

# **A practical guide to decision-support tools for smallholder agriculture in sub-Saharan Africa**

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## **1. Introduction**

Africa's basic industry is agriculture, providing about 35% of GNP, 40% of exports and 70% of employment. Given its size, agriculture should be the engine of economic growth, however, living conditions are in reality desperately poor. About 240 million citizens live on less than US\$ 1 a day, most of them in rural areas in smallholder farming families. Population growth is about 3% per year, exceeding growth in food production.<sup>1</sup>

Smallholder farmers in sub-Saharan Africa are facing difficult times and production levels are often far below what would be potentially possible under improved circumstances. Farmers are, however, strongly dependent on, and constrained by, what is often one of their most important assets: the soil. As external inputs are hardly used (the average fertilizer use in Africa is about 8 kg ha<sup>-1</sup>, compared to for example about 110 kg ha<sup>-1</sup> in India), nutrients for plant growth have to come from the soil. However, soils are inherently poor in Africa. Combined with the often-unfavorable climate this means that pressure on land is intense, even at relatively low population densities.

Over the last decade, much has been said and written about the mining of Africa's soils, i.e. extracting nutrients from the soil without replacing them. However, although important, such general statements hide farmer reality, as the farmer has to manage his soils in a very complex environment. Factors that play a role in his soil fertility management do not only pertain to those directly related to soil fertility such as inherent soil characteristics, history of land use, spatial differences in soil fertility, application of inorganic and organic fertilizer, but also to weather, the presence of weeds, pests and diseases and crop management, and beyond that to socio-economic aspects such as in- and output prices and labor availability. Appropriate soil fertility management should therefore integrate these issues into a broader framework of integrated soil fertility management (ISFM)

Until now, expert knowledge is undoubtedly the most important basis for decision-making in smallholder agriculture in sub-Saharan Africa. However, a number of developments challenge the primacy of experiential knowledge for decision-making in agriculture:

- In a rapidly changing world effective solutions of the past may not work in the present situation
- Increasing mobility renders experiential knowledge, obtained in a particular environment, less useful in another environment
- A rapidly increasing body of scientific knowledge permits making pre-assessments of issues that are new, and hence about which little experiential knowledge exists.

These developments and the complexity of farmer reality call for tools that can help decision-makers, be they farmers, extension officers, researchers, policy makers or traders improving the quality of their decisions.

Such *decision-support tools (DSTs) for smallholder agriculture* can help with the diagnosis and analysis of problems and opportunities related to soil fertility and identify

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<sup>1</sup> <http://www.worldbank.org/afri/overview.htm>

options for improved and integrated soil fertility management. DSTs may also contribute to replacing the classic ‘transfer of technology’ approach by more participatory approaches for technology development. Although, the ‘transfer of technology’ approach used to be quite successful in the past for cash crops, especially when combined with credit and secure prices, it has met with much less success for subsistence crops, where prices are usually not secure and credit is often not made available. In addition, extension messages were usually developed for very large regions, not taking into account the variability within those regions, let alone within farms. Near the end of the 1970s, more attention was paid to the constraints of the farmers and the complexity of farmer reality. On-station research was replaced by on-farm research and farmers became partners instead of passive receptors of information. This development, albeit laudable, was also facing problems, as taking variability into account implied a need to drastically increase agricultural research activities: solutions that work in a particular situation may not work in another situation. Under such conditions the traditional prescriptive approach does not work, and needs to be replaced by an ability to analyze and understand the situation, and to find an appropriate solution for the problem. Such ability can be obtained through the use of DSTs. They can assist with the identification of options for alternative crop and soil management interventions and ex-ante impact evaluation studies. The use of DSTs can, therefore, greatly facilitate participatory development and dissemination of ISFM options.

Despite their potential, DSTs are not widely used in sub-Saharan Africa. In 1999, the Africa-Division of the International Center for Soil Fertility and Agricultural Development (IFDC-Africa) started working on a project to evaluate and promote a set of DSTs for soil fertility management in smallholder farming in sub-Saharan Africa. The project entitled ‘A Client-Oriented Systems Toolbox for Technology Transfer Related to Soil Fertility Improvement and Sustainable Agriculture in West Africa’ (COSTBOX) was financed by the Eco-regional Fund to Support Methodological Initiatives, and carried out in collaboration with a number of national agricultural research institutes and universities in the region. The project started with a survey to investigate reasons behind the limited use of DSTs in Africa. Results (Struif Bontkes et al., 2001) and from others (Matthews et al., 2002) indicated the following:

- DSTs often fail to capture sufficiently the complexity of smallholder agriculture of sub-Saharan Africa
- Some DSTs require many data, that are often not available or that are of poor quality
- Lack of knowledge to use DSTs has prevented wide-spread use
- Institutions promoting the use of DSTs in sub-Saharan Africa often emphasize the use of one particular tool. However, the complexity and diversity in smallholder agriculture calls for a more flexible, problem-oriented approach requiring a set of decision support tools from which one or a combination of tools can be selected that can successfully address the problem.

To promote the use of DSTs, the project organized a number of training courses and workshops at national research institutes and agricultural universities of Ghana, Benin, Togo, and Nigeria. Researchers applied the DSTs to problems and opportunities of interest to farmers in their country. The number of DSTs gradually expanded as some problems could not be tackled by one particular DST alone. Contacts were, therefore, established with other modeling groups that are developing and introducing DSTs in sub-Saharan Africa. The COSTBOX project showed that the problem is not the handling of the tool, but rather the whole process of problem identification, identification of the appropriate tool(s), data collection, applying the tool and drawing conclusions from the results pertaining to the solution of the problem. Gradually the idea emerged to develop this guide to DSTs for

smallholder farming in sub-Saharan Africa presenting a range of DSTs and illustrating their use through a range of case studies with special reference to ISFM.

The next chapter presents a number of DSTs that can be used within the context of a participatory technology development approach to ISFM: an iterative learning cycle from diagnosis/analysis of the production environment, to identification of ISFM options, experimentation and evaluation, and scaling-out of successful technologies. Data requirements and potential users are briefly discussed, with more details on the specificity of the tools in Appendix I. It should be noted that, although it is attempted to present a wide variety of DSTs, the list of tools discussed here is by no means exhaustive. The DSTs presented here are oriented towards improved understanding of biophysical processes and interactions between soil, climate and animal and plant production systems. They mainly deal with nutrient aspects of soil fertility, mostly ignoring physical and biological aspects of ISFM. These non-nutritional effects are especially important when using organic amendments, and in combination with inorganic fertilizer use, they may lead to important gains in fertilizer use efficiency. Such synergies are not yet captured sufficiently in the DSTs that are available to date, and this is an important gap in our understanding of the potential of ISFM options in sub-Saharan Africa.

Most DSTs presented in this guide can be used for simple financial and risk analyses of alternative ISFM strategies.

