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Support for an Agroforestry Model User Group

Final Technical Report

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With links to supporting databases on:

[*Tree Parameterisation \(CEH\)*](#)

[*Tree Parameterisation \(ICRAF\)*](#)

[*Crop Parameterisation \(Cranfield\)*](#)

[*Crop User Interface \(Cranfield\)*](#)

[*Soils Parameterisation \(Wye & University of Brawijaya\)*](#)

[*Organic Resource Database \(Wye\)*](#)

And the [HyPAR](#), [SAFE](#) and [WaNuLCAS](#) websites

Contents

1	<i>Executive Summary</i>	2
2	<i>Background</i>	3
2.1	The Complexity of Agroforestry	3
2.2	Biophysical models	3
2.3	Socio-Economic Models.....	5
2.4	Modelling Frameworks.....	5
2.5	Conclusions	5
3	<i>Project Purpose</i>	7
4	<i>Research Activities</i>	9
4.1	Incorporate new crop routines from the CERES model in HyPAR and test with ICASA datasets... 9	
4.2	Upgrade the Graphical User Interface for the models	9
4.3	Provide access to international databases of soil, climate and yield information..... 9	
4.4	Develop a parameter selection system to assist users to ‘tune’ the three models for different crop, soil and tree combinations	10
4.5	Maintain email discussion group, newsletter, website with casestudies, manuals, workshops, tutorials etc.	11
4.6	Address key agroforestry questions in workshops:	11
4.7	Establish mechanisms to monitor dissemination and uptake of models, and assess impact on development and environment.....	12
4.8	Generate funding proposals using models and maintaining collaboration built in the workshops..	12
5	<i>Outputs</i>	13
6	<i>Contribution of Outputs</i>	15
7	<i>References</i>	18
8	<i>Appendix I: Report on Crop Parameterisation Issues</i>	20
8.1	Summary.....	20
8.2	Aims of the work	20
8.3	Parameter library	20
8.4	User interface to the crop parameter library	21
8.5	Model access to the crop parameter library	25
8.6	Socio-economic modelling	26
8.7	References	26
9	<i>Appendix II: Report on use of existing data to test “pedotransfer functions” for tropical soils</i>	27
9.1	Abstract.....	27
9.2	Introduction	27
9.3	Material and methods	28
9.4	Results	34
9.5	Discussion.....	48
9.6	Conclusions	49

9.7	Acknowledgements	50
9.8	References	50
10	<i>Appendix III: Options for Changing the Crop Modules in HyPAR</i>	57
10.1	Introduction	57
10.2	HyPAR	57
10.3	Decision Support System for Agrotechnology Transfer (DSSAT)	59
10.4	Combining Models	60
10.5	Merging HyPAR and CropGro.....	61
10.6	Revised Modification Options for HyPAR.....	62
10.7	Conclusions	65
10.8	References	65
11	<i>Appendix IV: Registered Users of the HyPAR Model</i>	66
12	<i>Appendix V: Attendees at the 1st SAMUG Workshop, Malang, Indonesia 30/6 – 5/7 2001</i>	72
13	<i>Appendix VI: Attendees at the 2nd SAMUG Workshop, Curitiba, Brazil, 4-9/11/2001</i>	74

1 Executive Summary

Agroforestry models are starting to be used in developing countries to understand the complexity of agroforestry practices and experimental results. However users have been frustrated by the difficulty in providing values for the 30-60 parameters needed to 'tune' the models for specific soil, crop and tree combinations. This project therefore aimed to increase uptake of previous research by allowing four groups with experience of building and using agroforestry models to develop common libraries of soil/tree/crop parameter values and support an international group of model-users through email support and focused workshops in Indonesia and Brazil.

Outputs were:

1. A revised HyPAR model incorporating approaches from the widely used and accepted CERES model which allows the FRP supported models easier access to the ICASA (International Consortium for Agricultural System Applications) databases of soil, climate and crop parameter information. This model is available for download through the [HyPAR Website](#).
2. A combined HyPAR/[WaNuLCAS](#) usergroup supported through project websites and email exchange of information.
3. A workshop (July 2001) was held in Indonesia with participation from Philippines, India, USA, Indonesia, Thailand, UK, Vietnam, Brazil, Uganda and Malaysia. Miniprojects included competition in alley cropping, land use on sloping catchments, soil carbon sequestration with different tree rotations; growing sugar cane on ultisols; sustainable fallow systems; palm systems under water stress.
4. A workshop (Nov 2001) was held in Brazil with participation from Brazil, Colombia, Ecuador, Mexico, Bolivia, Ecuador and Peru. Miniprojects included: effect of grazing intensity on productivity in silvopastoral systems; interactions and competition in multi-strata agroforestry; tree-tree competition, shade trees in a coffee based system; intercropping trees in sugarcane; tree crop interactions in rotational parkland systems in Mexico.
5. An Excel library of crop parameters was completed (based on with the DSSAT v4.5 crop modelling package) for maize, wheat, barley, rice, sorghum, millet, soybean, groundnut, chickpea, bean and cassava, together with a user interface in Delphi to facilitate manipulation of the parameter data (i.e. inputting, modifying, deleting parameter values) and to aid selection of appropriate parameters. Users can select crop and genotype information and the interface calculates (currently only for maize) phenology parameters given information on the dates that certain growth stages are achieved. A Delphi interface program to the crop parameter library has also been developed to provide access from crop models such as HyPAR and HyCAS.
6. An Excel parameter library is available for the main tropical soil taxonomic, textural and hydrological classes with look look-up tables to estimate soil-hydrology parameters from soil taxonomy structure ('pedotransfer functions'). Also provided is the WYE-TSBF database of organic residue quality which gives default parameters for input quality (%N, fibre, lignin and polyphenols) for a large range of organic materials including manures/mulches/prunings.
7. An Excel parameter library is available to allocate species functional groups based on their physiological and morphological characteristics (e.g. maximum height, wood density, leaf-thickness, leaf size, sapwood characteristics, root distributions, branching patterns etc), and complemented by studies of model sensitivity to the parameters used.
8. Many of the SAMUG programming and parameterisation activities will be continued through the EU Funded [SAFE](#) and [SAFODS](#) projects.

2 Background

2.1 *The Complexity of Agroforestry*

Much research and extension effort has been invested in tropical agroforestry by many national and international agencies. Yet it is still difficult to provide **predictive insight** into which types of tree-crop combination are appropriate for a specific location, and a particular farmer's objectives (Jagtap & Ong 1997). The interactions between trees, crops, soils, climates and people are so complex that there is no guarantee that the results observed at one site will be directly replicable at another. Research on the underlying processes can help to explain the reasons for observed differences, but the processes are so numerous that only computer models can hope to represent the rapidly changing interactions in time and space. Models are therefore integrators of our current understanding of complex agroforestry systems. They are used to pinpoint gaps in knowledge, to prioritise work on these; to extrapolate research results to new combinations of soil, climate, species and management system (too numerous to be studied with field experimentation), to provide decision support to researchers, extension agents and policy makers, and to develop team-work amongst researchers and extension agents.

2.2 *Biophysical models*

Biophysical models of agroforestry systems may be parameterised on one experiment and 'validated' against similar experiments. This provides a 'reality check', but models can be useful even when they "fail" if the reasons for discrepancy between assumptions in the model and the real world are analysed. Models can never make perfect predictions, and are never 'finished', and will seldom represent exactly the growing conditions of the user. Nor can they replace experimentation, but they do allow a large number of hypotheses, scenarios, and proposed 'experiments' to be evaluated. Coe (1999) has argued that field experimentation should not be undertaken unless the hypothesis can first be tested using a model. For example, the hypothesis might be that 'adding green mulch in alleys increases crop yield', but the model will demonstrate that crop-tree competition for water means that the hypothesis is only valid in situations with low nitrogen and high water supply. Research design should therefore be based on the results of initial simulations using bio-physical models (Table 1).

Several models of crop or tree monocultures exist. The ones that predict growth best at a given site often do so because they have been 'tuned' to one set of conditions, and they fail when applied to situations outside their calibration range. Attempts to combine models of different species have also been disappointing because many of the monoculture models inadequately represent the complex competition in space between the rooting systems of each species (Thornton *et al.* 1990).

Table 1 Possible outcomes and consequences for research design of testing hypothesis with models before starting field research .

Modelling Outcome	Impact on Research Design
Current models do not address the process or situations being investigated.	Collect those data which are required to parameterise additional processes or situations in appropriate models.
The hypothesis is not confirmed by the model, and it appears that the model assumptions are unrealistic.	Collect those data which are required to parameterise improved representations of existing processes in current models.
The hypothesis is not confirmed by the model, and it appears that the model assumptions are realistic.	Examine your research assumptions, and modify them to produce more comprehensive hypotheses.
The hypothesis is confirmed by the model	The research hypothesis conforms to current knowledge, and there may be more cost-effective objectives for field trials.

Biophysical models of agroforestry systems must pay particular attention to root architecture because tree roots have a capacity to absorb water and nutrients from great depths and horizontal distances. Indeed, scavenging of resources from neighbouring small-scale control plots was a neglected reason for the success of many agroforestry systems reported in early trials (Ong *et al.* 1991).

One of the first agroforestry models was titled 'Soil Changes Under Agroforestry (SCUAF)' (Young & Muraya 1990). As its name suggests, this predicted the effects of surface organic matter additions on soil erosion, and on the contents of water and nitrogen. However it did not represent the competition between trees and crops for water and nutrients, and is simplistic in its representation of light. Nonetheless it has been used in analyses of the cost-benefit of different hedgerow intercropping systems (Nelson *et al.* 1998).

A more complete agroforestry model of competition for light, water and nutrients was developed by Conijn (1995), which simulated the growth of grass in three concentric zones around individual trees, taking into account the vertical and horizontal distribution of tree roots, but with a rather simple representation of soil hydrology.

A silvopastoral model based on the Hurley Pasture Model (HPM) of carbon, water and nitrogen flux in grasslands (Thornley & Verberne 1989) has been used with a model of sheep growth, and empirical tree volume functions (Bergez *et al.* 1997), or merged (Arah & Hernandez 1997) with the more physiologically realistic Edinburgh Forest Model (Thornley & Cannell 1996). Neither of these models has been widely used or publicised.

A further approach was developed in the late 1990s using the Stella Modelling Environment, which allows users to modify parameters between simulations and modify the model structure comparatively simply. This model is called WaNuLCAS (van Noordwijk & Lusiana 1999), and represents light, water, nitrogen and phosphorus interactions in simultaneous and sequential agroforestry systems. It is based on above- and below-ground architecture, physiology and soil science, and permits investigation of short-term interactions and long-term trends in yield and fertility.

The Forestry Research Programme funded development of another agroforestry model under project R5621. HyPAR v1.0 (Mobbs *et al.* 1998) which combined the tropical crop model PARCH (Bradley & Crout 1994) with components of the tree model Hybrid v3.0 (Friend *et al.* 1997). HyPAR v1.0 calculated light interception and water use by a horizontally-uniform tree canopy (which was always above the crop), annual tree biomass increment (net primary productivity), the light and water available to an understorey crop and hence crop growth, and potential annual grain yield (assuming optimum management and no pests or pathogens). It included the soil water movement and uptake routines of PARCH, and utilised those parts of Hybrid which determine light interception, water use and tree productivity and biomass partitioning.

HyPAR was used by Cannell *et al.* (1998) to predict the 50-year mean 'potential' sorghum yields and overstorey net primary productivity in nine climates (348mm - 2643mm rainfall) with uniform overstorey leaf area indices of 0 to 1.5. They concluded that simultaneous agroforestry may enable more light and water to be 'captured' than sole cropping. However, in regions less than 800 mm rainfall, because of low water use efficiency of trees and sensitivity of crops to shading, it is difficult to increase **total** productivity without jeopardising food security. The authors recognised, however, that conclusions from this early version of HyPAR did not include the soil fertility relations of trees, their potential access to deep water-tables, and other economic benefits such as shade, fuel and fodder.

HyPAR version 2.0 introduced competition for nitrogen and was used by Lott *et al.* (1998) to test predictions of maize growth in Kenya. Later versions included improved soil water routines and options for management of the tree canopy. HyPAR v3.0 included daily allocation of tree photosynthate, routines to represent disaggregated (i.e. clumped) canopy light interception, and 3-D competition for water and nutrients between the roots of trees and crops. Only with this disaggregated version of HyPAR have users seriously started to test results against field results (Lott 1999). The current version of HyPAR is v4.5 which contains a number of improvements supported in the current project (q.v.)

A third model, HyCAS, was also developed as part of the FRP Agroforestry Modelling Project Phase II (R6348). It used the tree component of HyPAR, but combined this with a cassava model (GUMCAS - Matthews & Hunt 1994; Matthews & Lawson 1997), rather than the PARCH model. HyCAS demonstrated that linkage of a tree models with the range of crop models used in the International Consortium for Agricultural Systems Applications (ICASA - Jones *et al.* 1998, Hunt *et al.* 1998) initiative is possible.

Proposers of this project felt that UK tropical crop modelling effort could benefit considerably from closer cooperation with this international initiative (<http://www.icasanet.org>).

Other FRP projects¹ have contributed experimental results to help parameterise the models, and a number of training courses have been run to train scientists from universities and CGIAR/NAR institutes in their use and potential modification. Software, documentation, and newsletters are available from the web-site <http://www.nbu.ac.uk/hypar>.

It has not been possible to provide significant linkages between output from detailed biophysical models and models of profitability or farmers behaviour. This remains a long-term goal, and the current project has included presentations of socio-economic models at workshops.

2.3 Socio-Economic Models

Socio-economic models of agroforestry suffer in the same way as bio-physical models from the complexity of agroforestry systems. Cost-benefit techniques are well established in agricultural economics, and discounting techniques are available from forestry economics to estimate the present value of future costs and revenues. However, farmers practising agroforestry, particularly in the developing world, frequently do not make decisions to maximise their profits, even when 'profitability' includes a cash estimate for the non-market benefits of agroforestry. They may choose to optimise their use of labour, or land, rather than cash. They may prefer mixtures or strategies which minimise the risks involved in unfavourable weather, pests, or market fluctuations. They may prefer to use some of their resources (e.g. trees) as long-term insurance for future difficulties. There may be social, and land-tenure, constraints which restrict the ability to maximise personal profits. They may use tree-management techniques like pruning or thinning on only part of a field. They will often use trees as boundaries within or around a farm, and farmers make very sophisticated assessments of their impacts on local climate, water supplies and neighbouring fields.

Given this complexity it is understandable that, until recently, most assessments of agroforestry economics have concentrated on financial cost-benefit analyses from a planners or bankers point of view, rather than from that of the farmer. Estimates of likely profitability have used 'snapshot' and site-specific surveys of farmer's yields, with few attempts to examine the likely variability of these yields or the effects of changing species or management techniques. Recently however, much more recognition has been given to the need for economic analyses from the farmer's perspective, and improving computer hardware and software packages are making new techniques available to represent his/her multiple objectives in land management (e.g. Scherr 1995, Thomas & Willis 1999).

Additional funding sources have been explored to link predictive outputs from bio-physical models with multiple-objective household economic models, and GIS databanks of physical and economic information, and to move towards a true decision support system for agroforestry, which can potentially 'optimise' the agroforestry system recommended by an extensionist to meet the specific objectives of a given farmer.

2.4 Modelling Frameworks

Different model users have different requirements. Some value the flexibility to provide their own code from scratch based on a box and flow structure (e.g. AME - written in Prolog and Tcl/Tk Muetzelfeldt & Taylor 1997), while others like the bulk of programming to be done for them, but with changes permitted within an internationally recognised modelling package (e.g. WaNuLCAS - written in 'Stella'), a third group do not wish to programme at all, and are best served with models which others write, linked to 'user-friendly' graphical interfaces which facilitate their use (e.g. HyPAR - written in Fortran/Delphi). The Agroforestry Modelling Environment (AME), developed at the University of Edinburgh has received continuation funding in the FRP supported CIFOR-FLORES project (R7315), focusing on farmer's decisions at the forest margin. This software has continued to be developed and is available free of charge from the [SIMILE group](#).

2.5 Conclusions

Researchers in developing countries have been discouraged by the complexity of input parameters required for agroforestry models, and feel that they are too complicated even for initial use. The solution is not

¹ Notably: R4850, 5040, 5810, 6071, 6363, 6364, 6523

necessarily to simplify the models to a level where their predictive power is reduced, but to provide greater support to model users in setting the parameters and providing user-friendly interfaces to run the models.

A number of approaches were suggested in the proposal:

- developing libraries of parameters for different soil types, crop varieties, residue classes and tree species which provide 'best-bet' starting conditions for scenario modelling,
- replacing components of the HyPAR model with those from others used by a larger community of crop scientists who can provide access to libraries of parameter information.
- supporting email groups of users who can help each other overcome common difficulties
- developing training material, case studies and workshops to explain the models and agroforestry interactions generally.

The proposal stressed that while the HyPAR and WaNuLCAS models were useful to researchers, teachers and perhaps extension agents wishing to explore the interactions between different species, soils and climate conditions, the funding was too limited to allow much attention to be given to socio-economic issues.

A significant number of potential users of agroforestry models had been identified, in conjunction with ICRAF in SE Asia and in South America. They had expressed considerable interest in attending workshops.

3 Project Purpose

***Purpose:** To increase predictive understanding of researchers, trainers and dissemination officers of the impact of different management scenarios on farmer's decisions, based on the known effects of competition for light, water and nutrient resources on yields of trees and crops in agroforestry systems.*

Much agroforestry research information is unavailable to educationalists and extension officers, and the recommendation domain of specific technologies is uncertain because they have not been tried in a wide range of soil and climate conditions. The models proposed here synthesise experimental results and allow scientifically-based projections of likely yields and impacts of altered management and new environments. They can therefore be used jointly by researchers and extensionists to examine the consequences of farmer's and forester's land use decisions. Specific agroforestry problems will be addressed as case studies at the workshops to provide users with the expertise and confidence to apply the models to the real world.

Registered users of the HyPAR (Appendix IV) and WaNuLCAS models are located in research, education and government agencies in many countries. The original Concept Note for this final extension of the 'Agroforestry Modelling Project' suggested a 3-year project and with target institutions of ICRAF (Indonesia), CATIE (Costa Rica), CIAT (Bolivia) and the Univ. Harare (Zimbabwe). The agreed project was limited to 18 months and was focused on the two local workshops and the more limited goals of a) providing user support, and b) developing libraries of tree/crop/soil parameters to enable users to tune the models to their own requirements. The workshops were to be held in conjunction with ICRAF Indonesia and EMBRAPA Brazil: two organisations which had identified partner institutions, and which have a key role in training and dissemination.

Several completed DFID-FRP projects have produced data which can be used for model parameterisation. The DFID Natural Resources Systems Programme (NRSP) funded development of the PARCH model, which forms part of HyPAR. An evaluation meeting (RNRSP, Rothamstead 26.10.99) on uptake of the PARCH model identified the parameter database and user-support approach in this proposal as a priority. One of the report authors has completed a review of 'Applications of Crop/Soil Simulation Models in Developing Countries' for the DFID-NRSP (Matthews *et al*, April 2000).

The International Council for Research on Agroforestry (ICRAF) and other CGIAR Centres and NARS have conducted numerous agroforestry experiments, but they also recognise the dangers in applying given technologies beyond the environmental or social conditions represented in the experiment. Resources are limited, and permit only a restricted number of on-farm or on-station experiments can be conducted. ICRAF are not looking to models to extend the application domain of agroforestry technologies, and have suggested to their researchers that new experimentation should not take place unless the initial hypothesis has first been tested using an appropriate agroforestry model.

Both HyPAR and WaNuLCAS have been used in successful seminars and workshops, but users have identified four main impediments to uptake.

- (a) *Despite the sophisticated user interfaces provided for both models it has proven difficult for novice users to appropriately parameterise the models for new soils, climates and species mixtures – they often don't have access to appropriate literature and are uncomfortable with the assumptions which are sometimes required.*
- (b) *User support is spasmodic, being available at workshops but not being guaranteed in subsequent months because the family of users of both models is relatively small.*
- (c) *HyPAR and WaNuLCAS are probably the most comprehensive agroforestry models available in the world, but they both contain simplifications which mean that certain processes are not represented at the spatial- or time-scale that some users prefer.*
- (d) *The PARCH crop model, which is incorporated in HyPAR, is used by very few scientists or extension staff world-wide: mainly because it has been little reported in the international literature, and has not been validated for more than one or two environments. This was not the expectation in 1994-95 when the original DFID Agroforestry Modelling Project started, since at that time there were researchers at the Universities of Nottingham, Newcastle, Aberdeen, Cranfield and Reading who were contributing to PARCH as part of a long-term series of RNRSP projects. Since that time however there has been no*

support for the PARCH model and very little collection of parameterisation data. Potential users of HyPAR are greatly deterred for this reason.

Our proposals for user group support and a library of parameter values address problems (a) and (b). Problem (c) can usually be addressed if the user slightly modifies the code (WaNuLCAS) or the starting and running conditions (HyPAR). Problem (d) is recognised as the most serious bar to uptake of the HyPAR model.

The suggested solution was to integrate the Hybrid tree model with models from the International Consortium for Agricultural Systems Applications (ICASA), which include the well-known CERES and CROPGRO family of models, which share standardised databases of information. ICASA supports models developed as international collaborative efforts, and are now available for 16 crops, with accompanying databases of soil, climate and experimental information. Furthermore ICASA maintains a regular newsletter, runs frequent training courses and supports a self-help usergroup of more than 300 crop scientists world-wide. This is already an impressive example of international collaboration and they have welcomed the opportunity of providing agroforestry options within the ICASA framework. Furthermore ICASA has recently signed a memorandum of understanding with the Global Change in Terrestrial Ecosystems Programme (GCTE, part of International Geosphere-Biosphere Programme) and groups world-wide are collaborating within crop networks. Networks for wheat, rice, potato, and cassava are well established, while those for tropical cereals (sorghum, maize, and pearl millet) and grain legumes (groundnuts, soybeans, and chickpea) are being launched around Europe (www.icasanet.org/).

In the Agroforestry Modelling Project Phase II (R6348) CEH and Cranfield University collaborated in developing a combined agroforestry-cassava model using one of the ICASA models (GUMCAS). Thus the technical difficulties of incorporating the ICASA family of crop models into the HyPAR framework have been partially addressed, and it was felt that an updated and working integration of HyPAR and the ICASA CERES model could be developed within the timeframe of the current project. This would allow integration of tree routines with a wide range of cereal and legume crops and allow the UK to make a significant contribution to international collaboration within ICASA and extend its application further within developing countries.

This project was intended to run for only twelve months, but was extended for 9 months at no additional cost, to allow more work on the parameter databases, and linkages with other model developments (modularisation of the DSSAT models and development of the SAFE project)

One planned output from the project was to demonstrate that the agroforestry models are included as integral parts of other funding applications, guaranteeing their continued development and improvement independent of FRP support.

The models HyPAR and WaNuLCAS codens take different approaches and are aimed at different types of user. HyPAR provides rather detailed description of tree and crop growth, whose strength is physiological realism, but whose weakness is the difficulty in providing estimates for the large number of parameters, particularly for novice users. WaNuLCAS has a less detailed representation of spatial aspects of competition but the Stella modular modelling framework used allows easier access to the code and equations within the model. The aim of the current project was to demonstrate both models in regional workshops and ensure that significant numbers of researchers in the six target countries could apply the models to their own data, and disseminate the results of their simulations.

4 Research Activities

Sections follow the headings in the Project Proposal.

4.1 Incorporate new crop routines from the CERES model in HyPAR and test with ICASA datasets

Integration of the PARCH crop model with the Hybrid tree model began in 1994, at which time PARCH was being actively worked on by several university groups in the UK. Unfortunately this collaboration on crop modelling was not maintained and several alternative models emerged with different priorities and strengths. The original authors of PARCH have moved into other areas, and no user support is currently available. Nor has the expected body of parameterisation information for a range of crops been provided.

The FRP Agroforestry model used PARCH as a contribution to closer integration with other ODA research programmes. In retrospect, rather than using PARCH, it may have been preferable to integrate the tree model 'Hybrid; with one of the International Consortium for Agricultural Systems Analysis (ICASA) crop models. These are regularly used by crop scientists throughout the world, are backed up by numerous scientific publications, an extensive database of parameterisation, and a large usergroup where members help each other out with advice.

The original intention in this extension was for DC Mobbs to enhance HyPAR to provide routines from the CERES family of grain-crop models in replacement to the routines derived from PARCH. This change had also been requested by our collaborators in ICRAF and other research stations, who have experience with CERES or CROPGRO (ICASA models), but not with PARCH.

Significant improvements were made in the initial version of HyPAR (v3.0). Version 4.0 was released at the Indonesia workshop and completed at the end of July 2001. Version 4.5 was released for the Curitiba workshop, and is a significant rewrite of the existing HyPAR code to adapt it to the subroutine calling structures of the DSSAT/ICASA models. However, at this time we learned that the DSSAT/ICASA were in the process of rewriting their models in a more modern modular format. DC Mobbs has evaluated a preliminary version of this generic Cropping System Model (CSM), and compared it with a generic French crop model (STICS) which is being used in a, recently started, EU funded agroforestry modelling project (SAFE). It soon became apparent that there were major advantages to be gained in the SAMUG project collaborating with SAFE (q.v.), and further integration of the CERES crop routines did not take place (Appendix III).

4.2 Upgrade the Graphical User Interface for the models

Significant updates to the HyPAR user interfaces took place prior to the Indonesia workshop. These included the option for multiple crops in a single year, different pruning regimes for different trees, increased options for coppicing and thinning, and improved representations of multiple trees in a field.

A graphics bar was provided to interface with suites of Excel Macros, which now cope with initial problems experienced with implementation in languages such as French and Portuguese.

These changes are described in updated versions of the November 2001 versions of the [HyPAR Technical Manual](#), and [User Guide](#).

4.3 Provide access to international databases of soil, climate and yield information

The ICASA international consortium has created a single set of data file structures for both experimental documentation and model input. This set has encouraged good interaction between experimentalists and modellers, but is little used in the UK. ICASA continues to improve this standard and to make it available to users including those working with FAO, GCTE, IRRI and a range of international Agricultural Institutions. Cranfield University (see Section 4.4.1) have provided software to interface between the HyPAR and HyCAS models and these databases.

4.4 Develop a parameter selection system to assist users to 'tune' the three models for different crop, soil and tree combinations

HyPAR, HyCAS and WaNuLCAS have numerous parameter values which must be appropriately set to make predictions for specific combinations of soil, climate crop and tree types. HyPAR already provides access to a half-degree latitude/longitude database of monthly weather data, and can generate appropriate daily weather patterns from this, when users are not able to provide their own weather information. FAO databases of soil type and structure are also available, and could be distributed with the agroforestry model software once copyright details are cleared. The three partners will take responsibility separately for creation of databases of crop (Cranfield), tree (CEH) and soil (Wye) parameter information for the 3 project models, and jointly for design of an 'expert-system' front-end to the databases which guides users through the selection of parameter values based on 'fuzzy-matches' or 'taxonomic' or 'functional' similarity

4.4.1 Crop Parameters

Cranfield University have developed an [Excel library of crop parameters](#) supplied with the DSSAT v4.5 crop modelling package. Separate sheets are available for maize, wheat, barley, rice, sorghum, millet, soybean, groundnut, chickpea, bean and cassava were included. A [user interface](#) for the Excel database has also been provided in Delphi to facilitate manipulation of the parameter data (i.e. inputting, modifying, deleting parameter values) and to aid selection of appropriate parameters. Users can select crop and genotype information and the interface calculates (currently only for maize) phenology parameters given information on the dates that certain growth stages are achieved. A Delphi interface program to the crop parameter library has also been developed to provide access from crop models such as HyPAR and HyCAS. A household socio-economic model is also described. More details are provided in Appendix 1.

4.4.2 Soil Parameters

Wye College have developed an Excel [parameter library](#) for the main tropical soil taxonomic, textural and hydrological classes. Look-up tables have been developed to estimate soil-hydrology parameters from soil taxonomy structure ('pedotransfer functions'). Also provided is the WYE-TSBF² [database of organic residue quality](#) (Adams et al., 1997) which gives default parameters for input quality (%N, fibre, lignin and polyphenols) for a large range of organic materials including manures/mulches/prunings. A 'fuzzi' (e.g. color appearance and simple crushing tests) approach has been used to fine tune the inputs without the necessity for expensive additional measurements.

Soil water balance models generally require input parameters that are not available without considerable measurement efforts. Pedo Transfer Function's (PTF's) have been developed that predict relationships for θ -h-K relationships employing the measured percentages of clay, silt, organic matter content, and bulk density in temperate soils. However, as they are empirical, these PTF's may give erroneous, or even completely absurd predictions when used outside the range of soils from whose data they were derived. In tropical region, we believe that much work has already been invested in input and output parameters of PTF's, but those data has not yet been fully systematically recorded and then tested to PTF's. The objective of this study was to test the validity of general PTF's developed by Wosten *et al.* (1998) for "tropical" soil. Soil bulk density and clay content were the most important input parameters a PTF user needs to obtain valid results for the relations between soil water content (θ), water retention (h) and hydraulic properties (K). We obtained a satisfactory agreement between field observations and simulations on water retention for "tropical" soils and unsaturated hydraulic conductivity measured in ring samples boundaries for Ultisol. Water flow properties from ring samples and PTF, however, do not fully cover field behaviour, as they do not include macro-pore flow. The lack of hydraulic conductivity data is a very serious limitation on testing the PTF's in tropical soils. More information is provided in Appendix II

4.4.3 Tree Parameters

CEH have developed an [Excel database](#) to assist users allocate species to a certain number of functional groups based on their physiological and morphological characteristics (e.g. maximum height, wood density,

² Tropical Soils Biology and Fertility Programme

leaf-thickness, leaf size, sapwood characteristics, root distributions, branching patterns etc). This database has been complemented by studies on the sensitivity of the tree component of the HyPAR model to values of each of the main parameters used Appendix III

ICRAF have contributed another Excel database to help providing parameter values to run the WaNuCas model. This includes a [simple questionnaire](#) for farmers based on simple morphological characteristics like leaf thickness and tree height.

