TechnoGIN: a technical coefficient generator for cropping systems in Ilocos Norte province, Philippines

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Preface

This QASA report describes the features of TechnoGIN, which is a technical coefficient generator developed for cropping systems in Ilocos Norte province, Philippines. The parameters describing the inputs and outputs of a land use production system in quantitative terms are called technical coefficients. These are calculated using well-defined concepts and assumptions based on agro-ecological principles. TechnoGIN has been developed as part of the methodology for identifying optimal land use options for Ilocos Norte, using interactive multiple goal linear programming (IMGLP).

Estimation of input/output relations for current and future production activities at regional (sub-national) scale, is a component of the land use planning and analysis system (LUPAS), that was developed and put into effect for four case studies by the “Systems research Network for ecoregional land use planning in tropical Asia (SysNet)”. This network was launched in late 1996, to develop methodologies and tools for determining land use options and to evaluate these for generating options for policy and technical changes in selected areas.

The four study regions were: Haryana state (India), Kedah-Perlis region (Malaysia), Can Tho province (Vietnam) and Ilocos Norte province (Philippines). SysNet was co-ordinated by the International Rice Research Institute (IRRI). National Agricultural Research Centres from India, Malaysia, Philippines and Vietnam and various institutions and groups from the Wageningen University and Research Centre (WUR), The Netherlands, participated in the project.

The development of the LUPAS approach of SysNet continues since 2001 in the “Systems Research for Integrated Resource Management and Land Use Analysis In East And Southeast Asia (IRMLA)” project. IRMLA deepens and, methodologically, extends the case study of Ilocos Norte by concentrating on two municipalities in the province: Batac and Dingras. Other case studies include: Pujiang county, Zhejiang province, China; Tam Duong district (Tam Dao), Red River Delta, Vietnam; Omon district, Mekong Delta, Vietnam. Partners of IRMLA are Alterra, Plant Research International (PRI), and the Plant Production Systems group, Wageningen University, The Netherlands; Institute for Meteorology and Climate Research, Germany; Zheijiang University, China; Mariano Marcos State University (MMSU), Philippines; National Institute for Soils and Fertilisers (NISF), and the Cuu Long Delta Rice Research Institute (CLRRI), Vietnam.

The work presented in this report is the result of a 5 months internship (October 1999 – March 2000) of the first author (T.C. Ponsioen) at the International Rice Research Institute (IRRI) in Los Baños, Philippines. P.A.J. van Oort and T.C. Ponsioen are graduate students of the Plant Production Systems group at the Department of Plant Sciences, Wageningen University. A.G. Laborte and R.P. Roetter were members of the SysNet core team at IRRI.

In developing TechnoGIN, SysNet data sets from comprehensive farm surveys, and results from on-going yield gap modelling and spatial analysis generated by the Philippine and IRRI SysNet teams for Ilocos Norte case study were utilized.

The authors are grateful to the Municipal Agricultural Technicians in Ilocos Norte for their help in conducting the farm surveys of 1998/1999, Sergio Francisco (PhilRice), Marilou Lucas and Caloy Pascual (MMSU), Gigi Orno and Felino Lansigan (UPLB) and other members of SysNet-Philippines for organizing and compiling the farm survey data and retrieving various reports on physical resources and crop experiments in Ilocos Norte

Province for this study. We also would like to thank Christian Witt (IRRI) for support in incorporating the QUEFTS component and Don Jansen (PRI) for suggestions during the development of TechnoGIN. We thank Julie Cabrera and Benjie Nunez (IRRI) for assistance in preparing various databases and graphics. Special thanks go to Gon van Laar (Wageningen UR) for helping with the editing.

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Glossary

AGROTEC	Automated Generation and Representation of TEchnical Coefficients for analysis of land use options
CLRRI	Cuu Long Delta Rice Research Institute
GIS	Geographic Information System
IMGLP	Interactive Multiple Goal Linear Programming
IRMLA	Systems Research for Integrated Resource Management and Land Use Analysis In East And Southeast Asia
IRRI	International Rice Research Institute
LMU	Land Management Unit
LP	Linear Programming
LU	Land Unit
LUCTOR	Land Use Crop Technical coefficient generator
LUPAS	Land Use Planning and Analysis System
LUS	Land Use System
LUST	Land Use System at a defined Technology
LUT	Land Use Type
MGLP	Multiple Goal Linear Programming
MIP	Multiple Integer Programming
MMSU	Marianos Marcos State University
NISF	National Institute for Soils and Fertilisers
QUEFTS	Quantitative Evaluation of the Fertility of Tropical Soils
PhilRice	Philippine Rice Research Institute
PRI	Plant Research International
RUSLE	Revised Universal Soil Loss Equation
SOLUS	Sustainable Options for Land Use
SysNet	Systems research Network for ecoregional land use planning in tropical Asia
TC	Technical Coefficient
TCG	Technical Coefficient Generator
TechnoGIN	Technical coefficient Generator for Ilocos Norte
UPLB	University of the Philippines Los Baños
WOFOST	WOrld FOod Studies
WUR	Wageningen University & Research Centre

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Summary

This QASA report describes the features of TechnoGIN, which is a technical coefficient generator developed for cropping systems in Ilocos Norte province, Philippines. The parameters describing the inputs and outputs of a land use system in quantitative terms are called technical coefficients. These are calculated using well-defined concepts and assumptions based on agro-ecological principles. For combinations of land use types (crop rotations consisting of wet season rice with dry season rice, tomato, sweet pepper, garlic, onion, corn, eggplant, soybean, mungbean, groundnut, tobacco, melon and an optional third crop or a single crop sugarcane, mango, cassava), land units (defined by combining soil, topography, land use, administrative and climatic maps), target yields, and different production techniques with user defined input use efficiencies, technical coefficients are calculated including monthly evapotranspiration, monthly labour requirements, nitrogen, phosphorus and potassium fertiliser requirements and losses, and economic indicators. Inputs and outputs are calculated on a yearly basis and per hectare. The model uses geographical data (soil and land characteristics, climate), cropping data and socio-economic data from a field survey, crop data from literature and expert knowledge, and transfer functions and assumptions that can be modified in order to constantly improve the model output quality. The technical coefficients are used to analyse the impact of different land use systems and technology on the socio-economic, agronomic and environmental objectives at higher scales (municipality, province). Future policy scenarios with different policies can be evaluated using generated technical coefficients of multiple land use systems and techniques in land use optimisation models.

Samenvatting

Dit QASA rapport beschrijft de eigenschappen van TechnoGIN, een technische coëfficiënten generator, ontwikkeld voor gewas systemen in de provincie Ilocos Norte in de Filippijnen. De parameters die de inputs en outputs van een landgebruiksysteem in kwantitatieve termen beschrijven worden technische coëfficiënten genoemd. Deze worden berekend door gebruik te maken van goed gedefinieerde concepten en aannames gebaseerd op agro-ecologische principes. Voor combinaties van landgebruik types (gewasrotaties van rijst in het natte seizoen en in het droge seizoen rijst, tomaat, paprika, knoflook, ui, maïs, aubergine, soja, mungboon, pinda, tabak, watermeloen en eventueel een derde gewas of een enkel gewas suikerriet, mango, cassave), landeenheden (gedefinieerd door het combineren van bodem, landschap, landgebruik, administratieve en klimatologische kaarten), doelopbrengsten (welke actueel of theoretisch kunnen zijn), en verschillende productie technieken met gebruikers gedefinieerde input efficiëntie's, worden technische coëfficiënten uitgerekend, waaronder maandelijkse evapotranspiratie, maandelijkse arbeidsbehoeften, N, P en K behoeften en verliezen, en economische indicatoren. Het model gebruikt geografische data (bodem en landeigenschappen, klimaat), agronomische en sociaal-economische data van een veldinventarisatie onderzoek, gewasdata uit de literatuur en kennis van deskundigen, en functies en aannames die kunnen worden aangepast aan de jongste inzichten en gegevens, om de kwaliteit van de uitkomsten van het model te kunnen verbeteren. De technische coëfficiënten worden gebruikt om de bijdrage te analyseren van de verschillende landgebruiksystemen met een bepaalde techniek aan sociaal-economische, agronomische en milieutechnische doelen op systeem niveau (bedrijf, gemeente of provincie). Toekomstige beleidsscenario's kunnen worden geëvalueerd door gegenereerde technische coëfficiënten van meerdere landgebruiksystemen op te schalen in landgebruikoptimalisatie modellen.

1. Introduction

1.1 Use of technical coefficients in modelling frameworks

Agricultural research in South and Southeast Asia is increasingly challenged by the search for land use options that best match multiple development objectives of rural societies (e.g., increased income, employment, improved natural resource quality, food security). This calls, among others, for effective tools for resource use analysis at higher integration levels (e.g. village, province, state) to support decision-making with respect to land use. These tools should have the capabilities to:

- Identify potential conflicts among rural development goals, land use objectives, and resource use;
- Identify technically feasible, environmentally sound, and economically viable land use options that best meet a well-defined set of rural development goals.

During the last decade, interactive multiple goal linear programming (IMGLP; De Wit et al., 1988) has been proposed and put into effect for this purpose. Operational modelling frameworks based on IMGLP include GOAL (General Optimal Allocation of Land use) for Europe (Rabbinge and Van Latesteijn, 1998), SOLUS (Sustainable Options for Land Use) for Costa Rica (Bouman et al., 1999), and LUPAS (Land Use Planning and Analysis System; Fig. 1) developed within the “Systems research Network for ecoregional land use planning in tropical Asia (SysNet)” during 1996 - 2000 for four study regions in South and Southeast Asia: Haryana state (India), Kedah-Perlis region (Malaysia), Can Tho province (Vietnam), and Ilocos Norte province (Philippines) (Hoanh and Roetter, 1998, Roetter et al., 2000a). Table 1 contains the most important characteristics of the case studies. The approach is continued in the “Systems Research for Integrated Resource Management and Land Use Analysis In East and Southeast Asia (IRMLA)” with the multi-scaled case studies: Batac and Dingras municipalities, Ilocos Norte province, Philippines; Pujiang county, Zhejiang province, China; Tam Duong and Binh Xuyen districts (Tam Dao), Red River Delta, in North Vietnam; and O Mon district, Mekong Delta, in South Vietnam (Roetter, 2002). LUPAS consists of the following components:

- Databases on biophysical and socio-economic resources and development targets
- Input-output description of all promising production activities and technologies
- Multiple criteria decision method (optimisation)
- Sets of goal variables (representing specific objectives and constraints)

The input-output model describes the production techniques of land use systems, and quantifies the core information for identifying sustainable land use options. This information is presented in so-called *technical coefficients*. The main interrelated elements in the land use systems are the land use type, the production technique and the land unit. Here, the land use type is defined as a crop or crop rotation and the production technique is defined separately as a complete set of agronomic inputs to realise a particular (target) production level (Van Ittersum & Rabbinge, 1997). The land unit defines the land use system borders and describes the physical environment, which is homogeneous in climate, soil characteristics and quality, landscape and water resources.