The case study chapters, which follow, demonstrate how these tools can be used in practice and will show that they can be used at various spatial (farm, village, region) and temporal scales (days, growing season, years). The concluding chapter reflects on the links between the different case studies and on how to promote the use of the tools. We sincerely hope that this book will lead to increased use of the tools and feedback to its developers and that it will contribute to accelerated and sustainable development of the agricultural sector in sub-Saharan Africa.

## **2. Decision Support Tools (DSTs) for smallholder agriculture**

Farmer decision-making ranges from practical day-to-day decision making, to decision-making that affects the productivity of the land for several growing seasons to a number of years. Examples of short-term, day-to-day decision making include ‘when to apply fertilizer and how much’, ‘when to weed’, ‘when to irrigate’ etc. Medium-term, season-to-season decision making may involve choice of production system (e.g. ‘growing a leguminous crop in association with maize or two times a maize crop’), tillage system (e.g. ‘plowing or conservation tillage’), cultivar choice (e.g. short or medium duration) and sowing date (early or late). Long-term decision making may involve application of rock phosphate to improve the phosphorus supplying capacity of the soil over a number of years, inclusion of agro-forestry options into the production system, or investment in improved irrigation and drainage facilities.

DSTs presented in this guide range from simple rules of thumb (expert knowledge), to complex, crop growth simulation models. The following types are used in this guide:

- Decision trees that use rules of the thumb or quantitative information that can be obtained from databases
- Data bases that provide important information for decision making. Such databases may be separate (ORD, PRDSS) or integrated in another tool (almost all tools have a database). In some cases these data, such as soil data, are georeferenced.
- Cropping calendars

- Nutrient flow diagrams, showing the flows of the various nutrients, biomass, products and money between different production units and entering / leaving the farm. Tools exist that help in quantifying, calculating and visualising these flows (NUTMON).
- Tools to calculate optimal fertiliser doses / ratio's (NuMaSS, QUEFTS)
- Dynamic models that mimic an important aspect of an agricultural system (e.g. a model that simulates the development of soil carbon over a number of years: the Rothamsted Carbon model)
- Dynamic models that mimic the most important processes of the system of interest (e.g, models that simulate the effects of weather, soil, crop characteristics and crop management on yield, such as DSSAT, COTONS, APSIM and RIDEV)
- Tools that permit to estimate data, that are required by the more sophisticated tools, from data that can usually easily obtained by means of pedotransferfunctions. These are functions that use e.g. information about soil texture to calculate water holding capacity of the soil.

These tools differ in data requirements and potential users, although the ultimate beneficiary will always be the farmer.

These DSTs can be used in various stages of decision-making:

- Strategic site selection phase, to identify zones that satisfy a number of criteria (e.g. accessibility, climate, soils, production potential etc.)
- Diagnosis / analysis phase. Here DSTs help to identify and analyze the problem (e.g. the production is far below what may be expected, and that this is caused by nutrient leakages in the system)
- Identification and ex-ante evaluation of options for improvement, including financial consequences and risk analysis (e.g. what will be the yield if we change the N, P and K ratio's of the fertilizer or what is the risk of applying a particular combination of crop variety, fertilizer dose and sowing period).
- Interpretation of experiments (understand why you obtained the results you got and improving the DST with the experimental data)
- Scaling out. Results obtained in a limited area can be used in combination with DSTs for extrapolation to other, slightly different, areas.

When selecting a DST it is useful to ask a number of questions in order to see whether the tool is useful to solve the problem at hand:

- Does the tool address the question?
- Is the tool (and the necessary equipment to use it) available?
- What does it take to be able to use the tool? (user-friendliness, help-desk available)
- What is the (minimum) data requirement of the tool and are these data available?

Although a large number of DST have been developed over the past 10 - 15 years, they are very often not well tested under smallholder conditions in West Africa. Available DSTs should therefore be used with caution and their use should always be embedded in a broader decision-making framework, in which discussion with decision-makers, surveys, participatory on-farm research and on-station research play an important role.

### **3. Using DSTs for strategic site selection, technology development and dissemination**

#### **3.1 Strategic site selection phase**

Careful selection of intervention zones and key sites is a prerequisite for successful technology development. Such zones should satisfy criteria pertaining to e.g. soil fertility,

weather, distances to markets, population density and road network. Geographic Information Systems permit combining these characteristics. By combining the georeferenced soil and weather data with crop growth simulation models, such as DSSAT, APSIM and COTONS, crop yields can be estimated for each combination. If these yields are calculated for a number of years, using historical weather data, risk profiles for each crop can be developed. Combining these risk profiles with socio-economic data, crop suitability maps can be made. The crop growth simulation models can also help to quantify potential gains from alternative production systems or management options. DSTs are used in this phase as exploratory tools and are just one part of the decision-making process that will include, besides weather and soil data, mainly socio-economic factors (such as population density, farmer organizations, existing information and communication networks, scope for partnership building between agricultural development stakeholders etc.).

### **3.2 Diagnosis/ analysis phase**

#### *Problem identification and awareness creation*

Once key sites have been identified, the first step at community level will be to develop a common understanding of the local landscape, i.e. how it has been transformed over time and how this has affected soil fertility. Farmers may be asked what changes have occurred over the past 10 - 20 years, whether there are differences between farmers or between different parts of the village territory or with other villages they know.

In this guide ISFM is our focal point, but many issues are related to that. This implies that we should enter the discussions with the farmers with a broad view. To capture the interest of the farmers it is important to encourage them to express themselves about problems related to agricultural production. The discussion should go beyond the direct causes of low soil productivity, as there may be other constraints that prevent them from taking appropriate action to overcome those problems. At this stage it is useful to ask farmers to draw a map of their village territory and indicate different soil types, water availability and road infrastructure. Transect walks can greatly facilitate this process. Such a map can become an important information and communication tool in discussions at village level.

If soil types are identified, a soil map can be drawn and farmers can estimate the suitability of each soil type for different crops. It is important to analyze what indicators farmers for soil fertility. This may include color and texture of the soil and the growth of certain weed species when fallow. Farmers may also be aware of nutrient deficiency symptoms observed for different crops in certain fields.

#### *Analysis of yield gaps*

If records are available on farmer yields, an analysis can be made of average yields and best farmer yields on different soil types, to determine the scope for improvement within the farming community (yield gap 1 = best farmer yield – average yield). Simulation models (DSSAT, APSIM, COTONS) can also be applied to determine the real yield ceiling under given growth conditions (yield gap 2 = yield ceiling – best farmer yield). It should be realized that these yield gaps give indications about what is agronomically possible, not what would be economically optimal. Discussions with farmers may give hints about what ‘best farmers’ do differently. Crop growth simulation models may also be helpful to analyze farmer management practices, and identify areas for improvement.