4.5 Maintain email discussion group, newsletter, website with casestudies, manuals, workshops, tutorials etc.

There are around 150 registered users of the HyPAR model (Annex IV) and 250 users of WaNuLCAS. The project has not produced newsletters, but has maintained updated its website and maintained contact with users by email.

The 1st SAMUG workshop was organised from 30 June to 5th July 2001 in Malang, Indonesia in conjunction with ICRAF and University of Brawijaya. 30 delegates from 10 countries participated. Outputs were a) feedback from users to increase model friendliness; b) harmonisation of parameter requirements of the two models; c) initial development of soil, crop and tree parameter libraries; d) creation of CD containing all programs, datafiles and participants.

The 2nd SAMUG workshop was held in Curitiba from 4-9th November 2001. 25 Delegates from Brazil and 10 from other countries in Latin America participated (Appendix V). EMBRAPA were main local organisers. A CD was produced and participants enrolled in the usergroup. Participants modelled local crops and mixtures, including even coffee multi-strata systems. All instruction was in Portuguese or Spanish. A report on the workshop was presented on Brazilian TV.

4.6 Address key agroforestry questions in workshops:

Several key questions in agroforestry research were suggested in the project documentation (a) 'below what rainfall level is it inadvisable to conduct agroforestry'; (b) 'in what nutrient, soil and rainfall conditions is Leucaena alley-cropping advisable'; (c) 'what should be the timing and amount of green manure applied to maize crops in different soils and climates'.

These, and similar questions, have been the subject of much experimentation. Their answers depend on issues such as water use efficiency, access to deep water tables, nutrient scavenging from depths, interactions between water and nutrient limitations, use of pruning to control root growth, the decomposability of different leaf types, seasonal patterns of rainfall and drainage. They also depend on socio-economic issues such as availability of labour at key times of year, alternative uses for green-manure as forage, and the economic value of different agroforestry products.

Projects included at the Malang workshop included:

- Strategic Land Use Strategy for Sustainable Fallow System in Vietnam.
- Assessment of Light Competition in Gmelina-maize Contour Hedgerow System in the Philippine Uplands
- Intercropping of Sugarcane and Eucalyptus on ultisol in Brazil.
- Exploring the changes in run-off, water uptake and yield in Mahogany system intercropped with maize and cassava under various environmental conditions
- Feasibility of developing suitable simulation models for palms under water stress conditions.
- Different land use systems along a landscape transect in a mini-watershed.
- Carbon sequestration in agroforestry systems.
- Spatial effects of tree and maize intercropping.

Projects modelled at the Curitiba workshop included:

- Effect of grazing intensity on productivity in a silvopastoral system (including writing of a simple grazing module for WaNuLCAS).
- Interactions and competition in a multistrata agroforestry system.
- Shade trees in a coffee based system.
- Intercropping trees in sugarcane (PhD student of Meine).
- Tree crop interactions in parkland systems in Mexico.

- Cassava growth in agroforestry systems in the Amazônia region of Brazil.

4.7 Establish mechanisms to monitor dissemination and uptake of models, and assess impact on development and environment.

There has been a large uptake of the two models through training workshops and downloads from the websites. It is more difficult to demonstrate that the models have made a large impact on agroforestry research in developing countries. The OVI for this Activity was that there should be 50 model users actively applying at least one of the models to their own data by the end of project. This has been achieved, but the number of these studies appearing in the refereed literature is very much more limited. Amongst the recent applications are:

- Rowe, E.C., M. van Noordwijk, D. Suprayogo, and G. Cadisch. 2003. Measured and simulated nitrogen use efficiency in *Gliricidia* and *Peltophorum* hedgerow intercropping systems. Applied Ecology submitted.
- Rowe, E.C., M. van Noordwijk, D. Suprayogo, K. Hairiah, K.E. Giller, and G. Cadisch. 2003. Spatiotemporal uptake patterns of ¹⁵N after pruning a hedgerow intercropping system. Plant and Soil submitted.
- Didik Suprayogo: Simulation of lateral and vertical water and N movement in hedgerow intercropping systems.
- Suprayogo, D., M. van Noordwijk, K. Hairiah, and G. Cadisch. 2002. The inherent 'safety-net' of Ultisols: measuring and modelling retarded leaching of mineral nitrogen. European Journal of Soil Science 53:185-194.
- Suprayogo, D., K. Hairiah, M. van Noordwijk, K.E. Giller, and G. Cadisch. 2003. The effectiveness of hedgerow intercropping systems in reducing mineral N-leaching. European Journal of Soil Science in prep.
- Agustin Mercado (The Phillipines). Impact of Acacia mangium on intercropped crops and long-term soil fertility enhancement. PhD student.
- Yayha Abd Karim (Malaysia). New designs for rubber based systems. PhD student.
- Tee Tuan (Malaysia). Impact of intensification of pig production on environmental pollution and as an alternative organic resource for cropping systems. PhD student.

Uptake of model for successful project formulations:

- EU-INCO: Smallholder agroforestry options for degraded soils: Tree establishment in cropped fields (SAFODS). Indonesia-The Phillipines-France-Spain-UK.
- EU-INCO: 'Improved fallows by legume plants (trees, shrubs and grasses) in Eastern and Southern Africa'. Kenya-Zimbabwe-France-Belgium-UK.

4.8 Generate funding proposals using models and maintaining collaboration built in the workshops.

A major success for the HyPAR and WaNuLCAS teams was their participation in a EU funded project on 'Silvo Arable Forestry for Europe (SAFE)' which are using HyPAR and aNuLCAS as models for integrating crop and tree components but incorporating more detailed and comprehensive ideas on light interception, carbon allocation, root architecture, competition for nitrogen, soil hydrology, tree management, farm economics and upscaling to regions. A team of around 20 scientists, together with 5 extension authorities is involved in this project, and it represents an ideal strategy to ensure that the ideas developed in the AMP and SAMUG projects continue to be tested and made available to end users. More information is available on the [SAFE website](#).

5 Outputs

Planned outputs were:

1. A **revised** HyPAR model incorporating crop routines from the widely used and accepted CERES model which allows the FRP supported models to integrate directly with the large ICASA international collaborative modelling and database network.
2. An '**expert system**' to assist users to parameterise the soil, crop and tree components of the HyPAR/HyCAS/WaNuLCAS and other similar models.
3. Establishment of a combined HyPAR/HyCAS/WaNuLCAS **usergroup** supported through a project website, email-list, newsletter, and training packages containing user guides, technical manuals, tutorials, databases (soil, climate, crop, tree), graphical output macros and case studies.
4. Mid-term **workshops** in Brazil and Indonesia with additional participation from Bolivia, Costa Rica, Philippines, Vietnam, India and Nepal to collaboratively answer major questions in agroforestry.
5. Establishment of a **monitoring structure** to record the distribution and uptake of project outputs, collaboration, new proposals and long-term legacy.

Quarter	Output Milestone addressed (number)	Activity Milestone addressed (number)	ACTIVITY MILESTONES (narrative description)	Achieved?
Q1 May- June	1	1.1	Production of HyPAR v4 allowing two/three crops per year	Yes
		1.2	Produce Improved HyPAR Graphical User Interface (GUI)	Yes
	4	4.1	Preparation for first workshop (Indonesia, 1-7 July)	Done – details of both models circulated to participants
Q2 July- Sept.	1	1.1	Include Hybrid tree routines in CROPGRO and test with DSSAT/ICASA standard files.	Partially – not completed because waiting for a new (modular) version of CROPGRO and model development continued in SAFE project (with STICS crop model)
		1.2	Upgrade Delphi User Interface for use with new model.	Yes
	2.	2.2	Design databases for tree, crop, soil parameters.	Yes
	3	3.1	Establish usergroup and email support for participants at first workshop.	Yes – but continuing use of models by workshop participants is limited
	4	4.1	Hold and write up Indonesia workshop.	Yes – very successful
		4.2	Workshop presentation of socio-economic models.	Yes – two models demonstrated.
	1	1.1	Integrate CERES with Hybrid and test.	No – see above
Q3	1	1.2	Refine HyPAR Graphical Interface.	Partially – see above

Oct.- Dec.	2.	2.1	Expert system to help with parameter choice.	Yes – good for soils and crops, less information for trees
		2.2	Complete databases for tree, crop and soil parameters.	Yes
	3	3.1	Include 2 nd workshop participants in user-group, 1 st Newsletter.	Partially – users circulated with information but no newsletter
		3.2-3.4	Users model shared problems.	Yes – though workshops and emails
	4	4.1	Prepare, hold and write up 2 nd workshop.	Yes – held successfully in Brazil
	5	5.1	Monitoring of model uptake and user-group traffic.	Partially – there has been only limited uptake of models
Q4 Jan.- March	3	3.1	2 nd Newsletter. Continuing user support	No – newsletter not produced
	4	4.2	Report on integration with socio-economic models	Yes – presentations made at workshops
	5	5.1	Draft report on model uptake	Partially – model users are known
		5.2	Draft funding proposals	Yes – and SAFE project funded by the EU
		5.3	Draft final report	No – agreed postponement
Q5-7 April- December	5	5.1	Report on model uptake and usergroup success in meeting participants' objectives.	Yes – in final report
		5.2	Funding proposals to 2+ donors	Two EoIs presented to EU FP6
		5.3	Final report and drafts of 3+ scientific papers	Yes

6 Contribution of Outputs

Both models and the parameter libraries are provided to assist national and international researchers to: a) understand the complexity of their research results; b) focus on collecting new data for least-understood processes, and c) extrapolate results to environmental conditions outside those of current experiments.

The models have 300 registered users around the world. They have made a significant contribution to training and education in agroforestry, and understanding the complexity of agroforestry systems. Greater extension effort has been put into the WaNuLCAS model and successful use of this is reported in a number of scientific and popular papers, and continues to be supported by ICRAF. The HyPAR model is no longer supported by CEH and staff have moved elsewhere. However two European Union funded projects continue to develop models of agroforestry systems, and undertake experimental measurements to help parameterisation.

Both WaNuLCAS and HyPAR have grown into large models which are complex to parameterise and use. Both remain in need of significant testing, improvement of sub-models and comparison with experimental data. They also need linkage to socio-economic models and data. It doubtful that it will be worthwhile in the near future to closely-link complex biophysical models with socio-economic models of similar complexity. However biophysical modellers should be aware to the input requirements need in socio-economic models, and should focus processes and uncertainties which are most important for the end users. There remains a retain a range of modelling approaches at different levels of scale and complexity, and to periodically start developing models again using new insights.

Adaptations of both models and parameterisation techniques are being developed in EU projects which stemmed from current and previous FRP projects. The European and international collaboration developed in the EU-SAFE project is seen as a major output from the FPR's modelling effort.

7 Dissemination

7.1 Publications

Lawson, GJ., Cadisch G., Matthews, R., Mobbs, DC. & Suprayago D. 2003 Support for an Agroforestry Model User Group - Final Technical Report 77pp.

Suprayogo, D., Widiyanto, G. Cadisch, and M. van Noordwijk. 2003. A Pedotransfer Resource Database (PTFRDB) for tropical soils: test with the water balance of WaNuLCAS. Geoderma submitted.

Ong, C., M. Van Noordwijk, and G. Cadisch. 2003. Belowground Interactions in Tropical Agroecosystems with Multiple Plant Components CAB International, Wallingford.

Rowe E: Simulations of rainfall intensities, nitrogen fixation and pruning regime in maize-tree based intercropping systems. PhD Thesis Currently two papers submitted:

Rowe, E.C., M. van Noordwijk, D. Suprayogo, and G. Cadisch. 2003. Measured and simulated nitrogen use efficiency in *Gliricidia* and *Peltophorum* hedgerow intercropping systems. Applied Ecology submitted.

Rowe, E.C., M. van Noordwijk, D. Suprayogo, K. Hairiah, K.E. Giller, and G. Cadisch. 2003. Spatio-temporal uptake patterns of ¹⁵N after pruning a hedgerow intercropping system. Plant and Soil submitted.

Suprayogo, D: Simulation of lateral and vertical water and N movement in hedgerow intercropping systems. PhD Thesis. Currently two papers submitted.

Suprayogo, D., M. van Noordwijk, K. Hairiah, and G. Cadisch. 2002. The inherent 'safety-net' of Ultisols: measuring and modelling retarded leaching of mineral nitrogen. European Journal of Soil Science 53:185-194.

Suprayogo, D., K. Hairiah, M. van Noordwijk, K.E. Giller, and G. Cadisch. 2003. The effectiveness of hedgerow intercropping systems in reducing mineral N-leaching. European Journal of Soil Science in prep.

Suprayogo, D., Widiyanto, G. Cadisch, and M. van Noordwijk. 2003. A Pedotransfer Resource Database (PTFRDB) for tropical soils: test with the water balance of WaNuLCAS. Geoderma submitted

7.2 Follow up projects/proposals:

The EU-Quality of Life Project SAFE (

The EU-INCO SAFODS project will a) continue to develop tree libraries and improved tree modules to provide a wider applicability of WaNuLCAS; b) development of new tools to integrate spatial issues and livelihood criteria.

The EU-INCO IMPALA project will develop a new soil module based on measurable soil pools.

The EU-FP6 SEAMLESS³ Proposal (System for Environmental and Agro-ecological Modelling; Linking European Science and Society) will be developed focusing on biophysical and socio-economic analysis at a range of scales.

The EU-FP6 FARMTREE⁴ Proposal (Farming With Trees: a bio-economic-toolkit enhancing multi-functionality in European agriculture) will be developed by the SAFE project focusing on the non-market benefits and policy implications of agroforestry in Europe.

³ SEAMLESS is a proposed Integrated Project (led by Wageningen Agricultural University) aims at developing a framework for integrated assessment capable of dealing with urgent and interrelated problems that European agriculture, environment and land use face. The framework (SEAMLESS – System for Environmental and Agro-ecological Modelling; Linking European Science and Society) adopts a systems approach, covers the entire range of possible land use systems in Europe and facilitates an integrative bio-physical and socio-economic analysis at different scales. Present European research has insufficient capacity, is fragmented and poorly co-ordinated, and needs this integrative and new research activity. Out of the complex issues faced by the EU, we propose 3 to be examined that demonstrate the potential of the framework, i.e. enlargement of the EU; development of sustainable production systems and ideotyping and testing of new land use systems and crop varieties.

The EU-FP6 SEMAFOR⁵ Proposal (Farming with Trees for Diversified and Sustainable Management of Resources) focuses on environmental enhancement, economic viability and/or amenity improvement.

The EU-FP6 DRYRAST⁶ Proposal (Dryland Rehabilitation using Agroforestry Systems in the Tropics) focuses on the role of agroforestry in mitigating pressures on soil resources from climate change and increasing population pressure.

7.3 Promotion:

ICRAF continue to promote WaNuLCAS through workshops and conferences. Modelling workshop during SAFODS project in Phillipines. Other partners will promote the modelling approach during continuation projects.

⁴ FARMTREE is a proposed Integrated Project (led by the Centre for Ecology and Hydrology) it defines 'tree farming' as including trees planted in wide-spaced lines amongst crops or pasture; used along field boundaries, roads or streams; scattered unevenly in parkland; or established in narrow strips for as riverine buffers or shelterbelts. The 'scientific aim' of this proposal is to mobilise European expertise to quantify the environmental and economic impact of planting trees on farms and to produce a bio-economic toolkit which predicts the benefits to different stakeholders (farmers, foresters, governments) of the economic (crop and tree income, employment, grants) and environmental (carbon sequestration, fire control, water supply, nutrient- filtration, landscape diversity, biodiversity) services provided. The 'societal aim' is to stimulate a significant increase in agroforestry. The indicator is an increase, in target regions, of trees planted on working farms by 25% over a 5-year period.

⁵ SEMAFOR is a Network of Excellence led by INRA. Its premise is that many of the current intensive agricultural systems are not sustainable in the long term, which results in a search for alternative sustainable land use practices. Trees have been shown to enhance the environment. Agroforestry can be defined as the integration of forest trees and agricultural activities within a farm holding in order to contribute to environmental enhancement, economic viability and/or amenity improvement. The increased complexity of agroforestry systems requires a better integration of multidisciplinary research. The Network of Excellence will i) reinforce the links between scientists currently involved in agroforestry research, ii) facilitate the involvement of scientists who are experts in other disciplines, iii) increase and strengthen the links between scientists and end-users.

⁶ DRYRAST is a proposed Integrated Project focusing on the fact that drylands especially in Africa are suffering from pressure caused by a growing human population and livestock grazing. Soil degradation leads to increasing risks of crop failure. Global climate change contributes to these pressures. It is therefore important to provide research that supports the efforts of local researchers and extension officers to promote integrated farming systems of trees and crops which maximise farmers' revenue in poor environmental conditions. It is also important to develop an integrated modelling tool which assimilates our best knowledge of the biophysical processes controlling competition for light, water and nutrients between trees and crops in agroforestry systems, and which uses these predictions in conjunction with a model of socio-economic processes to represent farmer households and how farmers might allocate their scarce resources of land, labour and finance in selecting different management methods in response to changing food supply, market prices, climate change mitigation incentives, population density and other external pressures.

8 References

References

- Arah J & Hernandez S (1997). *Coupling forest and crop models: the Hurley Pasture and Edinburgh Forest Models*. 48-57 In: *Agroforestry Modelling and Research Co-ordination. Annual Report 95-96, DFID-FPR Project R5652*.
- Bergez JE, Etienne M & Balandier P (1997). *Always: a biophysical plot based silvopastoral model*. In: *L'agroforesterie pour un developpement rural durable*, 391-394. Atelier International, CIFOR/IUFRO, Montpellier, France.
- Bradley RG & Crout NMJ (1994). *The PARCH User Guide*. Tropical Crops Research Unit, University of Nottingham, Sutton Bonnington. 122p
- Cannell MGR, Mobbs, DC & Lawson GJ (1998). *Complementarity of light and water use in tropical agroforests. II. Modelled theoretical tree production and potential crop yield in arid to humid climates*. *Forest Ecology and Management*, 102: 275-282.
- Coe, R (1999). *Researching multistrata agroforestry systems: diversity for progress*. *Proceedings of an International Symposium on 'Multi-strata agroforestry systems with perennial crops' held at CATIE, Turrialba, Costa Rica February 22-27 1999*. 2-5.
- Conijn JG (1995). *RECAFS: a model for resource competition and cycling in agroforestry systems: Model Description and User Manual*. *Rapports PSS No 12*. AB-DLO, Wageningen, The Netherlands,
- France J. and Thornley J.H.M.(1984) *Chapter 3 Techniques: Mathematical Programming, Mathematical Models in Agriculture* Butterworths London p37-68
- Friend AD, Stevens, AK, Knox RG, Cannell, MGR (1997). *A process-based terrestrial biosphere model of ecosystem dynamics (Hybrid v3.0)*. *Ecological Modelling* 95 (2-3), 249-287.
- Hunt, L. A. et al. (1998). *Data for model operation, calibration, and evaluation*. . In: Tsuji, G.Y. et al.(eds.), *Understanding Options for Agricultural Production*. Kluwer Academic Publishers, Boston. pp. 9-39.
- Jagtap S & Ong, C (1997). *Perspectives on issues, needs, and opportunities for agroforestry models*. *Agroforestry Forum* 8(2): 2-4
- Jones J.W. et al. 1998. *Decision support system for agrotechnology transfer: DSSAT v3*. In: Tsuji, G.Y. et al. (eds.), *Understanding Options for Agricultural Production*. Kluwer Academic Publishers, Boston. pp. 157-177.
- Lott JE, Black CR & Ong CK (1998). *Comparison of output from HyPAR with observed maize yields in CIRUS*. *Report to DFID-FRP from Nottingham University (R5810)*. 45p. Sutton Bonnington.
- Matthews RB & Hunt LA (1994). *GUMCAS: a model describing the growth of cassava (Manihot esculenta L. Crantz)*. *Field Crops Research* 36: 69-84.
- Matthews RB & Lawson GJ (1997). *Structure and applications of the HyCAS model*. *Agroforestry Systems* 8(2): 14-17.
- Mobbs DC, Cannell MGR, Crout NMJ, Lawson GJ, Friend AD & Arah J (1998). *Complementarity of light and water use in tropical agroforestry. 1. Theoretical model outline, performance and sensitivity*. *Forest Ecology and Management* 102: 259-274.
- Nelson RA, Cramb RA Menz KM & Mamicpic MA (1998). *Cost-benefit analysis of alternative forms of hedgerow intercropping in the Philippine uplands*. *Agroforestry Systems* 39: 241-262.
- Ong CK, Corlett JE, Singh, RP & Black CR (1991). *Above and below ground interactions in agroforestry systems*. 45-58. In: *Agroforestry: principles and practice*, Jarvis PG (ed). Elsevier.
- Scherr SJ (1995). *Economic analysis of agroforestry systems: the farmer's perspective*. In: *Costs, Benefits, and Farmer Adoption of Agroforestry - Project Experience in Central America and the Caribbean*. CATIE-IFPRI-World Bank Project.
- Thomas TH & Willis RW (1999). *Integrating biophysical and spreadsheet economic models of agroforestry*. *Report to DFID-FRP Agroforestry Modelling Project from UCNW (available through www.nmw.ac.uk/ite/edin/agro)*.
- Thornley JHM & Cannell MGRC (1996). *Temperate forest responses to carbon dioxide, temperature and nitrogen: a model analysis*. *Plant, Cell and Environment* 19: 1331-1348.
- Thornley JHM & Verberne ELJ (1989). *A model of nitrogen flows in grassland*. *Plant, Cell and Environment* 12: 863-886.

Thornton PK, Dent JB & Caldwell RM (1990). Applications and issues in the modelling of intercropping systems in the tropics. *Agriculture, Ecosystems and Environment* 31: 133-146.

van Noordwijk M & Lusiana B (1999). WaNuLCAS 1.2. Background to a model of water nutrient and light capture in agroforestry systems. Working Document, ICRAF, Bogor, Indonesia.

Young A & Muraya P (1990). Soil Changes Under Agroforestry. Computer program with user's handbook. Version 2. ICRAF: Nairobi.

9 Appendix I: Report on Crop Parameterisation Issues.

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9.1 Summary

A library of crop parameters supplied with the DSSAT v4.5 crop modelling package was created in Excel. Separate sheets with parameters for maize, wheat, barley, rice, sorghum, millet, soybean, groundnut, chickpea, bean and cassava were included. A user interface for the Excel database was then developed in Delphi to facilitate manipulation of the parameter data (i.e. inputting, modifying, deleting parameter values) and to aid selection of appropriate parameters. Users can select crop and genotype information and the interface calculates phenology parameters given information on crop growth rates. A Delphi interface program to the crop parameter library has also been developed to provide access from crop models such as HyPAR and HyCAS. A household socio-economic model is also described.

9.2 Aims of the work

The Terms of Reference read “**Cranfield** will develop a database of crop parameters and associated accessing software suitable for use with the HyPAR, HyCAS and WaNuLCas models. The database structure will follow ICASA guidelines for compatibility with international crop parameter databases. ICASA (International Consortium for Agricultural Systems Applications) emerged from the combination of two large projects involved in the use of systems analysis techniques in agricultural research - the IBSNAT and SARP projects. The IBSNAT (International Benchmark Sites Network for Agrotechnology Transfer) project emphasised a systems approach for technology transfer, a research user-oriented package referred to as DSSAT (Decision Support System for Agrotechnology Transfer, Jones & et al., 1998), minimum data set concepts (Hunt & et al., 1998), and training for adoption and use of crop models and DSSAT for research purposes. The SARP (Systems Analysis for Rice Production) approach emphasised the training of participants on understanding the mechanisms in rice production systems for model development and application for specific purposes. Several other research networks (e.g. GCTE - Global Change in Terrestrial Ecosystems) are starting to use the data standards documented by ICASA. Providing a link between these databases and the HyPAR, HyCAS and WaNuCas models will help ensure the international uptake and use of the models.”

9.3 Parameter library

A library of parameters was constructed using the crop parameters supplied with the DSSAT v3.5 crop modelling package. For ease of use and editing by users, it was decided to do this in Excel. The database consisted of a single Excel file (‘Crop parameters.xls’) with separate sheets for each crop. A single file allows easier handling compared to separate files for each crop as the original DSSAT package uses. Parameters for maize, wheat, barley, rice, sorghum, millet, soybean, groundnut, chickpea, bean and cassava were included. The structure of each page followed closely the standardised format defined by the ICASA documentation (Hunt *et al.*, 1994).

This can be summarised briefly as follows. Rows within a spreadsheet page may be of four types:

- a. a title row, denoted with a * (asterisk) in the first cell (‘A1’) of the page.
- b. a header row, (denoted with an @ symbol as the first character located in column A) and the row before the parameter data begins. Each cell in the row must contain an unique identifier (up to 10 characters in length) for each of the columns containing parameter data later on. Rows before the header row are not treated as parameter data rows.
- c. a comment row, denoted with an ! (exclamation mark) as the first character, and located in column A of any row within the spreadsheet.

- d. parameter data rows, containing alphanumeric data. These must occur after the header (@) row with each data row representing parameter data for a single crop genotype. The number of cells in each row containing data must correspond to the number of cells in the header line containing the parameter identifier. Data in columns without a parameter identifier will be ignored.

9.3.1 Parameter descriptions

Descriptions of each parameter are stored in the cells below the title row of each crop sheet, but before the cells containing the parameter identifiers denoted by an '@' symbol in the first position. These descriptions can be strings of any length to help the user to know what each parameter represents, and appear as hints when the cursor is placed over the parameter codes on the bottom of the form. In general, these are the same parameter descriptions that are at the top of most of the DSSAT genotype files, but the user is free to modify these if desired. In addition, the cells in the database containing these descriptions must be coloured as specified by the ParameterDescriptorColor parameter in the GUMPARAM1.INI file. The GUMPARAM1 program searches for cells of this colour in each sheet when loading the parameter descriptions. By default, this colour is yellow (\$0000:FFFF), but if a different colour is preferred, then the ParameterDescriptorColor parameter in the GUMPARAM1.INI file must be altered or else the program will not be able to locate any parameter descriptions.

An example of these parameter descriptions for maize is given in Figure 1.

VAR#	Identification code or number for a specific cultivar
VAR-NAME	Name of cultivar
ECO#	Ecotype code or this cultivar, points to the Ecotype in the ECO file (currently not used).
P1	Thermal time from seedling emergence to the end of the juvenile phase (expressed in degree days above a base temperature of 8°C) during which the plant is not responsive to changes in photoperiod.
P2	Extent to which development (expressed as days) is delayed for each hour increase in photoperiod above the longest photoperiod at which development proceeds at a maximum rate (which is considered to be 12.5 hours).
P5	Thermal time from silking to physiological maturity (expressed in degree days above a base temperature of 8°C).
G2	Maximum possible number of kernels per plant.
G3	Kernel filling rate during the linear grain filling stage and under optimum conditions (mg/day).
PHINT	Phylochron interval; the interval in thermal time (degree days) between successive leaf tip appearances.

Figure 1: Example of the parameter descriptors for maize. Names on the left are the parameter identifiers used at the top of each column in the database.

9.3.2 Default genotype group parameter values

For each crop, default genotype groups may be specified. In general, these are the same groups that are given in most of the ICASA genotype files, but the user is free to modify these if desired. In addition, the cells in the database containing the parameter values for these groups must be coloured as specified by the DefaultsColor parameter in the GUMPARAM1.INI file. The GUMPARAM1 program searches for cells of this colour in each sheet on first entering it. By default, this colour is silver (\$00C0:C0C0), but if a different colour is preferred, then the DefaultsColor parameter in the GUMPARAM1.INI file must be altered or else the program will not be able to locate any default genotype groups.

9.4 User interface to the crop parameter library

A user interface for the Excel database was developed in Delphi to facilitate manipulation of the parameter data (i.e. inputting, modifying, deleting parameter values) and to aid selection of appropriate parameters. This is a stand-alone EXE file called GUMPARAM1.EXE, and requires the 'Crop parameters.xls' file to be present in order to run.

9.4.1 Main screen

On starting, GUMPARAM1 displays a main screen with a number of panels (see Figure 2). In many cases, hints are given about the function of different components on the main screen by resting the cursor for a few seconds on the particular component. A brief description of each of these panels is given in Table 2.