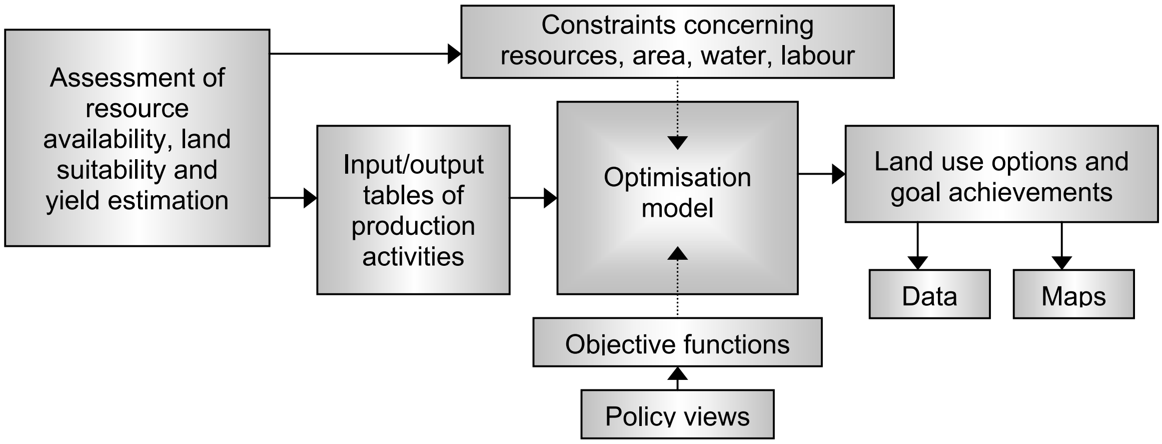


Figure 1. Structure of modelling system LUPAS

Table 1. Main characteristics of the four study regions and IMGLP models (status: June 2000)

Items	Haryana (India)	Kedah-Perlis (Malaysia)	Ilocos Norte (Philippines)	Can Tho (Vietnam)
Total area (mil ha)	4.42	1.02	0.34	0.30
Agricultural land area (mil ha)	3.72	0.54	0.11	0.25
Population (mil persons)	16.5	1.64	0.50	1.89
Agricultural labour (mil persons)	2.76	0.28	0.36	0.93
Agro-ecological units	87	19	37	26
Administration units	16	11	23	7
Land units	208	60	200	78
Land use types	13	18	23	19
Products	11	15	17	18
Crops	10	16	21	28
Technology levels	5	3	2	2
Objective functions	14	12	11	10

The target-oriented approach, which is a fine tuning of inputs to realize a particular yield level that takes place in a certain physical environment (Van Ittersum and Rabbinge, 1997), enables us to quantify the required amount of various inputs such as labour, water, fertiliser, and their monetary values to obtain a certain amount of output in different land use systems. Besides marketable products and crop residues, also undesirable outputs (side effects) of the production process on the resource base (such as soil nutrient depletion) and pollution of the environment (such as methane emission or nitrate leaching) are considered as important technical coefficients for evaluating land use systems. Such side effects are often expressed in sustainability indicators (such as effects of biocides on health and environment).

Change in production technique is expressed in changed input-output relations. Some inputs are interchangeable, for example herbicides, hand labour (weeding) and use of animals or machines for ploughing. The different techniques can have large implications on the quantification of the inputs and outputs.

Production techniques can also be described by the efficiency of certain inputs, for example irrigation techniques (surface water or groundwater, sprinkler or furrow irrigation), and fertiliser application techniques (single or split applications, balanced applications of nitrogen, phosphorus and potassium and other nutrients). Differences in efficiencies of production techniques can be ascribed to differences in farmers’ knowledge (education), infrastructure (market for inputs and outputs), labour availability, investment cost, logistical problems (storage, scale), theft, etc.

In IMGLP models applied in explorative land use studies, technical coefficients are used to characterize all relevant *current* and *possible future (alternative)* production activities and techniques for a target region. The current production activities and techniques are based on surveys and other sources, while the possible future production activities are based on production ecological insight that considers improved techniques, resulting in more efficient use of inputs and/or higher yields (Section 2.2). The target region is sub-divided into land management units (LMUs), which are relatively homogenous in their biophysical (temperature, precipitation, soil texture, slope, etc.) and socio-economic properties (input and output prices, administrative unit).

1.2 Introduction to land use issues in Ilocos Norte province

Ilocos Norte province in north-western Luzon has about 0.5 million inhabitants and a total land resource of nearly 0.34 million ha. Mean annual precipitation in the province ranges from 1700 mm in the southwest to above 2400 mm in the eastern mountain ranges. The region has large forest resources (46% of the total area) and 38% of the total area is classified as agricultural land. Rice-based production systems prevail. Occurrence of typhoons mostly between August and November has considerable adverse effects on agricultural production. Soils are developed from very diverse materials. In the lowlands, sandy loam soils developed from alluvial deposits are predominant (Fig. 2).

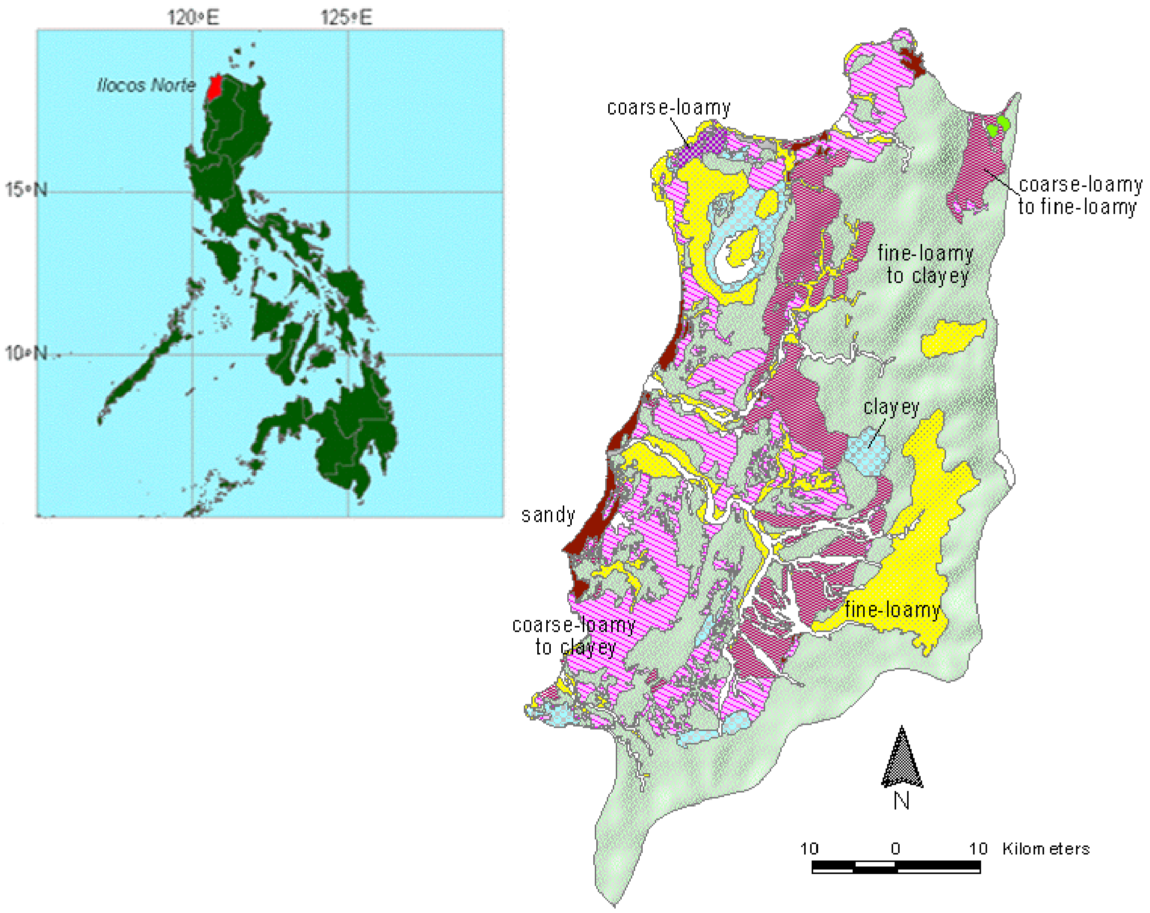


Figure 2. Map of the Philippines, and soil texture groups in Ilocos Norte province

Rice is grown in the wet season (June – October) whereas diversified cropping (tobacco, garlic, onion, maize, sweet pepper and tomato) is practised in the dry season, using irrigation (mainly) from groundwater. A fairly well developed marketing system facilitates this relative intensive production system of rice and cash crops (Lucas et al., 1999). A policy document of the provincial Government of Ilocos Norte of 1999 identifies low levels of agro-fishery productivity and income as major constraints to further development. Major causes include underdeveloped irrigation systems and low average farm size. Meetings with the Ilocano stakeholders since 1997 (Roetter et al., 2000b) revealed that the major issue for the province was the assessment of trade-offs between rice production and farmers' income. Environmental issues, such as soil erosion and water pollution with nitrates, needed to be addressed as well. These issues determine the type of inputs and outputs to be quantified.