#### *Analysis of yield limiting or reducing factors*

In any debate on crop production it is essential to consider which factors are limiting or reducing crop growth. Soil fertility will often be a limiting factor, but it should be realized that crop growth in farmers' fields may also suffer from water stress or from incidence of pests, diseases and weeds. Also current management practices may prevent the farmer from obtaining better yields, such as choice of variety, plant population, sowing data and the type of fertilizer applied. In the latter case, crop response to fertilizer application may be disappointing due to the fact that the type of fertilizer applied does not match the requirements of the soil, e.g. soils that are low in K will not respond to large doses of N or P. Tools such as QUEFTS and NuMaSS may help detecting the limiting nutrient(s). QUEFTS is a simple and suitable tool to analyse the effectiveness of the N, P and K ratio's used, requiring a limited number of soil fertility parameters. NuMaSS can help diagnosing soil fertility problems related to N, P and soil acidity. Although NuMaSS requires more data than QUEFTS, it includes an extensive database, including pictures of crops suffering from nutritional disorders, nutrient contents of crops and soil data.

Similarly, a farmer who is using Phosphate Rock (PR) may be faced with a very poor response of the crop. In that case he may be using the wrong type of Phosphate Rock (PR): a type that is not suitable for his soil or his crop. Especially the pH of the soil may play a crucial role. Here PRDSS (Phosphate Rock Decision Support System) may be used. The PRDSS is a data base that includes a large number of PR and allows matching these types with a particular combination of soil, climate and crop, where after it provides information regarding the uptake of P in the first year from this type of PR and compares it to the uptake from P when triple super phosphate TSP would have been applied.

A poor response to fertilizer may also be due to other causes, such as shallow soil depth, the production potential of the crop / variety, weed competition or the wrong combination of planting date and variety. For the analysis of such type of causes crop simulation tools, such as DSSAT, APSIM, COTONS or RIDEV, may be useful.

Besides biophysical limitations, others may play a role as well such as harvest and post harvest practices, but also labor shortage, lack of credit or unfavorable weather may result in delayed start of the growing season or harvest affecting yield levels. Another important tool in farmer discussions will, therefore, be the cropping calendar. Such a calendar may first be drawn for the main cropping season and major crop but may be extended later to include other important aspects, e.g. to identify peaks in labor demand.

#### *Analysis of nutrient flows*

Soil fertility management implies transport and transformation of nutrients. Farmers transport material that contains nutrients be it harvested products, manure, fertilizer or straw used to build roofs. Some processes may lead to a loss of nutrients, e.g. burning of straw will result in almost complete loss of carbon and nitrogen. Nutrient flow analysis is a potentially powerful tool to understand the complexity of farming and its impact on soil fertility. It is important to realize that such analyses try to model a complex reality and should, therefore, used with care. Boundaries of the farming system that is analyzed, and boundaries of its subsystems (e.g. rice production system, vegetable production system, animal production system, and household system) should be clearly defined. A first qualitative DST that can be used is resource flow mapping. Farmers are asked to indicate flows of material entering and leaving their fields or their farm as a whole. Such an analysis may give first indications of soil fertility management practices that are unbalanced, i.e. nutrients are leaving the field, but no nutrients are added. To compare flows, there is, however, a need to express them in the same unit, e.g. kg of nitrogen, phosphorus or potassium. This means that one needs to know the concentration of nitrogen in e.g. manure, millet grains and millet straw, etc. and the amount of dry matter (at

Table 1 DSTs for the diagnostic phase of participatory technology development.

<b>Goal</b>	<b>Tools</b>	<b>Data requirements</b>	<b>Potential users</b>
Common understanding of the landscape	<ul style="list-style-type: none"> <li>• Discussions with farmers (current land use and history)</li> <li>• Transect walks</li> </ul>	Very limited	Farmers, extension, research
Spatial variability in soil fertility	<ul style="list-style-type: none"> <li>• Transect walks</li> <li>• Mapping (soils, land suitability)</li> <li>• Pictures (nutrient deficiency symptoms)</li> </ul>	Very limited	Farmers, extension, research
Identification of yield gaps	<ul style="list-style-type: none"> <li>• Comparing yields between among farmers and fields</li> <li>• DSSAT, APSIM, COTONS</li> </ul>	Very limited High	Farmers, extension, research Research
Identification of factors limiting or reducing crop growth	<ul style="list-style-type: none"> <li>• Cropping calendars, field observations, yield records</li> <li>• QUEFTS, NuMaSS, PRDSS</li> <li>• DSSAT, APSIM, COTONS, RIDEV</li> </ul>	Limited Medium High	Farmers, extension, research Research research
Identification of leaks, losses, un-tapped resources	<ul style="list-style-type: none"> <li>• Resource flow maps</li> <li>• NUTMON</li> </ul>	Limited Medium	Farmers, extension, research research

0% moisture) that is produced, transformed or transported. NUTMON may be used here to help quantifying the resource flows at field as well as farm level. One of the problems in quantifying these flows, is often the lack of data on nutrient contents. NUTMON includes databases not only on nutrient contents of crops, manures etc., but it also provides estimates of the production of animal manure, household waste, human excreta, and feed intake of the animals.

Table 1 gives an overview of DSTs that can be employed during this diagnostic phase of the participatory technology development cycle. Such tools are usually re-employed during the identification of options addressing the problem and/or opportunities identified during this phase.

### **3.3 Identification of ISFM options**

At the end of the diagnostic phase a number of problem or opportunity areas will have been identified. The next challenge is to identify potential solutions that may help to solve the problem or exploit the opportunity. The search for such ISFM options may include the use of DSTs, however, it should be stressed here that as people discuss the results of the diagnostic studies, options certainly will already become apparent. Field visits among participating farmers and to other areas may also be organized. Researchers and extension personnel may contribute to these discussions through the use of a number of qualitative and quantitative DSTs. This may help to screen the options generated, and retain the most promising ones for further testing. It may be useful to draw up a list of criteria that should be satisfied for the solution of the problem. This may help to avoid only including aspects that can be addressed by the DST, as other aspects may be more important bottlenecks.

Options related to ISFM can be grouped as follows:

- Adding organic or inorganic fertilizer
- Reducing nutrient losses
- Better management of available resources
- Improving input use efficiency

#### *Adding organic or inorganic fertilizer*

One of the options is to focus on building nutrient capital in the long term through fallowing, application of organic matter, or application of one-time high doses of inorganic P or phosphate rock.

Organic matter management to increase soil organic matter requires a long-term view. The Rothamsted Carbon model (ROTH) has been developed to estimate the effect of organic amendments on different types of soil organic carbon over a longer time frame. To be able to differentiate between the decomposability of the various sources of organic matter, the organic resource decision-support tool (ORD) may be a useful database. The ORD provides data on N, lignin and polyphenol content. High quality materials (high N, low lignin, low polyphenol) release a large proportion of N very rapidly, in advance of the main period of N-uptake by the crop and contribute little to soil organic matter build-up. They are in principle a good substitute for mineral fertilizers, however, large quantities will still be required because of the relatively low N content (rarely above 4%). Materials of lower quality (high lignin or high polyphenol) release a smaller total proportion of their N at as low continuous rate and contribute more to soil organic matter build-up. Such materials can be used as a mulch for erosion control and to conserve water, or be mixed with fertilizer or added to compost. The database associated with the DST provides average values for a large range of organic resources in terms of %N, %P, % lignin and % polyphenol.