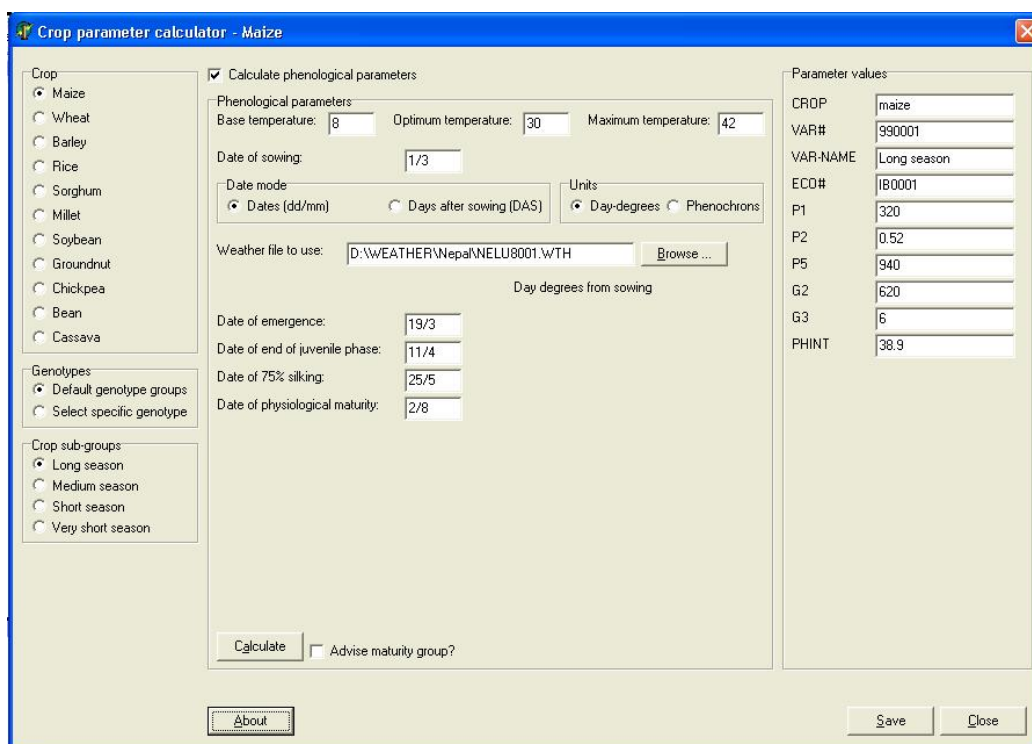


Figure 2: The main screen of GUMPARAM1.

Table 2: Panels on the main screen and their descriptions.

Panel name	Description
Crop	Radio button box used to select the desired crop species
Genotype	Radio button box used to select whether to use default genotype parameter values or whether to select specific genotypes.
Crop sub-groups	Radio button box used to select a particular sub-group of genotypes if the 'Default genotype groups' option was selected in the 'Genotype' panel.
Select existing genotype	Drop-down combo box used to select a particular genotype if the 'Select specific genotypes' option was selected in the 'Genotype' panel.
Phenological parameters	Used to calculate phenological parameter values from observed data (i.e. dates of specific crop stages and recorded weather data). This can also be used to advise which maturity group a particular genotype may belong to. At present this facility is only available for maize.
Parameter values	Contains parameter values for the specified crop genotype. These can also be edited manually and saved to the Excel database.

9.4.1.1 Selecting a crop

Crops are selected by clicking the appropriate button in the 'Crop' radio button box. As soon as this is done, GUMPARAM1 switches to the appropriate spreadsheet page in the Excel database, extracts the parameter

descriptions, default parameter values, and a list of available genotypes for that crop. Parameter identifiers and values are displayed in the 'Parameter values' panel on the right of the main screen.

9.4.1.2 Selecting a genotype

It is possible to select either default genotype groups or specific genotypes present in the Excel database by clicking the appropriate button in the 'Genotypes' radio button box.

In the first case, if the 'Default genotype groups' option is selected, any genotype groups specified in the spreadsheet page (in cells shaded with the colour specified by the DefaultsColor parameter in the GUMPARAM1.INI file) are displayed in the 'Crop sub-groups' radio box on the left of the main screen. Any one of these groups can be selected at a time, and the appropriate crop parameters will be displayed in the 'Parameter values' panel at the right of the screen.

If the 'Select specific genotype' option is selected, a drop-down combo box appears containing the names of all available genotypes for that crop. Any one of these genotypes can be selected at a time, and the appropriate crop parameters will be displayed in the 'Parameter values' panel at the right of the screen.

9.4.1.3 Calculating phenological parameter values

Sometimes a user may have data on a specific crop genotype they have been using in their experiments, and want to calculate the appropriate parameters from this data for use with a crop model. A facility for calculating phenological (crop development) parameters from observations of the dates of crop stages and the associated weather data is provided in the 'Phenological parameters' panel of GUMPARAM1.

Before using this facility, it is necessary to ensure that the 'Calculate phenological parameters' checkbox is checked (i.e. there is a or a shown in the checkbox, depending on the operating system, rather than being blank). If the checkbox is blank, the 'Phenological parameters' panel will be inactivated and will appear in faint outline only.

Firstly, the cardinal temperatures (i.e. the base temperature, T_{base} ; the optimum temperature, T_{opt} ; and the maximum temperature for crop development, T_{high}) for the crop must be entered. All temperatures are in °C. By default, these are 8°C, 30°C and 42°C, which are typical for many tropical crops, including maize. However, any of these can be changed by editing the appropriate value.

Next, the date of sowing must be specified in the format dd/mm, where dd is the day of the month, and mm is the month of the year. For example, March 1 would be entered as 1/3. It is not necessary to specify a year, as this is taken to be the year of the weather data that is provided (see below).

Next, the date mode must be selected. This allows the user to specify the times of particular crop stages (e.g. flowering, maturity, etc.) as either absolute dates (in the same format as described above for the date of sowing), or as relative days after sowing. For example, for a sowing date of March 1, the time of emergence on March 19 could be represented either as 19/3 or as 18 days after sowing.

Next, the user must select whether he/she wants the parameter values to be in day degrees (°Cd) or as phenochrons (sometimes called phenological days). Most of the DSSAT models use °Cd, and the default mode is set to this. However, some models use phenochrons (a phenochron is a fixed unit of crop development defined as the increment in development occurring over a day at the optimum temperature and photoperiod) and so it is useful to have the option for the parameter values to be displayed in this unit.

Next the user must specify a valid weather data file. This weather file must be in the format defined by the ICASA standards⁷ (Hunt *et al.*, 1994). Further details of the format can be found in these publications. An example of the first few lines of an ICASA weather file is shown in Figure 3. The Browse button can be clicked to allow the user to locate a weather file to use in the same or another directory.

*WEATHER DATA: Lumle Agricultural Research Station, Pokhara, Nepal

⁷ See also Hunt *et al.*, 2000. 'ICASA files for experimental and modelling work', online at <http://icasanet.org/standards/index.html>

```

! Converted from Excel file "d:\weather\nepal\Nepal-Lumle met data 1970-97.xls" on 24/10/00 at
17:36:51

! SRAD data converted from sunshine hours using A=0.25 and B=0.5

! MNVP data converted from relative humidity data

@ INSI      LAT      LONG      ELEV      TAV      AMP
  NELU      28.28    83.82    1675     -99.     -99.

@DATE  SRAD  TMAX  TMIN  RAIN  EVAP  MNVP  WIND  ACO2
80001  13.5  13.0  4.0  0.0  1.3  0.73  73.0  -99.
80002  15.6  13.0  4.9  0.0  1.9  0.94  101.0 -99.
80003  15.6  12.8  4.0  0.0  1.6  0.83  64.0  -99.

```

Figure 3: First few lines of a weather file in ICASA format.

Finally, the user must enter the dates (or days after sowing if that model is selected, see above) of key stages in the development of the crop (emergence, end of the juvenile phase, 75% silking, physiological maturity, for maize). All, some or none of these dates may be entered, only those with valid values entered will be used in the calculations. Dates must be entered in the same dd/mm format as described above, while days after sowing must be a valid integer value.

If all the fields have been filled in correctly, pressing the ‘Calculate’ button results in calculation of the phenological time from sowing based on the measured temperature data in the specified weather file. Depending on the units chosen (see above), this phenological time will be in day degrees or phenochrons. If the units used are day degrees, some of the calculated values can be entered in the appropriate edit boxes in the ‘Parameter values’ panel at the right of the screen. For example, P1 is the thermal time from sowing to the end of the juvenile phase, and P5 is the thermal time from 75% silking to physiological maturity (to obtain the correct value for this, it would be necessary to subtract the thermal time at 75% silking from the thermal time at physiological maturity, as the accumulated values of thermal time since sowing are calculated).

If the user wants some guidance as to which maturity group his/her particular variety falls into (for example, to obtain appropriate values for parameters other than the phenological parameters), the ‘Advise maturity group?’ checkbox should be checked. This time, on clicking the ‘Calculate’ button, a dialog box appears advising the user which maturity group his/her genotype matches the closest. The option to use the parameters for this maturity group in the ‘Parameter values’ panel is also given.

At present this facility to calculate crop phenology parameters only exists for maize. It is hoped to add this functionality to the other crops at a later date.

9.4.1.4 Editing parameter values

The user can edit any of the parameter values displayed in the edit boxes of the ‘Parameter values’ panel on the right of the main screen. This is done by clicking the appropriate box to position the cursor in it, and typing in the desired value. Any changes are detected, and the user will be prompted as to whether these changes should be saved on changing to a new genotype, or on exiting from GUMPARAM1 (see below).

New parameters for a given crop cannot be added via the GUMPARAM1 interface, and must be added manually to the database. However, any modifications made in this way should be detected by GUMPARAM1 and displayed in the ‘Parameter values’ panel the next time it runs.

9.4.1.5 Saving parameter values to the Excel database

The parameter values in the edit boxes of the ‘Parameter values’ panel on the right of the main screen can be saved to the Excel database by clicking the ‘Save’ button at the bottom right of the screen. If the genotype (as defined by the VAR# parameter) already exists in the database, the user is prompted as to whether the values displayed should overwrite the existing values. If the genotype doesn’t exist in the database, the user is prompted as to whether it should be added. If ‘Yes’ is clicked, the values displayed are written to the row after the last row of existing parameter values.

9.4.1.6 Exiting from the GUMPARAM1 database interface

Exiting from the GUMPARAM1 database interface is by clicking the ‘Close’ button on the bottom right of the main screen. If any of the displayed parameter values have been changed, the user will be prompted as to whether these are to be saved to the Excel database or not.

9.4.2 *Initialisation file*

GUMPARAM1 also has an initialisation file called GUMPARAM1.INI containing basic information that the program needs to run. On starting up, GUMPARAM1 reads this file and configures itself according to the settings of the parameter values in the file. On closing, it also saves the current settings. At present, there is little scope for the user to alter these parameter settings from within GUMPARAM1, which must be done by manually editing the initialisation file using a text editor such as NotePad. For example, if so desired, the name of the Excel database file could be changed by setting the ParameterFileName equal to another existing file.

Table 3: List of parameter names in the GUMPARAM1.INI initialisation file, their descriptions, and default values.

Parameter name	Description	Default value
ParameterFileName	Name of the Excel crop parameter library file.	Crop parameters.xls
WeatherFileName	Name of the default weather file used in the phenology calculator facility.	D:\WEATHER\Nepal\NELU8001.WTH
DefaultTbase	Default base temperature (°C) used in the phenology calculator facility.	8
DefaultTopt	Default optimum temperature (°C) used in the phenology calculator facility.	30
DefaultTmax	Default maximum temperature (°C) used in the phenology calculator facility.	42
ParameterDescriptorColor	Colour code used for the parameter descriptors on each spreadsheet page.	65535 (yellow)
DefaultsColor	Colour code used for the default genotype sub-group parameters on each spreadsheet page.	12632256 (silver)
DefaultCropAtStartUp	Crop to display on starting GUMPARAM1.	maize

9.5 *Model access to the crop parameter library*

An interface program in Delphi is also currently being developed to provide access to the Excel crop parameter library by the crop models (particularly HyPAR and HyCAS). This is being done by creating a dynamic linked library (DLL) providing simple routines that can be called by the crop model program, irrespective of the programming language it is written in. Thus, the calling program will only need to specify the crop species, and genotype ID code, and the interface will return a variable length string containing the required parameter values separated by semi-colons in the form (for a maize genotype)

```
CROP=maize; VAR#=99001; VAR-NAME='Long season'; ECO#=IB0001; P1=320; P2=0.52; P5=940; G2=620; G3=6; PHINT=38.9
```

which the calling program will need to decode to obtain the correct parameter values. Passing the parameters as a variable length string is necessary as each crop has a different number and type of parameters.

9.6 Socio-economic modelling

A framework for socio-economic modelling has been developed, and a prototype model implementing this framework is being constructed using concepts from the WaLNuCAS, HyPAR, and other models. The approach has focused on processes occurring at the household level rather than the individual commodity level, and includes the biophysical processes of crop, weed, tree and animal growth, water, carbon and nitrogen fluxes through the farm, as well as economic and labour flows. Household reserves, such as food, money, milk, fodder, seed, manure and fertiliser are also incorporated. Flows of these resources between different components of the farm are controlled by farmer activities, which are the result of decisions that the household makes based on its own internal state and its perception of the outside world. The model, therefore, incorporates elements of the natural, human and financial capitals in the Sustainable Livelihoods framework. Various types of household can be accommodated, ranging from resource-poor to resource-rich. A field associated with the household may have a number of crops, trees and weeds growing in it simultaneously, thereby simulating an agroforestry system. The model will be used in the first instance to evaluate potential agroforestry interventions in existing systems and the likelihood of uptake of these interventions, using criteria such as their contribution to household finances, food production, alleviation of risk, and labour demands in relation to other farm enterprises (e.g. is there a conflict of labour between pruning trees and harvesting of the main crop rice?). The underlying question in each case will be 'Does it make sense to the farmer to adopt this new technique?'

9.7 References

- Hunt, L.A. & et al., 1998. Data for model operation, calibration, and evaluation. In: G.Y. Tsuji, G. Hoogenboom & P.K. Thornton (Editors), *Understanding Options for Agricultural Production. Systems Approaches for Sustainable Agricultural Development*. Kluwer Academic Publishers, Dordrecht, Netherlands, pp. 9-39.
- Hunt, L.A., Jones, J.W., Hoogenboom, G., Godwin, D.C., Singh, U., Pickering, N., Thornton, P.K., Boote, K.J. & Ritchie, J.T., 1994. General input and output file structures for crop simulation models. In: P.F. Uhlir & G.C. Carter (Editors), *Crop Modelling and Related Environmental Data*. CODATA, Paris, pp. 35-72.
- Jones, J.W. & et al., 1998. Decision support system for agrotechnology transfer: DSSAT v3. In: G.Y. Tsuji, G. Hoogenboom & P.K. Thornton (Editors), *Understanding Options for Agricultural Production. Systems Approaches for Sustainable Agricultural Development*. Kluwer Academic Publishers, Dordrecht, Netherlands, pp. 157-177.

10 Appendix II: Report on use of existing data to test “pedotransfer functions” for tropical soils

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10.1 Abstract

Soil water balance models generally require input parameters that are not available without considerable measurement efforts. Pedo Transfer Function's (PTF's) have been developed that predict relationships for θ -h-K relationships employing the measured percentages of clay, silt, organic matter content, and bulk density in temperate soils. However, as they are empirical, these PTF's may give erroneous, or even completely absurd predictions when used outside the range of soils from whose data they were derived. In tropical region, we believe that much work has already been invested in input and output parameters of PTF's, but those data has not yet been fully systematically recorded and then tested to PTF's. The objective of this study was to test the validity of general PTF's developed by Wosten *et al.* (1998) for “tropical” soil. Soil bulk density and clay content were the most important input parameters a PTF user needs to obtain valid results for the relations between soil water content (θ), water retention (h) and hydraulic properties (K). We obtained a satisfactory agreement between field observations and simulations on water retention for “tropical” soils and unsaturated hydraulic conductivity measured in ring samples boundaries for Ultisol. Water flow properties from ring samples and PTF, however, do not fully cover field behaviour, as they do not include macro-pore flow. The lack of hydraulic conductivity data is a very serious limitation on testing the PTF's in tropical soils.

10.2 Introduction

Soil water balance models generally require input parameters that are not available without considerable measurement efforts. Pedo Transfer Function's (PTF's) have been developed that derive soil water functional properties from more readily available parameters. Data sets underlying these functions largely consist of temperate soils. However, as they are empirical, these PTF's may give erroneous, or even completely absurd predictions when used outside the range of soils from whose data they were derived. Hodnett and Tomasella (2001) reported that the majority of “tropical” soils have finer texture class (clay, sandy clay and silty clay) than “temperate” soils. These differences have major implications for the use of PTF's derived for temperate soils if applied to the tropical soils.

In tropical region, we believe that much work has already been invested in the direct measurement on the soil conductivity and retention functions, but the potential of PTF's has not yet been fully explored. Some PTF's models have already been developed such as the Brooks-Corey (1964), Campbell (1974, 1985), Mishra *et al* (1989), PARCH- Van Genuchten (Arah, 1997?), Rawls and Brakensiek (Rawls *et al* , 1991), Tomasella and Hodnett (1998) and Wosten *et al.* (1998). Those PTF's predict relationships for water content (θ), water retention (h) and hydraulic properties (K) employing, for example, the measured percentages of clay, silt, organic matter content, and bulk density. To develop ‘pedotransfer function’ for tropical soil, we will use continuous PTF's (Wosten *et al.*, 1998) and then we go on to test θ -h predictions obtained using these PTF's against independently –measured θ -h data from wide range of tropical soils.

The objective of this project is to (1) to test the existing ‘pedotransfer functions’ against independently –measured water content (θ), water retention (h) and hydraulic properties (K) data from a wide range tropical soils. In particular search available Asian databases and combine with existing ones to derive a set or various sets of pedotransfer functions valid for a wide range of soils and for the different models

10.3 Material and methods

10.3.1 Theory of pedotransfer functions

Soil water balance models require a number of soil water relationships: the moisture retention curve, giving the relation between volumetric soil water content (θ) and pressure head (h) and that between hydraulic conductivity (K) and pressure head or water content.

To predict these input parameters, continuous PTF's (Table 4), developed by Wösten *et al.* (1998), were used to parameterise the hydraulic equations of van Genuchten (1980)

$$\theta(h) = \theta_r + \frac{\theta_s - \theta_r}{\left(1 + |\alpha h|^n\right)^{1-1/n}} \quad (1)$$

$$K(h) = K_s \frac{\left(\left(1 + |\alpha h|^n\right)^{1-1/n} - |\alpha h|^{n-1}\right)^2}{\left(1 + |\alpha h|^n\right)^{\left(1-1/n\right)(l+2)}} \quad (2)$$

where:

- $\theta(h)$: volumetric soil-water content as function of the hydraulic head or matric potential ($\text{cm}^3 \text{cm}^{-3}$)
- θ_r : residual volumetric soil-water content where the gradient $d\theta/dh$ become zero ($h \rightarrow -\infty$) or the soil water content ($\text{cm}^3 \text{cm}^{-3}$) at some large negative value of pressure head
- θ_s : saturated (s) volumetric soil-water content ($\text{cm}^3 \text{cm}^{-3}$)
- $K(h)$: soil hydraulic conductivity as function of the pressure head (cm day^{-1})
- K_s : saturated soil hydraulic conductivity (cm day^{-1})
- h : hydraulic head (cm)
- α : parameter describing the shape of the curve. This parameter approximately equals the inverse of the pressure head at the inflection point where $d\theta/dh$ has its maximum value, and defines the extent of the first, almost flat, part of the curve from saturation (cm^{-1})
- l : dimensionless parameter that determines the slope of the hydraulic conductivity curve in the range of more negative values of soil hydraulic head (h)
- n : dimensionless parameter that determines the rate at which the s-shaped retention curve turns towards the ordinate for large negative values of h , thus reflecting the steepness of the curve.

Table 4 Continuous PTF's for the prediction of θ - h - K relationships in temperate soils of the Netherlands and UK (after Wösten *et al.*, 1998).

$$\theta_s = 0.7919 + 0.00169*Cl - 0.29619*BD - 0.00000149 Si^2 + 0.0000821 OM^2 + 0.02427/Cl + 0.01113/Si + 0.01472*Ln(Si) - 0.0000733*OM*Cl - 0.000619*BD*Cl - 0.001183*BD*OM - 0.0001664*TS*Si$$

$$K_s = \text{Exp}(7.755 + 0.0352*Si + 0.93*TS - 0.967*BD^2 - 0.000484*Cl^2 - 0.000322*Si^2 + 0.001/Si - 0.0748/OM - 0.643*Ln(Si) - 0.01398*BD*Cl - 0.1673*BD*OM + 0.02986*TS*Cl - 0.03305*TS*Si)$$

$$\alpha = \text{Exp}(-14.96 + 0.03135*Cl + 0.0351*Si + 0.646*OM + 15.29*BD - 0.192*TS - 4.671*BD^2 - 0.000781*Cl^2 - 0.00687*OM^2 + 0.0449/OM + 0.0663*Ln(Si) + 0.1482*Ln(OM) - 0.04546*BD*Si - 0.4852*BD*OM + 0.00673*TS*Cl)$$

$$l = ((10*(\text{Exp}(0.0202 + 0.0006193*Cl^2 - 0.001136*OM^2 - 0.2316*Ln(OM) - 0.03544*BD*Cl + 0.00283*BD*Si + 0.0488*BD*OM)) - 10) / (1 + (\text{Exp}((0.0202 + 0.0006193*Cl^2 - 0.001136*OM^2 - 0.2316*Ln(OM) - 0.03544*BD*Cl + 0.00283*BD*Si + 0.0488*BD*OM))))$$

$$n = \text{Exp}(-25.23 - 0.02195*Cl + 0.0074*Cl - 0.194*OM + 45.5*BD - 7.24*BD^2 + 0.0003658*Cl^2 + 0.002885*OM^2 - 12.81/BD - 0.1524/Si - 0.01958/OM - 0.2876*Ln(Si) - 0.0709*Ln(OM) - 44.6*Ln(BD) - 0.02264*BD*Cl + 0.0896*BD*OM + 0.00718*TS*Cl) + 1$$

Cl is percent clay (i.e. percent < 2 μm); Si is percent silt (i.e. percent 2 μm < Cl < 50 μm); OM is percent organic matter; BD is bulk density (g cm⁻³); TS is a switch, with a value of 1 for topsoil and 0 for subsoil; Ln is the natural logarithm.

10.3.2 The data

Data used in this study were taken from the Indonesian-soil database collected by Center for Soil Agroclimate Research, Bogor, and some unpublished research that available in Soil Science Department, Brawijaya University, Soil Science Department Gajah Mada University, and Soil Science Department, Bogor Agriculture Institute. Soil data base were collected by Hodnett and Tomasella (1999) (that originally from two databases, WISE and IGBP-DIS), from Oak Ridge National Laboratory, Distributed Active Archive Center (ORNL DAAC), and from The Woods Hole Research Center (WHRC) were used also for this study. The soil data base were used to obtain (1) input parameters for PTF's (bulk density, soil texture and soil organic matter contents), and (2) output parameter for PTF's (volumetric soil water content at different pressure head) and then to test their relationship between measured volumetric soil water content and predicted by the PTF's at different pressure head.

After the initial selection of "tropical" soils, the data for those soil horizons with volumetric soil water content at different pressure head were extracted. In most cases, 5 points, including saturation and 'wilting point' (pF 0, 1, 2, 2.5 and 4.2), were available to test the predicted by the PTF's. In some cases there were available of volumetric soil water content at 7 points pressure head (pF 0, 1, 1.5, 2, 2.5, 3, 4.2). After this sorting, the data available were reduced to just 1815 horizons from 988 soil profiles in 24 countries. Details of the data extracted are shown in Table 5.

Table 5 “Tropical” soils data from several data base (see § 2.2), by soil texture classes within soil types, and their country distribution

Soil Taxonomy	Class texture	Number of pedons	Number of soil layers	Source of Country (no of pedon/ no of soil layers in each country)
Alfisols	Clay	36	89	Indonesia (19/59), Brazil (4/8), Ecuador (2/3), Mozambique (1/1), Jamaica (1/1), Kenya (2/3), Peru (1/2), Nicaragua (2/6), China (2/4), Nigeria (1/1), Puerto Rico (1/1)
	Silty Clay	10	18	Indonesia (6/10), Kenya (1/1), Nicaragua (1/1), China (1/1), Puerto Rico (1/5)
	Sandy Clay	3	3	Brazil (2/2), Nigeria (1/1)
	Clay Loam	13	16	Indonesia (9/11), Ivory Coast (1/1), Brazil (1/1), Peru (1/1), China (1/2)
	Silty Clay Loam	6	12	Indonesia (2/7), China (1/2), Jamaica (1/1), Kenya (1/1), Puerto Rico (1/1)
	Slity Loam	3	5	Indonesia (3/5)
	Sandy Clay Loam	10	11	Indonesia (2/2), Brazil (3/3), Mozambique (1/1), Ivory Coast (1/2), China (1/1), Nigeria (2/2)
	Loam	5	13	Indonesia (3/11), Brazil (1/1), Peru (1/1)
	Sandy Loam	6	8	Brazil (1/1), Kenya (1/2), Peru (1/2), China (1/1), Nigeria (2/2)
	Loamy Sand	2	3	Brazil (1/1), Kenya (1/2)
Andisols	Clay	2	2	Indonesia (1/1), Colombia (1/1)
	Clay Loam	5	5	Indonesia (5/5)
	Silty Clay Loam	5	7	Indonesia (4/6), Colombia (1/1),
	Silty Loam	8	14	Indonesia (7/11), Hawaii (1/3)
	Sandy Clay Loam	3	3	Indonesia (3/3)
	Loam	13	20	Indonesia (11/17), Nicaragua (1/2), Hawaii (1/1)
	Sandy Loam	7	12	Indonesia (5/9), Colombia (1/2), Nicaragua (1/1)
	Loamy Sand	2	3	Indonesia (1/1), Nicaragua (1/2)
	Sand	2	5	Indonesia (1/5), Hawaii (1/1)
Aridisols	Clay	1	2	Mali (1/2)
	Sandy Clay Loam	3	4	Mali (2/2), Kenya (1/2)
	Sandy Loam	1	3	Kenya (1/3)
	Loamy Sand	2	3	Mali (1/2), Kenya (1/1)
Entisols	Clay	19	37	Indonesia (19/37)
	Slity Clay	6	8	Indonesia (5/7), Mali (1/1)
	Clay Loam	4	6	Indonesia (4/6)
	Silty Loam	12	15	Indonesia (7/9), Mali (1/1), Ecuador (1/1), Colombia (1/2), Nicaragua (1/1), China (1/1)
	Slity Clay Loam	4	4	Indonesia (2/2), Ecuador (1/1), China (1/1)
	Loam	9	17	Indonesia (5/7), Ecuador (2/2), Peru (1/6), Nicaragua (1/2)

Soil Taxonomy	Class texture	Number of pedons	Number of soil layers	Source of Country (no of pedon/ no of soil layers in each country)
Entisols	Sandy Loam	21	43	Indonesia (16/35), Kenya (1/3), Zambia (1/1), Peru (2/3), Colombia (1/1)
	Loamy Sand	9	16	Indonesia (5/11), Ecuador (1/1), Peru (2/3), Costa Rica (1/1)
	Sand	12	24	Indonesia (4/8), Mali (1/1), Brazil (1/2), Malaysia (2/3), Peru (3/7), Nigeria (1/3)
Histosols	Silty Clay	1	1	Indonesia (1/1)
Inceptisols	Clay	85	171	Indonesia (62/128), Brazil (2/5), Ecuador (1/1), Sri Langka (1/8), Cuba (5/10), Peru (3/7), Philippine(2/2), Nicaragua (1/1), Costa Rica (1/3), China (5/12), Puerto Rico (2/2)
	Silty Clay	27	38	Indonesia (24/33), Philippine (2/4), Costa Rica (1/1)
	Sandy Clay	4	6	Indonesia (3/5), Peru (1/1)
	Clay Loam	42	77	Indonesia (29/57), Peru (4/10), Cuba (1/1), Philippines (2/2), China (3/4), Costa Rica (1/1), Puerto Rico (2/2)
	Silty Clay Loam	24	37	Indonesia (20/30), Philippine (3/5), Costa Rica (1/2)
	Silty Loam	22	33	Indonesia (18/25), Brazil (1/1), Ecuador (1/1), Rwanda (1/5), Costa Rica (1/1)
	Sandy Clay Loam	24	39	Indonesia (17/29), Ecuador (1/1), China (1/1), Sri Langka (2/3), Peru (3/5)
	Loam	42	67	Indonesia (24/36), Brazil (1/2), Ecuador (5/11), China (1/1), Peru (4/6), Cuba (3/3), Colombia (1/3), Costa Rica (1/2), Puerto Rico (2/3)
	Sandy Loam	35	63	Indonesia (20/34), Brazil (1/1), Ecuador (4/7), Ivory Cost (1/3), Sri Langka (2/6), Peru (3/5), Costa Rica (3/6), Puerto Rico (1/1)
	Loamy Sand	7	12	Indonesia (2/4), Brazil (1/1), Zambia (1/3), Peru (1/1), Costa Rica (2/3)
	Sand	4	4	Indonesia (1/1), Ecuador (2/2), Costa Rica (1/1)
Mollisols	Clay	19	68	Indonesia (13/56), Ecuador (1/1), Mozambique (1/3), Peru (1/1), Cuba (2/5), China (1/2)
	Silty Clay	6	6	Indonesia (2/2), Peru (1/1), Cuba (1/1),
	Sandy Clay	2	2	Indonesia (2/2)
	Clay Loam	11	21	Indonesia (6/11), Brazil (1/1), Ecuador (1/2), Peru (1/5), Cuba (1/1), Nicaragua (1/1)
	Silty Clay Loam	6	11	Indonesia (3/4), Peru (2/5), Nicaragua (1/2)