1.3 TechnoGIN and other technical coefficient generators

A technical coefficient generator (TCG) is a tool for creating an input - output matrix for all relevant combinations of land (management) units, land use types and production techniques that form part of a (regional) land use modelling framework (Section 1.1). In recent years, several TCGs have been developed for the purpose of explorative land use analysis under multiple goals (Hengsdijk et al., 1996; 1998; Bouman et al., 1998; Jansen, 2000).

TCGs have different structures, options, user interfaces, database management systems, etc. These differences partly depend on the programmers' preferences, but more importantly on the biophysical and socio-economic characteristics of the case study and the objective functions, constraints and other optimisation settings defined in the IMGLP model. Apart from representing unique combinations of socio-economic and biophysical conditions, any province or region differs in some specific policy issues and in data availability.

TechnoGIN is a TCG that was developed specifically to calculate technical coefficients for cropping systems in Ilocos Norte province, Philippines, in the context of the SysNet project (Hoanh et al., 1998, Roetter et al., 2000). However, it can be used in other cases where similar agro-ecological conditions occur and at different scales (e.g. municipality or farm household level: Batac and Dingras) and can be adapted where extra data are available or data are lacking. It is also possible to develop a new TCG by using parts of TechnoGIN. For the development of TechnoGIN some of the concepts of other TCGs were used (Hengsdijk et al., 1996, 1998; Jansen, 2000).

In TCGs, land use systems are often described on a yearly basis with a single crop or a crop rotation or on a basis of several years in case of perennial crops or crop rotations covering more than one year. Because of these time intervals and the static nature of LP models, TCGs have to assume a certain balance of inputs and outputs that enter and leave the land use systems, otherwise inputs and outputs cannot be assumed stable over the years. In case the balance is negative or positive, this is presented clearly in the technical coefficients. The prerequisite of a balance mainly applies to plant nutrients, which are built up in the soil or are depleted, resulting in unsustainable (not reproducible) input/output combinations for those land use systems. TechnoGIN calculates balanced input/output relations on a yearly basis (there is no yearly net inflow or outflow of materials that determine the productivity and environmental soundness of the system). Considering the high level of complexity of all processes involved in determining inputs and outputs, the lack of knowledge and the technical problems of programming the numerous combinations of crops, rotations of multiple years are not considered. This makes it hard to simulate land use systems that change from year to year.

In TechnoGIN, technology levels are defined, representing different sets of production techniques that are presently used and/or improved compared to the actual situation, with higher fertiliser, biocide and/or water use efficiencies (Sections 2.2, 3.8 and 4.6). For example, an actual technique in which a much higher proportion of nitrogen is applied compared to phosphorus and potassium, which results in much higher nitrogen losses than in balanced applications, can be simulated by setting the technology related correction factor for nitrogen recovery to less than those for phosphorus and potassium, for the designated technology level (e.g. technology level A). Likewise, the use of biocides can be increased or decreased, resulting in the same yield, compared to the data on biocides based on farm surveys (which are used in case the technology related correction factors for the different types of biocides are set to one). Crop evapotranspiration can also be increased or decreased, implying a less or more efficient use of water resources, respectively.

Similar to LUCTOR (Land Use Crop Technical coefficient generatOR; Hengsdijk et al., 1998) and AGROTEC (Automated Generation and Representation Of TEchnical Coefficients for analysis of land use options; Jansen, 2000), TechnoGIN is programmed in Microsoft Excel (Microsoft, 1999a) with macro programming in Microsoft Visual Basic for Applications (Microsoft, 1999b), which is included in Excel 97 and later versions. This has some advantages over using other database formats and (compiled) executable files. The most obvious advantages are manageability, accessibility and adaptability. The approach of AGROTEC of limiting the amount of calculations in the Excel worksheets is also followed in TechnoGIN. The only worksheet equations in TechnoGIN are those that are necessary for the “Solver” add-in module (a module in Excel that offers various optimisations algorithms, such as linear programming, multiple integer programming and non-linear programming, available in the Microsoft Excel 97 and later versions installation disk; Appendix I). Solver is used for the QUEFTS (Quantitative Evaluation of the Fertility of Tropical Soils; Janssen et al., 1990; Witt et al., 1999) and “fertiliser cost” models.

To make the TCG and databases better manageable and accessible, TechnoGIN consists (unlike other TCGs and other similar models) of only one file, wherein data sets and model parameters are organised into different worksheets.

In TechnoGIN, ecoregions are defined as physical areas grouping LMUs into lowland and upland LMUs, depending on the average slope within the borders of the LMU, and dividing the lowland LMUs into lowland rainfed and lowland irrigated (where there are irrigation schemes that allow for surface water irrigation). Technology levels and target yields (Section 2.2) are defined by the user per ecoregion.

1.4 Structure of TechnoGIN

The TechnoGIN Excel file consists of three different kinds of objects: 1) databases; 2) user forms for database management and selections of land use types, land units and target yields for model runs; 3) a macro (including the Solver models) for calculating the technical coefficients (Fig. 3).

The worksheets named “Water”, “Nutrient”, “Efficiency”, "Technology", “Crop”, “LUT”, “LMU”, and “Labour” contain the databases that are used in the macro to calculate the technical coefficients of the combinations of land use types (LUTs), land management units (LMUs), target yields, and technology levels. The latter are defined by production

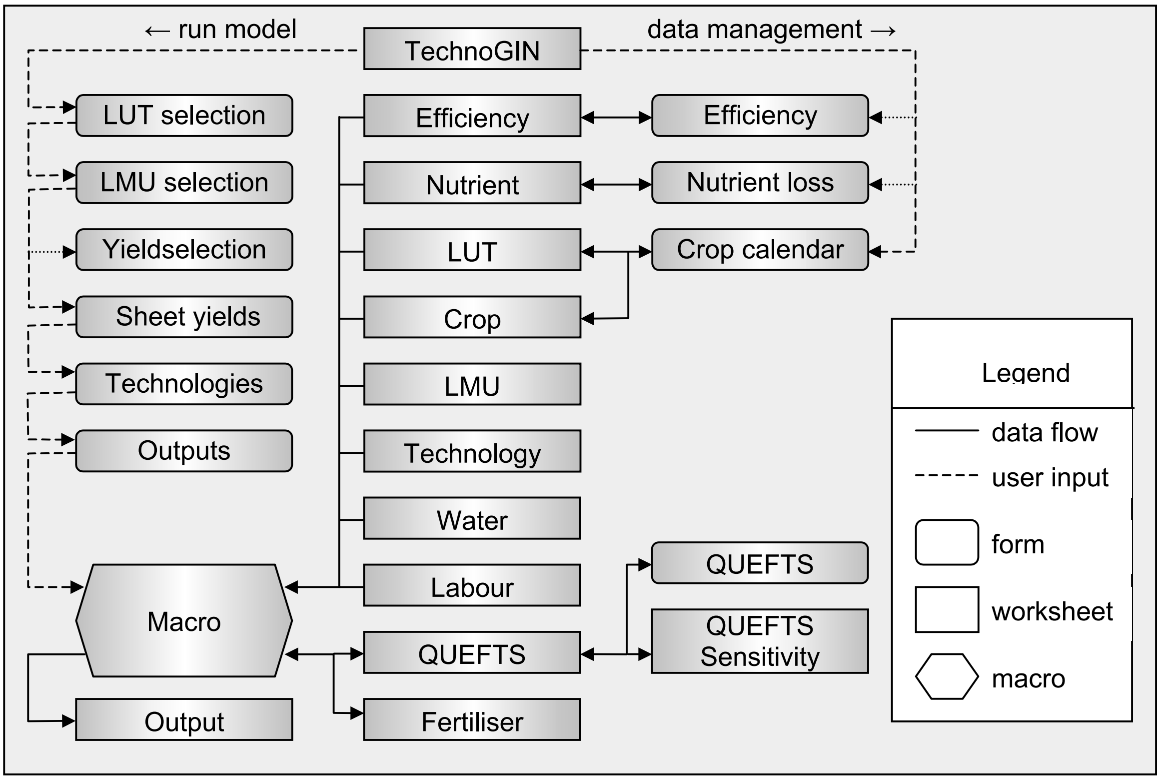


Figure 3. Schematic overview of TechnoGIN objects

techniques, which have consequences for the efficiencies and calculations of several technical coefficients.

The combinations are selected in user forms (interactive windows that appear on the computer screen after clicking buttons in the worksheets and other user forms) named: “LUT selection”, “LMU selection”, “yield selection”, and "technologies". User-defined target yields per LUT and ecoregion (lowland rainfed, lowland irrigated, and upland rainfed), and selected technology levels per LUT, can be stored in the LUT sheet and used in later selections. The “sheet yields” form can be called in the “yield selection” form to use stored yields or the form appears automatically when yields for all selected combinations are available (in this case the "yield selection" form can be called to select different yields).

The main sheet of TechnoGIN that appears after opening the file (Fig. 4) contains a menu of buttons for initiating the selection of LUTs, LMUs, target yields, and technology levels to run the model, sensitivity analysis for data used in QUEFTS, and database management ("Yield related efficiencies", "Technology efficiencies", "Nutrient loss parameters", “Cropping calendar”, “Nutrient cycling parameters”).

1.4.1 Databases

The land use types are defined as a yearly crop or sequence of crops, a cropping calendar, and a crop residue strategy. There are 27 land use types specified in the LUT sheet (Table 2), which are considered important or promising in Ilocos Norte. There are 23 crops defined in the crop sheet, which contains data for calculating nutrient uptake, water, biocide, and labour input.