Also APSIM and the newest version of DSSAT allow simulating the build up of organic matter over a longer period.

The build up of the stock of P in the soil proves still to be difficult to simulate, although APSIM and DSSAT are currently attempting to incorporate it into their models.

Although phosphate rock is usually applied to build up a stock of P, the Phosphate Rock Decision Support System does not calculate the effect on the stock of P over a longer period.

Fertilizer may also be used for the short term gain, i.e. obtaining a high yield, e.g. by applying mineral fertilizer, manure and the use of green manure.

As already discussed under diagnosis, it is important that the fertilizer applied matches the requirements of the soil and the intended crop. QUEFTS and NuMaSS are suitable DST's for determining fertilizer requirement: QUEFTS for N, P and K, and NuMaSS for N, P and lime. QUEFTS takes interactions between N, P and K into account and allows determining the optimal ratios of N, P and K.

Crop simulation models take only the effects of N-fertilizer into account.

Combined use of organic and inorganic fertilizers may be especially beneficial as often synergies are observed from such combined use, and fertilizer use efficiency may be enhanced substantially because of the non-nutritional benefits of organic amendments. For example, green manures or crop residues may serve as a mulch to suppress weeds and may greatly improve soil-water availability in the root zone. Increases in soil organic matter content may improve soil structure, CEC, pH and water holding capacity. However, this type of interaction is hardly captured in DSTs available to date.

Also crop rotation may contribute to soil fertility improvement such as the rotation of cereals with legumes. A Decision Support System for the use of legumes has been developed to estimate the feasibility of their use.

#### *Reducing losses of nutrients from the farm*

Resource flow mapping in combination with the cropping calendar DST will help identifying visible flows and losses occurring at field or farm level. NUTMON is a tool that facilitates quantification of the flows, including flows that are invisible to the farmers, such as volatilization of N, and quantification of leaching losses. Losses may also occur due to the application of imbalanced fertilizer doses, or in cases where other soil factors are limiting, e.g. drought prone soils, sandy soils with a very low CEC or soils with low pH. In such soils fertilizer uptake by the crop will be sub-optimal, resulting in losses. Similarly inappropriate timing of fertilizer application may increase losses from the system. The use of QUEFTS, NuMaSS and crop growth simulation models can be of use to address this issue.

#### *Better management of available resources*

Resource flow diagrams may be helpful to identify resources that are not used in the best possible way, but that are not lost from the system. An example would be the potential to use human excreta deposited in latrine pits, or composting of organic residues available on the farm. The ORD decision-support tool may be used to identify organic resources most suitable for composting or direct application as mulch or nutrient provider. Some organic resources, that have high decomposition rates should mainly be considered as suppliers of nutrients, while the slow decomposers can be used for the build up of soil organic matter. ORD provides information on different types of organic resources and best use in terms of ISFM.

### *Increasing external input use efficiency*

Nitrogen and phosphorus are the elements that limit crop growth most in sub-Saharan Africa. N is the most dynamic element and will be easily lost from the system. The plant may not take up P directly, but it will rarely be lost from the root zone. However, some soils may fix large amounts of P, rendering them unavailable for uptake by the crop. Increasing input use efficiency in terms of nutrients is, therefore, especially important for nitrogen. Two factors are very important: the recovery of applied N in the crop, and the use of plant N to produce harvestable dry matter, i.e. the physiological N use efficiency. The product of N recovery (kg plant N per kg N applied) and physiological N use efficiency (kg grain per kg plant N) is the agronomic efficiency (kg grain per kg N applied).

N recovery may be enhanced through improved crop management and crop choice. Synchronization of plant demand for nutrients and fertilizer application may greatly enhance recovery and DSTs such as DSSAT, APSIM, COTONS and RIDEV may help identifying optimal intervals for fertilizer application as a function of cultivar choice and sowing date. Local varieties may perform better without inputs than improved varieties, while improved varieties perform better in a favorable environment with inputs. Similarly sowing time and sowing density affect yield potential and hence fertilizer requirement. Crop growth simulation models may be used to determine yield potential and corresponding nutrient demand of the cultivar.

Weeds, pests and diseases may constitute bottlenecks, and it may be better to spend the available money on weeding or prevention of pests and diseases than on fertilizer. Some DSTs such as APSIM include the effect of weed competition on crop growth and this DST may be used to set threshold dates for weeding. Frequent field observations, discussions among farmers and placing the timing of farmer management interventions on a cropping calendar will, however, usually be the best way to identify important growth reducing factors and alternative management strategies.

### *Profitability and risk analyses*

Risk is a very important factor for farmers. Farmers that are prone to risk will not be ready to make investments in external inputs, other than those that will reduce such risks. DSTs such as APSIM, DSSAT, RIDEV and COTONS can be used to assess the risk due to climate variability of sowing date, fertilizer applications, plant densities, introduction of new crops and varieties, etc.

While the above is directly related to crop production issues, also other factors must be taken into account. Profitability of a crop is also influenced by other factors, such as input and output prices, marketability of the product, storage facilities, value of secondary products, labor requirement, labor availability and wages. Also the socio-economic / institutional environment may be important: taxation, access to credit, access to input (and output) markets, landownership (farmers who are not owner of the land they cultivate may be reluctant to invest in soil fertility), poverty level of the farmer (poor farmers are likely to be more risk averse than rich farmers). Such factors are, however, not dealt with in the DSTs presented in this guide.

Table 2 gives an overview of the DSTs that can be used in the identification of ISFM options as outlined above.

## **3.4 Experimentation**

After ISFM options have been identified, DSTs are useful to help narrowing down the range of feasible solutions for further on-farm or on station testing. The role of models is much smaller in this final decision stage, as models are rarely sufficiently reliable to replace practical testing. DSTs can be used, however, to interpret experimental results, e.g. to estimate the effect of erratic rainfall during the growing season on crop growth and establishment (e.g. with DSSAT, COTONS or APSIM). DST's may even be helpful in detecting errors in the data.

On the other hand, the availability of experimental results should be used to evaluate and improve the DSTs. It is therefore important that prior to the experiment a list should be prepared of observations to be made during the growth cycle.

### 3.5 Scaling out

Technologies that show good promise can be diffused among farmers at the keysite or beyond. During this phase, DSTs may again be used as exploratory tools, matching the requirements of the technology with environmental characteristics. This could again be done in combination with Geographic Information System to indicate best-bet regions for dissemination of the technology.

Table 2 DSTs especially useful during the identification of suitable ISFM options.

Identification of ISFM options				Time span
Fertilizer application	Reduce losses from the system	Better management of available resources	Improve external input use efficiency	
	QUEFTS NuMaSS		QUEFTS NuMaSS	Medium term
	NUTMON	NUTMON		Medium term
PRDSS			PRDSS	Medium to long term
ORD		ORD	ORD	Medium to long term
RIDEV, DSSAT, APSIM, COTONS	RIDEV, DSSAT, APSIM, COTONS		RIDEV, DSSAT, APSIM, COTONS	Variable
ROTH				Long term
DST Legumes				

### 4. Using the tools

Who are the users of these tools? A distinction should be drawn between those who are the final target group of the tools and those who are the users of the tools. The tools are meant to help improving the lives of the smallholder farmer and his or her family in sub-Saharan Africa. However, it is unrealistic to suppose that he or she will also be the user. The direct users are likely to be scientists, and for the simpler tools also planners and extension staff. As

it has become clear, the tools should be used while closely interacting with the target population.