Soil Taxonomy	Class texture	Number of pedons	Number of soil layers	Source of Country (no of pedon/ no of soil layers in each country)
Mollisols	Silty Loam	7	13	Indonesia (3/7), Ecuador (1/2), Nicaragua (2/2), Puerto Rico (1/2)
	Sandy Clay Loam	7	9	Indonesia (4/4), Brazil (1/2), Peru (1/2), Puerto Rico (1/1)
	Loam	9	15	Indonesia (3/6), Ecuador (1/1), Peru (2/4), Nicaragua (3/4)
	Sandy Loam	4	6	Indonesia (3/5), Brazil (1/1)
	Loamy Sand	1	3	Indonesia (1/3)
	Sand	1	4	Indonesia (1/4)
Oxisols	Clay	52	126	Indonesia (11/25), Brazil (13/41), Mozambique(1/2), Gabon (2/6), Malaysia (4/7), Kenya (2/5), Zambia (1/4), Cuba (2/9), Costa Rica (2/3), China (2/5), Puerto Rico (3/19)
	Silty Clay	4	6	Indonesia (1/1), Puerto Rico (1/2), Brazil (2/3)
	Sandy Clay	3	4	China (1/2), Indonesia (1/1), Kenya (1/1)
	Clay Loam	3	5	China (1/3), Mozambique (1/1), Indonesia (1/1)
	Sandy Clay Loam	9	17	Indonesia (1/2), Brazil (3/8), China (1/1), Gabon (1/3), Kenya (2/2), Zambia (1/1)
	Loam	1	1	Brazil (1/1)
	Sandy Loam	6	12	Gabon (1/1), Kenya (2/3), Zambia (1/2), Peru (1/4), Colombia (1/2)
	Loamy Sand	2	4	Kenya (1/1), Peru (1/3)
	Sand	2	2	Peru (1/1), Brazil (1/1)
Spodosols	Sandy Loam	1	1	Peru (1/1)
	Loamy Sand	2	6	Indonesia (1/3), Peru (1/3)
	Sand	1	2	Brazil (1/2)
Ultisols	Clay	64	128	Indonesia (41/68), Mozambique (1/3), Brazil (1/1), Ecuador (2/5), Ivory Coast (4/5), Kenya (2/4), Zambia (1/1), Philippine (1/3), Colombia (2/6), China (5/13), Nigeria (1/1), Puerto Rico (3/18)
	Silty Clay	12	18	Indonesia (6/8), Mali (1/2), Ecuador (1/2), Kenya (2/3), China (1/2), Brazil (1/1)
	Sandy Clay	16	19	Indonesia (9/11), Ivory Coast (1/1), Malaysia (2/2), Colombia (1/1), China (3/4)
	Clay Loam	33	46	Indonesia (26/36), Brazil (1/1), Gabon (1/2), Zambia (1/1), Colombia (1/1), China (1/2), Nigeria (1/1), Puerto Rico (1/2)]

Soil Taxonomy	Class texture	Number of pedons	Number of soil layers	Source of Country (no of pedon/ no of soil layers in each country)
Ultisols	Silty Clay Loam	12	14	Indonesia (7/8), Ecuador (1/1), Colombia (2/3), China (1/1), Brazil (1/1)
	Silty Loam	3	3	Indonesia (1/1), mali (1/1), China (1/1)
	Sandy Clay Loam	50	98	Indonesia (34/74) Brazil (2/2), Ivory Coast (2/2), Gabon (1/1), Malaysia (3/6), Kenya (1/3), Colombia (2/3), China (4/5), Nigeria (1/2)
	Loam	20	35	Indonesia (16/30), Brazil (1/1), Colombia (2/3), Puerto Rico (1/1)
	Sandy Loam	22	31	Indonesia (17/26), Gabon (1/1), Colombia (2/2), China (1/1), Nigeria (1/1)
	Loamy Sand	8	10	Indonesia (4/6), Brazil (1/1), Ivory Coast (1/1), Kenya (1/1), Nigeria (1/1)
Vertisols	Clay	19	80	Indonesia (11/51), Mali (1/2), Cuba (3/7), Philiphines (1/3), Nicaragua (1/3), Puerto Rico (2/14)
	Silty Clay	4	5	Indonesia (2/2), Ecuador (1/2), Cuba (1/1)
	Clay Loam	3	3	Ecuador (1/1), Cuba (1/1), Philippine (1/1)
	Silty Clay Loam	2	2	Cuba (2/2)

10.3.3 Measurement of soil-water retention and hydraulic conductivity

During the collection of soil data base, we found that there was lack of hydraulic conductivity data. To test the PTF's, therefore, we use only one result of field measurement done in Ultisol, North Lampung, Indonesia. The hydraulic conductivity of soil was determined by two methods, i.e. a laboratory and a field method. The unsaturated hydraulic conductivity measured in the laboratory was determined with the "Hot Air Method" (Arya *et al.*, 1975) using coring cylinders (10 cm long with a 5 cm diameter). Unsaturated hydraulic conductivity under field conditions was measured *in situ* using the instantaneous profile method (Libardi *et al.*, 1980). To avoid uptake of water by roots of trees and crops, and evaporation, a 1.0 width x 2.0 m long x 1 m deep soil profile was isolated with a plastic sheet. The plot was irrigated with 80 mm of water (during a 100 minutes period) for 2 days before the drainage test and for the time of the drainage test, to ensure maximum wetness and moisture uniformity. After the second irrigation ceased, the plot surface was covered with plastic sheet. Value of water contents at every 10 cm soil depth until 0.8 m were measured using a neutron probe. The neutron probe readings were taken at several minute intervals initially and then less frequently up to 31 days after irrigation ceased. The hydraulic conductivity was calculated using the approach by Libardi *et al.* (1980).

10.3.4 Comparison of θ -h-K relationship between measurements and pedotransfer simulations

The comparison of the θ -h relationship between measurements and pedotransfer simulations are presented as the relationship between measured volumetric soil water content and predicted by the PTF's at different pressure head. The measurement data and predicted by the PTF's were plotted and fitted using simple linear regression with Sigma Plot Version 4.0 (Norby *et al.*, 1990).

For evaluating θ -K relationships, laboratory and field data were selected only from pF 2 to pF 4.2. Van Den Berg and Louters. (1986) reported that the hot air method is a suitable tool for obtaining the diffusivity at moisture contents for pF 2 and upwards. Hydraulic conductivity data above pF 4.2 (wilting point) are less relevant for evaluating water movements in agroforestry systems as these are most important in the range of pF 0 – 4.2. The laboratory, PTF's and field data were plotted and fitted using linear regression with Sigma Plot Version 4.0 (Norby *et al.*, 1990). The statistical significance of differences between those relations were evaluated using linear regressions with groups with Genstat 5.0 (Payne *et al.*, 1987).

10.4 Results

10.4.1 Sensitivity analysis of PTF's

To evaluate the sensitivity of θ -h-K relationships in PTF's to the main parameters, data ranges for the bulk density, soil texture and soil organic contents that were considered realistic and consistent with the soil analysis data for a tropical soils, were used as input data for the simulation (Table 6). The simulations suggested that the effect of soil organic matter content on θ -K was relatively small and affected mainly the relatively dry soils (Figures 1 and 2). Bulk density had the opposite effect on the θ -h-K relationship compared to soil organic matter. The bulk density exerted a strong influence in wet soils (for $\theta < 0.3 \text{ m}^3 \text{ m}^{-3}$) increasing θ at low pF. Although the PTF's were also slightly sensitive to the silt content, the clay content had the largest effect on θ and K at the same point of soil water potential (especially for $\theta > 0.3 \text{ m}^3 \text{ m}^{-3}$). Therefore, the particle size distribution (soil texture) had the most significant influence on the PTF's in the tested range relevant for a tropical soils.

Table 6 Default data variation of the bulk density, soil texture and soil organic matter content used as input for the PTF simulations for a Plinthic Kandiudult

Input parameter	Standard data for simulation	Variation allowed for simulation
Soil organic matter content (%)	1.0	0.1, 1.0, 2.0, 3.0
Soil bulk density (g cm^{-3})	1.4	1.2, 1.4, 1.6, 1.8
Clay content (%)	30	15, 30, 45, 60
Silt content (%)	30	15, 30, 45, 60

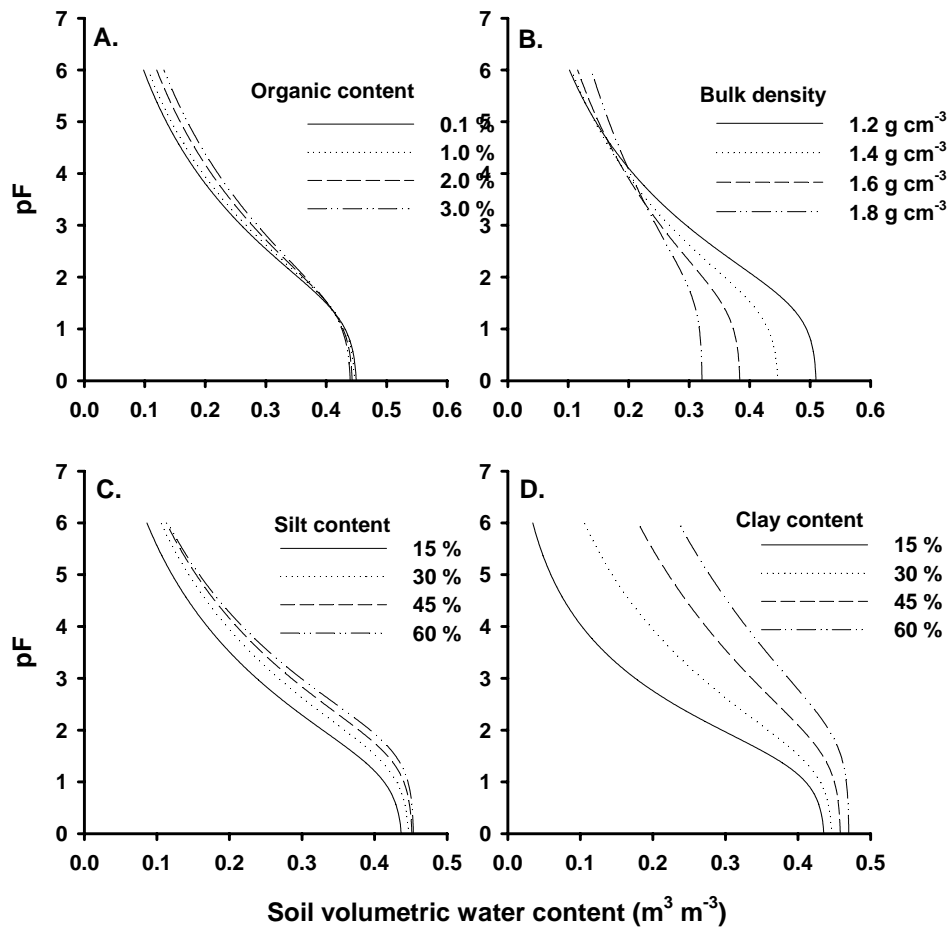


Figure 1: Sensitivity of PTF predictions on soil water content and retentions relationships varying: A. soil organic matter content, B. bulk density, C. silt content and D. clay content.

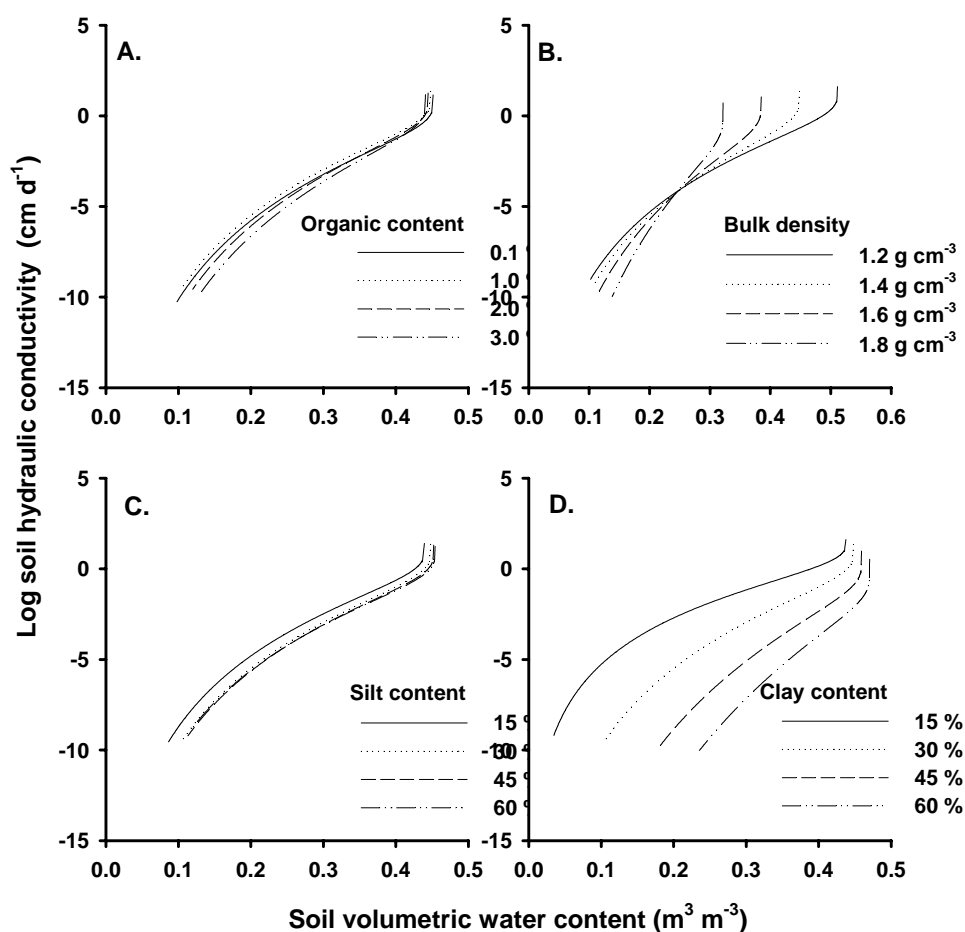


Figure 2: Sensitivity of PTF predictions on soil water content and hydraulic conductivity relationships varying: A. soil organic matter content, B. bulk density, C. silt content and D. clay content.

10.4.2 Comparison at the θ - h - K relationship between measurement and pedotransfer simulation

Predicted volumetric soil water content (VWC) using these PTF outputs resulted in a relatively good fit into the 1:1 line graph for the most soil types at different soil texture classes compared to the measured data (Figure 3.A-I). In Alfisols, these PTF outputs appears to be a tendency for an underestimation at low water content and an overestimation or fit at higher soil water content in relatively fine texture, but an underestimation at all range of water content compared to the measured data (Figure 3.A).

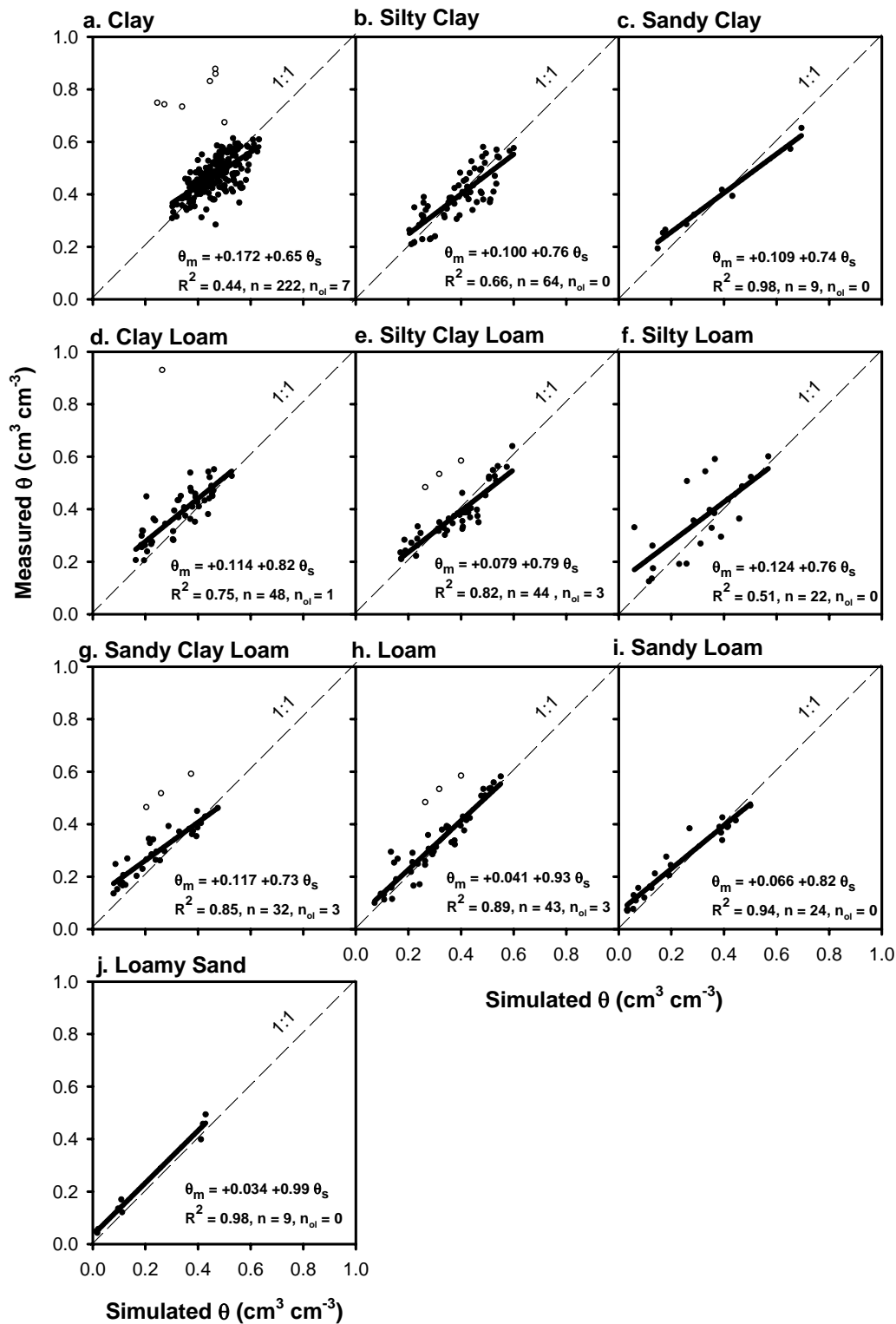


Figure 3.A: Laboratory measured and simulated (using input data extracted from data base as described in see § 2.2 for PTF's and Eq. 1+2) volumetric water content (θ) at different pressure head of Alfisols and their different soil texture classes.

In Andisols, many examples of soil texture classes these PTF outputs appears to be a tendency for an underestimation at low water content and an overestimation or fit at higher soil water content compared to the measured data, except in loam texture classes is underestimate at all ranges water content and in clay loam texture classes overestimate at low water content and a fit at higher soil water content (Figure 3.B).

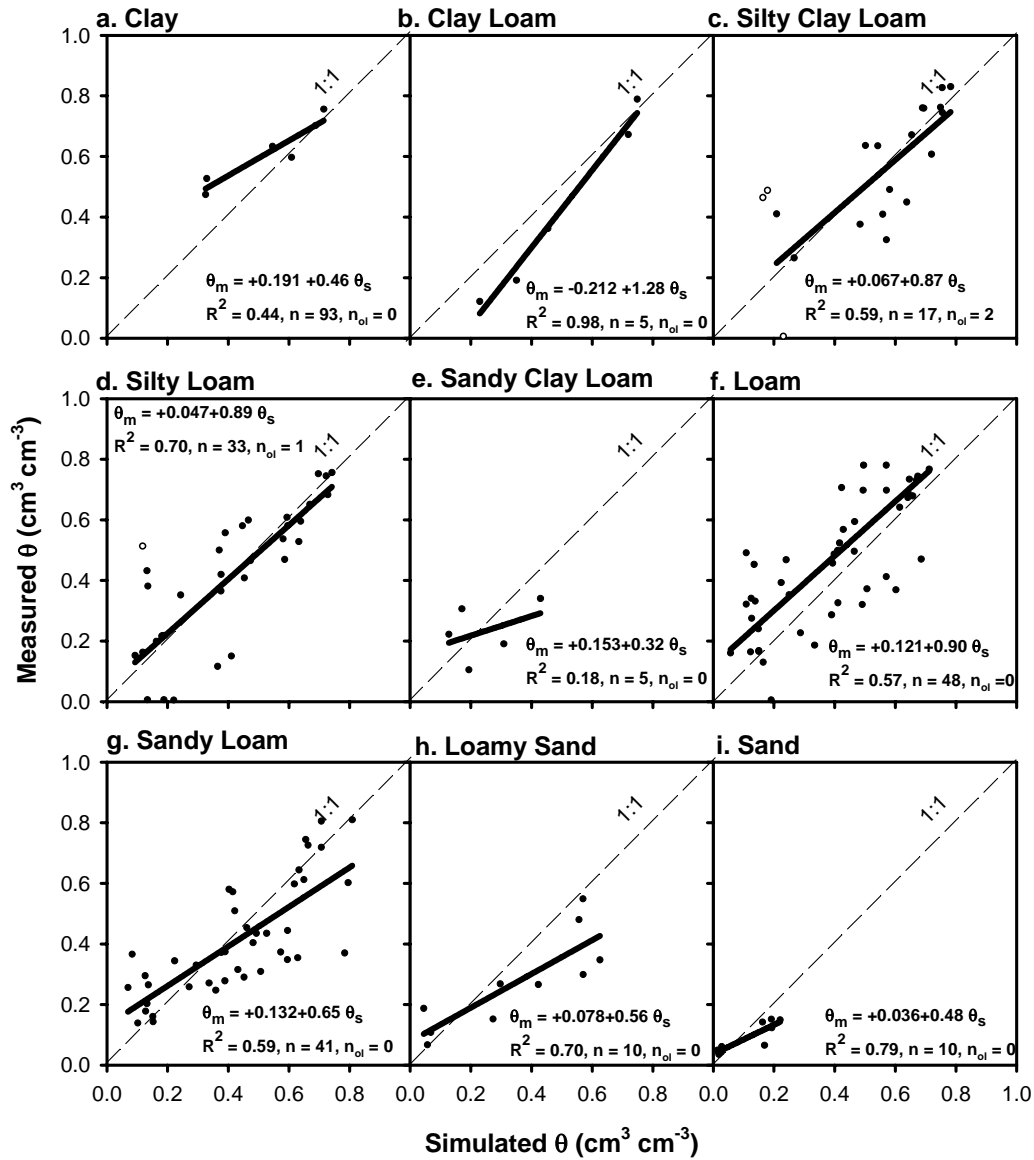


Figure 3.B: Laboratory measured and simulated (using input data extracted from data base as described in see § 2.2 for PTF's and Eq. 1+2) volumetric water content (θ) at different pressure head of **Andisols** and their different soil texture classes.

In Aridisols, relatively a few soil samples of water content at different soil texture classes, and these PTF outputs appears to be a tendency for fit at most ranges of soil water content compared to the measured data, (Figure 3.C).

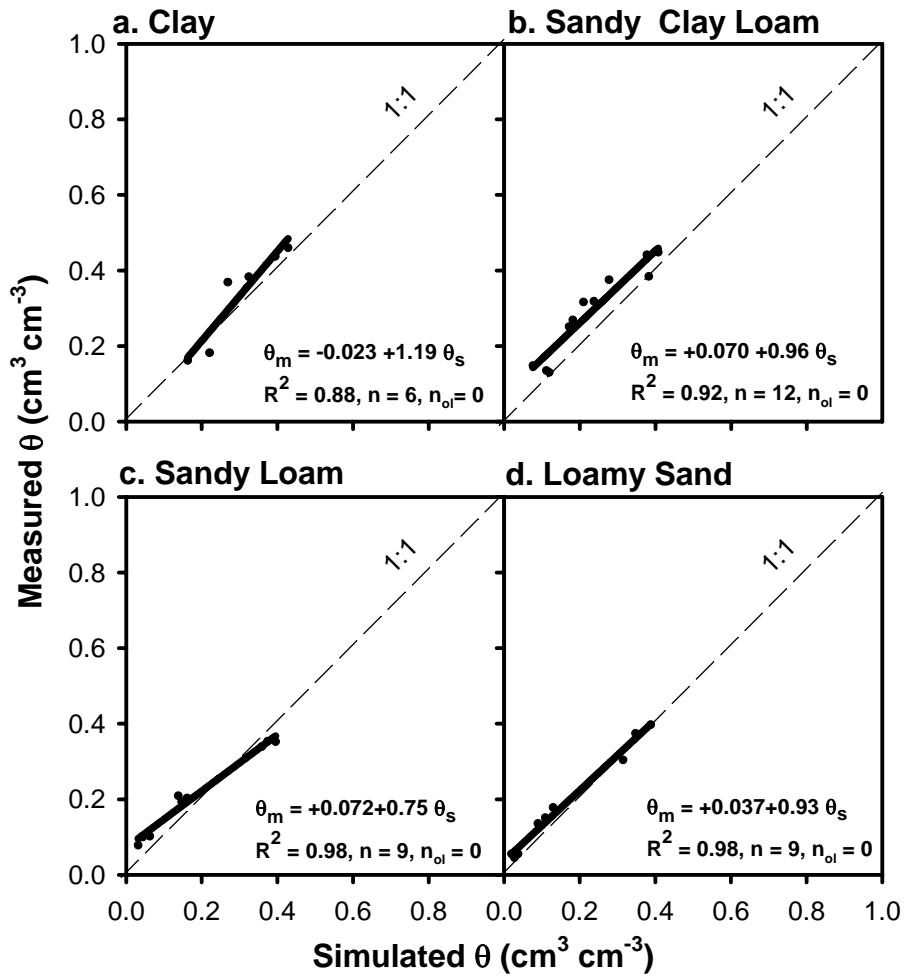


Figure 3.C: Laboratory measured and simulated (using input data extracted from data base as described in see § 2.2 for PTF's and Eq. 1+2) volumetric water content (θ) at different pressure head of **Aridisols** and their different soil texture classes.

In Entisols, many examples of soil texture classes and these PTF outputs appears to be a tendency for an underestimation at low water content and an overestimation or fit at higher soil water content compared to the measured data, (Figure 3.D).

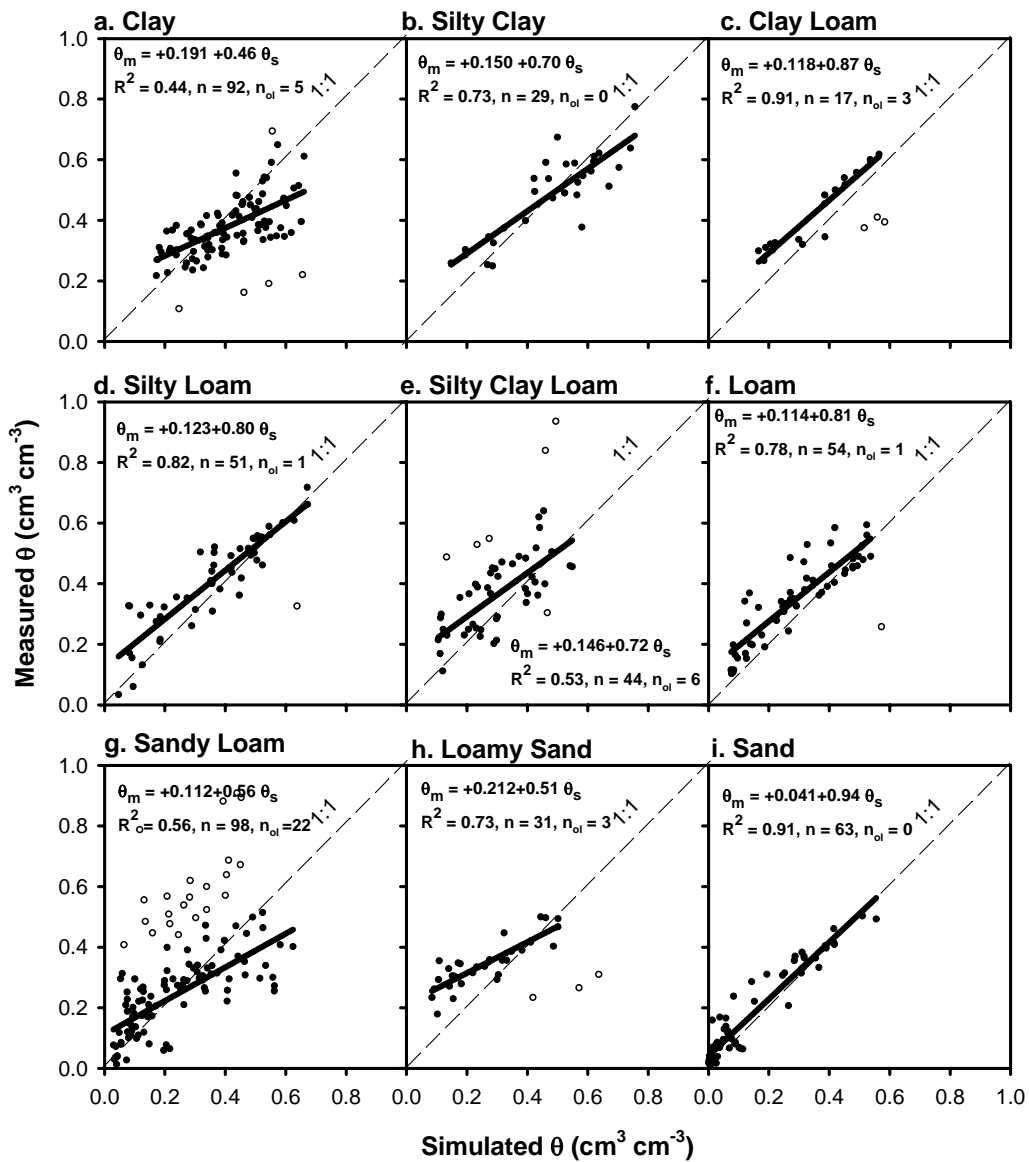


Figure 3.D: Laboratory measured and simulated (using input data extracted from data base as described in see § 2.2 for PTF's and Eq. 1+2) volumetric water content (θ) at different pressure head of *Entisols* and their different soil texture classes.