The LMU sheet contains 24 LMUs suitable for cropping (Appendix II). The LMUs were defined by the Bureau of Soils (1985a). Soil chemical properties and texture point data were averaged for each LMU (the LMUs have an average size of 10,000 ha). The slope and altitude are included in the database. Annual precipitation was determined per LMU by

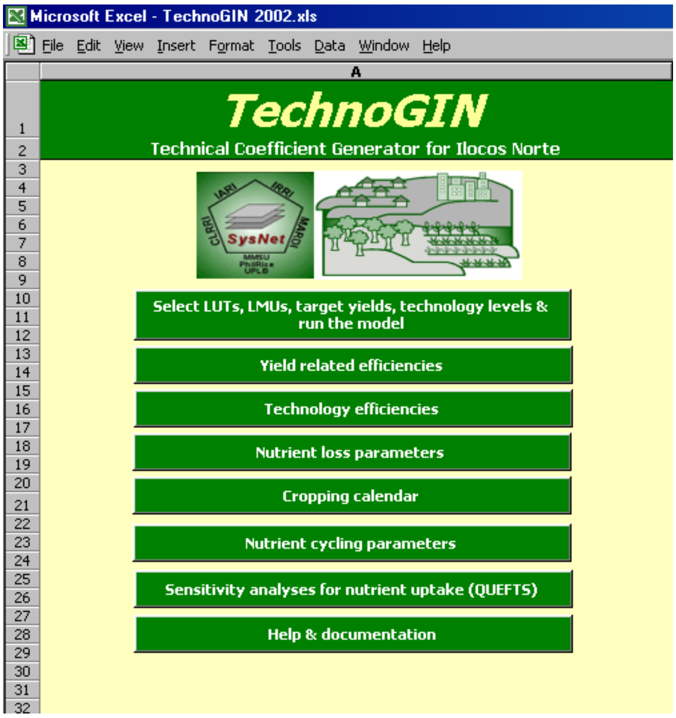


Figure 4. Screenshot of the main sheet with menu buttons

overlaying the LMU map with the annual precipitation map in a geographic information system (GIS).

Three ecoregions are defined, based on water availability, temperature and susceptibility to erosion: irrigated (lowland), rainfed lowland (tube-well irrigation is possible and usual) and rainfed upland. LMUs with steep slopes (average of 8% and steeper) are considered upland ecoregions, and assumed unsuitable for surface water irrigation. LMUs with average slopes lower than 8% are considered suitable for rainfed and irrigated agriculture. Soil and precipitation data are used to calculate nitrogen (N), phosphorus (P) and potassium (K) flows.

Parameters of the transfer functions calculating nutrient relationships are stored in the nutrient sheet. For mineral fertilisers application (N, P and K), biocides application (pesticides, herbicides and fungicides), and water use, the utilisation efficiencies (losses from the system) depend on the crop type in the LUT, selected target yields (which in turn depend on maximum yields of the crops), and on farmers' practices (present and future technology levels). The yield related efficiency parameters are stored in the efficiency sheet and the technology related efficiency parameters are stored in the technology sheet. The contents of the databases are described in detail in Chapter 3.

Table 2. Most prominent and/or promising land use types of Ilocos Norte used in TechnoGIN

1	Rice-White corn	10	Rice-Cotton	19	Rootcrop
2	Rice-Yellow corn	11	Rice-Sweet potato	20	Rice-Rice-Rice
3	Rice-Garlic	12	Rice-Soybean	21	Rice-Garlic-Mungbean
4	Rice-Mungbean	13	Rice-Onion	22	Rice-White corn-Mungbean
5	Rice-Peanut	14	Rice-Sweet pepper	23	Rice-Watermelon
6	Rice-Tomato	15	Rice-Eggplant	24	Rice-Mungbean-Yellow corn
7	Rice-Tobacco	16	Rice-Vegetables	25	Rice-Sweet pepper-Yellow corn
8	Rice-Fallow	17	Mango	26	Rice-Tomato-Yellow corn
9	Rice-Rice	18	Sugarcane	27	Rice-Onion-Mungbean

1.4.2 User forms

User forms in TechnoGIN are of two kinds: those for database management to make the data more accessible and those for model run selections. The user forms for database management include the forms named “Efficiency”, “Nutrient loss”, “Crop calendar”, and “QUEFTS” (Fig. 3). The user forms to select LUTs, LMUs, target yields, and technology levels make it possible for the user to make single or multiple selections. The selected target yields and technology levels can be stored in the LUT sheet, so they can be used in future selections. When the user has finished the selection, the macro is activated. A macro is a series of commands and functions that are stored in a Visual Basic module (a text page that can be edited in the Visual Basic editor, which is called by pressing the Alt and F11 keys simultaneously while Excel is opened or by clicking Tools → Macro → Visual Basic Editor). Detailed descriptions of the selection procedures and the database management forms are found in chapter 4.

1.4.3 The macro

The macro starts the calculations with QUEFTS calculating the nutrient uptake, using maximum dilution and accumulation of N, P, and K (kg harvestable product kg^{-1} N, P and K, respectively) in each crop per LUT. Per crop, yield related efficiencies are determined by linearly interpolating several reference efficiencies defined in the Efficiency sheet. The evapotranspiration is calculated per dekad. A dekad is a period of 10 days between the 1st and 10th and the 11th and 20th of each month, the last dekad of the month having 8 to 11 days (World Meteorological Organization, 1992). The reference evapotranspiration calculated by WOFOST (Boogaard et al., 1998) and extrapolated for different altitude classes is multiplied by the crop coefficient and the water use efficiency to obtain the water use per dekad. The labour requirements are divided over the cropping duration, and the harvesting labour is adjusted for the target yield. Finally, dekad data are transformed into monthly values to allow for integration with other data.

Total cost of biocides per crop is calculated from the amount used, the efficiency and biocide prices. Other costs (fuel, machinery) are directly copied from the crop sheet. The farm gate price is multiplied by the target yield. When all calculations per crop are completed, the calculations start for the LMUs.

Mineral fertiliser requirements are calculated based on nutrient withdrawal and supply from natural resources, taken into account the losses of applied fertilisers. The fertiliser cost model calculates the fertiliser cost by using the Solver module (Fertiliser sheet). The calculations for fertiliser input are repeated if more than one LMU is selected for the evaluated land use type. Calculations are repeated for each selected yield, ecoregion, etc.

When all calculations are finished, the output is presented in the output sheet, which will be copied and saved in a separate file, if requested by the user. The output sheet contains the following output groups:

- Monthly evapotranspiration
- Monthly labour requirements
- Fertiliser requirements and nitrogen loss
- Nitrogen cycling components
- Phosphorus cycling components
- Potassium cycling components
- Purchased bags of fertilisers (fertiliser cost model output)
- Biocide use
- Economic inputs and outputs

In the output form, which appears when the selection of LUTs, LMUs, target yields and technology levels is finished, output groups can be selected for the output sheet. Chapter 2 presents details of the macro.

Chapter 3 describes the databases and the functionality of the user forms are explained in Chapter 4. Chapter 5 concludes with a discussion on data quality and process knowledge. Several exercises for learning how to work with TechnoGIN are included in Appendix IV.

2 Calculations of technical coefficients

2.1 Programming in Excel

The calculations of the technical coefficients generated by TechnoGIN are performed by a macro, which contains the commands and functions that are repeated automatically for a user-defined selection of land use types (LUTs), land management units (LMUs), ecoregions, target yields and technology levels.

Macros in Microsoft Excel 97 and later versions (Microsoft, 1999a) are written in Visual Basic programming language (Microsoft, 1999b). The Visual Basic editor is opened by pressing the Alt and F11 keys at the same time while Excel is opened or by clicking Tools → Macros → Visual Basic Editor. The options of programming in Excel are as limiting as in programming in any version of Visual Basic, unless the direct link libraries (compiled files with commands and functions and the extension ".dll") are installed in the computer. However, the options that are available in any personal computer, with Microsoft Excel 97 or later versions installed, are sufficient to make a functional, efficient and user-friendly technical coefficient generator (TCG). User forms can be programmed for selections, database management, mathematical calculations, and loops to repeat the calculations for different combinations of LUTs, LMUs, ecoregions, target yields and technology levels. A danger with programming Excel macros is that different versions of Microsoft software are not always compatible.

A macro in Excel is able to call the Solver optimisation software that can be installed from the Microsoft Excel or Office installation disk (Appendix I). Solver offers various optimisations algorithms, such as linear programming, multiple integer programming and non-linear programming. It is used for solving optimisation problems found in nutrient uptake at different target yields (QUEFTS) and selection of fertilisers with different combinations of nitrogen (N), phosphorus (P) and potassium (K).

In the main sheet ("TechnoGIN") that appears after opening the Excel file, several command buttons enable the user to call user forms (interactive windows for database management and user-defined selections for model runs). By clicking the "Select LUTs, LMUs, target yields, technology levels & run the model" button, the "LUT selection" form will appear. The commands and functions of each button and box (in a box selections are made or data is changed by the user) are written in separate pages of the Visual Basic editor for each object in the Excel file (an object is e.g. a worksheet or a user form; Fig. 3). Program variables that are assigned values from user-input or read from the worksheets can be used in the commands and functions of different objects.

TechnoGIN uses arrays (an array is a variable with many compartments to store values, while a typical variable has only one storage compartment in which it can store only one value), in order to store the user-defined selection of the land use types (LUTs), land management units (LMUs), and target yields per ecoregion (lowland irrigated, lowland rainfed and upland rainfed). The arrays are used in commands and functions of different user forms and in the macro that calculates the technical coefficients for the selected combinations. The macro is written in a module, which is a page in the Visual Basic editor that contains procedures with commands and functions and can be started for example by clicking a button in a user form. The procedure that contains the calculation of the TCs in TechnoGIN is a Sub-procedure that starts with the statement "Sub TechnoGIN()" and ends with the statement "End Sub". By using the "For" and "Next" statements in this procedure, the calculations between these statements are repeated for every LUT that is defined in the LUT sheet. If the LUT is not selected in the user form (if the array “lutselect()” for a LUT, counting from “lutnr” = 1, 2, 3, to the total number of LUTs “nrluts”, does not equal *True*) then the calculations are skipped by going from “GoTo Nextlut” to the “Nextlut:” statement without executing the statements in-between (the lines with three dots represent lines with statements that are not shown):

```
For lutnr = 1 To nrluts
  lutname = LUTSheet.Cells(4 + lutnr, 3)
  If lutselect(lutnr) <> True Then GoTo Nextlut
  ...
  ...
Nextlut:
Next
```

The variable “lutname” is the name of the LUT and is displayed in the QUEFTS and Fertiliser sheets to keep the user informed about which LUT is being evaluated during a run. The name is read in the LUT sheet, in the 4^{th} + lutnr row and 3^{rd} column (LUTSheet.Cells(4 + lutnr, 3)).