However, the experiences of the COSTBOX project are that the application of models by scientists is still far away from being common practice.

This is partly due to the fact that few African agronomists have been exposed to the use of decision support tools. But there is also the problem of tools not being tuned to the problem at hand and lack of reliable data. This is a serious limitation for the application of the more sophisticated tools. This implies that efforts should continue to expose agronomist to the use of these tools, to integrate systems analysis and modelling in curricula of the universities, to develop georeferenced data bases on weather and soils, and to fine tune models to the various agro-ecological situations. Such efforts are already going on in various countries, and an increasing number of scientists are becoming enthusiastic about using such tools.

However, in view of the existing limitations, DSTs should be cautiously used, and it is important to keep in mind that decision support tools should not replace the decision-making activity, but are just an aid to sound decision-making. For instance, when comparing a number of options, the usefulness of the DST lies in the relative yields (option A gives a better result than option B), rather than in the absolute values of the yields.

Under African conditions, DSTs may play a role in discussing problems, options for improvement and interpreting experimental results. A useful effect of such tools is also that data are more purposefully collected and used; it also helps to analyze field- and lab data, and check their reliability as they can help discovering inconsistencies in the data. And finally, if DSTs are used more frequently this will give exciting opportunities to evaluate and improve them.

## **References**

- Matthews, R.B. and W Stephens (Eds.) (2002) : Crop-Soil Simulation Models: Applications in Developing Countries. Edited by, Cranfield University, UK pp.304
- Struif Bontkes, T.E., U. Singh and V. Chude, 2001. Problems and opportunities in adopting system tools for decision-making related to soil fertility improvement in Africa. Paper presented at the INRM 2001 Workshop, Cali, Colombia.

## QUEFTS

Name : QUEFTS: Quantitative Evaluation of the Fertility of Tropical Soils.

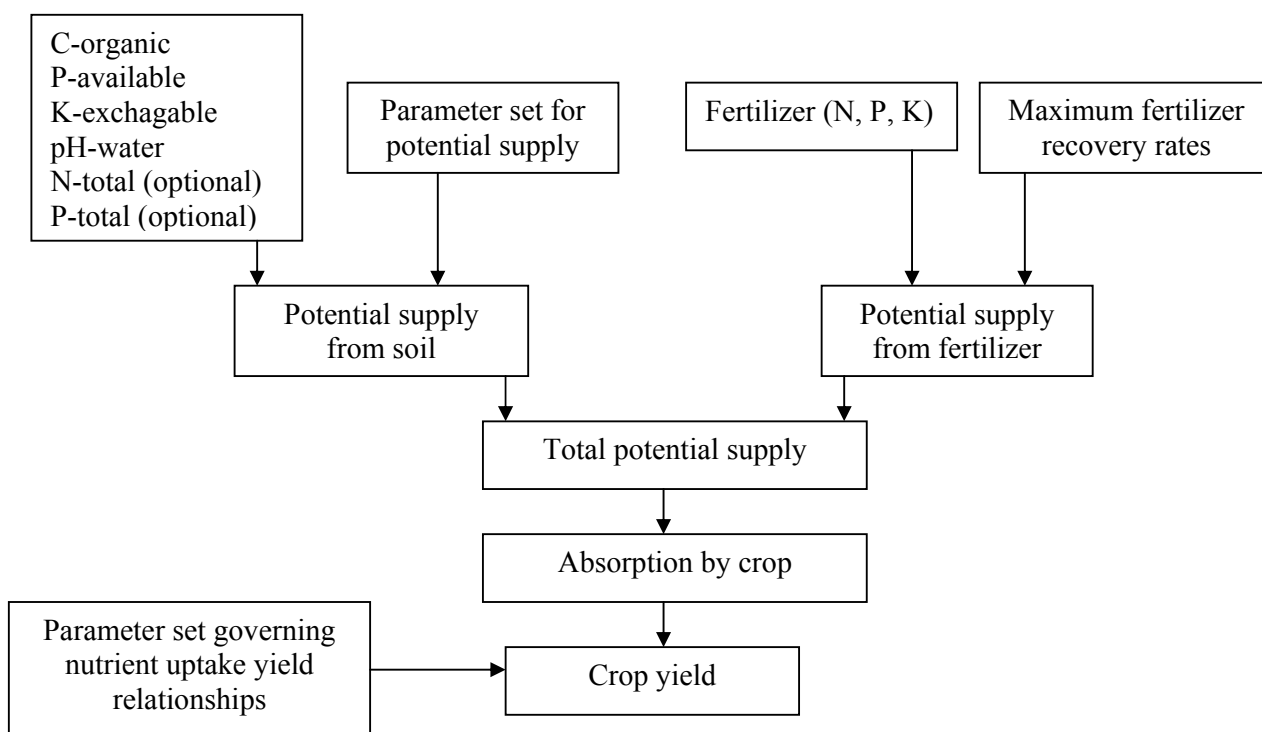
Authors: B.H.Janssen, B.H., F.C.T. Guiking, D. Van der Eijk, E.M.A. Smaling, J. Wolf and H. Van Reuler, Wageningen University and Research Center, Wageningen, The Netherlands

e-mail : Bert.Janssen@wur.nl

The software can be obtained from the above mentioned e-mail address

The model was developed at the Wageningen University in the eighties.

It is a simple static model that runs under DOS. It permits the calculation of the yield of a crop based on a number of soil parameters that are generally available. The model was tested for maize in Suriname and in two agro-ecological regions in Kenya. However, it is possible to use it also for other crops and other agro-ecological regions by adapting the parameters.



In addition the model permits to make a simple economic analysis about the profitability of the use of fertilizer. An interesting feature of the model is the determination of the optimal ratio between N, P and K fertilizer.

### References:

Janssen, B.H., F.C.T. Guiking, D. Van der Eijk, E.M.A. Smaling, J. Wolf and H. Van Reuler (1990): A system for quantitative evaluation of the fertility of tropical soils (QUEFTS). *Geoderma* 46, p. 299 -318

Janssen, B.H. (1998): Efficiency use of nutrients: an art of balancing. *Field Crops Research* 56, p. 197 – 201

Smaling, E.M.A. and B.H. Janssen (1993): Calibration of QUEFTS, a model predicting nutrient uptake and yields from chemical soil fertility indices. *Geoderma* 59, p. 21 – 44

## DSSAT

Name : Decision Support for Agrotechnology Transfer  
Authors : The International Benchmark Sites Network for Agrotechnology Transfer  
E-mail : icasa@icasa.net  
website : <http://www.icasa.net/dssat/index.html>  
To acquire the software the website should be consulted.