In Histosols, only one soil profil with silty clay soil texture classes and these PTF outputs appears to be a tendency an overestimation for at low water content and an underestimation at higher soil water content compared to the measured data, (Figure 3.E).

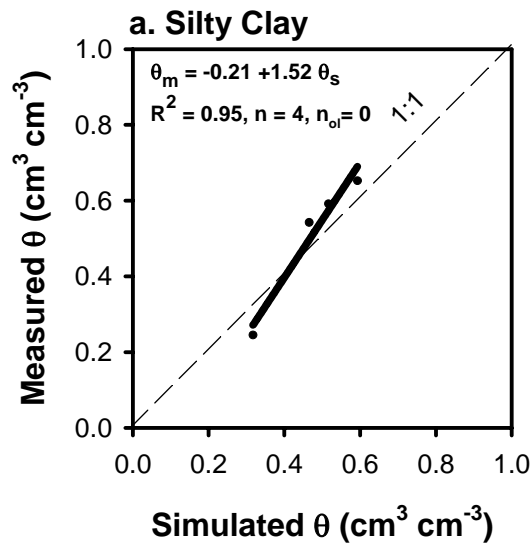


Figure 3.E: Laboratory measured and simulated (using input data extracted from data base as described in see § 2.2 for PTF's and Eq. 1+2) volumetric water content (θ) at different pressure head of **Histosols** with silty clay soil texture classes.

In Inceptisols, Oxisols and Ultisols, many examples of soil texture classes and these PTF outputs appears to be a tendency for an underestimation or fit at low water content and an overestimation or fit at higher soil water content compared to the measured data, (Figure 3.F, H and J respectively). In Mollisols, Spodosols and Vertisols, however, many examples of soil texture classes and these PTF outputs appears to be a tendency for an underestimation at low water content and also an underestimation or fit at higher soil water content compared to the measured data, (Figure 3.G,I and K respectively).

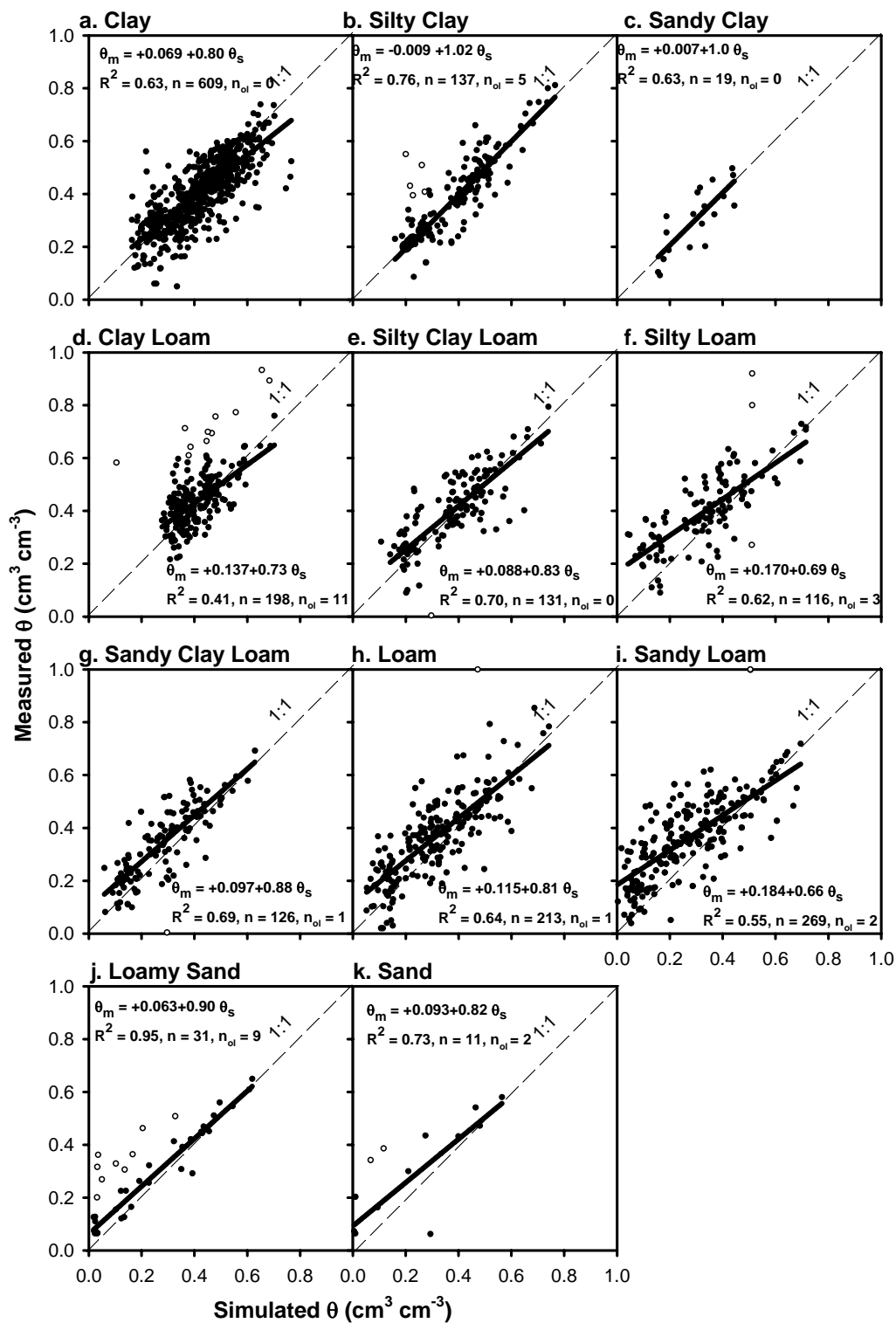


Figure 3.F: Laboratory measured and simulated (using input data extracted from data base as described in see § 2.2 for PTF's and Eq. 1+2) volumetric water content (θ) at different pressure head of *Inceptisols* and their different soil texture classes.

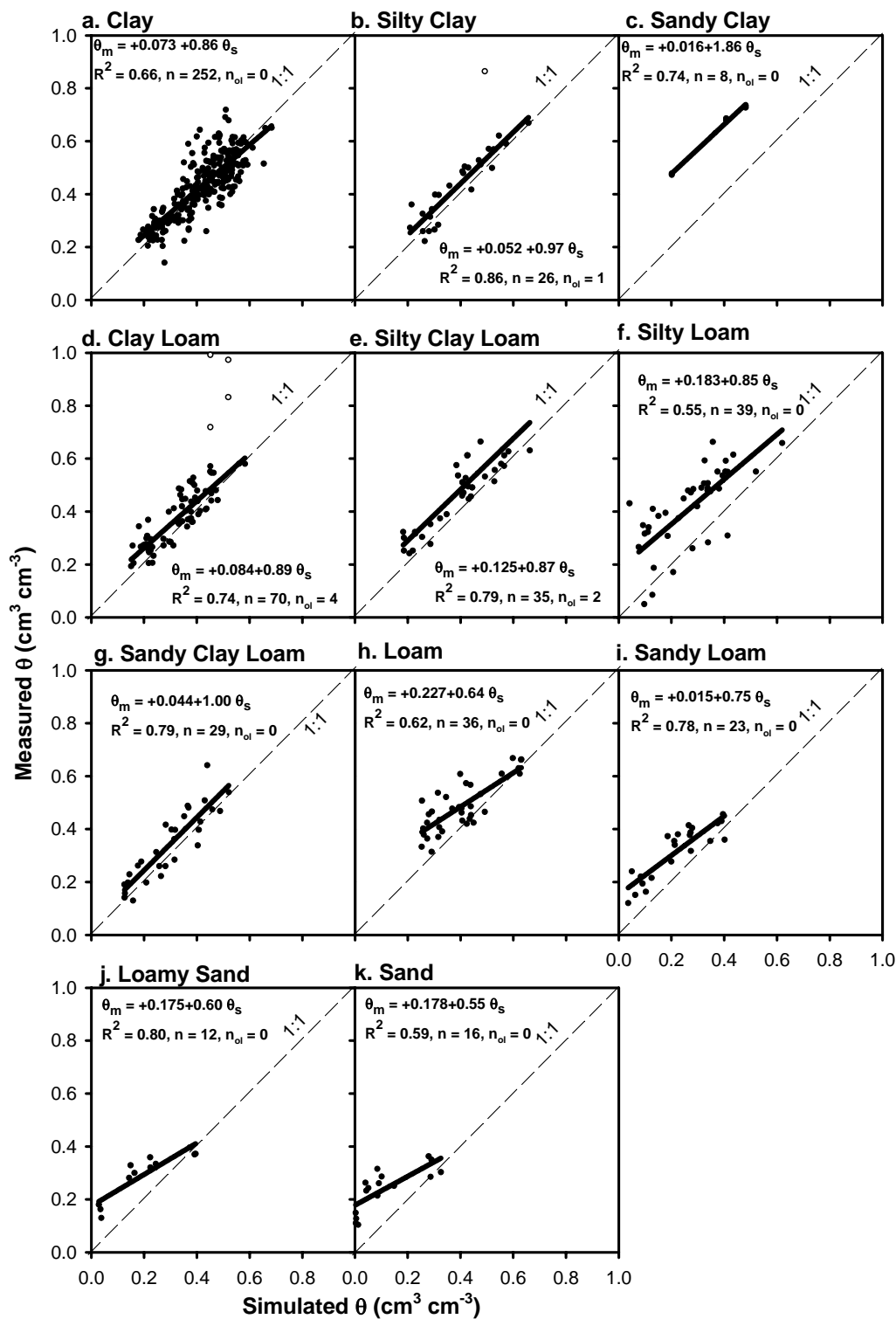


Figure 3.G: Laboratory measured and simulated (using input data extracted from data base as described in see § 2.2 for PTF's and Eq. 1+2) volumetric water content (θ) at different pressure head of **Mollisols** and their different soil texture classes.

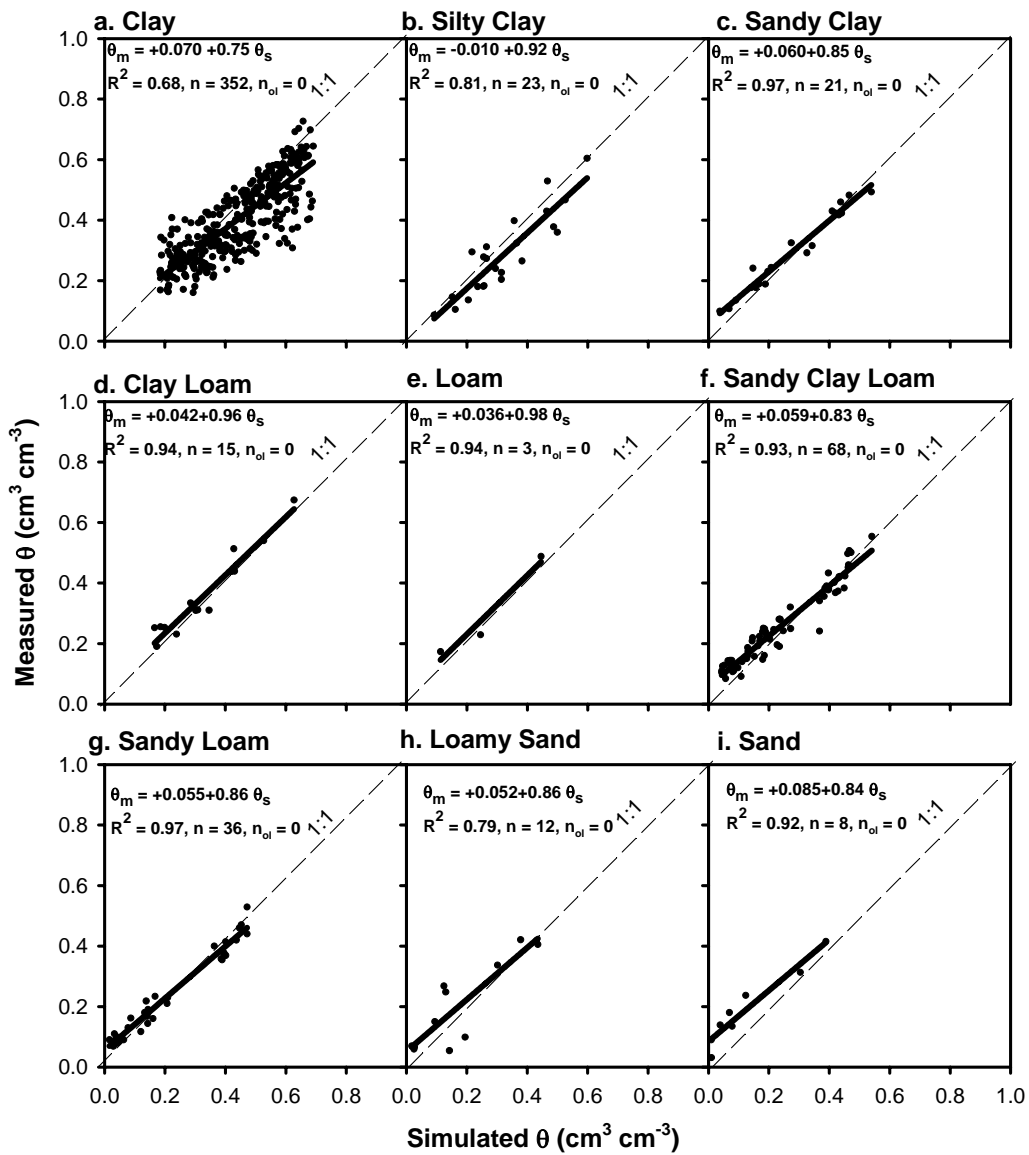


Figure 3.H: Laboratory measured and simulated (using input data extracted from data base as described in see § 2.2 for PTF's and Eq. 1+2) volumetric water content (θ) at different pressure head of *Oxisols* and their different soil texture classes.

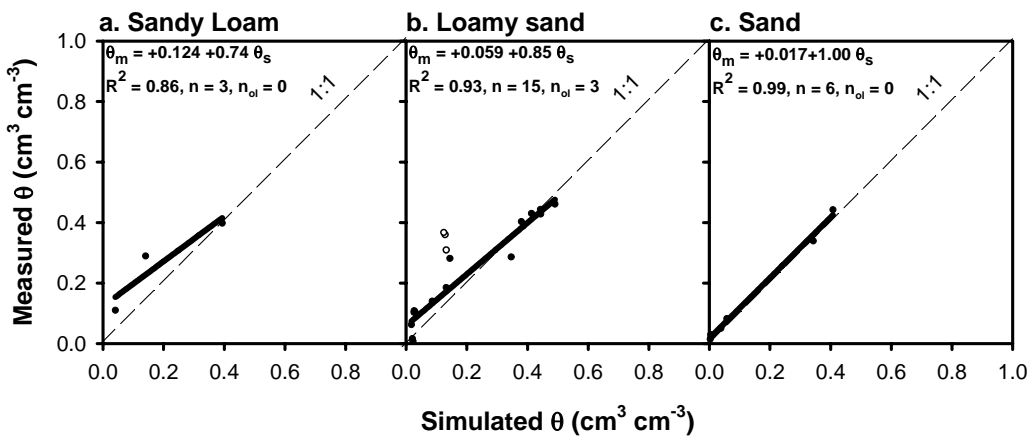


Figure 3.1: Laboratory measured and simulated (using input data extracted from data base as described in see § 2.2 for PTF's and Eq. 1+2) volumetric water content (θ) at different pressure head of *Spodosols* and their different soil texture classes.

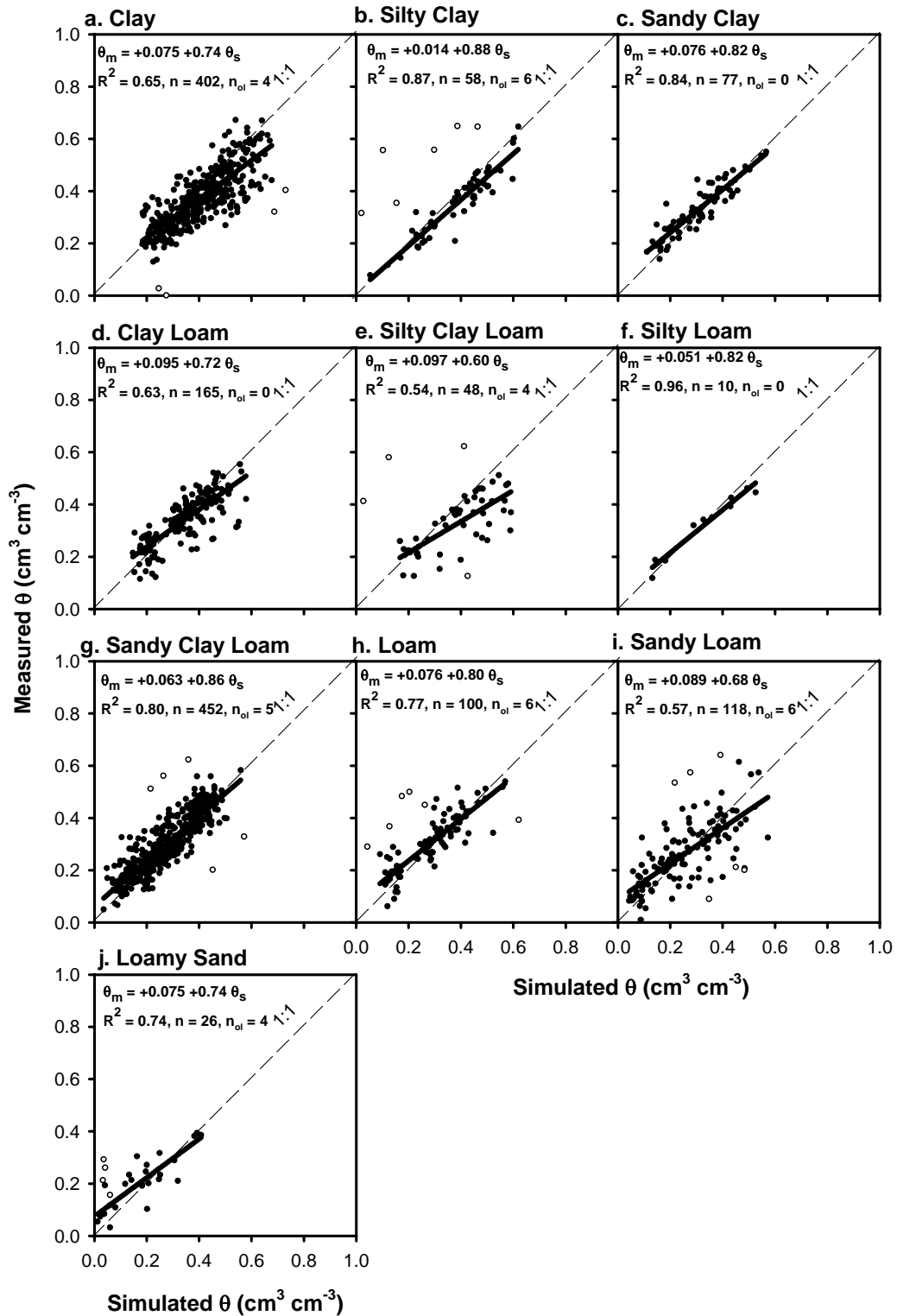


Figure3.J: Laboratory measured and simulated (using input data extracted from data base as described in see § 2.2 for PTF's and Eq. 1+2) volumetric water content (θ) at different pressure head of *Ultisols* and their different soil texture classes.

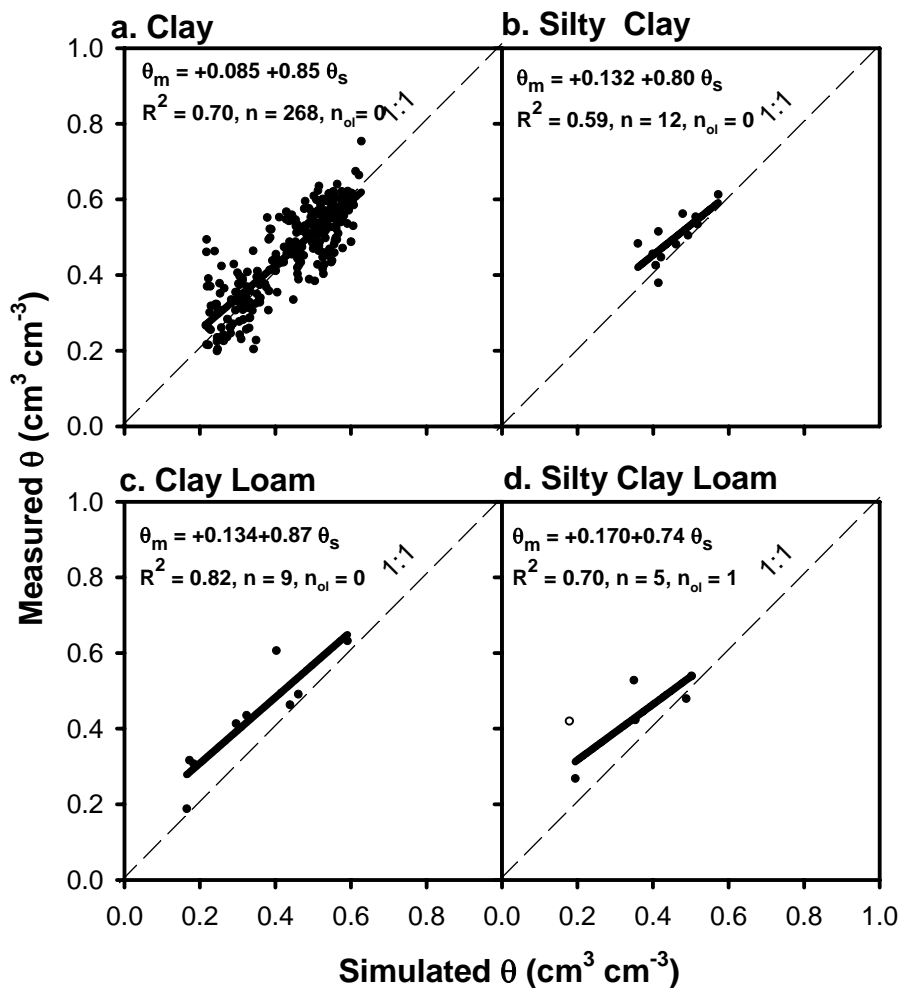


Figure3.K: Laboratory measured and simulated (using input data extracted from data base as described in see § 2.2 for PTF's and Eq. 1+2) volumetric water content (θ) at different pressure head of *Vertisols* and their different soil texture classes.

The soil hydraulic conductivity measured using the hot air method (laboratory data where the soil samples were taken using ring samplers) or using instantaneous profile methods (field data), were compared with simulated data using PTF's outputs (Figure 4 and Table 7). At pF 2 to 4.2 the hydraulic conductivity data as measured in the laboratory were similar to the simulations with the PTF's but the field data were higher compared to the laboratory data (Figure 4). However, *in situ* field data were more scattered than the laboratory data. The soil hydraulic conductivity measured using the hot air method was not statistically significant different from that obtained by the PTF in all soil depths (Table 4).

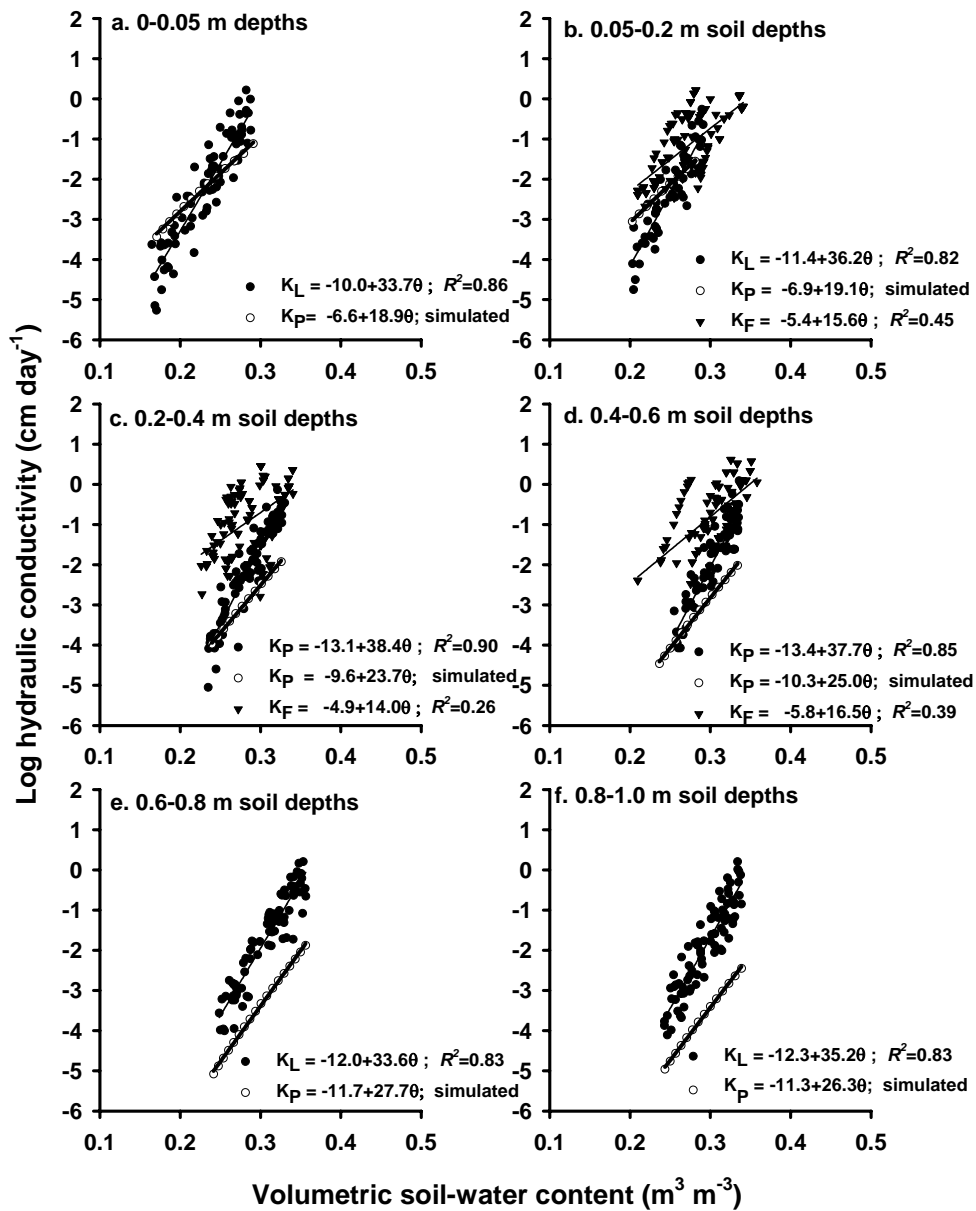


Figure 4: Measured laboratory (K_L ; hot air methods) or in situ (K_F ; field) and simulated (K_P ; using Eq. 1+2 and inputs data from Table 5 for PTF's) hydraulic conductivity and soil water content relationships between ρF 2-4.2 at different depths of a Plinthic Kandiudult.

Table 7 Statistical comparison of the parameters of the linear relationships between \log_{10} soil hydraulic conductivity (cm day^{-1}) and volumetric soil water content (cm cm^{-3}) obtained by different methods and at different soil depths in a Plinthic Kandiuult.

Soil depths (m)	Methods	Constant	Slope
0-0.05	Laboratory	-10.0 a	+0.37 a
	PTF's	-6.6 a	+0.19 a
0.05-0.2	Laboratory	-11.4 a	+0.36 a
	PTF's	-6.9 ab	+0.19 ab
	Field	-5.4 b	+0.16 b
0.2-0.4	Laboratory	-13.1 a	+0.38 a
	PTF's	-9.6 ab	+0.24 ab
	Field	-4.9 b	+0.14 b
0.4-0.6	Laboratory	-13.4 a	+0.38 a
	PTF's	-10.3 ab	+0.25 ab
	Field	-5.8 b	+0.17 b
0.6-0.8	Laboratory	-12.0 a	+0.34 a
	PTF's	-11.7 a	+0.28 a
0.8-1.0	Laboratory	-12.3 a	+0.35 a
	PTF's	-11.3 a	+0.26 a

Figures carrying the same letter within a column at the same depth are not significantly different at $P < 0.05$, based on the comparison of parameters using linear regressions with groups.