Within the lutnr-loop there is another loop that repeats the calculations for the three ecoregions (the eco-loop). Within the eco-loop there is a loop that repeats the calculations for the different target yields per LUT-ecoregion combination (the Y-loop). Within the Y-loop there is a loop that repeats the calculations for each technology level (the t-loop). Within the t-loop there is a loop that repeats the calculations for the different crops in the LUT (the crp-loop). After the crp-loop some calculations are made to add values of the crops in the LUT. Then there is another loop within the t-loop (technology level) that repeats the calculations for every LMU (the lmunr-loop). Within the lmunr-loop a second crp-loop is activated to calculate the nutrient balances for each cropping season. Box 1 gives a simplified representation of the macro (the Sub-procedure “Sub TechnoGIN()”) including the various loops. In the next sections, a description is given of the calculations printed in bold in Box 1. Section 2.3 describes the QUEFTS calculations, Section 2.4 the nutrient cycling, Section 2.5 the yield related efficiencies, Section 2.6 the calculations per dekad and Section 2.7 the farm survey data.

2.2 Target yields

All technical coefficients calculated in TechnoGIN are related to the target yield, which is defined per ecoregion by the user in the forms that precede a run (Section 4.4), The target yields can be the averages (or other statistical indicators) of yields found in farm surveys or experiments, referred to as actual yields. They can also be estimates of potential or water-limited yields using regression models or physiologically based crop growth simulation models (e.g. WOFOST; Boogaard et al., 1998), referred to as alternative yields.

It is up to the user which cultivars are used for defining the target yields and harvest indices and nutrient concentrations in the crops can be modified for the cultivar specific characteristics in the sheet that contains crop specific data (Section 3.2). The maximum yield is defined as the highest potential yield in the province (paragraph 3.2.1), and is used as a reference for describing relations between the yield of harvestable product and nutrient uptake (Section 2.3), fertiliser use efficiency (paragraph 2.4.7), biocide use (though this relation is difficult to determine; Section 2.7), water use (evapotranspiration, paragraph 2.6.2) and other inputs. The target yield always needs to be lower than the maximum yield, so if the user wants to evaluate a target yield that is higher than the

```
Sub TechnoGIN()
...
For lutnr = 1 To nrluts
    If lutselect(lutnr) <> True Then GoTo Nextlut
    lutname = LUTSheet.Cells(4 + lutnr, 3)
    For eco = 1 To 3
        ...
        For Y = 1 To 10
            ...
            For t = 1 To 4
                If Tech(t) = 0 Then GoTo Notech
                ...
                For crp = 1 To 3
                    crop(crp) = LUTSheet.Cells(4 + lutnr, 3 + crp)
                    If crop(crp) = Empty Then GoTo NoCrop
                    ...
                    yield(crp) = lutyields(lutnr, crop(crp), eco, Y)
                    If yield(crp) = Empty Then GoTo Noyield
                    ...
                    ' QUEFTS calculations
                    ' Yield related efficiencies
                    ' Calculations per dekad
                    ' Farm survey data
                    ...
                Next
NoCrop:
                ...
                ' Per month data
                ...
                lmunr = 0
                For lmunr = 1 To nrlmus
                    If lutlmueco(lutnr, lmunr, eco) <> True Then GoTo Nextlmu
                    ...
                    For crp = 1 to 3
                        ...
                        ' Nutrient cycling
                    Next
                    ...
                    ' Fertiliser cost model
                    ' Evapotranspiration
                    ' Preparing output
                    ...
Nextlmu:
                Next
Noyield:
            Next
Notech:
        Next
Nexteco:
    Next
Nextlut:
Next
...
End Sub
```

Box 1. Simplified representation of the TechnoGIN subroutine (the three dots represent the lines that are not included in this box)

maximum yield, the latter needs to be changed in the sheet that contains crop specific data (paragraph 3.2.1).

The possibility of selecting more target yields per LUT-ecoregion combination enables the user to compare the usually lower actual yields with alternative yields. Besides differences in efficiencies because of yield differences, TechnoGIN also enables the user to evaluate different techniques that have effect on the efficiencies, defined in the technology levels. For example, land use systems with relatively high yields, needing high amounts of mineral fertilisers, are less efficient than land use systems with relatively low yields, needing low amounts of mineral fertilisers, using the same production techniques. However, in the alternative land use systems, different techniques can be introduced that include more efficient application of mineral fertilisers, e.g. split applications and better timing.

2.3 QUEFTS calculations

2.3.1 Introduction

The QUEFTS (Quantitative Evaluation of the Fertility of Tropical Soils) approach used in TechnoGIN is based on the work of Janssen et al. (1990), Smaling & Janssen (1993) and Witt et al. (1999). The QUEFTS version of Witt et al. (1999) uses the Solver spreadsheet module in Microsoft Excel that enables linear programming (LP) to estimate the nutrient uptake at a target yield using maximum dilution and maximum accumulation of nitrogen, phosphorus and potassium (kg harvestable product kg^{-1} N, P and K, respectively) as constraints. For more complete information on QUEFTS, we refer to the references mentioned above. Here the adjustments for TechnoGIN are explained.

2.3.2 Optimisation and constraints

The target yield is approached in the LP program by optimising the yield that is calculated in the QUEFTS sheet with several formulas. The Solver is programmed to maximise the yield by changing the cells in the sheet that contain the potential supplies of N, P and K, which are needed for realising the user defined target yield.

The values of several cells in the sheet are subject to constraints that limit the LP model in assigning values to the changeable cells. The yield that is calculated in the sheet should not exceed the target yield (GT <= YieldTarget). In QUEFTS, values to express the N, P and K use efficiencies, are the so-called internal N efficiency (IEN), internal P efficiency (IEP), and the internal K efficiency (IEK), which are the yield divided by the N, P and K uptake, respectively. There are six constraints, which ensure that the internal efficiencies of N, P and K do not exceed the maximum accumulation of N, P and K or drop below the maximum dilution of N, P and K.

- Internal nitrogen efficiency (IEN) >= maximum accumulation of nitrogen (aN)
- Internal nitrogen efficiency (IEN) <= maximum dilution of nitrogen (dN)
- Internal phosphorus efficiency (IEP) >= maximum accumulation of phosphorus (aP)
- Internal phosphorus efficiency (IEP) <= maximum dilution of phosphorus (dP)
- Internal potassium efficiency (IEK) >= maximum accumulation of potassium (aK)
- Internal potassium efficiency (IEK) <= maximum dilution of potassium (dK)

However, in the version of Witt et al. (1999) it is not possible to evaluate different values of maximum accumulation and dilution of N, P and K without having to calibrate the model for N:P:K uptake ratios by using the following constraints in a separate Solver module:

- Actual yield <= target yield
- Uptake K / potential supply K = uptake P/ potential supply P
- Uptake N / potential supply N = uptake P/ potential supply P
- Uptake N / potential supply N >= 0.95

To avoid that the Solver has to solve the problem in two runs, the following approach, which estimates the N:P:K uptake ratio, was followed:

- The initial potential supply of N must equal the average dry weight concentration of N in the plant divided by the average dry weight concentration of P in the plant
- The initial potential supply of P must equal 1
- The initial potential supply of K must equal the average dry weight concentration of N in the plant divided by the average dry weight concentration of P in the plant

The Solver parameters window (Fig. 5) of QUEFTS is called by clicking Tools → Solver while the QUEFTS sheet is activated.

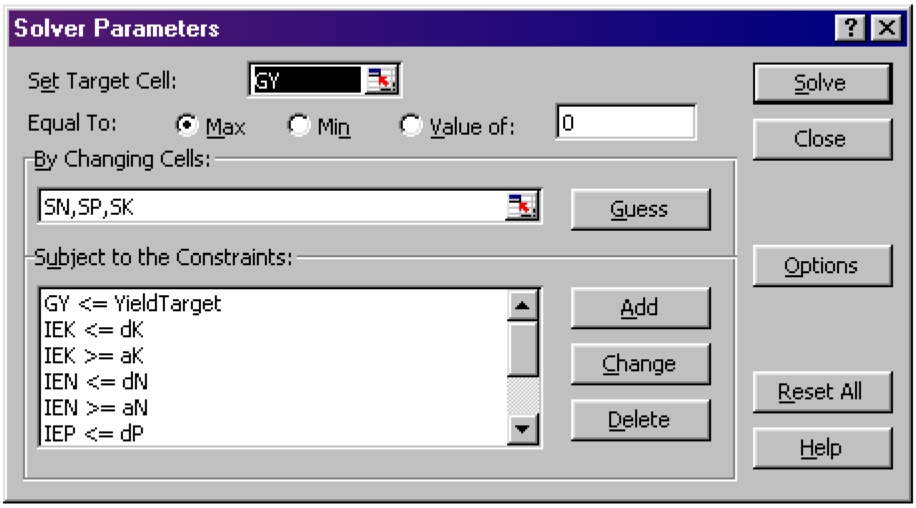


Figure 5. The Solver parameters window of QUEFTS in TechnoGIN

2.3.3 QUEFTS in the macro

Firstly, the data are read from the Crop sheet (potential yield; harvest index; minimum and maximum N, P and K content in harvestable product, and crop residues).

```
pot_yld = CropSheet.Cells(4 + crop(crp), 4)    ' potential yield
HI = CropSheet.Cells(4 + crop(crp), 5)         ' Harvest Index
N_min_hp = CropSheet.Cells(4 + crop(crp), 8)   ' min. N % in harvest. prod.
N_max_hp = CropSheet.Cells(4 + crop(crp), 9)   ' max. N % in harvest. prod.
P_min_hp = CropSheet.Cells(4 + crop(crp), 10)  ' min. P % in harvest. prod.
P_max_hp = CropSheet.Cells(4 + crop(crp), 11)  ' max. P % in harvest. prod.
K_min_hp = CropSheet.Cells(4 + crop(crp), 12)  ' min. K % in harvest. prod.
K_max_hp = CropSheet.Cells(4 + crop(crp), 13)  ' max. K % in harvest. prod.
N_min_ss = CropSheet.Cells(4 + crop(crp), 14)  ' min. N % in crop residues.
N_max_ss = CropSheet.Cells(4 + crop(crp), 15)  ' max. N % in crop residues.
P_min_ss = CropSheet.Cells(4 + crop(crp), 16)  ' min. P % in crop residues
P_max_ss = CropSheet.Cells(4 + crop(crp), 17)  ' max. P % in crop residues.
K_min_ss = CropSheet.Cells(4 + crop(crp), 18)  ' min. K % in crop residues
K_max_ss = CropSheet.Cells(4 + crop(crp), 19)  ' max. K % in crop residues
```