DSSAT 3.5 is a DOS-based software package integrating the effects of soil, crop phenotype, weather and management options. By simulating probable outcomes of crop management strategies, DSSAT offers users information with which to rapidly appraise new crops, products, and practices for adoption.

DSSAT also allows users to compare simulated outcomes with observed results.

The DSSAT software allows linking the crop models and linkage with Geographic Information Systems (GIS).

The following crops are included:

wheat	sorghum	peanut	millet	tomato
maize	dry bean	cassava	soybean	sunflower
barley	chick pea	potato	sugarcane	pasture

### DSSAT is being used as:

- As a teaching and training tool by providing interactive responses to "what if" questions related to improved understanding of the influence of season (weather), location (site and soil) and management on growth processes of plants.
- As a research tool, to derive recommendations concerning crop management and to investigate environmental and sustainability issues.
- As a business tool, to enhance profitability and improve input marketing.
- As a policy tool, for yield and area forecasting and land use planning.

The present version is DSSAT v3.5, but by the end of 2002 a Windows based version (DSSAT 4) will be released. This new version will also include: banana, cabbage, cotton, cowpea, faba bean, pepper, pineapple, tao and velvet bean.

The following minimum data set is required:

1. Weather: latitude and longitude, daily solar radiation, maximum and minimum air temperature and rainfall
2. Soil: upper and lower horizon depths, texture, bulk density, organic carbon, pH and aluminum saturation, and
3. Management: planting date, dates when soil conditions were measured prior to planting, planting density, row spacing, planting depth, crop variety, irrigation, and fertilizer practices.

There exists a very lively listserver for DSSAT users and others interested in crop model development, crop model applications and decision support systems (see website).

### Reference

Jones, J.W., G.Y. Tsuji, G. Hoogenboom, L.A. Hunt, P.K. Thornton, P.W. Wilkens, D.T. Imamura, W.T. Bowen and U. Singh (1998): Decision support system for agrotechnology transfer: DSSAT v3. in: G.Y. Tsuji et al. (eds): Understanding options for Agricultural production, p. 157 – 177. Kluwer Academic Publishers.

## APSIM

Name : Agricultural Production Systems Simulator (APSIM)  
Authors : Agricultural Production Systems Unit (APSRU is a joint research unit of Queensland Departments of Primary Industries (DPI) and Natural Resources and Mines (DNRM) and CSIRO Divisions of Sustainable Ecosystems (CSE) and Land & Water (CLW).  
Address : APSRU, PO Box 102, Toowoomba, Queensland, 4350, Australia  
E-mail : APSIMHelp@tag.csiro.au  
Michel. Robertson@tag.csiro.au  
Website : <http://www.apsru.gov.au/Products/apsim.htm>  
Availability : APSIM software can only be issued to licensed users, but a demo-version can be downloaded from Internet

APSIM is a modeling environment that uses various component modules to simulate cropping systems in the semi-arid tropics. Modules can be biological, environmental, managerial or economic and are linked via the APSIM "engine".

APSIM can simulate the growth and yield of a range of crops in response to a variety of management practices, crop mixtures and rotation sequences, including pastures and livestock. It can do this on the short as well as on the long term, permitting to obtain insight in long-term trends in soil productivity due to fertility depletion and erosion.

It contains modules that permit the simulation of crop – weed interactions, soil organic matter rundown, nutrient leaching, soil erosion, soil structural decline, acidification and soil phosphorus. There is, however, no current capability to deal directly with effects of salinization, insects, diseases or biodiversity loss.

The following crops can be simulated:

Maize	soybean	Chickpea	Lucerne
Sorghum	Barley	Mungbean	Annual medic
Millet	Groundnut	Lupin	Pinus radiata
Wheat	Canola	mucuna	Eucalyptus sp.
Sugarcane	Cotton	Hemp weeds	
Fababean	Cowpea	Sunflower	

### Data requirements:

1. Site : Latitude, soil texture and depth, slope slope length
2. Climate : Daily max and min temperature, solar radiation and rainfall
3. Crop phenology : Crop type and cultivar, days to flowering, days to maturity
4. Soil Water, N and P: soil moisture contents per layer at drained upper limit and lower limit, NO<sub>3</sub>-N, soil carbon per layer, total soil N of the top layer, soil bulk density per layer, P-extractable and P-sorption for each layer
5. Surface residues: crop and manure type and quantities, C, N and P contents, NH<sub>4</sub>- and NO<sub>3</sub>-N and available P of manures, percentage groundcover for surface applied materials
6. Management: dates of all operations, sowing depth, plant density, type and amount of fertilizer, tillage (type, depth, fraction of above ground materials incorporated)

### Reference

McCown, R.L., Hammer, G.L., Hargreaves, J.N.G., Holzworth, D.P. and Freebairn, D.M., 1996. APSIM: A novel software system for model development, model testing, and simulation in agricultural research. *Agricultural Systems* 50, 255-271.

## THE ROTHAMSTED CARBON MODEL

Name : RothC-26.3

Authors: K. Coleman and D.S. Jenkinson, 1999)

Address : IACR - Rothamsted, Harpenden, Herts, AL5 2JQ, UK

E-mail : Coleman@bbsrc.ac.uk

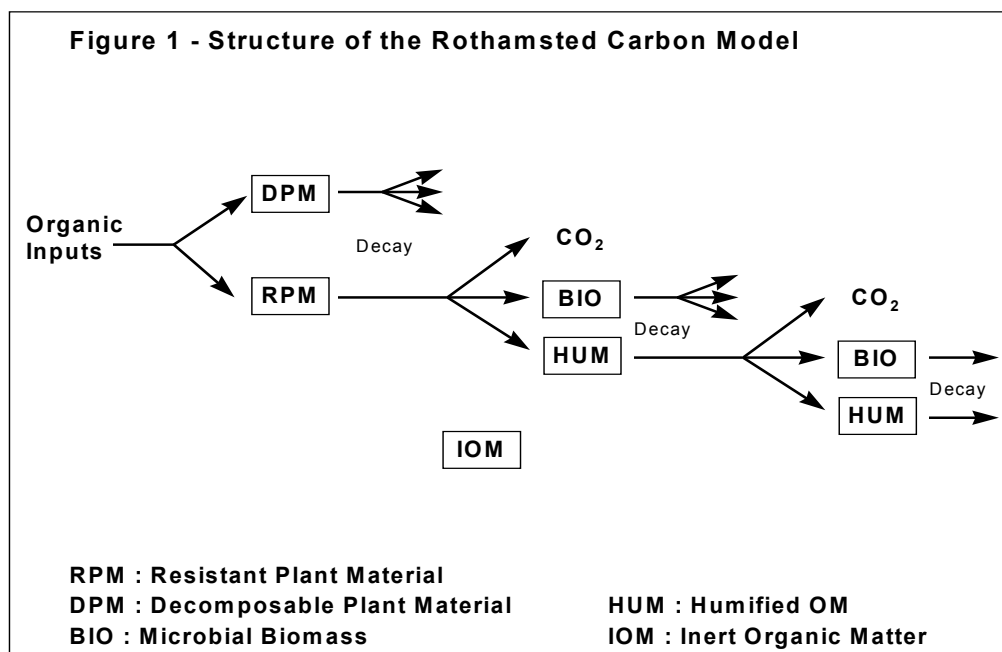
Website: <http://www.iacr.bbsrc.ac.uk/aen/carbon/rothc.htm>

The model is freely available and can be downloaded from the website

The Rothamsted Carbon Model (RothC-26.3) allows calculating the effect of organic matter management on the development of soil organic carbon in non-waterlogged topsoils over a period ranging from a few years to a few centuries. It takes thereby into account the quality and quantity of the organic matter added, soil type, temperature, moisture content and plant cover on the turn over process.