10.5 Discussion

10.5.1 Input parameter for PTF's

Based on the sensitivity analysis of the PTF's it was concluded soil organic matter had little effect on the θ -h-K relationship in the investigated soil. Within the soil organic matter range considered viable for a "Tropical" soils, we therefore suggest that the average SOM content of the soil profil within soil texture classes and soil types is sufficient as an input value of soil organic matter content for PTF.

The bulk density on the other hand exerted a large effect on the θ -h-K relationship on relatively wet soils. Hill and Summer (1967) also found that the bulk density had a greater affect on the water retention at matric potential > -33 kPa. When bulk density decreases, the water retention below pF 3 increases (Figure 1) and hence the capacity of soil to retain water available for crops increases. Therefore, these results can be interpreted in that the bulk density is a reflection of soil structure characteristics. Given the large impact bulk density had on the θ -h-K relationship, particularly at higher soil moisture, it appears necessary to use measured values of bulk density for each soil type and their soil texture classes for the PTF's. The bulk density from this data bases is also still can be used for the simulation at acceptable result when there is no measurement data available.

To estimate the θ -h-K relationship, the particle size distribution (especially clay content) had the most significant effect on the PTF's simulations at all matric potentials. Hence, soil texture strongly reflects soil structure and soil surface area. Although, Rawls *et al.* (1991) concluded that soil texture was only a critical parameter at low soil water potentials (< -150 kPa) or a reflection of soil surface area only. Because of the large impact of clay content in the PTF's it is important to select adequate physical separation methods. Both

H₂O₂ and sufficient sodium hexametaphosphate were needed to achieve adequate dispersion (Suprayogo, 2000). The PTF's exclude the effect of coarse fragments (> 2 mm) and clay mineralogy. The coarse fragments have been shown to be important when they comprise more than 10% of the soil volume (Peterson *et al.*, 1968). With regard to the clay mineralogy, the 2:1 layer silicates, especially montmorillonite, have the greatest effect, whereas the 1:1 non-expandable clays (kaolinite) have the least impact on the swelling and shrinking of soil to modify the pore distribution (Baumer and Brasher, 1982). Thus including both clay mineralogy and coarse fragments to consider during the evaluation of the model simulation is suggested.

10.5.2 Comparison of the θ -h-K relationship between field measurements and pedotransfer simulations

With regard to the relevance of PTF's for the prediction of θ -h-K relationships, a key question is whether or not results of the PTF's can be used with confidence as an input in models such as the agroforestry model WaNuLCAS (Van Noordwijk and Lusiana, 1999) or HyPAR (Mobbs, *et al.*, 1998). The θ -h relationship (pF curve) predicted from PTF's resulted in a good fit with laboratory measured data of volumetric soil water content (Figure 3). The scattering of the laboratory data of the volumetric soil water content at different potential head was mainly due to the soil variability in the different soil profiles and random error during the soil sampling and soil samples laboratory analysis.

The θ -K relationship predicted from PTF's agreed well with laboratory data at moist soil conditions (pF 2 to 4.2) (Figure 4 and Table 7). Van Den Berg and Louters (1986) stated that the hot air method is suitable for obtaining the diffusivity at moisture contents for pF 2 and upwards. Therefore, θ -K data below pF 2 were excluded in this PTF's validation. Our result also indicated that hydraulic conductivity measured using the hot air method under dry soil conditions (pF >4.2) gave unreliable values (data not presented) and θ -K data above pF 4.2 were also excluded in this PTF validation. Values at pF >4.2 are less relevant for evaluating water movements in tree-crop interactions as these are mostly important in the range of pF 0 – 4.2. In wet conditions, it is highly recommended to test soil hydraulic conductivity with other methods (springling infiltrometer, isolated soil column, spherical cavity, or pounded disk field methods) as recommended by Dirksen (1990). In our loamy textured soil, the simulated hydraulic conductivity showed a good fit, but with increased clay content (subsoil), the simulated hydraulic conductivity was under estimated at all θ conditions. Van Grinsven *et al.* (1985) also found that the hot air method is applicable to loamy textured soils at higher soil water contents.

The field data showed that hydraulic conductivity in the topsoil was very similar to laboratory data and simulated PTF data at the available range of soil water contents. However, in the subsoil (below 0.4 m) field K(θ) were higher than the laboratory data and simulated data (Figure 4). This field behaviour of hydraulic conductivity may be mainly caused by structural changes such as effects of old tree root channels that can create macro-pore flow (Van Noordwijk *et al.*, 1991) on soil fauna effects. However, the PTF's currently available do not yet take into account the effect of microaggregates in soils and also structure-related macro-pore flow, because they were derived from laboratory data obtained from small ring samples (Stole *et al.*, 1996).

10.6 Conclusions

PTF's for obtaining relationships between soil water content (θ)-water retention (h) and hydraulic properties (K) for a "tropical" soils were almost sensitive to soil bulk density and clay content. The PTF's can be used with confidence as an input in models such as the agroforestry model WaNuLCAS (Van Noordwijk and Lusiana, 1999) or HyPAR (Mobbs, *et al.*, 1998) in "tropical" soils. The θ -h relationship (pF curve) predicted from PTF's resulted in a good fit with laboratory measured data of volumetric soil water content at different potential head, for most "tropical" soils. The PTF's tested gave a good prediction of the θ -K relationships derived from laboratory data (ring samples) at pF 2 to 4.2, but did not fully account for field behaviour (soil structural changes, macro-pore flow). This implies that the soil physical description required by the PTF's appears to be adequate for the relatively slow processes of water uptake in non-saturated soil (pF 2 to 4.2) for the investigated Plinthic Kandudult. However, the rapid processes during rain and infiltration events will need additional attention, as they can be modified by growing and decaying roots, earthworms and other biological processes, as well as by a gradual decay of soil structure in the absence of new structure formation. The lack of hydraulic conductivity data is a very serious limitation on testing the PTF's.

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10.8 References

- Abas,A dan Abdurachman,A.1985. Pengaruh Pengelolaan Air dan Tanah terhadap Efisiensi Penggunaan Air Padi Sawah di Cihea Jawa Barat. Hal 2. Di dalam Jurnal Penelitian Tanah dan Pupuk. Departemen Pertanian. Badan Penelitian dan Pengembangan Pertanian.Bogor
- Afandi,R.A.,Rosadi,B.,Manik,T.K.,Senge,M.,Adachi,T. dan Oki,Y.1998. Pengaruh Pengelolaan gulma di Bawah Tanaman Kopi terhadap beberapa Sifat Fisika Tanah Pangamatan Tahun Pertama. Di dalam Jurnal tanah Tropika tahun IV no. 7 Juli-Desember 1998
- Anderson, J.M. and Ingram, J.S.I., 1993. Tropical Soil Biology and Fertility: A Handbook of Methods. CAB International, Wallingford, UK, p 93-94.
- Anonymous,1976.Reconhecimento Pedológico na Área de São Félix do Xingú. Belém, Pará, Brasil (Aditivo 1). Ministério das Minas e Energia & SUDAM
- Anonymous,1981. Projeto RADAMBRASIL Volumes 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 22, 25, 26, 27, 29, and 31. Rio de Janeiro, Brasil. Ministério das Minas e Energia
- Anonymous,1982. Soil Survey Kali Sereng Watershed Area (DAS KALI KONTO-EAST JAVA) An Interim Report (April 1982). NUFFIC-Unibraw. Soil Science Project.
- Anonymous,1983.Levantamento de Reconhecimento de Solos e Aptida Agrícola das Terras da Área do Polo Tapajós Estado do Pará. Boletim de Pesquisa No, Rio de Janeiro, Brazil (Aditivo 3) EMBRAPA/SNLCS
- Anonymous,1984.Levantamento de Reconhecimento de Solos e Aptida Agrícola das Terras da Área do Polo Carajás Estado do Pará. Boletim de Pesquisa No 29, Rio de Janeiro, Brazil (Aditivo 2).EMBRAPA/SNLCS
- Anonymous,1976. Survey dan Pemetaan Tanah Daerah Sungai Rokan (Riau). Hal 290-327. Departemen Pekerjaan Umum dan Tenaga Listrik. Departemen Pertanian. Badan Penelitian dan Pengembangan Pertanian. Puslittanak.Bogor
- Anonymous,1981. Pemetaan Tanah Semi Detail Daerah Kasai Rengat (WPP VII/A) Propinsi Riau. Kerjasama Proyek Penelitian Pertanian Menunjang Transmigrasi dengan Fakultas Mekanisasi dan THP IPB.Puslittanak.Bogor
- Anonymous,1981. Survey Kapabilitas Tanah Daerah Pasir Pangarayan (WPP XII A, SKP J) Propinsi Riau. Hal L-09 – L-47. Proyek Penelitian Pertanian Menunjang Trnasmigrasi. Departemen Pertanian. Badan Penelitian dan Pengembangan Pertanian. Puslittanak. Bogor
- Anonymous,1982. Survei Kapabilitas Tanah Daerah Meulaboh WPP Va SKP C Daerah Istimewa Aceh. Hal L-12 - L-61 .Proyek Penelitian Pertanian Menunjang Transmigrasi. Badan Penelitian dan Pengembangan Pertanian. Bogor
- Anonymous,1982. Survei dan Pemetaan Tanah Semi Detail Daerah Aluepenyering (WPP V) Propinsi Daerah Istimewa Aceh. Hal 136-153. Kerjasama Proyek Penelitian Pertanian Menunjang Transmigrasi dengan Fakultas Mekanisasi dan THP IPB.Puslittanak.Bogor
- Anonymous,1982. Pemetaan Tanah Semi Detail Daerah Limbah Liam (WPP V/D) Propinsi Sumatera Selatan. Hal 160-182. Kerjasama Proyek Penelitian Pertanian Menunjang Transmigrasi dengan Fakultas Mekanisasi dan THP IPB.Puslittanak.Bogor
- Anonymous,1983. Laporan Survei Kapabilitas Tanah Daerah Bangkinang WPP X/SKPA. Hal III-10 - L-43 Kerjasama Proyek Penelitian Pertanian Menunjang Transmigrasi dengan Fakultas Pertanian .Unila . Badan Penelitian dan Pengembangan Pertanian. Bogor

- Anonymous,1983. Laporan Survei Kapabilitas Tanah Daerah Kota Nibong WPP Vi SKP D Kabupaten Aceh Selatan Propinsi daerah Istimewa Aceh. Hal L-09 - L-32 .Proyek Penelitian Pertanian Menunjang Transmigrasi. Badan Penelitian dan Pengembangan Pertanian. Bogor
- Anonymous,1983. Survei Kapabilitas Tanah Daerah Kota Nibong WPP Vc SKP C (Seuna'am) Kabupaten Aceh Barat Propinsi daerah Istimewa Aceh. Hal 86-110.Proyek Penelitian Pertanian Menunjang Transmigrasi. Badan Penelitian dan Pengembangan Pertanian. Bogor
- Anonymous,1983. Survei Kapabilitas Tanah Daerah Lamno (WPP IV/ SKP A) Daerah Istimewa Aceh. Hal L-10 - L-32 .Proyek Penelitian Pertanian Menunjang Transmigrasi. Badan Penelitian dan Pengembangan Pertanian. Bogor
- Anonymous, 1984. Soils & Soils Conditions kalikonto Upper Watersheed, East Java. Pp 7-26. Unibraw. Malang. Agricultural University Wageningen, Project Nuffic-Unibraw-LHW-Soil Science Project Kali Konto Malang ATA-206
- Anonymous,1987. Survei dan Pemetaan Tanah Tingkat Tinjau Propinsi Daerah Istimewa Aceh (Kabupaten Aceh Besar, Pidie, Aceh Utara dan Aceh Timur). Hal LI-7 – LV 10. Proyek Pengelolaan Data Base Tanah. Puslittanak. Bogor
- Anonymous,1988. Report on Detailed Soil Survey of Sumber Petung Area Malang Regency. Hal 33. In Upland Agriculture and Conservation Project Center for Soil Research. Bogor
- Anonymous,1988. Survei dan Pemetaan Tanah Tingkat Tinjau (Updating) Propinsi Lampung Kabupaten Lampung Utara dan Lampung Tengah. Hal 43-120. Proyek Pengelolaan Data Base Tanah. Puslittanak. Bogor
- Anonymous.1989.Buku Lampiran Deskripsi Serie Tanah dan Interpretasinya Kriteria Penilaian Sifat-Sifat Tanah. Klasifikasi UNIFIED, AASHTO dan *Model Farming System* serta Pengertian Istilah.Tim Survei Tanah Das Brantas Pusat Penelitian Tanah. Proyek Pertanian Lahan Kering dan Konsevasi Tanah kerja sama Bappeda TK I Propinsi Jatim dengan Pusat Penelitian Tanah Bogor
- Anonymous,1991.Characterização Físico Hídrica dos Principais Solos da Amazônia Legal: Volume I - Estado do Pará. Relatório Técnico. Belém PA Brasil (Aditivo). EMBRAPA/FAO
- Anonymous,1997. Pemetaan Tanah semi Detail Daerah WPP XVI, Sekayu (Daerah Lambanakar TL. Jangko.SKPA) Propinsi Sumatera Selatan Pusat Penelitian Tanah. Proyek Penelitian Pertanian Menunjang Transmigrasi. Departemen Pertanian. Badan Penelitian dan Pengembangan Pertanian. Hal 110-149
- Anwar,E.K.,Suriadikarta,D.A dan Suganda,H.2000. Pengaruh Amelioran dan Tata Mikro terhadap Ketersediaan Air Tanah untuk Menetapkan Pola Tanam di Lahan Rawa Pasang Surut. Hal 435-442 . Di dalam Prosiding Seminar Nasional Reorientasi Pendayagunaan Sumberdaya Tanah, Iklim dan Pupuk. Puslittanak. Departemen Pertanian. Badan Penelitian dan Pengembangan Pertanian. Bogor
- Arah, J. 1997. Approaches to modelling soil hydrology. Institute of Terrestrial Ecology. Edinburgh.
- Arya, L.M., Farrell, D.A. and Blake, G.R., 1975. A field study of soil water depletion patterns in presence of growing soybean roots. I. Determination of hydraulic properties of the soil. Soil Science Society of America Journal, 39: 424-430.
- Baumer, O.W. and Brasher, B.R., 1982. Prediction of water content at selected suctions. America Society of Agricultural Engineers, 82: 25-90.
- BMSF-Project, 1996. Guide to Field Experiments on Biological Management of Soil Fertility in North Lampung Sumatra. Soil Science Department, Faculty of Agriculture, Brawijaya University, Malang, Indonesia.
- Bouma, J. and Van Lanen, J.A.J., 1987. Transfer functions and threshold values; from soil characteristics to land qualities. In: K.J. Beek (Editor), Quantified Land Evaluation. International Institute Aerospace Survey Earth Science ITC, Enschede, The Netherlands, p. 106-110.
- Brooks, R.H. and Corey, A.T. 1964. Hydraulic properties of porous media. Hydrology Paper No 3. Civil Engineering Dept. Colorado State Univ., Fort Collins, Colorado.
- Buntoro,J.1990. Kajian Pengaruh Pemberian Limbah Alkohol Bekonang terhadap Kemantapan Agregat dan Permeabilitas Tanah Alfisol. Tesis Pascasarjana UGM. Yogyakarta. Hal 20
- Campbell, G.S. 1974. A Simple method for determining unsaturated hydraulic conductivity from moisture retention data. Soil Science 117:311-314.
- Campbell, G.S. 1985. Soil Physics with BASIC: Transport Models for Soil-Plant Systems. Elsevier. New York. Pp 150.
- Darmawan,W. 1994. Sifat Fisik dan Kimia Tanah Lapangan Rumpuk. Skripsi. Faperta. IPB. Bogor. Hal 27-55

- Darusman dan Karim,A.1998. Keragaman Sifat Fisik tanah Andisol sebagai Fungsi Lereng pada Tiga Tipe Penutupan Lahan di Aceh Tengah. Di dalam Jurnal Agriivita .Volume 2. No.2. Faperta. Universitas Syah Kuala, Darussalam, Banda aceh. Hal 10-109
- Dariah,A.,Budhayastoro,T.,Sudjarwadi,D.,Suganda,H.,1997. Pengaruh Kehilangan Lapisan Tanah akibat Proses Erosi terhadap Produktivitas Ultisol Kentrong. Hal 90-93. Di dalam Bidang Fisika dan Konservasi Tanah & Air serta Agroklimat & Hidrologi. Departemen Pertanian. Badan Penelitian & Pengembangan Pertanian. Puslittanak. Bogor.
- Dewi,R. Pengaruh berbagai Tipe Penggunaan Lahan terhadap Morfologi dan Tingkat Perkembangan Tanah berasal dari Abu Vulkan di Lereng Barat Gunung Kelud Tesis. Faperta. Unibraw. Malang
- Dewi,H.1995. Penggunaan Tanaman Penutup Tanah & Pupuk TSP dalam Usaha Rehabilitasi Sifat Fisik & Kimia Tanah Bekas Penambangan Bahan Baku Semen (Pasir Silika) Cibinong. Skripsi. Faperta. IPB. Bogor. Hal 24-67
- Dirksen, C., 1990. Unsaturated Hydraulic Conductivity, Raport 5. Vakgroep Hydrologie, Bodemnaturkunde en Hydraulica, Landbouwniversiteit, Wageningen, The Netherlands.
- Ermanto,B.1995. Pengaruh Pemberian Pupuk Organik dan Mulsa terhadap beberapa Sifat Fisik dan Kimia Tanah serta Produksi Bunga Mawar (Rose Hybrida) pada Andosol (Typic Hapludand) Pacet. Skripsi. Faperta. IPB. Bogor. Hal 11-46
- Fakhmansyah,F.1998. Pengaruh SistemRatoon pada berbagai kelerengan terhadap perubahan Sifat Fisik tanah podsolik Tesis Pascasarjana UGM. Yogyakarta. Hal 70-84
- Farikhah,V.1999. Peranan Akar Tanaman Pagar (*Glyricidia sp & Pelthophorum dasyrrachis*) sebagai “ Jala Penyelamat Hara “ dalam Sistem Budidaya Pagar pada Ultisol Lampung. Skripsi. Faperta. Unibraw. Malang. Hal 8-54
- Gusdinar,D.H. 1992. Pengaruh Pemberian Bahan Organik dan Kalsit terhadap beberapa Sifat Fisik dan Kimia Tanah serta Pertumbuhan Tanaman Jagung (*Zea mays L*) pada Bahan Tanah Bekas Pertambangan Mangan Daerah Karangnunggal Tasikmalaya. Skripsi. Faperta. IPB. Bogor. Hal 20-69
- Haerudin,A.2000. Kesesuaian lahan Tembakau Besuki Na Oogst (No) berdasarkan Sifat Fisika dan Kimia Tanah pada Daerah Tradisional dan Pengembangan di Kabupaten Jember. Skripsi. Faperta. Unibraw. Malang
- Hafida,I.A. 1992. Pengaruh Pembuangan B3 Organik terhadap Serapan Logam Berat Tembaga (Cu) dan Kromium (Cr) beberapa Sifat Fisik Tanah serta Pertumbuhan dan Prodiuksi Kangkung Darat (*Ipomea Reptans*) pada Latosol Darmaga. Hal 23-57
- Hartati ,S.1998.Hubungan Kerapatan Perakaran Tanaman dengan Sifat Fisik Tanah pada Berbagai Sistem Pola Tanam pada Ultisol Lampung Utara. Skripsi. Faperta. Unibraw. Malang. Hal 88-90
- Hariyanta,1992. Pengaruh berbagai Tanaman Penutup Tanah terhadap beberapa Perubahan beberapa Sifat Fisik dan Kimia Tanah. . Skripsi. Faperta. IPB. Bogor. Hal 22-64
- Herliyanto,L. 1992. Pengukuran Erodibilitas Tanah dan Usaha Pemanfaatan *Setaria Splendida Staf* untuk mengurangi Erosi yang terjadi pada Tanah Kering Terbuka (Subsoil Inceptisol) di Proyek Pengembangan Wilayah Kecamatan Sagaranten, Kabupaten Sukabumi. Skripsi. Faperta. IPB. Bogor. Hal 68-70
- Hikmatullah, Subagyo,H.,Sukarman dan Prasetyo ,B.H. 1999. Karakteristik Andisol Berkembang dari Abu Vulkanik di Pulau Flores, Propinsi NTT. Hal 3-8. Di dalam Jurnal Tanah dan Iklim No 17 Tahun 1999. Departemen Pertanian. Badan Penelitian & Pengembangan Pertanian. Puslittanak. Bogor.
- Hikmatullah, Subagyo,H.Kurnia,U dan Amin,L.I.2000. Evaluasi Erosi dan Siltasi Danau Tondano Berdasarkan Sifat Hidrologi & Tanah di Daerah Aliran Sungainya. Hal 14. Di dalam Jurnal Tanah dan Iklim No 18 Desember 2000. Departemen Pertanian. Badan Penelitian & Pengembangan Pertanian. Puslittanak. Bogor.
- Hill, J.N.S. and Summer, M.E., 1967. Effect of bulk density on moisture characteristics of soils. Soil Science, 103: 234-238.
- Hodnett, M.G., 2000. Derivation of Pedo Transfer Functions (PTFs) for the prediction of the water release curve of tropical soils.(in prep.).
- Hodnett, M.G. and Tomasella, J. 2001. Obtaining Van Genuchten parameters for tropical soils for the HYPAR agroforestry model. (under prep.).
- Jannah,R. Hubungan Sifat Fisik Tanah dengan Perkembangan Perakaran dan Produksi Tanaman Jagung (*Zea mays*) pada Lahan Bekas Alang-alang setelah ditanami beberapa Tanaman Penutup Tanah. Skripsi. Faperta. Unibraw. Malang. Hal 23-31

- Kesumawati,L. 1995.Efektivitas Penambahan Pasir dan Bahan Organik terhadap beberapa Sifat Fisik Tanah Vertisol Lakasantry Surabaya. Skripsi. Faperta. IPB. Bogor. Hal 12-33
- Klute, A., 1986. Methods of Soil Analysis, Part 1. Physical and Mineralogical Methods. American Society of Agronomy Madison, Wisconsin.
- Jannah,R. Hubungan Sifat Fisik Tanah dengan Perkembangan Perakaran dan Produksi Tanaman Jagung (*Zea mays*) pada Lahan Bekas Alang-alang setelah ditanami beberapa Tanaman Penutup Tanah. Skripsi. Faperta. Unibraw. Malang. Hal 23-31
- Kesumawati,L. 1995.Efektivitas Penambahan Pasir dan Bahan Organik terhadap beberapa Sifat Fisik Tanah Vertisol Lakasantry Surabaya. Skripsi. Faperta. IPB. Bogor. Hal 12-33
- Lawson, G.J., D.C., M., Brown, T., Crout, N.M.J. and Friend, A.D., 1998. The HyPAR Agroforestry Model, User Guide-Version 2.5. Institute of Terrestrial Ecology, Edinburgh, UK.
- Libardi, P.L., Reichardt, K., Nielsen, D.R. and Biggar, J.W., 1980. Simple field methods for estimating soil hydraulic conductivity. Soil Science Society American Journal, 44: 3-7.
- Lilie,P.1994.Tingkat Kesuburan Lahan untuk Tanaman Coklat (*Theobroma Cacao* L) pada beberapa Satuan Peta Produksi Coklat sebagai Dasar Pengembangan. Skripsi. Faperta. Unibraw. Malang
- Mardani,D.Y.1997. Pengaruh Kompos Limbah Industri Gula terhadap sifat Fisik & Kimia Typic Hapludalf serta Pertumbuhan dan Produksi Kedelai.Tesis. Pasca Sarjana Faperta. IPB. Bogor. Hal 29-77
- Maroeto.2000. Studi Perkembangan “*Andic Properties*” Terhadap Kelas Kesesuaian Lahan dan Produksi Teh (*Camelia Sinensis*). Tesis. Faperta. Unibraw. Malang
- Mega,I.M.1991. Gatra Kimiawi dan Mineralogi Tingkat Perkembangan Tanah Banjar topografi (Toposequence) Lereng Selatan Gunung Batukaru Bali. Tesis Pascasarjana UGM. Yogyakarta. Hal 92-100
- Mishra, S., Parker, J.C. and Singhal, N. 1989. Estimation of soil hydraulic properties and their uncertainty from particle size distribution data. Journal of Hydrology 108: 1-18.
- Mulyono,1986. Pengaruh Interaksi Perlakuan Bahan Organik dan Pemampatan terhadap Dinamika Lemas pada tanah Vertisol. Tesis Pascasarjana UGM. Yogyakarta. Hal 19
- Mustofa,A.1994. Pengaruh Jenis Tanaman Pagar dengan Jenis Tanaman Tertentu dengan Pola Alley Cropping terhadap beberapa Sifat Fisik dan Kimia Tanah serta Produktivitas Tanaman Kacang Tunggak (*Vigna Unguiculata* (L) Walp) pada Ultisol Kentrong. Skripsi. Faperta. IPB. Bogor. Hal 20-50
- Nasution,H.1997.Pengaruh Pengelolaan Tanaman terhadap Struktur dan Beberapa Sifat Fisik Tanah Podsolik Merah Kuning (Ultisol). Tesis. Faperta. Unibraw. Malang
- Nelson, D.W. and Sommers, L.E., 1982. Total carbon, organic carbon, and organic matter. In: A.L. Page, R.H. Miller and D.R. Keeney (Editors), Methods of Soil Analysis Part 2. Chemical and Microbiological Properties, Second Edition. American Society of Agronomy Inc., Soil Science Society of America Inc., Madison, Wisconsin, USA, p. 539-580.
- Nilasari.1995. Evaluasi Ketersediaan Lemas Tanah Akibat Penyisipan Tanaman Penutup Tanah di Pertanaman Campuran pada Tanah Typic Haplustalfs. Skripsi. Faperta. Unibraw. Malang. Hal 31.-76
- Norby, J., Rubenstein, S., Tuerke, T., Farmer, C.S. and Bennington, J., 1990. Sigma Plot : Scientific graph system. Jandel Scientific, Corte Madera.
- Nurhayati,E.1997. Penggunaan Vermi Kompos dan Pupuk NPK untuk Perbaikan beberapa Sifat Fisik & Kimia Tanah Latosol Darmaga (Oxic Dytropept) serta Kualitas Pertumbuhan Rumput Bermuda (*Cynodon Dactylon*) Varietas Evergreen.. Skripsi. Faperta. IPB. Bogor. Hal 13-50
- Nurhidayati.1998. Studi Infiltrasi pada Tanah dengan Dua Lapisan yang berbeda melalui Pengujian dan Evaluasi Model Infiltrasi *Philip* dengan Teknik *Falling Head vs Constan Head*. Tesis. Faperta. Unibraw. Malang
- Nursulistyo,H.1994. Pengaruh Pemberian Cacing Tanah (*Pheretima sp*) dan Jenic Mulsa terhadap beberapa Sifat Fisik Tanah dan Produksi Kedelai (*Glycine Max* (L) Merrill) pada Latosol di Subang Jawa Barat. Skripsi. Faperta. IPB. Bogor. Hal 32-51
- Payne, R.W., Lane, P.W., Ainsley, A.E., Bicknell, K.E., Digby, P.G.N., Harding, S.A., Leech, P.K., Simpson, H.R., Todd, A.D., Verrier, P.J. and White, R.P., 1987. Genstat 5 reference manual. Clarendon Press, Oxford.
- Peterson, G.W., Cunningham, R.L. and Matelski, R.P., 1968. Moisture characteristics of Pennsylvania soils: I. Moisture retention as related to texture. Soil Science Society American Proceeding, 32: 271-275.