The data required by QUEFTS are calculated and copied in the QUEFTS sheet. The values of maximum dilution of N, P and K are calculated by taking the reciprocal of the average minimum concentrations of N, P and K in the plant (corrected for harvest index). The values of maximum accumulation of N, P and K are calculated similarly with the maximum concentrations instead of the minimum concentrations. The values are inserted in the sheet in the cells that have names (e.g. Range("dN"); names were assigned by selecting a cell in a worksheet and clicking Insert → Name → Define). The target and maximum yields are converted from ton per ha to kg per ha. The target yield is retrieved from an array that contains the target yields per crop in the LUT (yield(crp), with crp = 1, 2, and 3).

```
QUEFTSheet.Activate
Range("dN") = HI(crp) * 100 / (N_min_hp * HI(crp) + N_min_ss * (1 - HI(crp)))
Range("aN") = HI(crp) * 100 / (N_max_hp * HI(crp) + N_max_ss * (1 - HI(crp)))
Range("dP") = HI(crp) * 100 / (P_min_hp * HI(crp) + P_min_ss * (1 - HI(crp)))
Range("aP") = HI(crp) * 100 / (P_max_hp * HI(crp) + P_max_ss * (1 - HI(crp)))
Range("dK") = HI(crp) * 100 / (K_min_hp * HI(crp) + K_min_ss * (1 - HI(crp)))
Range("aK") = HI(crp) * 100 / (K_max_hp * HI(crp) + K_max_ss * (1 - HI(crp)))
Range("YieldTarget") = 1000 * yield(crp)
Range("Ymax")        = 1000 * pot_yld
```

The initial potential supply of N is equalled to the average % of N in the plant divided by the average % of P in the plant, the initial potential supply of P is equalled to 1 (the average % of P in the plant divided by the average % of P in the plant) and the initial potential supply of K is equalled to the average % of N in the plant divided by the average % of P in the plant. By setting the initial values as described above the N:P:K uptake ratio is estimated, so that it is within the uptake/ supply constraints.

```
ISN = (((N_min_hp * HI(crp) + N_min_ss * (1 - HI(crp))) + _
        (N_max_hp * HI(crp) + N_max_ss * (1 - HI(crp)))) / 2) / _
      (((P_min_hp * HI(crp) + P_min_ss * (1 - HI(crp))) + _
        (P_max_hp * HI(crp) + P_max_ss * (1 - HI(crp)))) / 2)
ISP = (((P_min_hp * HI(crp) + P_min_ss * (1 - HI(crp))) + _
        (P_max_hp * HI(crp) + P_max_ss * (1 - HI(crp)))) / 2) / _
      (((P_min_hp * HI(crp) + P_min_ss * (1 - HI(crp))) + _
        (P_max_hp * HI(crp) + P_max_ss * (1 - HI(crp)))) / 2)
ISK = (((K_min_hp * HI(crp) + K_min_ss * (1 - HI(crp))) + _
        (K_max_hp * HI(crp) + K_max_ss * (1 - HI(crp)))) / 2) / _
      (((P_min_hp * HI(crp) + P_min_ss * (1 - HI(crp))) + _
        (P_max_hp * HI(crp) + P_max_ss * (1 - HI(crp)))) / 2)
'
Range("SN") = ISN
Range("SP") = ISP
Range("SK") = ISK
```

The next statement runs the Solver model that is defined in the QUEFTS sheet. The words “userfinish:=True” in the statement means that there will not be a message after every solution that Solver finds.

```
solversolve userfinish:=True
```

There is a check if Solver is actually working. A message will be shown which informs the user that there could be problems with the Solver add-in in the Microsoft Excel that is installed in the users personal computer. See also Appendix I for instruction on how to install the Solver.

```
If SN(crp) = ISN Then
  ' (message)
  Exit Sub
End If
```

When the yield is maximised to approach the target yield by changing the supplies (SN, SP, and SK), the values are read for the different crops (crp-loop), from the cells in the QUEFTS sheet with the similar names.

```
SN(crp) = Range("SN")
SP(crp) = Range("SP")
SK(crp) = Range("SK")
```

2.4 Nutrient cycling

2.4.1 Nutrient flows and assumptions

Flows of nitrogen, phosphorus and potassium in and out and between different components (organic and inorganic nutrient pools, plants and animals) of the land use system are calculated in TechnoGIN per season (Fig. 6) based on soil properties (clay content), precipitation, crop characteristics, management efficiency, etc. Some of the included nutrient flows are expected to have little influence on the total balance of the systems (irrigation, free living N-fixation, capillary rise, dissolution sedimentation), and other flows are assumed to be in balance (run-off/ run-on, erosion/ sedimentation, immobilisation/ mineralization). They are included for evaluation and consistency of the model. The yearly mineral fertiliser applications are calculated in a way that makes sure that the inflows in the mineral and organic pools are equal to the outflows out of the pools, so that the fertiliser applications and target yields can be repeated for many years without mining the soil or building up a nutrient reserve in the pools. Most parameters for the

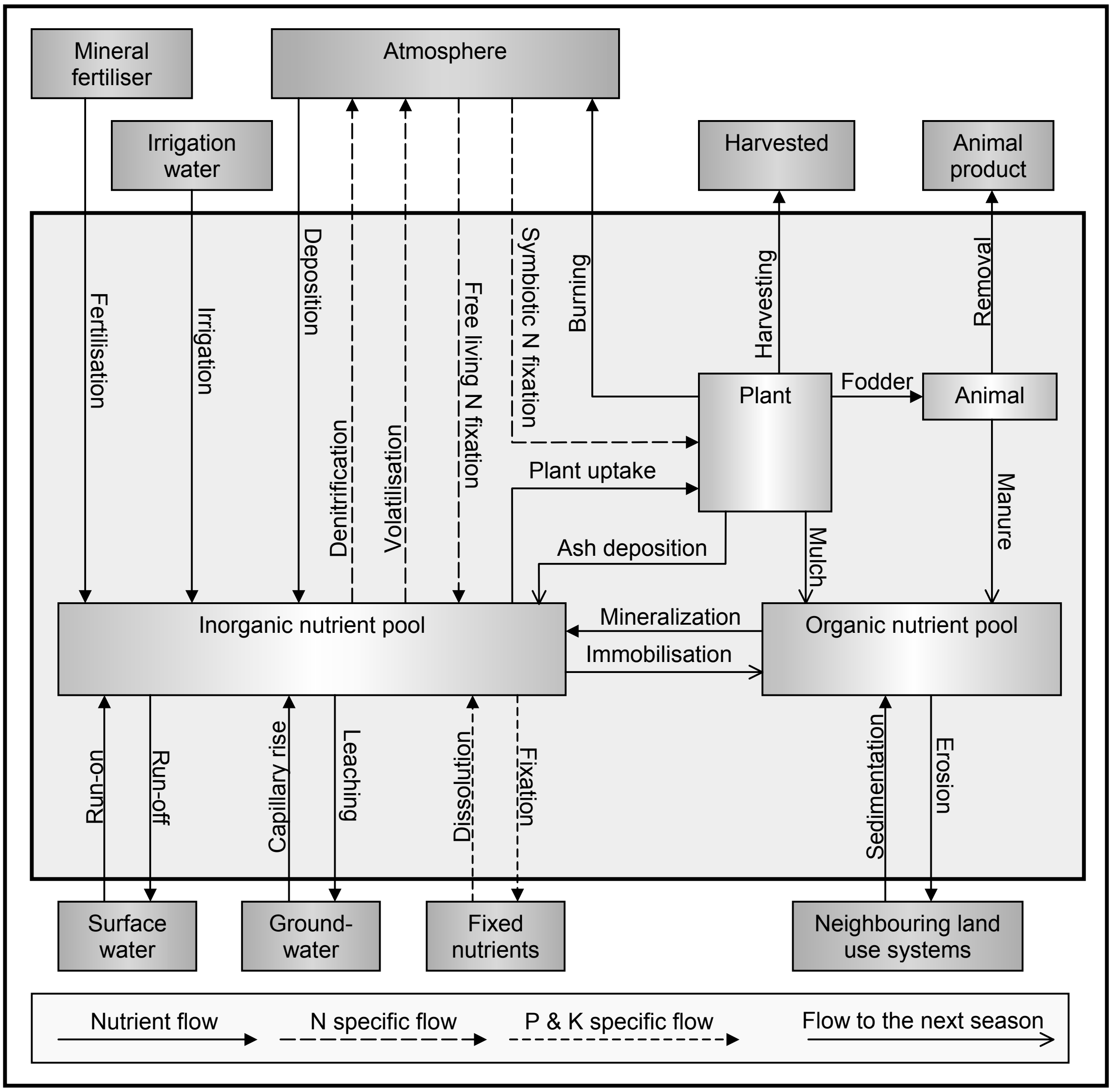


Figure 6. Nutrient flows in and out of a cropping season in a land use system and between its components

transfer functions that calculate the different flows are read from the Nutrient sheet (if not otherwise specified, the parameters discussed in this section are found in the Nutrient sheet). All flows are calculated in kilograms.