Soil organic carbon is split into four active compartments and a small amount of inert organic matter (IOM). The four active compartments are Decomposable Plant Material (DPM), Resistant Plant Material (RPM), Microbial Biomass (BIO) and Humified Organic Matter (HUM). Each compartment decomposes by a first-order process with its own characteristic rate. The IOM compartment is resistant to decomposition.

The structure of the model is shown below.



Both DPM and RPM decompose to form CO<sub>2</sub>, BIO and HUM. BIO and HUM both decompose to form more CO<sub>2</sub>, BIO and HUM.

The model uses a monthly time step to calculate total organic carbon (ton / ha), microbial biomass carbon (ton / ha) and  $\Delta^{14}\text{C}$  (from which the equivalent radiocarbon age of the soil can be calculated) on a years to centuries time scale. It needs few inputs and those it needs are easily obtainable.

**Data requirement**

The model requires the following data:

1. monthly rainfall
2. monthly evapotranspiration (mm)
3. average monthly mean temperature (°C)
4. percentage clay
5. an estimate of the decomposability of the incoming plant material – the DPM / RPM ratio
6. soil cover: is the soil bare or vegetated
7. monthly input of plant residues (ton C / ha), including C released from roots during crop growth. This can be calculated by running the model in the ‘inverse’ mode.
8. monthly input of farm yard manure (ton C/ha)
9. Depth of soil layer sampled (cm)

For a more information: see the manual, that can be downloaded from the website.

## NUTMON

Name : Monitoring nutrient flows and economic performance in tropical farming systems  
Authors : J. Vlaming, H. van den Bosch, M.S. van Wijk, A. de Jager, A. Bannink and H. van Keulen,  
Adress : Alterra, Green World Research. P.O. Box 47, NL-6700 AA Wageningen, The Netherlands  
Agricultural Economics Research Institute, LEI. P.O. Box 29703, 2502 LS, The Hague, The Netherlands  
E-mail : NUTMON-support@alterra.wag-ur.nl  
Web-site : <http://www.nutmon.org/index.htm>

Copies of NUTMON - Toolbox can be requested through this site for a fee of € 250 per copy. The toolbox is available for free for universities, national research institutes and NGOs in developing countries.

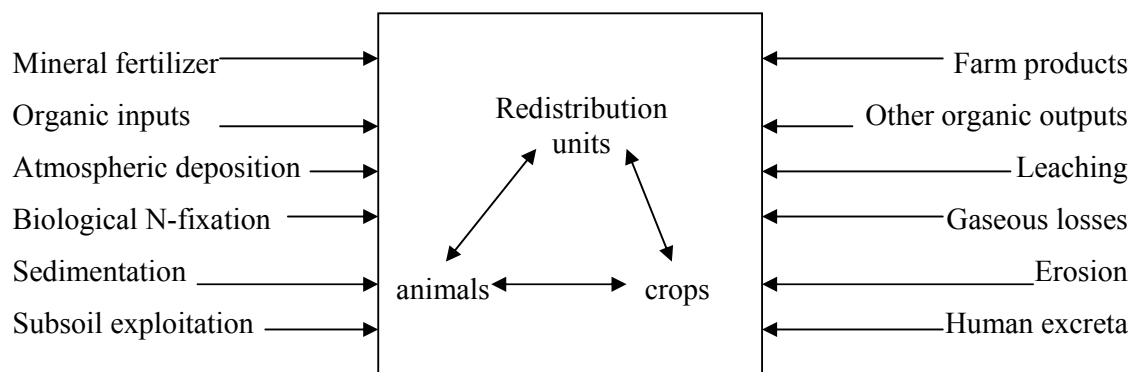
The toolbox was developed model at the Wageningen University and Research Center during the nineties in close collaboration with institutions in Kenya, Uganda and Burkina Faso.

NUTMON is an integrated, multidisciplinary methodology, which targets different actors in the process of managing natural resources in general and plant nutrients in particular.

The NUTMON-Toolbox consists of a questionnaire, a manual and several software modules that are specifically designed to facilitate monitoring and analysis of nutrient flows and economic performance at farm level.

The software permits to carry out a quantitative analysis, which generates important indicators such as nutrient flows, nutrient balances, cash flows, gross margins and farm income.

NUTMON considers the following nutrient flows:



NUTMON requires a substantial amount of data :

Soil : C, N, P and K contents, bulk density, slope, mineralisation rate, rootable depth, enrichment factor and erodibility

Weather: monthly rainfall, rainfall erosivity (USLE R-factor)

Crop : crop type, area, yield (grain, straw), destination of products, crop calendar

Animals: type, growth and composition, production, livestock confinement per month

Redistribution units: size and quality of latrines, compost pits, manure heaps etc.

Management : internal and external inputs per field, animal and redistribution units

In addition, information is required about nutrient contents of all products, prices, feed requirement, production of human and animal excreta, production of household waste, losses through burning etc., for which NUTMON provides default values.

## **COTONS**

Name : COTONS  
Authors : Eric Jallas, Philip Bauch, San Turner, Pierre, Martin, Michel cretent and Ron Sequiera  
Address : Cirad, Avenue d'Agropolis, 34398 Montpellier Cedex 5, France  
E-mail : jallas@cirad.fr  
cretenet@cirad.fr  
Website :  
<http://www.cirad.fr/presentation/programmes/coton/projets/decision/simulation.shtml>

COTONS is a physiologically detailed simulation model of the growth and the development of the cotton plant that runs under Windows. It is based on the GOSSYM model developed in the seventies. It consists of a plant model and a soil model. Weather information, cultural practices and genetic characteristics drive the plant model. Plant development is limited by water and nitrogen supply and also by soil water potential status. The model runs on a daily basis.

A special feature of the model is that the development of one or more plants is visualized on the screen, showing the development of branches, leaves, flowers and roots. This can be done for an average plant but it can also introduce variability between plants.

The model can be used for various purposes e.g.:

- To evaluate the adaptability of a variety to well defined agroecological conditions
- To evaluate the reaction of the variety to damage to the leaves or fruits caused by insects
- To identify production limiting factors, such as nutrients, water supply or plant density
- To evaluate the effects of impediments to root growth
- Prediction of yields

### **Data requirement**

Weather: latitude, daily rainfall. Radiation, minimum and maximum temperatures and wind speed

Soil : depth of soil layers, texture, bulk density, available water at field capacity, saturation and wilting point, levels of nitrate, ammonia, organic matter and water per layer.