- Prabowo,B.E. 1992. Pengaruh Pemberian Kotoran Sapi dan Kapur terhadap beberapa Sifat Fisik dan Kimia Tanah serta Pertumbuhan Tanaman Jagung (*Zea Mays* L) Varietas Pioner pada Tanah Podsolik Merah Kuning Gajrug Bogor. Skripsi. Faperta. IPB. Bogor. Hal 20-49
- Prasetyo,B.H., Kaslan,B and Sosiawan, H.2001. Chemical, Physical and Mineralogical Properties of Soil Developed From Andesitic Volcanic Materials in Mount Unggaran , Central Java. Pp 156-162. In Agrivita vol. 22 no.3. Faperta. Unibraw. Malang
- Prasetyo ,B.H.,Hikmatullah, Subagyo,H., dan Sosiawan, H.1999. Mollisols di Daerah NTT : Komposisi Mineral, Sifat-sifat Fisik, Kimia dan Morfologinya. Hal 28-37. Di dalam Jurnal Tanah dan Iklim No 17 Tahun 1999. Departemen Pertanian. Badan Penelitian & Pengembangan Pertanian. Puslittanak. Bogor
- Pujiati,S.2000. Sifat-sifat Fisik Tanah pada Suatu Transek di Kebun Percobaan fakultas Pertanian IPB Darmaga. Skripsi. Faperta. IPB. Bogor. Hal 65-66
- Purnomo,C.A.1995. Pengaruh Pemberian Abu Batubara dan Kotoran Sapi terhadap Perubahan Sifat Fisik tanah dan Pertumbuhan Tanaman Jagung (*Zea Mays* L) Hibrida pada Typic Hapludult dari Gajrug. Skripsi. Faperta. IPB. Bogor. Hal 15-51
- Purwanto,S.1991. Penyidikan Tingkat Perkembangan Sifat Fisik Tanah pada Katena Tenggara Gunung Arjuno. Tesis Pascasarjana UGM. Yogyakarta. Hal 52-73
- Rachman,N.D.1992. Peranan Jenis Tanaman Legum dalam Memperbaiki Sifat Fisik dan Kimia Tanah pada Tanah Marjinal (Tropudult) Lampung Tengah. Skripsi. Faperta. IPB. Bogor. Hal 3-40
- Rawls, W.J., Gish, T.J. and Brakensiek , D.L., 1991. Estimating soil water retention from soil physical properties and characteristics, *Advances in Soil Science*. Springer-Verlag, New York, p. 213-234.
- Santoso,B.1997. Studi on The Mineral, Physical & Chemical Properties of Soil Derived From The 1919, 1951, 1966 and 1990 Eruptions of Mount Kelud. Agrivita, Volume 16 No 1. Faperta. Unibraw. Malang. Pp 33-34
- Setiyadi,S. 1997. Pengkajian Beberapa Sifat Fisik Tanah di Bawah Sistem Budidaya Lorong pada Ultisol Lampung. Skripsi. Faperta. Unibraw. Malang. Hal 15-58
- Setiyawati,T.B.1987. Pengaruh Perbedaan Ukuran Guludan terhadap Erosi dan Limpasan Permukaan. Tesis. Faperta. Unibraw. Malang. Hal 26
- Sholihah,A.1992. Pengaruh Dosis dan Macam Bahan Organik Terhadap Sifat Fisik Tanah Tropopsamments Desa Sumberputih Wajak Malang Selatan. Skripsi. Faperta. Unibraw. Malang. Hal 28-78
- Sitarasmi,D. 1982. Perbandingan Penggunaan Bahan Organik (Amina) PVA (Poly Vinyl Alcohol) dan lateks sebagai *Soil Conditioner* dalam Ketahanan Erosi pada Tanah Andosol. Tesis Pascasarjana UGM. Yogyakarta. Hal 14-17
- Slamet,G.1992. Pengaruh Teknik Konservasi Tanah, Pertumbuhan , Produksi dan Kandungannya dalam Jaringan Tanaman Kangkung (*Ipomea Reptans* Poir) serta Perubahan Sifat Fisik Tanah Akibat Limbah Industri yang Mengandung Timbal . Skripsi. Faperta. IPB. Bogor. Hal 33-84
- Soil-Survey-Staff, 1992. Key to Soil Taxonomy. Pocahontas Press, Blackburg, USA.
- Stole, J., Wesseling, J.G. and Wösten, J.H.M., 1996. Pedotransfer functions for hydraulic and thermal properties of soil and the tool HERCULES. Report 126, DLO Winard Staring Centre, Wageningen.
- Subagyo,1993. Pengaruh Pemberian Pupuk Kandang Terhadap beberapa Sifat Fisik Typic Tropustalf di Lahan Kering Putukrejo Kalipare Malang. Skripsi. Faperta. Unibraw. Malang. Hal 67-70
- Suganda,H. Kusnadi,H dan Kurnia,U.1999.Pengaruh Arah Barisan Tanaman dan Bedengan dalam Pengendalian Erosi pada Budidaya Sayuran Dataran Tinggi. Hal 57. Di dalam Jurnal Tanah dan Iklim No 17 Tahun 1999. Departemen Pertanian. Badan Penelitian & Pengembangan Pertanian. Puslittanak. Bogor.
- Suhardojo,B.1994. Penilaian Kesesuaian Lahan Menggunakan Metode CSR/FAO (1983) & Water Sheed Sufficiency Di Lahan Kering di Kecamatan Wagir. Kabupaten Malang. Skripsi
- Suharsono,1989. Perbandingan Metode Penetapan Konduktivitas Hidrolik Jenuh *Constant Head Guelph Penmeameter* & *Constant Head* dengan Silinder Kecil pada Ultisol Lampung. Skripsi. Faperta. Unibraw. Malang. Hal 27-42
- Sujatmiko,1992. Pemetaan Tanah Semi Detail & Evaluasi Kesesuaian Lahan untuk Tanaman Teh pada Lahan PT Perkebunan XIII, Afdeling Malabar selatan Desa Banjarsari, Kecamatan Pangalengan, Kabupaten Bandung. Skripsi. Faperta. IPB. Bogor. Hal 12-67
- Suherman,D.1992. Evaluasi Ketersediaan Air pada Lahan Kering untuk Tanaman Jagung dengan menggunakan program IRSIS (*Irigation Scheduling Information System*). Skripsi. Faperta. Unibraw. Malang

- Supadminingsih, E. 1999. Dinamika Morfologi, Perkembangan dan Klasifikasi Tanah Sulfat Masam pada berbagai Sistem Pengelolaan Lahan. Tesis. Faperta. Unibraw. Malang
- Suprayogo, D. 2000. Testing the Safety-Net Hypothesis in Hedgerow Intercropping: Water Balance and Mineral-N leaching in the Humid Tropics. Thesis. Imperial College of Science, Thechnology and Medecine, University of London.
- Suriadi, E. 1992. Pengaruh Flemingia Congesta dan Strip Akar Wangi pada Pertanaman Jagung (*Zea Mays* L.) terhadap Aliran Permukaan, Erosi dan Produktivitas Lahan di Latosol Citayam. Skripsi. Faperta. IPB. Bogor. Hal 28-53
- Susilowardhani, T. 1995. Rehabilitasi beberapa Sifat Fisik dan Kimia Tanah dengan Penambahan Zeolit, Bahan Organik serta Penanaman Rumput Vetiver (*Vetivera Zizanoides*) pada tanah Bekas Tambang Pasir Silika Cibinong. Skripsi. Faperta. IPB. Bogor. Hal 19-48
- Sutanto, A. 1993. Penentuan Dinamika Ketersediaan Air bagi Tanaman Tumpang sari antar Jagubg dan Ketela Pohon pada Lahan Kering Desa Putukrejo, Kecamatan Kalipare Malang. UPN Veteran. Faperta. Surabaya. Hal 25-27
- Syarbini, M. 1997. Perubahan Morfologi, Genesa dan Klasifikasi Ultisol akibat Perubahan Penggunaan Lahan di Kalimantan Selatan. Tesis. Faperta. Unibraw. Malang
- Syarif, M. 1992. Pengaruh Budidaya Sawah terhadap Perubahan sifa-sifat ultisol di Daerah jambi. Tesis Pascasarjana UGM Program KPK Unibraw. Yogyakarta. Hal 97-98
- Tomasella J. and Hodnett, M.G. 1998. Estimating soil water retention characteristics from limited data in Brazilian Amazonia. *Soil Sci* 163 (3), 190-202.
- Tala'ohu, H.S., Sukamana, S., Erfandi, D. dan Sudjarwadi, D. 1997. Reklamasi Tanah Timbunan Sisa Galian Penambangan Batubara & Monitoring Erosi di Tanjung Enim. Hal 47-50. Di dalam Bidang Fisika dan Konservasi Tanah & Air serta Agroklimat & Hidrologi. Departemen Pertanian. Badan Penelitian & Pengembangan Pertanian. Puslittanak. Bogor.
- USDA, 1975. Soil Taxonomy: Basic System of Soil Classification for Makaing Interpreting Soil Survey. Agriculture Handbook No 436. Washington, pp 754.
- Utomo, S. 2001. Karakterisasi Sifat Fisik Tanah untuk Evaluasi Kesesuaian Lahan Kedelai (*Glycine max* L) pada Lahan Sawah di Mojokerto. Skripsi. Faperta. Unibraw. Malang
- Van Den Berg, J.A. and Louters, T., 1986. An Alogarithm for computing the relationship between difusivity and soil moisture content from the hot air method. *Journal of Hydrology*, 83: 149-159.
- Van Den Berg, M., Klamt, E., Van Reeuwijk, L.P. and Sombroek, W.G., 1997. Pedotranfer functions for the estimation of moisture retention characteristics of Ferralsols and related soils. *Geoderma*, 78: 161-180.
- Van Genuchten, M.T.H., 1980. A closed-form equation for predicting the hydraulic conductivity of unsaturated soils. *Soil Science Society American Journal*, 44: 892-898.
- Van Grinsven, J.J., Dirksen, C. and W., B., 1985. Evaluation of the hot air methods for measuring soil water difusivity. *Soil Science Society American Journal*, 49: 1093-1099.
- Van Noordwijk, M. and Lusiana, B., 1999. WaNuLCAS 2.0.: Backgrounds of a models of water, nutrient and light capture in agroforestry systems. International Centre for Research in Agroforestry (ICRAF), ICRAF-S.E. Asia, Bogor.
- Van Noordwijk, M., Widiyanto, Heinen, M. and Hairiah, K., 1991. Old tree root channels in acid soils in the humid tropics: Important for crop root penetration, water infiltration and nitrogen management. In: R.J. Wright, V.C. Baligar and R.P. Murrmann (Editors), *Plant-Soil Interactions at low pH*. Kluwer Academic Publishers, The Netherlands, pp. 423-430.
- Westhoek, H. 1984. Soils and Soil Conditions of The Muneng Agricultural Experiment Station. Soil Science Department, Faculty of Agriculture. Brawijaya University. Malang.
- Widiyanto. 1981. The use of soil textural and organic carbon data to predict capacity of available water in some soils from Indonesia. Thesis. M.Sc-Course in Soil Science and Water Management, Wageningen Agricultural University. The Netherlands.
- Widyatmiko, B. 1998. Evaluasi Kesesuaian Lahan untuk Tanaman Teh (*Camelia assamica* L) dengan menggunakan metode CSR/FAO Staf (1983) di Kebun Kertowono PTP Nusantara XII (Persero) di Gucialit Lumajang. Skripsi. Faperta. Unibraw. Malang
- Wösten, J.H.M., Finke, P.A. and Jansen, M.J.W., 1995. Comparison of class and continuous pedotransfer functions to generate soil hydraulic characteristics. *Geoderma*, 66: 227-237.

- Wösten, J.H.M., Lilly, A., Nemes, A. and Le Bas, C., 1998. Using existing soil data to derive hydraulic parameters for simulation models and in land use planning, SC-DLO, Agricultural Research Departement, Winand Staring Centre for Integrated Land, Soil and Water Research, Wageningen, The Netherlands.
- Wulansari,R.1992. Pengaruh Logam Berat Timbal & Kadmium (Cd) terhadap Pertumbuhan , Produksi & Kandungannya dalam Jaringan Tanaman Kangkung (*Ipomea Reptans Poir*) serta Perubahan Sifat Fisik Tanah akibat Limbah Industri yang mengandung Timbal. Skripsi. Faperta. IPB. Bogor. Hal 31-81
- Zaenal,K.1985. Hantaran Hidrolik Jenuh pada beberapa Tanah Daerah Istimewa Yogyakarta. Tesis Pascasarjana UGM. Yogyakarta. Hal 18-30
- Zakiah,K.1994. Pengaruh Tanaman Penutup Tanah Leguminose & Pemupukan Fosfat terhadap Produktivitas Tanah Inceptisol. Skripsi. Faperta. IPB. Bogor. Hal 33-87
- Zulkarnain.1995. Pemanfaatan Cacing Tanah (*Pheretima sp*) dan Tanaman Penutup Tanah dalam Usaha Rehabilitasi tanah Bekas Tambang Batubara di Senakin Barat. Kalimantan Selatan. Skripsi. Faperta. IPB. Bogor. Hal 10-30

11 Appendix III: Options for Changing the Crop Modules in HyPAR

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11.1 Introduction

The proposal for FRP Project R7397 (SAMUG) included a commitment to ‘*Incorporate new crop routines from the CERES model in HyPAR and test with ICASA datasets*’. An ‘expert system’ to facilitate the use of ICASA datasets has been developed by Cranfield University (Annex 1). The PARCH model, whilst initially supported by the DFID Systems Programme, appeared to be no longer used in the research community, still less amongst extensionists. Furthermore the libraries of crop parameters expected when the FRP Agroforestry Modelling Project commenced had not been developed. When the SAMUG proposal was written it seemed appropriate to replace PARCH routines with those from one of the DSSAT⁸ crop models. CERES is a generic grain model and was the original target. However doubts soon arose about the wisdom of this route:

CERES is non-modular Fortran code, and is written in a way that makes incorporation in HyPAR difficult – the DSSAT team are engaged in production of a modular crop model, and it was decided to evaluate this as an alternative

An EU funded project, titled ‘Silvo Arable Forestry for Europe (SAFE) commenced in November 2001 (Lecomte 2002), and includes the use of a generic French crop model called STICS (Bresson 2002) which may be a better alternative to PARCH or CERES.

This Appendix summarises options for using CERES or STICS in HyPAR.

11.2 HyPAR

11.2.1 The HyPAR model

HyPAR models the growth of trees and crops in agroforestry systems. The tree growth components are based on those in the Hybrid model v3.0 (Friend, 1997). Hybrid is an individual-based plot model, driven by daily weather, that can predict how tree species interact with atmospheric and soil processes. The crop components are based on the tropical crop model, PARCH (Bradley & Crout, 1994).

Versions of the model after HyPAR v4.0 run continuously from year to year allowing several annual crop seasons to be studied, with one or two crops per year. The model is supplied with parameter files for two crops, sorghum and maize, and 8 tree types. HyPAR includes options for management including fertiliser addition to the soil and tree pruning for example. Full details are available on the project web site, www.edinburgh.ceh.ac.uk/hypar.

11.2.2 HyPAR Code

The precursor to HyPAR, Hybrid v3.0, was written using standard Fortran77. The code is contained in a single file and the subroutines access variables via common blocks. The subroutines are built around physical processes (photosynthesis, phenology, allocation etc) and operate at a daily or annual timescale. A large portion of the code deals with handling replicate plots and multiple sites for large areas (regional or global) and competition between tree species. There is no user interface, the program is run from the command line using text input and output files and was designed primarily for use on a Unix platform.

⁸ Decision Support System for Agrotechnology Transfer – DSSAT (deesat) is a microcomputer software program combining crop soil and weather data bases and programs to manage them, with crop models and application programs, to simulate multi-year outcomes of crop management strategies. As a software package integrating the effects of soil, crop phenotype, weather and management options, DSSAT allows users to ask "what if" questions and simulate results by conducting, in minutes on a desktop computer, experiments which would consume a significant part of an agronomist's career – see <http://www.icasa.net/dssat/index.html>.

PARCH is written in Visual Basic, with a DOS menu-style interface for PCs. The program includes routines for plotting graphs and analysing the output. The subroutines are also built around similar physical processes running on a daily timestep.

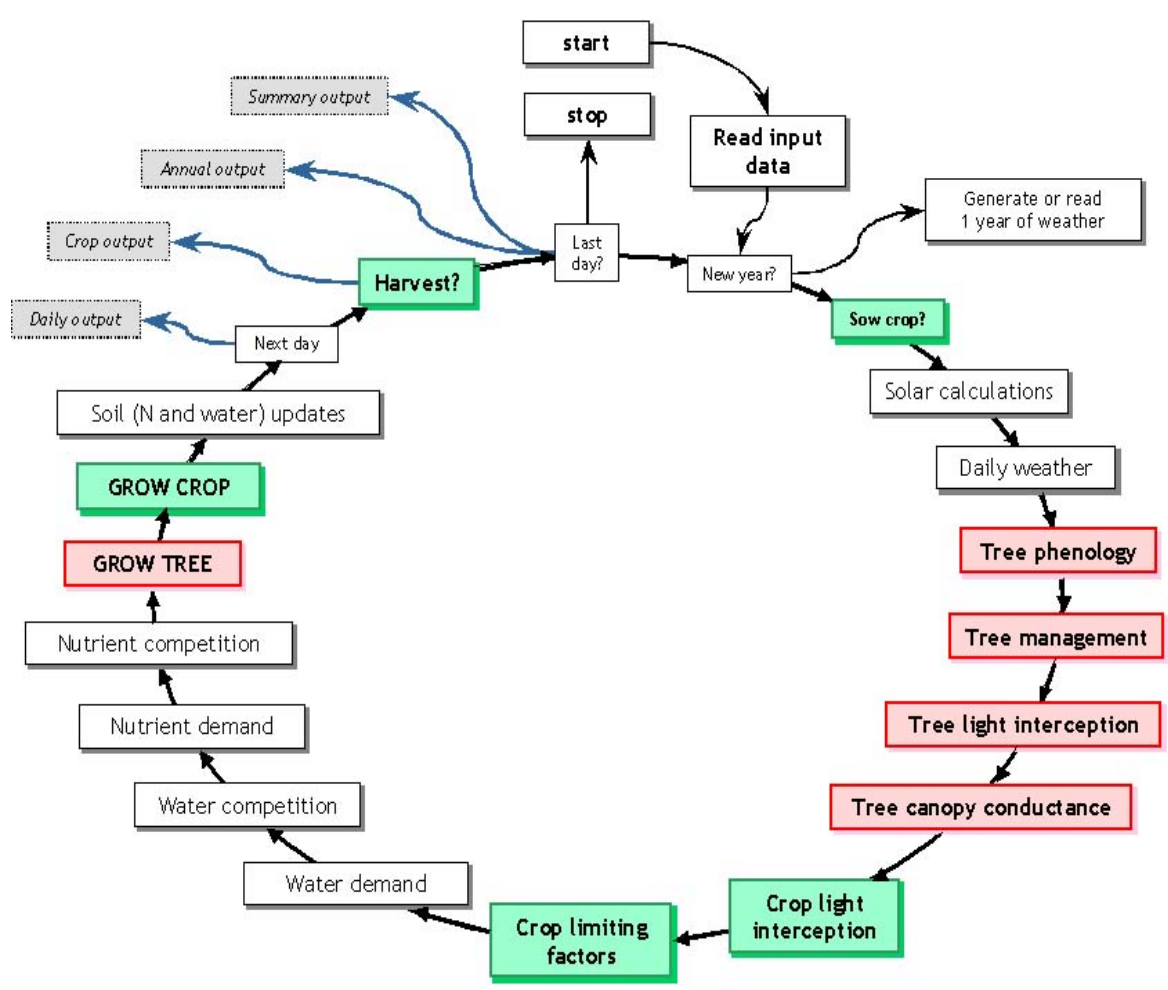


Figure 4 Daily cycle of subroutine calls in HyPAR v4.5

In outline, HyPAR was constructed by removing the multi-site code from Hybrid, converting PARCH to Fortran77 (removing the user interface code) then adding the required crop subroutines into the Hybrid main program in the appropriate order to model dynamic interaction on a daily timestep, as shown in Figure 1. This process was carried out in stages, first adding competition for light, then competition below ground between tree and crop, then adding more advanced soil water routines etc. The process was complicated by the need to avoid duplicate variable names in the two sets of code – many of which were hidden in common blocks. The underlying code in HyPAR v4.5 (and later) is Fortran77 with some Fortran90 features. Model development was carried out at the same time as the two code blocks were merged. Where time allowed, common blocks were removed from key subroutines and the variables passed as arguments for clarity.

Many of the subroutines contain code for modelling tree or crop processes separately, as in the original programs, but there are a number of new subroutines written specifically for HyPAR. The new routines are mainly concerned with competition between plants, the new soil submodel and the disaggregated canopy option.

The current version, v5.0, has 155 subroutines and 42 functions contained within 68 files (see Appendix 1). There are 16 common blocks but these are contained within four files which function essentially like four modules (the Fortran90 system similar to common blocks). In HyPAR v5.0, there are a few small common

blocks but the majority of variables are passed as arguments to each subroutine (which means the argument list is long but it is clear exactly which variables are used by that subroutine).

The HyPAR model code can be compiled and run from the command line – the program reads input from ASCII files and creates text output files in a format suitable for reading into a spreadsheet program like Microsoft Excel. In addition to the model itself, there is a graphical user interface (PC version only) which simplifies the process of preparing the input files and a set of Excel macros to assist in the analysis of the output. HyPAR simulations can be prepared and executed with or without the interface.

11.3 Decision Support System for Agrotechnology Transfer (DSSAT)

11.3.1 DSSAT Crop models

The Decision Support System for Agrotechnology Transfer (DSSAT) is a microcomputer software program combining crop soil and weather data bases and programs to manage them, with crop models and application programs, to simulate multi-year outcomes of crop management strategies. As a software package integrating the effects of soil, crop phenotype, weather and management options, DSSAT allows users to ask "what if" questions and simulate results by conducting experiments which would consume a significant part of an agronomist's career (from <http://www.icasa.net/dssat>). DSSAT v3.5 includes models for more than 16 different crops as part of the CropGro and CERES models (maize, wheat, soybean, peanut, rice, potato, tomato, drybean, sorghum, millet, pasture, chickpea, cowpea, velvetbean, brachiaria grass, and faba bean).

11.3.2 DSSAT Code

The DSSAT program includes a DOS-based menu-style user interface, which creates an intermediate ASCII input file, and a set of Fortran routines that read the intermediate file and carry out the required simulation.

The code for the CropGro models (i.e. without the interface) is written in Fortran77 and consists of 186 subroutines and 24 functions contained within 100 separate files.

11.3.3 DSSAT-CSM model

The DSSAT cropping system model (CSM) is a new implementation of the individual crop models contained in DSSAT v3.5. The re-designed and revised CSM has a modular structure designed to allow replacement or addition of modules (see *Figure 5*). It currently contains models of 16 crops derived from the old DSSAT CROPGRO and CERES models. The DSSAT-CSM components describe the time changes in the soil and plants that occur on a single land unit in response to weather and management.

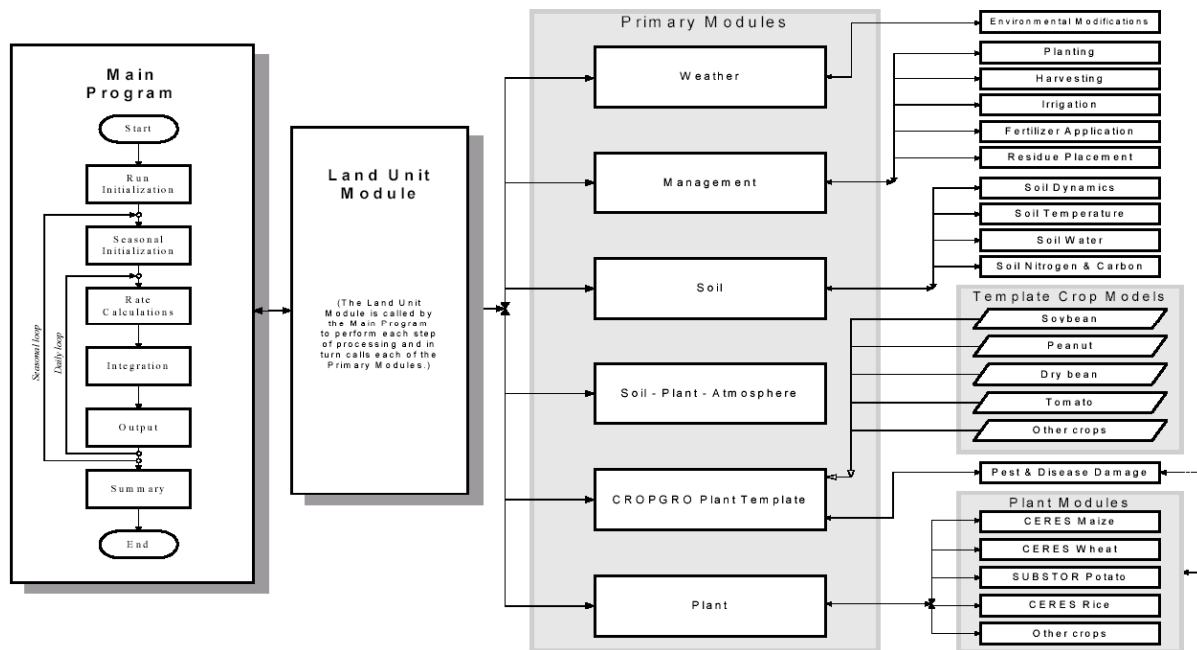


Figure 5: CSM overview of components and modular structure

11.3.4 DSSAT-CSM code

A pre-release version of the DSSAT-CSM code was provided (simulation models only, without the interface) and consists of 137 Fortran files.

The DSSAT-CSM has

- a main driver program,
- a land unit module,
- modules for the primary components that make up a land unit in a cropping system
 - weather,
 - soil,
 - plant,
 - soil-plant-atmosphere interface,
 - management components.

(see Table 8) Each module has six operational steps; run initialisation, season initialisation, rate calculations, integration, daily output, and summary output. The main program controls when each of these steps is active. This programming style allows each module to read its own inputs, initialise itself, compute rates, integrate its own state variables, and write outputs completely independent from the operation of other modules. Only a few “interface” variables are communicated to and from each module. This allows one to “unplug” a module and replace with a different one as long as it communicates the same variables to the rest of the modules, even if the parameters, state variables, and module input files are different. The concept of “interface” variables is critical to the modular approach used in DSSAT-CSM.

11.4 Combining Models

When building a new model based on existing models it is preferable to go back to the original descriptions (from published literature and manuals) and build a new implementation. In recent years there has been an increase in the number and complexity of available modelling packages (ModelMaker, Matlab/Simulink,

Stella, etc) and programming tools (Simile, ??) and a corresponding increase in the demands from end-users for more sophisticated model interfaces. Each program has to balance the usefulness of the model as a tool for research, the ease of use for the end-user and the efficiency and flexibility of the source code.

In practise most model programs are very large and have been developed over many years by teams of modellers and to recode would be very time-consuming, even assuming the precursor models are fully documented. Also, the existing program will have been tested and any new code would have to be retested from scratch adding more time to the development.

Ideally it should be possible to reuse the **core** source code within a new framework. The ease with which this can be achieved depends on the similarity of the two programs (e.g. language, complexity, programming style) and the level of documentation!

11.5 Merging HyPAR and CropGro

The crop component of HyPAR is based on PARCH. The available parameter files enable only varieties of sorghum and maize to be modelled. The PARCH model is no longer supported by the original authors so new parameter sets cannot easily be developed or tested outside HyPAR. It was decided that version 5 of HyPAR should include alternative crop species – ideally by incorporating established crop models that are well supported. One option is to use the one or more of the DSSAT crop models CropGro or CERES. An alternative strategy would be to add a tree option to the DSSAT crop models as a new agroforestry modelling system.

HyPAR and the DSSAT crop models are of similar complexity and operate at the same time-scale and the source codes are both written in Fortran. Sharing methods or code between two is not an unreasonable task.

After considering the alternative strategies, it was decided that the most appropriate option (given the time constraints and future plans for HyPAR) was to add the necessary subroutines from the CropGro (or CERES) crop models into HyPAR rather than attempt to add the tree routines into the code for CropGro. The DSSAT system also includes a standard format for data input and output files. It was proposed that HyPAR v5 or later is adapted to conform to these standards.

The DSSAT and the HyPAR code structures have many differences although the underlying biophysical models are similar. As a first step towards integration of CropGro routines, the ‘time’ (calendar date and simulation time) structure of HyPAR was amended to fit in with that of the DSSAT models. Thus, HyPAR v4.5, instead of having nested loops for simulation run, calendar year, season and day, has a single loop based on the date with events triggered as appropriate (e.g. new climate generated or read in on each January 1st). Once this common ‘time’ framework was established the main programs for HyPAR and CropGro looked similar and it was easier to see how the crop model routines could be integrated for HyPAR v5.0.

In HyPAR, the input files (intermediate files created by the Graphical User Interface or edited ‘by hand’) are opened, read once and closed at the start of the simulation run and the variables stored and passed to subroutines as required. In the DSSAT code, the main input file (also an intermediate file created by the user interface) is opened, read and closed many times by each subroutine that needs an input values. The difference in style seems minor but does make it more tedious to exchange sections of code. HyPAR v5.0 (unreleased) has one main input file with sections similar to that in the DSSAT file as a step towards compatibility. If this version is to be continued, the code could be further modified to use the standard DSSAT input file with individual subroutines accessing the file as required.

The next stage was to extract the appropriate routines for crop growth from CropGro and either replace the PARCH routines or add them as an alternative crop option in HyPAR. This proved to be a complex procedure because of the different structures of the two programs. The crop subroutines in HyPAR are distributed in the code between tree subroutines (to keep functionally similar biological processes together) whereas in CropGro the modular framework scheme uses conditional calls within larger subroutines which are called many times. In addition, the soil subroutines in HyPAR are separate (enabling the crop and tree roots to compete on a daily basis) whereas CropGro has its own soil code so either these routines had to be removed, or the tree root routines would be required to interact with the CropGro soil.

It became clear that many of the difficulties encountered were being addressed in the current phase of producing a modular version of DSSAT (the DSSAT-CSM), so continuing with the ‘CropGro’ route seemed

an inefficient duplication of effort. One motivation for changing HyPAR is to be compatible with the DSSAT models, so any amendments should reflect the current DSSAT-CSM methods.

Rather than replace parts of HyPAR with code from CropGro, more flexible solutions would be to either use modules from the new DSSAT-CSM in HyPAR or add tree modules to the CSM.

11.6 Revised Modification Options for HyPAR

The overall aim is to create a model for agroforestry systems, which includes a variety of tree and crop species, and can realistically model the interaction and competition for resources both spatially and over time. In addition, the implementation of this model should be ‘user-friendly’ – for the end-users, the modellers and the programmers!

As before, this could be achieved by further modification of HyPAR – adding extra crop routines – or by incorporating trees into the DSSAT-CSM crop modelling system.

11.6.1 Adding trees to the DSSAT-CSM.

HyPAR can be used in two ways to model agroforestry, with a uniform or a disaggregated tree canopy above a crop.

