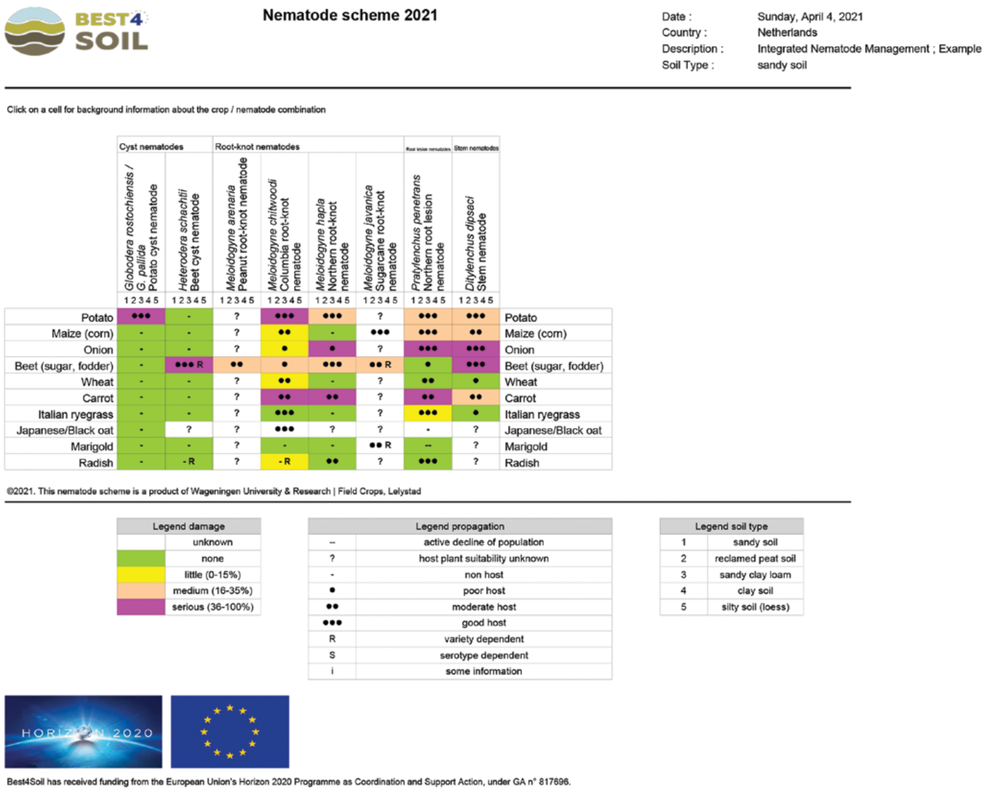



**Fig. 60.7.** Nematode scheme of the Best4Soil Decision Support System. The colours express the sensitivity for damage, the dots the host status of the crop. Figure courtesy of Wageningen University & Research, Field Crops.

(Hijink and Oostenbrink, 1968). An example of the nematode scheme is given in Fig. 60.7.

## Pros and cons

We contacted a large number of colleagues worldwide and were surprised at the low numbers of DDT and DSS available for use in INM. Decision support systems work as crystallization points of knowledge. Loose chunks of knowledge are brought together with local data from the growers so that the best INM measures can be followed over the short and long term. In this way, knowledge improves INM and impacts practical agriculture at the farm level. Conversely, it becomes clear where 'black holes' exist in our knowledge of nematode–crop interactions and how our research agenda should be prioritized.

The implementation of DSS demands a high standard of knowledge and education in farming, extension services and research. Many countries/regions cannot meet these requirements. For example, access to DSS requires Internet with sufficient bandwidth and availability at many levels of decision making. This high level of Internet availability is not yet standard in large parts of the world. A prerequisite for using DSS is a link to mobile phone technology. In many countries, telephone networks are often better developed than the Internet such as in Africa and India (Baumüller and Kah, 2020). DSS development for use on laptop computers needs to be adaptable to all digital information carriers and available worldwide.

When switching from chemical treatments to knowledge-driven and complex INM solutions, education and extension are the most important parts of transformation. Baseline information, data sharing and converting data into management tools is a big hurdle to success. As in many areas of science, big data without proper tools ends in a digital traffic jam. An important issue is how to create confidence in the data and tools. The potential of INM is based on data combined with knowledge and this requires ambition and action in the realm of DSS in nematology. A good starting point would be the development of an Internet platform of nematological tools.

There are limitations to all DSS in that they need to be adaptable to conditions as well as the customs and laws in the country targeted for use. This is often a difficult barrier in making them important nationally and globally. Limitations include:

- deficits in Internet coverage;
- grower suspicion of data collection;
- overcoming farmer independence;
- presence of quarantine nematodes;
- resolution of satellite images;
- major data protection problems; and
- need for ground truth verification.

## Outlook: a vision of the future

INM will advance in importance and become more knowledge intensive as crop production is influenced by: (i) global food security related to human population growth; (ii) environmental protection issues; (iii) public concern for safe food; and (iv) the ever-present impact of climate volatility on nematode damage. INM using DSS will evolve into highly efficient, tailor-made systems that ensure the production of healthy crops in a clean environment. Some of the expected future developments connected to the main pillars of INM (see Figure 1.1 in this volume) are discussed below.

### Prevention

Geo information systems will stack sampling data and historical information to prevent production of 'nematode-free' propagating material in nematode infested fields for both local and export markets. The tracking and tracing of seed and planting material back to the producer will need to be improved due to regulatory controls.

### Cultivar choice and crop rotation

Knowledge of the levels of cultivar resistance and/or tolerance and relation to yield loss will be available in databases that make the design of smart rotations possible.

### Targeted control

Both the use of nematicides and alternative control methods will be optimized and used when damage thresholds are exceeded. Remote sensing will allow treatment of clusters where infestations exceed thresholds.

### Monitoring and remote sensing

The use of multiple soil temperature/moisture sensors coupled with mathematical models will allow exact monitoring of nematode population development over time and allow prediction of *Pi* before the next susceptible crop. This information will be incorporated into DSS programs. The use of remote sensing and NDVI technology will enable exact determination of nematode distribution and coupled with precision mechanization, allows precise placement of chemical and biopesticides.

### Molecular soil biodiversity tracking

The development of deep sequencing will allow full scans of soil samples for nematodes and microbial antagonistic diversity and will expand the knowledge bank for use in DSS management programs.

### Holistic crop and field management systems

Last but not least, the future of INM lies with holistic approaches to field management. We believe this is where the great leap forward must be made.

Future crop and nematode management must include all the pillars of INM as well as the following: soil fertility, carbon sequestration, water quality, resilience to climatic volatility, biodiversity maintenance, as well as weed and soilborne pathogen management. The process of DSS development will probably begin with high-value horticultural and industrial crops and where IT is highly developed and accessible to farmers. Farmers and extension agents in the decennia will NOT indiscriminately ask themselves what type of management a field requires for sustainable production but will use advanced DSS for their decision-making process.

Building DSS at this level of integration will provide a platform where all disciplines meet and develop interdisciplinary approaches that give the best possible answers to healthy agricultural production based on the best knowledge available.

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