Management : variety, spacing, dates and quantities of fertilizer, irrigation and growth regulators

## NUTRIENT MANAGEMENT SUPPORT SYSTEM (NuMaSS)

Name : NuMaSS

Authors: Osmond, D.L., T.J. Smyth, R.S. Yost, D.L. Hoag, W.S. Reid, W. Branch, X. Wang and H. Li (2002). Nutrient Management Support System (NuMaSS) v.2. Soil Management Collaborative research Support Program, Technical bulletin No. 2002-02, North Carolina State University, Raleigh, NC

Address : Soil Science Department, Box 7619, North Carolina State University, Raleigh, NC 27695

E-mail : Jot\_Smyth@ncsu.edu

NuMaSS is a tool that diagnoses soil constraints and selects appropriate management practices, based on agronomic, economic and environmental criteria for location specific conditions. NuMaSS integrates three existing nutrient decision support systems: Acid Decision Support System (ADSS), Nitrogen Decision Support System (NDSS) and the Phosphorus Decision Support System (PDSS). The three systems are integrated as modules into one system with a shared interface.

NuMaSS consists of 5 programmatic sections:

1. Geography: distinguishes between humid / tropical, wet / dry and semi-arid
2. Diagnosis: provides an early indication whether there is a nutrient management problem diagnoses soil constraints. There are 4 subsections:
  - intended crop (name, target yield and Al-saturation must be provided)
  - previous cropping
  - soil order (USDA taxonomy). Default values for soil data is available
  - plant: plant analysis, nutrient deficiency symptoms, indicator plants
  - The result of the diagnosis is the likelihood of an acidity, nitrogen or phosphorus constraints
3. Prediction: organic application, lime application, nutrient application
4. Economics
5. Results

The required inputs vary per module:

ADSS	NDSS	PDSS
soil order	The module uses an extensive database	Intended crop
crop critical % Al saturation	intended crop	Soil test P method
exchangable Al	intended crop yield	Soil test P-value
Effective cation exchange capacity	plant N	Percent clay content
bulk density	amount of organic amendment	Fertilizer type
% clay or textural class	amount of residues	Application method
		Application depth

## **PRDSS**

Name : Phosphate Rock Decision Support System  
Authors : U. Singh, P. Wilkens, J. Henao, N. Chien. D. Hellums and L. Hammond  
Address : IFDC, PO Box 2040, Muscle Shoals, AL 35662, USA  
E-mail : [usingh@ifdc.org](mailto:usingh@ifdc.org)  
Website : [http://ifdc.2kweb.net/Global\\_Presence/Research\\_and\\_Development/index.html](http://ifdc.2kweb.net/Global_Presence/Research_and_Development/index.html)

This is an expert system for estimating agronomic efficiency of freshly applied phosphate rock. It is a data base that includes a large number of sources of phosphate rock and evaluates their feasibility under diverse soils (texture, cec and pH), crops and climatic conditions. It compares P-uptake from phosphate rock with the P-uptake from triple super phosphate TSP in the first year of application. The current version of PRDSS does not estimate residual effect of phosphate rock.

## **ORD**

Name : Organic Resource Database  
Authors : Tropical Soil Biology and Fertility Programme and Wye College, University of London  
Address : TSBF, PO Box 30592 Nairobi, Kenya  
E-mail : [tsbinfo@tsbf.unon.org](mailto:tsbinfo@tsbf.unon.org)  
Website : <http://www.wye.ac.uk/BioSciences/soil/>  
Reference : Palm, C.A., C.N. Gachengo, R.J. Delve, G. Cadisch and K.E. Giller (2001) : Organic inputs for soil fertility management in tropical agroecosystems : application of an organic resource database. *Agriculture, Ecosystems and Environment* 83, p. 27 –42

The Organic Resource Database contains information on organic resource quality parameters including macronutrient, lignin and polyphenol contents of fresh leaves, litter, stems and / or roots from almost 300 species found in tropical agroecosystems. Data on the soil and climate from where the material was collected are also included as are decomposition and nutrient release rates of many of the organic inputs.

Examples of its use are :

- to help select organic resources for a particular purpose
- to develop hypotheses on the decomposition rates of organic resources based upon C/N ratio's, lignin and polyphenol contents
- to use it as a database couples to models and decision support tools

## **SOILPAR**

Name : Soil Parameters Estimate  
Authors : Marcello Donatelli and Marco Acutis  
Address : Research Institute for Industrial Crops, Via di Corticella 133, 40128  
Bologna, Italy Tel +39 051 6316843 Fax +39 051 37485  
E-mail : [isci-crop@iol.it](mailto:isci-crop@iol.it)  
Website : [www.isci.it](http://www.isci.it)

The software is available free of charge for non-profit organizations

*SOILPAR* 2.00 is a Win 98/2000/XP program to estimate soil physical and hydrological parameters using different methods. Hydrological parameters can be estimated from a variable number of commonly available soil parameters (according to the method of estimate) such as soil texture, organic carbon, soil pH, and cation exchange capacity. Different methods allow estimating hydrological parameters using either point or function pedotransfers. The characteristic matrix potential/soil water content curve can also be estimated. The programs allows converting different textural classes. A geo-referenced soil database is maintained, including soil profile information, measured and estimated data. Soil profile sites can be visualized on a ArcView/ArcInfo shape file.

## **SOIL-WATER PARAMETERS**

Name : ESTIMATING SOIL-WATER CHARACTERISTICS FROM TEXTURE  
Author : K. E. Saxton, USDA/ARS, Pullman, WA 99164-6120  
E-mail : [ksaxton@wsu.edu](mailto:ksaxton@wsu.edu)  
Website : <http://www.cahe.wsu.edu/~bsyse/faculty/saxton.html>  
Reference : K.E. Saxton et al., 1986, Estimating generalized soil-water characteristics from texture. Soil Sci. Soc. Amer. J. 50(4):1031-1036

Based upon percentages silt, sand, clay and loam, it provides estimates of wilting point, field capacity, saturated hydraulic conductivity and available water.

**DST LEGUMES**

Name : A decision tree on the feasibility of the use of legumes in Africa.  
Authors : Breman, H. and H. van Reuler, IFDC, Lomé, Togo  
Address : IFDC Africa Division, BP 4483 Lomé, Togo  
E-mail : hbreman@ifdc.org  
Documentation: Legumes: when and where an option? In: Vanlauwe, B., Diels, J., Sanginga, N., Merckx, R. (Eds.), Integrated plant nutrient management in sub-Saharan Africa: From concept to practice. CAB International, Wallingford, Oxon, UK., pp. 285 -298.

This decision tree assesses the feasibility of legume use under biophysical and socioeconomic conditions prevalent in SSA. The decision tree takes factors into account such as prevalence of N-deficiency in soils, protein deficiency, price ratio between N and P fertilizer and intended use of legumes.