2.4.2 Cropping season

The nutrient balance is calculated for the three cropping seasons separately. In Ilocos Norte a wet cropping season can be distinguished (roughly between July and October), a dry cropping season (November – April), and a "dry-to-wet" cropping season (March – June). Part of the nutrients from crop residues of one cropping season return to the inorganic nutrient pool in the following cropping season by mineralization. A positive balance in a season is considered a gain to the system. If a negative balance occurs, the seasonal fertiliser requirements are calculated to realize equilibrium, without taking positive balances in other seasons into account (yearly fertiliser requirements are the sums of the positive and negative balances of the three seasons). Expected losses associated with the application of fertiliser requirements are taken into account.

Seasonal precipitation is calculated by dividing the monthly precipitation into dekads. A two season fallow period is considered as one season. The following lines start the crp-loop (for the three cropping seasons), within the lmu-loop. The start and end dekads of the fallow period are calculated from the end dekad of the preceding crop and the start dekad of the first crop, which are read from the LUT and Crop sheet. The technology related nutrient efficiencies are set to 1 if there is no crop (except when the fallow period lasts two seasons and the third season is evaluated). If a crop is grown, the start dekad is read from the LUT sheet and the end dekad is calculated from the crop duration, which is read from the Crop sheet.

```
For crp = 1 To 3
  If crop(2) = 0 And crp = 3 Then
    GoTo NoCrp
  ElseIf crop(crp) = 0 Then
    start_dekad = LUTSheet.Cells(4 + lutnr, 12 + crp - 1)
    cropduration = CropSheet.Cells(4 + crop(crp - 1), 23)
    start_dekad = start_dekad + (cropduration / 10)
    end_dekad = LUTSheet.Cells(4 + lutnr, 12 + 1) - 1
    EffN_tec = 1
    EffP_tec = 1
    EffK_tec = 1
  Else
    start_dekad = LUTSheet.Cells(4 + lutnr, 12 + crp)
    cropduration = CropSheet.Cells(4 + crop(crp), 23)
    end_dekad = start_dekad + (cropduration / 10) - 1
  End If
  If start_dekad > end_dekad Then end_dekad = end_dekad + 36
  dekads_season = end_dekad - start_dekad + 1
  start_month = Int(start_dekad / 3)
  start_monfr = 1 - (start_dekad / 3 Mod 1)
  end_month = Int(end_dekad / 3)
  end_monfr = 1 - (end_dekad / 3 Mod 1)
  Prec = 0
  For d = start_month + 1 To end_month - 1
    If d > 12 Then dc = d - 12 Else dc = d
    Prec = Prec + Rain(dc)
  Next
  If start_month > 12 Then start_month = start_month - 12
  If end_month > 12 Then end_month = end_month - 12
  Prec = Prec + start_monfr * Rain(start_month) + _
              end_monfr * Rain(end_month)
```

2.4.3 Inflows of mineral nutrients

Irrigation

Nutrient inputs via irrigation water are based on the N, P and K concentrations of the irrigation water (kg l^{-1}) and the total amount of irrigation water used per crop (mm; retrieved from the Crop sheet). The concentrations (N_con, P_con, and K_con) are currently set to zero.

```
If crop(crp) = 0 Then IrrWat = 0 Else _
   IrrWat = CropSheet.Cells(4 + crop(crp), 78)
N_con = Range("N_con")
P_con = Range("P_con")
K_con = Range("K_con")
N_irr = N_con * IrrWat * 10000
P_irr = P_con * IrrWat * 10000
K_irr = K_con * IrrWat * 10000
```

Run-on

The amount of nutrients yearly received by the system via run-on is related to the slope and adjusted for the length of the cropping season. The regression coefficients (aN_ron, aP_ron, and aK_ron) are currently set to zero.

```
aN_ron = Range("aN_ron")
aP_ron = Range("aP_ron")
aK_ron = Range("aK_ron")
N_ron = aN_ron * Slope * dekads_season / 36
P_ron = aK_ron * Slope * dekads_season / 36
K_ron = aK_ron * Slope * dekads_season / 36
```

Wet and dry deposition

Yearly gains of nutrients by wet deposition are related to the square root of the accumulated precipitation (Smaling et al., 1993). Default values for the parameters aN_dep, aP_dep, and aK_dep are 0.140, 0.032, and 0.092 kg ha^{-1} $mm^{-0.5}$, respectively.

```
aN_dep = Range("aN_dep")
aP_dep = Range("aP_dep")
aK_dep = Range("aK_dep")
N_dep = aN_dep * Sqr(Prec)
P_dep = aP_dep * Sqr(Prec)
K_dep = aK_dep * Sqr(Prec)
```

N-fixation by free-living bacteria

Supply of nitrogen by non-symbiotic N fixation is related to precipitation (Smaling et al., 1993). Default values for the parameters aN_fix and bN_fix of 0.005 kg ha^{-1} y^{-1}, and -4.75 kg ha^{-1} y^{-1} mm^{-1}, respectively, are used. The bN_fix parameter is adjusted for the length of the cropping season. The worksheet-function "Max" ensures that the result cannot become negative.

```
aN_fix = Range("aN_fix")
bN_fix = Range("bN_fix")
N_fix = WorksheetFunction.Max(0, _
        aN_fix * Prec + bN_fix * dekads_season / 36)
```

Symbiotic N-fixation
The amount of N-fixation by symbiotic bacteria is calculated as a fraction of the total N uptake of the crop. For leguminous crops the fraction (fnfix(crp); retrieved from the Crop sheet) is assumed to be 0.8 (Giller, 2001).

```
N_sym = fnfix(crp) * SN(crp)
```

Capillary rise
Gains of nutrients to the system through capillary rise are assumed to be a fixed amount per year. This amount is read from the nutrient sheet and adjusted for the length of the cropping season. The regression coefficients (aN_cap, aP_cap, and aK_cap) are currently set to zero.

```
aN_cap = Range("aN_cap")
aP_cap = Range("ap_cap")
aK_cap = Range("aK_cap")
N_cap = aN_cap * dekads_season / 36
P_cap = aK_cap * dekads_season / 36
K_cap = aK_cap * dekads_season / 36
```

Dissolution
The dissolution rates of mineral phosphorus and potassium are also assumed to be at a fixed rate per year. This amount is adjusted for the length of the season. The regression coefficients (aP_dis and aK_dis) are currently set to zero.

```
aP_dis = Range("aP_dis")
aK_dis = Range("aK_dis")
P_dis = aP_dis * dekads_season / 36
K_dis = aK_dis * dekads_season / 36
```

2.4.4 Crop uptake and cycling of nutrients

Crop uptake
Crop nutrient uptake is calculated in QUEFTS (Section 2.3). The total uptake is equalled to the nutrient weight of the crops (SN(crp), SP(crp), and SK(crp)), except for crops with symbiotic nitrogen fixing bacteria (paragraph 2.4.2).

```
N_upt = SN(crp) * (1 - fnfix(crp))
P_upt = SP(crp)
K_upt = SK(crp)
```

Harvested nutrients in crop product
The harvested nutrients are calculated with the average nutrient concentrations of the harvestable product (frN_hp(crp), frP_hp(crp), and frK_hp(crp)) and crop residue per crop (frN_ss(crp), frP_ss(crp), and frK_ss(crp)) and the harvest indices (HI(crp)).

```
N_har = SN(crp) * HI(crp) * frN_hp(crp) / _
       (HI(crp) * frN_hp(crp) + (1 - HI(crp)) * frN_ss(crp))
P_har = SP(crp) * HI(crp) * frP_hp(crp) / _
       (HI(crp) * frP_hp(crp) + (1 - HI(crp)) * frP_ss(crp))
K_har = SK(crp) * HI(crp) * frK_hp(crp) / _
       (HI(crp) * frK_hp(crp) + (1 - HI(crp)) * frK_ss(crp))
```

Amount of nutrients in the crop residues

Because all nutrients taken up from the inorganic nutrient pool are considered lost from the inorganic nutrient balance in a cropping season and part of the nutrients in the crop are considered a gain to the inorganic nutrient balance of the following cropping season (depending on the crop residue strategy defined in the LUT sheet), the amount of nutrients in the crop residues of the previous crop is calculated. The previous crop number (pcrp) is 3, 1 and 2 if the evaluated cropping season is 1, 2, and 3, respectively.

```
N_str(pcrp) = SN(pcrp) * (1 - HI(pcrp) * frN_hp(pcrp) / _
              (HI(pcrp) * frN_hp(pcrp) + (1 - HI(pcrp)) * frN_ss(pcrp)))
P_str(pcrp) = SP(pcrp) * (1 - HI(pcrp)) * frP_hp(pcrp) / _
              (HI(pcrp) * frP_hp(pcrp) + (1 - HI(pcrp)) * frP_ss(pcrp))
K_str(pcrp) = SK(pcrp) * (1 - HI(pcrp)) * frK_hp(pcrp) / _
              (HI(pcrp) * frK_hp(pcrp) + (1 - HI(pcrp)) * frK_ss(pcrp))
```

Fodder

Part of the crop residues is fed to animals (this is defined in the LUT sheet per crop). In order to calculate the amount of nutrients that are consumed by animals and return to the organic nutrient pool of the evaluated cropping season in the form of manure, the amount of nutrients in the previous crop's residues that is fed to animals is calculated. The fractions of nutrients in the crop residues that are fed to animals are defined in the LUT sheet (fr_fod(pcrp)).

```
fr_fod(crp) = LUTSheet.Cells(4 + lutnr, 6 + crp)
N_fod = fr_fod(pcrp) * N_str(pcrp)
P_fod = fr_fod(pcrp) * P_str(pcrp)
K_fod = fr_fod(pcrp) * K_str(pcrp)
```

Removal of animal product

Part of the crop residues that is consumed by animals is removed from the system with the animal product. This fraction is read from the nutrient sheet and set to 0.2 (this value also includes the losses of nitrogen due to volatilisation of urine).

```
fr_ani = Range("fr_ani")
N_ani = fr_ani * N_fod
P_ani = fr_ani * P_fod
K_ani = fr_ani * K_fod
```