In ‘uniform’ mode, the tree canopy is essentially a simple homogenous layer shading the crop from above and extracting water and nutrients from the soil. To mimic the effect of a tree in the CSM, a simple option could be added where the crop experienced reduced light, water and nutrient resources. However, but the competition effect would not be dynamic and there would be no information about the virtual ‘tree’.

The CSM has a facility to add extra crops using a template – adding a tree model could be achieved by adding it as another crop using this template. However, the task would then be to allow the two ‘crops’ to grow at the same time in the same field and compete for resources. This would require a detailed knowledge of the model and the program. The CSM team who are familiar with the program would be able to do this in far less time than a novice user.

In the HyPAR spatially ‘disaggregated’ mode, the trees have a location within a field so that the shading pattern and below-ground competition varies for different crop plants depending on distance and orientation from the trees(s). Incorporating this into DSSAT-CSM would require extensive modification and would have to be a task for the CSM designers.

11.6.2 Adding new crops to HyPAR

The CSM was designed to allow modules to be added or removed within the framework. To add a new crop to HyPAR the basic aim would be to take the appropriate crop module(s) from the CSM and incorporate them into the HyPAR main program, ensuring that the “interface” variables were connected appropriately.

Table 8 gives a summary description of modules in the DSSAT-CSM

Based on information given in Jones et al (2002?) summarised in Table 8, incorporating the DSSAT crop models into HyPAR would require the CropGro Crop Template Module, the Individual Plant Growth Modules and the Management Operations Module plus parts of the Soil–Plant–Atmosphere module and Soil module, depending partly on whether the PARCH code is removed completely or maintained as an optional crop.

From the point of view of the *model* there are many similarities, both models include the same basic processes at a similar level of detail, so it should be possible to simply substitute the PARCH crop routines with DSSAT crops. Unfortunately, from the point of view of the source code it is not so simple. How are the crop processes represented? Which modules are required and how and where should these modules be included in the code of HyPAR? Is the code compatible (F77/F90)? In addition we have to consider the input/output of variables to and from the program, the declaration and choice of variable names and, more importantly, the interaction between the tree and crop routines during a simulation day.

Table 8 Summary description of modules in the DSSAT-CSM.

Modules	Sub Modules	Behavior	Comment re HyPAR
Main Program (DSSAT-CSM)		Controls time loops, determines which modules to call based on user input switches, controls print timing for all modules.	HyPAR v5 main program has broadly similar structure and function.
Land Unit		Provides a single interface between cropping system behavior and applications that control the use of the cropping system. It serves as a collection point for all components that interact on a homogenous area of land.	No equivalent as a separate module/subroutine.
Weather		Reads or generates daily weather parameters used by the model. Adjusts daily values if required, and computes hourly values	Based on the same weather generator but HyPAR does not use hourly values. May need to use some or all of this module for the new crop routines
Soil	Soil Dynamics	Computes soil structure characteristics by layer. This module currently reads values from a file, but future versions can modify soil properties in response to tillage, etc.	HyPAR has a detailed soil submodel offering different options for pedotranfer function calculation and hydrology model. Within the code, most soil variables are 3 dimensional arrays to allow for the grid system under a disaggregated tree. It would therefore be preferable to keep the HyPAR soil code. Based on outputs listed in Appendix 2, table 2, HyPAR cannot produce all the variables output from the DSSAT soil module. This may mean extra functionality has to be added to HyPAR (eg soil temperature).
	Soil Temperature Module	Computes soil temperature by layer.	
	Soil Water Module	Computes soil water processes including snow accumulation and melt, runoff, infiltration, saturated flow and water table depth. Volumetric soil water content is updated daily for all soil layers. Tipping bucket approach is used.	
	Soil Nitrogen and Carbon Module	Computes soil nitrogen and carbon processes, including organic and inorganic fertilizer and residue placement, decomposition rates, nutrient fluxes between various pools and soil layers. Soil nitrate and ammonium concentrations are updated on a daily basis for each layer.	
Soil – Plant – Atmosphere (SPAM)		Resolves competition for resources in soil-plant-atmosphere system. Current version computes partitioning of energy and resolves energy balance processes for soil evaporation, transpiration, and root water extraction.	This module would be needed in HyPAR v5, with modifications to allow for competition with the tree(s) and correct interaction with the soil submodel.
CROPGRO Crop Template Module		Computes crop growth processes including phenology, photosynthesis, plant nitrogen and carbon demand, growth partitioning, and pest and disease damage for crops modeled using the CROPGRO model crop Template (soybean, peanut, dry bean, chickpea, cowpea, faba bean, tomato, Macuna, Brachiaria, Bahiagrass).	These modules are the main ones to be incorporated into HyPAR v5.
Individual Plant Growth Modules	CERESMaize; CERESWheat; CERESRice; SubStorPotato; Other plant models	Modules that simulate growth and yield for individual species. Each is a separate module that simulates phenology, daily growth and partitioning, plant nitrogen and carbon demands, senescence of plant material, etc.	
Management Operations	Planting	Determines planting date based on read-in value or simulated using an input planting window and soil, weather conditions.	All these functions are currently carried out within the PARCH sections of the HyPAR code –

Module	Harvesting	Determines harvest date, based on maturity, read-in value or on a harvesting window along with soil, weather conditions.	this module would need to be incorporated into v5, with appropriate links to soil and litter submodels
	Irrigation	Determines daily irrigation, based on read-in values or automatic applications based on soil water depletion.	
	Fertilizer	Determines fertilizer additions, based on read-in values or automatic conditions.	
	Residue	Application of residues and other organic material (plant, animal) as read-in values or simulated in crop rotations.	

HyPAR was not designed using the same modular philosophy as DSSAT-CSM. Although the modules from DSSAT-CSM are well-defined, the input/output variables do not match those used in HyPAR for the PARCH routines (square peg, round hole!). The calling structure of HyPAR is ‘flat’ – most of the subroutines are called directly by the main program or at most 2 or 3 levels down from it. Crop processes are mixed with tree and soil processes during a ‘model day’ whereas only the ‘Land Module’ is called by the DSSAT-CSM main program.

The DSSAT-CSM main program has a section to set up the simulation run (which reads and interprets the command line arguments), then a section to call the Land Module six times with different switches, ending with a section to close the run.

The first option considered was to call only the Land module from the HyPAR main program, similar to the method used in the CSM main program.

The main program in HyPAR v4.5 was not readily divided up into the six operational sections expected by the CSM code (run initialisation, season initialisation, rate calculations, integration, daily output, and summary output). Recoding of the HyPAR main program for version 5.0 has addressed this in part by matching the ‘time’ structure and naming standard of DSSAT. However, the system for the input of data (such as start time etc) is very different in the two programs. It took more than 6 days to sort, rewrite and debug the code to allow the Land Module to compile and run without error inside the HyPAR main program. At the time of writing, the Land Module is called once for run initialisation and appears to function – but there is no interaction between the module and HyPAR beyond a few ‘time’ variables used to set up the controls.

The next planned stage would be to call the Land Module (at least) five more times with the appropriate switches set for each of the necessary stages. The Land Module may need to be called for each ‘plot’ in disaggregated mode, if this is the case it will greatly slow down the execution of the program. Once this is done, the daunting task is to work out how the two sections of code should interact, *i.e.* which variables need to be shared and modified to model tree-crop competition.

Calling the Land Module from HyPAR was a small first step which suggests the full process would take several weeks if not months to complete. Part of the problem is that the CSM reads data directly from an intermediate file which is normally created by the DSSAT front end. The intermediate file is difficult to read and modify ‘by hand’ without a full understanding of DSSAT. If HyPAR v5 is to be used the parameter input method has to be modified. If the program is to remain compatible with DSSAT then the HyPAR code must be adapted to use the DSSAT intermediate file. At the moment, variables such as start date, run duration and other options are read in twice, once by each set of code. HyPAR v5 no longer works with the Graphical User Interface. The interface will have to be changed to accommodate the new crops and to read/create the intermediate file.

The second option considered was to discard the Land module and use only the core crop model modules.

Using the Land Module it would be very difficult to identify and correctly pass back the appropriate variables to the tree and soil routines. Logically the trees should be within the Land module not above it. Thus, it would be more appropriate to use just the *submodules* (listed in Table 8), but detaching these from the Land Module has its own set of problems and would be very time-consuming. It would clarify the task if the numerous run type, treatment, pest control or management options were removed from DSSAT to leave only the core crop models but, again, this would be a lot of work for someone not familiar with CSM so has not been attempted here.

In addition, HyPAR has separate routines for printing the output files. Variables required for output are passed to the dedicated output routines so these would have to be amended (i.e. crop parts deleted) or the required crop variables passed to these routines as well (each module in the CSM creates its own output). Alternatively, HyPAR v5 could adopt the DSSAT-style method where each module prints its own output files. This would be feasible but the HyPAR Excel macros would have to be rewritten.

11.7 Conclusions

The original plan was to keep the HyPAR v5.0 main program structure as it is and call the new CSM modules in the appropriate order. The HyPAR main program is important because of the need to accommodate the multi-plot 'disaggregated' canopy option. However, the DSSAT-CSM is a complex program which has a large set of options relating to management, pests, treatments etc as well as 16 crop models. Including the whole DSSAT-CSM, leaving the modules intact, proved to be unrealistic given the different program structures of the two sets of code.

A more reasonable approach would be to identify and utilise only the crop routines that are directly relevant to the existing HyPAR program (v5.0). Disentangling the essential crop model code is a major undertaking that would take many weeks. For HyPAR v5.0 to be useful for end-users time would have to be spent ensuring that the program can correctly use the DSSAT-style intermediate input file and work effectively with a new Graphical Interface.

However, the end result would simply be a version of HyPAR with new crop options. As the proposed structure of HySAFE is very different from HyPAR the integration process would have to be repeated from scratch by the HySAFE team. Many of the problems with integrating the DSSAT-CSM code are due to the construction of HyPAR and the HySAFE team is already committed to a different strategy that means recoding most of HyPAR. However, as the HySAFE model is object-oriented and closer to the modular design of DSSAT it is likely that the DSSAT-CSM modules could be used with less reprogramming.

Success for HySAFE largely depends on consistent support from a crop modelling team. This cannot be assumed from the DSSAT team and our advice is therefore to continue development of the STICS crop modelling framework using a recoded version of the core Hybrid single tree model ('Supertree').

11.8 References

Bradley RG & Crout NMJ (1994). PARCH-Users Guide. Tropical Crops Research Unit, University of Nottingham: Sutton Bonnington. 124p.

Bresson et al

Friend, A. D., A. K. Stevens, R. G. Knox, and M. G. R. Cannell, (1997) A process-based, terrestrial biosphere model of ecosystem dynamics (Hybrid v3.0), *Ecol. Modell.*, 95, 249-287.

J. W. Jones, G. Hoogenboom, C. H. Porter, K. J. Boote, W. D. Batchelor, L. A. Hunt⁵, P. W. Wilkens⁶, U. Singh, A. J. Gijssman, and J. T. Ritchie, (unpublished) The DSSAT Cropping System Model, For Special Issue of European Journal of Agronomy.

Lecomte, I. (2002) What HySAFE model structure in CAPSIS modelling environment? Project web site, <http://www.ensam.inra.fr/safe/>

12 Appendix IV: Registered Users of the HyPAR Model

Last name	First name	Email address	Address	Country	Justification (truncated by Groupwise print!)
Abamo	Antonio	tony.abamo@eudoramail.com			
Arah	Jon	J.ARAH@CGIAR.ORG			
Armitage	Ian	ian.armitage@xtra.co.nz	50 RANUI TERRACE, TAWA	New Zealand	I am a consultant in a new ADB-funded agro-forestry programme in northern Lao PDR. I believe the model will be helpfu
Auclair	Daniel	auclair@cirad.fr	UMR AMAP (Botanique et Bioinformatique de l'Architecture des Plantes;	France	for improving the SAFE model
Baharuddin		ntfps@yahoo.com	jurusan kehutanan Fakultas Pertanian dan Kehutanan Unhas	Indonesia	education
Barrios	Luis Enrique García		El Colegio de la Frontera Sur	Mexico	Designing agroforestry systems (sivopastoral, mixed tree coffe plantations , intercrops etc)
Bellow	John	jgbe@gnv.ifas.ufl.edu	3525 SW 28th Street	USA	(CATIE workshop)
Benitez	Manuel	ebvbg77@ccma.csic.es	Centro de Ciencias Medioambientales	Spain	Afforestation research training
Bittencourt	Jefferson	jeffbitt@agrarias.ufpr.br	R: dos Funcionários, 1540	BRASIL	To evaluate the influence of forest activities on hydrological processes.
Bongi	Guido	g.bongi@iro.pg.cnr.it	CNR IRO	Italy	I work as senior fellow for National Sciencefoundation of Italy, the CNR.
Boshell	Francisco	fboshell@cable.net.co	Calle 123 No. 7 - 07 Ofic 608	Colombia	For academic purposes. I am a professor of Agricultural Meteorology at the National University of Colombia. Thanks in
Brown	Doug	drb33@cornell.edu		U.S.A	I am in the process of reviewing various integrated models as oart of a new bio-economic modelling initiative. Hence, I a
Burgess	Paul	P.Burgess@cranfield.ac.uk	Cranfield University,	UK	Teaching
Bussiere		bussiere@antilles.inra.fr	INRA APC	Guadeloupe - France	As a participant to the SAFE project
Cadisch	Georg	g.cadisch@ic.ac.uk			
Cai	Hoang Huu	lnxh@hcm.vnn.vn			
Carlton	Matt	Matt@Carltons.freeseve.co.uk	36 Cooper Close	England	Environmental modelling for use in my studies,
Chakravarty	Biprajit	enmin@vsnl.com	F-23/43, Sector-3,	India	For calculation of water and nutrient requirements for biomass development in environmental management.
Chander	Subhash	pramodag@vsnl.com			
Chandrasekhar	T.R.	Chandratr@hotmail.com	The Rubber Research Institute of India	India	I am wrking on growth and its modelling of Hevea brasiliensis trees. I wish to gain knowledge and information from the m
Changjun	Yin	yincj@mail.forestry.ac.cn	Research Management Division,	China	I want to use this model to analysis the water dynamic of agrifirestry in Huang Huai Hai Plain of China.

Changjun	Yin	xxb01@mail.forestry.ac.cn Department of Agroforestry,
Chirwa	Paxie	sbxpcw2@szn1.agric.nottingham.ac.uk
Chuangmu	Zheng	zcm@webmail.hzau.edu.cn Dept.of Resource and Enviroment
Coe	Ric	R.COE@CGIAR.ORG
Conforte	Jorge Conrado	conrado@ltid.inpe.br Av. dos Astronautas,1758
Cronje	Johan	jcronje@nsnper1.up.ac.za P.O. Box 12952
Crowley	Kevin	kevin.crowley@bbsrc.ac.uk
Delgado	Marc Elgin M.	gin_hic@edsamail.com.ph IBS, UP Los Banos
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Dupraz	Christian	dupraz@ensam.inra.fr INRA, UMR SYSTEM, 2, Place Viala, 34060
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Giannino		giannino@unina.it via Universita 100
Gilaert	M. B.	ebvbg77@ccma.csic.es CCMA/CSIC
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Hassanin	Wael	hassanin@zarm.uni-bremen.de Fallturm
Hernandez	Salvador	salvador@srv0.bio.ed.ac.uk
Hidayati	Rini	rinih@scientist.com
Hilger	Thomas H.	t-hilger@uni-hohenheim.de Universität Hohenheim (380)
Hindsen	Goran	hindsen@algonet.se
Hung	Pham Trinh	lnxh@hcm.vnn.vn

China I'm a researcher of Agroforestry. I'm very interest in competition and water consumption in

P.R.C Want to apply it in subtropical area!

Brazil Research

South Africa As part of our ongoing agroforestry research programme we are assessing the viability of alleycropping with specific em

UK preliminary investigation of agroforestry models

Philippines Research and Education

France I'm a member of the computer scientists team from the SAFE project.

USA personal, curious

France Study what would be relevant for the SAFE (Silvoarable Agroforestry For Europe) project

Indonesia To help decide suitable planting distances for trees in a community plantation forest scheme where intercropping is one

Intefacing with forest reflectance models for remote sensing of biophysical factors.

Italy to see the programm and the possible application.

Spain Researcheducational

Mexico Teaching and research

USA High School Education - HS Biology and Geology.

Germany for personal using in some fluid problems

Germany Since the mid eighties, our institute is involved in research on agroforestry, mainly in Benin West Africa, but also in Latin

Sweden Private

Iwald	Johan	j.iwald@cgiar.org	
Jalid	Nursal	n.jalid@cgiar.org	
Jalloh	Mohamadu Boyie	p51313@stud.upm.edu.my	C/o Prof Wan Sulaiman Wan Harun Malaysia For research
Jianping	Ge	ge-jp@263.net	Beijing normal University China research
Jinlian	Shi	yincj2000@263.net	Beijing Forestry University China learn how to build a agroforestry model suitable for china.
Johnston	Mark	johnston@derm.gov.sk.ca	Forest Ecosystems Branch Canada We are doing research on the opportunities for agroforestry in the prairies of central Canada. We are particularly interest
Jouve	E	ejouve@hotmail.com	SRADP office Indonesia Design and promote integrated estate crops integrated models
June	Tania	taniajune@yahoo.com	
Karray	Abid	Djehane.esalem@lemel.fr	B.P. 434 Tunisia I preper a thesis on modelling water use in intercropping system: olive tree-potatoes
Khasa	Damase	damase.khasa@ualberta.ca	Department of Renewable Resources (751GSB) CANADA http://www.rr.ualberta.ca/staff/khasa.htm
Kim	Kwang-ho	kaniska1@snu.ac.kr	Division of Applied Biology and Chemistry College of Agriculture Life SciencKorea I will use your model in appling on my model of BPH(BrownPlant Hopper). I have met a problem of inserting a daily weat
Kiparski	Guntram Ramutis	guntram@purdue.edu	Graduate Research Assistant USA I am planning on doing some simulations
Kobiyama	Masato	kobiyama@agrarias.ufpr.br	UFPR/SCA/DS Brazil To realize studies on agroforestry (palm tree + banana + cassaba + other crops) in the Graduate course program of Agro
Lawson	Gerry	GJL@ceh.ac.uk	UK
Leal	Alex	alexleal@pr.gov.br	Caixa Postal 481 Brazil
Lecomte	Isabelle	isabelle.lecomte@ensam.inra.fr	INRA France Testing hypar before the Wageningen session.
Lee	joon-Ho	jh7lee@plaza.snu.ac.kr	School of Agricultural Biotechnology, Korea Educating dynamics of agro-forestry ecosystems
Legal	Iris	essc@admu.edu.ph	Philippines as reference
Lewis	Doug R	dlewis@ed.sac.ac.uk	SAC UK Comparisons with other forest models.
Li	DaoFeng	lidf@hotmail.com	Institute of Environment Sciences P.R.C. I am PH.D student in Beijing Normal University.
Lines	Glenn A.	GAL@chemonics.mg	Madagascar As we are an agricultural development project working in Madagascar to reduce rural poverty while protecting precious b
Livesley	Stephen	stelives@cyllene.uwa.edu.au	University of Western Australia Australia
Lojka	Bohdan	blojka@hotmail.com	Institute of Tropical and Subtropical Agriculture Czech Republic PhD studies evaluation of agroforestry systems
Lu	Jian-hua	jji@ast590.tea.ac.cn	Institute of Atmospheric Physics, China to simulate the npp of some biomes in china

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Oltchev	Alexander	aoltche@gwdg.de Institute of Bioclimatology
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Ong	Chin	C.ONG@CGIAR.ORG
Palma	Joao	joao.palma@fal.admin.ch
Park	Hong-Hyun	hhpark@plaza1.snu.ac.kr Agricultural biology, SNU

Scotland Currently carrying out my honours project on agroforestry. Looking into modelling aspect of systems.

Indonesia

Canada The model could be used as a reference for similar type of work at Agriculture and Agri-Food Canada.

Spain To run model with from different scenarios of silvoarable systems under mediterranean conditions, in the context of an e

IRAN IN MY TEACHING COURSES.AND ALSO I WANT TO USE IT IN MY RESEARCH ON IRANIAN TRADITIONAL

The Netherlands Uncertainty analysis SAFE project

OrientPHILIPPINES

Yugoslavia math

Colombia To investigate interactions in resource capture of=

USA Familiarize myself with the Hybrid model

Bolivia For agroecological assessment to indigenous people in amazonian basin

UK As part of background research into specimen tree growth and agriculture for a MSc dissertation

Thailand now I have class about modelling and I need to know about this model and I think this model be used for my study.

Germany To simulate possible responses of forest ecosystems to environmental changes

Japan To use for researches on agroforest in Asia and effects of climate change.

Kenya

Switzerland phd research

Republic of korea I want to simulate spider population dynamics under several variables in

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Sianturi	Paian	P.Sianturi@cgjar.org	Situ Gede - Sindangbarang Jero
Sitompul	S. M.	smtom@malang.wasantara.net.id	
Skrishna		skrishna@cscs.ch	

paddy field.

Netherlands As a accompanying model for water resources studies.

Mexico

Togo Improve agricultural research

Brazil

Italy research

UK (Formerly Geography, King's College London and PARCH model user)

Philippines Instruction and Research Application

Indonesia research

Norway Ph.D. thesis, experimental threatment of data

UK Research on N cycling in agroforestry

Costa Rica Teaching

Philippines academic (teaching) purposes , research proposals

Brazil Aplicação para fins didáticos no ensino de Sistemas Agro Florestais.

México Investigación

Indonesia for simulation model on agroferstry research in east java forest

Mexico Comparative studies

USA Research. I am a graduate student at Arizona State Univ

Germany I'm writing on a chapter for my thesis which deals with agroforestry modeling. In this respect I want to describe and comp

Iran I want to use for my teaching.

Ireland Assessment purposes as I am in the process of building a bio-economic model of poplar agroforestry for my Masters.

Indonesia To enrich the falor of the research undertaken in CIFOR. The research was on validation of a physiological-based model

Switzerland Micro-climatic data

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Zhai	Tong	tzhai@ecn.purdue.edu Department of Agricultural Biological Engineering
Zhang	Hailin	zh hailin@263.net Crop Sciences College
Zhangjujiang		weixinping@263.net Xian university of technology

USA To review the model for possible use to assess practices that sequester

Indonesia Research tools

Indonesia TEACHING MATERIAL FOR STUDENTS, AND LOOKING THE POSSIBILITY FOR RESEARCH TOOL AT SAMUG AN

Scotland Initially learning about the model and its potential

Brasil from Curitiba workshop

France research

Brazil As a educational tool for my doctor degree at Universidade Federal de Vicosa - Brazil

Indonesia

The Netherlands education, research

Australia Orchard production (citrus olives)

Philippines as reference

Germany Work in agroforestry systems in Bolivia

Germany Education

Australia Investigation for teaching purposes

Japan Learning and studying the agroforestry modelling.

USA Research

China Try to it simulate

China research

13 Appendix V: Attendees at the 1st SAMUG Workshop, Malang, Indonesia 30/6 – 5/7 2001

1. Agustin Mercado Jr. ICRAF - Philipines junm@cdo.weblinq.com
2. Dr. Ajay Kumar Upadhyay India Council of Agricultural Research India ajayk_upadhyay@yahoo.com
3. Antonio P. Abamo Department of Ag. Economics ,Visayas Tel: 049 5360242 tony.abamo@eudoramail.com
State College Agriculture (VISCA). 39 Demarces Ville, College Laguna Philippines
4. Dr. Arjan Gisjman University of Florida, AGijsman@mail.ifas.ufl.edu USA
5. Ir. Betha Lusiana, MSi ICRAF – INDONESIA Tel: 62 251 625415 b.lusiana@cgiar.org PO BOX 161,
Bogor Fax: 62 251 625416 INDONESIA
6. Canesio D. Predo Visayas State College Agriculture Tel: 63(53)3352653 cdpredo@philwebinc.com,
(VISCA), 6521-A Baybay, Leyte cdpredo@yahoo.com Philippines
7. Chalathorn Sritulanon Forest Research Office, Royal Forest Tel: 66(02)5798775 Chalathorn@hotmail.com
Department. 61 Paholyothin Road, Jatujuk, Fax: 66(02)5798775 Bangkok, 10900, Thailand
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Laguna 4031 Philippines
9. Dr. Deena Mobbs Centre for Ecology and Hydrology, Bush Tel: 44 131 445 8559 dcmo@ceh.ac.uk Estate,
Penicuik, Fax: 44 131 445 394 Midlothian, Scotland. EH26 0QB
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12. Dr. Gerry Lawson Centre for Ecology and Hydrology, Bush Tel: 44 131 445 8559 gjl@ceh.ac.uk Estate,
Penicuik, Fax: 44 131 445 394 Midlothian, Scotland. EH26 0QB
13. Dr. Hoang Huu Cai University of Agriculture and Forestry, Thu Tel: 84 8 8960713 lnxh@hcm.vnn.vn Duc
District, Ho Chi Minh City Vietnam 84 8 8963352 Fax: 84 8 8960713
14. Ina Guillermo CIFOR, PO Box 6596, JKPWB 10065 Tel: 62 251 622 622 i.guillermo@cgiar.org Bogor
Indonesia Fax: 62 251 622 100
15. Johan Iwald ICRAF – INDONESIA Tel: 62 251 625415 j.iwald@cgiar.org PO BOX 161, Bogor Fax:
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Brawijaya University 62-341 553623 Jl. Veteran, Malang 65145 Fax: 62 341 56433
17. Luis Fernando Guedes Sao Paolo University. Tel: 62 251 625415 l.guedespinto@cgiar.org Pinto
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20. Ir Nursal Jalid, MS Dept. Agronomy, IPB Tel: 0251-620469 INDONESIA
21. Pham Trinh Hung University of Agriculture and Forestry, Tel: 84 8 8963352 lnxh@hcm.vnn.vn Faculty
of forestry-UAF, Thu Duc-Ho Chi Fax: 84 8 8960713 Minh City Vietnam
22. Ir. Rachmat Mulia ICRAF – INDONESIA Tel: 62 251 625415 r.mulia@cgiar.org, PO BOX 161, Bogor
Fax: 62 251 625416 INDONESIA
23. Ir Rini Hidayati, MS FMIPA, IPB. Jur. Geomet jalan Raya Tel: 62 251 376817 rinih@scientist.com
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24. Dr. Robin Matthews Institute of Water and Environment Tel: 44 (0)1525 r.b.matthews@cranfield.ac.uk

- Cranfield University, Silsoe, 863008 <http://www.silsoe.cranfield.ac.uk/iwe/p> Bedfordshire MK45 4DT Fax: 44 (0)1525 eople/RobinMatthews.htm UNITED KINGDOM 863384
25. Dr. S. M. Sitompul Faculty of Agriculture Tel: 62 341 564443 smtom@malang.wasantara.net.id Brawijaya University Jl. Veteran, Malang 65145
26. Dr. Sara Namierembe Makerere University Tel: 256 41 543648 agrofor.foresmuk@infocom.co.ug Faculty Of Forestry And Fax: 256 41 533574 Nature Conservation P.O. Box 7062 Kampala, UGANDA
27. Dr. Sri Rahayu Utami Faculty of Agriculture el: 62 341 564355 Soilub@malang.wasantara.net.id Brawijaya University 62 341 553623 Jl. Veteran, Malang 65145 Fax: 62 341 56433 28. Ir Subekti Rahayu ICRAF – INDONESIA Tel: 62 251 625415 s.rahayu@cgiar.org PO BOX 161, Bogor Fax: 62 251 625416 INDONESIA
29. Dr. Subhash Chander Centre for Application of Systems Tel: 91 11 5755866 pramodag@vsnl.com Simulation, Cass NRL Building, Indian 91 11 5811112 Agriculture Research Institute, New Delhi- Fax: 91-11-5811112 110012, India
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14 Appendix VI: Attendees at the 2nd SAMUG Workshop, Curitiba, Brazil, 4-9/11/2001.

Brazilian Participants

1. Aurenny Maria Pereira Lunz Norte
2. Silvio Brienza Junior Norte
3. Silas Mochiutti Norte
4. José Henrique de Albuquerque Rangel Nordeste
5. Maurílio José Alvim Sudoeste
6. Marcelo Arco-Verde Norte
7. Dr. Paulo César Fernandes Nordeste
8. Tatiana Deane de Abreu Sá Norte
9. Celso Luís Bergo Norte
10. Vanda Gorete Souza Rodrigues Norte
11. Gladys Ferreira de Sousa Norte
12. Jorge Ribaski Sul
13. Paulo Henrique Caramori Sul
14. Leila Sobral Sampaio Sudeste
15. Renato Luiz Grisi Macedo Sudeste
16. Carlos Alberto Moraes Passos Centro Oeste
17. Vanderley Porfírio da Silva Sul
18. Antônio de Arruda Tsukamoto Filho Sudeste
19. Adriano Lopes Pereira de Melo Centro Oeste
20. Jorge Luiz Vivan Sul
21. Jamir Luís Silva da Silva Sul
22. Romualdo Maestri Sudeste
23. Sandra da Rosa Andrade Sudeste
24. Aliete Villacorta de Barros Norte
25. Ciro Abbud Righi Sudeste

Other Latin American Participants

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5. Cristina Yépez PRONATURA crisyopez@hotmail.com México
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7. Luis Arévalo ICRAF ICRAF-ADMPUCALLPA@cgiar.org Perú
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9. Noel Ortuno PROINPA gaguirre@proinpa.org Bolivia
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