Manure

The amount of nutrients in manure that is added to the organic nutrient pool is equalled to the amount of nutrients in fodder minus the amount of removed nutrients in animal products.

```
N_man = N_fod - N_ani
P_man = P_fod - P_ani
K_man = K_fod - K_ani
```

Burning

The amount of nutrients lost from the system by burning is equal to the fraction of crop residues from the previous crop, multiplied by the fraction of the burnt nutrients that are lost to the atmosphere (frN_bls, frP_bls, and frK_bls). For N the fraction is assumed to be 0.8 and for P and K zero.

```
frN_bls = Range("frN_bls")
frP_bls = Range("frP_bls")
```

```
frK_bls = Range("frK_bls")
N_bur = frN_bls * fr_bur(pcrp) * N_str(pcrp)
P_bur = frP_bls * fr_bur(pcrp) * P_str(pcrp)
K_bur = frK_bls * fr_bur(pcrp) * K_str(pcrp)
```

Ash deposition
Part of the nutrients in the crop residues that are burnt, return to the inorganic nutrient pool through ash deposition.

```
N_ash = (1 - frN_bls) * fr_bur(pcrp) * N_str(pcrp)
P_ash = (1 - frP_bls) * fr_bur(pcrp) * P_str(pcrp)
K_ash = (1 - frK_bls) * fr_bur(pcrp) * K_str(pcrp)
```

Litter and mulch
Part of the previous crop's residues that is not fed to animals or burnt, is added to the organic nutrient pool as mulch.

```
N_res = N_str(pcrp) * (1 - fr_bur(pcrp) - fr_fod(pcrp))
P_res = P_str(pcrp) * (1 - fr_bur(pcrp) - fr_fod(pcrp))
K_res = K_str(pcrp) * (1 - fr_bur(pcrp) - fr_fod(pcrp))
```

2.4.5 Outflows of mineral nutrients

Run-off
The yearly amount of nutrients lost from the inorganic nutrient pool by run-off is related to slope. The seasonal amount is adjusted for the length of the cropping season. The regression coefficients (aN_rof, aP_rof, and aK_rof) are currently set to zero.

```
aN_rof = Range("aN_rof")
aP_rof = Range("aP_rof")
aK_rof = Range("aK_rof")
N_rof = aN_rof * Slope * dekads_season / 36
P_rof = aK_rof * Slope * dekads_season / 36
K_rof = aK_rof * Slope * dekads_season / 36
```

Denitrification
Nitrogen loss fraction of inorganic nitrogen due to denitrification is based on a transfer function related to clay content of the soil (%) and precipitation (mm), based on Smaling et al. (1993). Values for aN_den, bN_den, and cN_den of 0.0013 kg ha^{-1} (100 kg clay kg^{-1} $soil)^{-1}$, 0.0001 kg ha^{-1} mm^{-1}, and 0 kg ha^{-1} were used, respectively.

```
aN_den = NutRecSheet.Range("ClayNden")
bN_den = NutRecSheet.Range("PrecNden")
cN_den = NutRecSheet.Range("cNden")
frN_den = aN_den * Clay + bN_den * Prec + cN_den
```

Volatilisation
The N loss fraction due to volatilisation is assumed to be related to clay content in case of anaerobic rice or a fixed value for other crops. The regression parameter aN_vol is multiplied by 100 - Clay (%) to calculate the N loss fraction due to volatilisation and is set to 0.003 for anaerobic rice. For other crops, the value is set to 0.05, based on Hengsdijk et al. (1998), and is not corrected for clay content.

```
If crp = 1 And crop(crp) < 6 Then
    ' Volatilisation (anaerobic)
    aN_vol = NutRecSheet.Range("N_volae")
    frN_vol = aN_vol * (100 - Clay)
```

```
    ...
  Else
    ' Volatilisation (aerobic)
    aN_vol = NutRecSheet.Range("NVF")
    frN_vol = aN_vol

aN_vol = NutRecSheet.Range("NVF")
frN_vol = aN_vol
```

Leaching

For anaerobic rice, the N and K loss fractions due to leaching are set to a constant value for all land use systems (0 for K and 0.05 for N). For other crops they are based on the relationship between the loss fraction, clay content and precipitation (Smaling et al., 1993). The N and K leaching fraction at 0 and 2500 mm precipitation are linearly interpolated for the seasonal precipitation. Different values are read for different clay content classes (Table 3).

Table 3. N and K leaching fractions

Clay content classes	**Precipitation**	
	0 mm	2500 mm
Nitrogen leaching		
Clay < 35%	0.29	0.47
35 ≤ Clay < 55%	0.23	0.35
Clay ≥ 55%	0.17	0.22
Potassium leaching		
Clay < 35%	0.09	0.11
35 ≤ Clay < 55%	0.07	0.10
Clay ≥ 55%	0.06	0.08

```
If crp = 1 And crop(crp) < 6 Then
    ...
    ' Leaching (anaerobic)
    frN_lch = Range("N_lchae")
    frK_lch = Range("K_lchae")
  Else
    ...
    ' Leaching (aerobic)
    If Clay < 35 Then
        N_lchmin = Range("NLLC15")
        N_lchmax = Range("NLLC25")
        K_lchmin = Range("KLLC15")
        K_lchmax = Range("KLLC25")
    ElseIf Clay < 55 Then
        N_lchmin = Range("NLMC15")
        N_lchmax = Range("NLMC25")
        K_lchmin = Range("KLMC15")
        K_lchmax = Range("KLMC25")
    Else
        N_lchmin = Range("NLHC15")
        N_lchmax = Range("NLHC25")
        K_lchmin = Range("KLHC15")
        K_lchmax = Range("KLHC25")
    End If
    aN_lch = N_lchmin
    bN_lch = (N_lchmax - N_lchmin) / 2500
    aK_lch = K_lchmin
    bK_lch = (K_lchmax - K_lchmin) / 2500
    frN_lch = aN_lch + Prec * bN_lch
    frK_lch = aK_lch + Prec * bK_lch
```

```
End If
```

Phosphorus and potassium fixation

Fixation of P is assumed to be equal for all land use systems. The P-fixation fraction (frP_fix) is set to 0.7 based on Hengsdijk et al. (1998).

```
frP_fix = NutRecSheet.Range("PFF")
```

The K loss fraction due to K-fixation is assumed to be related linearly with the clay content. The K-fixation fraction at 0% clay is estimated at 0.1 (aKF). The K-fixation fraction at 100% clay is estimated at 0.25 (bKF). K-fixation losses at intermediate clay levels are based on linearly interpolated values.

```
aKF = Range("KFFmin")
bKF = (Range("KFFmax") - Range("KFFmin")) / 100
frK_fix = aKF + Clay * bKF
```

Immobilisation

The immobilisation rate is assumed to equal the mineralization rate. The parameters aN_imm, aP_imm and aK_imm are currently set to zero.

```
aN_imm = Range("aN_imm")
aP_imm = Range("aP_imm")
aK_imm = Range("aK_imm")
N_imm = aN_imm
P_imm = aP_imm
K_imm = aK_imm
```

2.4.6 Organic pool

Sedimentation

The sedimentation rate of nutrients is assumed to be a fixed rate per year, related to slope. This rate is adjusted for the length of the season. The regression coefficients (aN_sed, aP_sed, and aK_sed) are currently set to zero.

```
aN_sed = Range("aN_sed")
aP_sed = Range("aP_sed")
aK_sed = Range("aK_sed")
N_sed = aN_sed * Slope * dekads_season / 36
P_sed = aP_sed * Slope * dekads_season / 36
K_sed = aK_sed * Slope * dekads_season / 36
```

Soil erosion

Nutrients lost by soil erosion are calculated by the Revised Universal Soil Loss Equation (Renard et al., 1997). The equation consists of 6 factors: soil erodibility (K), slope steepness (S), support practice (P), slope length (L), rainfall (R), and cover management (C). For calculating the K-factor, the permeability value has to be converted from meters per day (as it is read from the LMU sheet) to inch per hour (Perm_inch). The resulting values are then converted into permeability classes (Perm_classes). The texture factor SandSilt, that is also needed to calculate the K-factor, is a function of sand and silt content in the soil (in %). The K-factor is a function of Perm_class, SandSilt and organic matter (OM, in %). The S- and P-factors are calculated with slope and the L- and R-factors are assumed constant. The C-factor is read from the crop sheet.

```
Perm_inch = Permeability * 100 * 0.3937 / 24
Perm_class = IIf(Perm_inch < 0.05, 1, IIf(Perm_inch < 0.2, 2, _
             IIf(Perm_inch < 0.8, 3, IIf(Perm_inch < 2.5, 4, _
```

```
             IIf(Perm_inch < 5, 5, IIf(Perm_inch < 10, 6, 7))))))
SandSilt = (Silt + (Sand / 3)) * (Silt + Sand)
K_factor = (((0.00021 * (12 - OM) * (SandSilt ^ 1.14)) + 2.5 * _
           (Perm_class - 3)) / 100) / 7.59
S_factor = (0.43 + 0.3 * Slope + 0.043 * (Slope ^ 2)) / 6.613
P_factor = (0.2 + 0.03 * Slope)
L_factor = Sqr(100 / 22.13)
R_factor = 0.3
C_factor = CropSheet.Cells(4 + crop(crp), 76)
A_USLE = K_factor * S_factor * P_factor * _
         L_factor * R_factor * C_factor / 1000
' erosion loss
frN_ero = A_USLE
frP_ero = A_USLE
frK_ero = A_USLE
```

Mineralization

The amount of nutrients that is mineralised in one season is equal to the nutrients in mulched crop residues (from the previous crop), and in manure (from animals that consume the crop residues of the previous crop), immobilised nutrients, and nutrients from sedimentation, that are not eroded.

```
N_min = (N_res + N_man + N_imm + N_sed) * (1 - frN_ero)
P_min = (P_res + P_man + P_imm + P_sed) * (1 - frP_ero)
K_min = (K_res + K_man + K_imm + K_sed) * (1 - frK_ero)
```

2.4.7 Recovery fractions, mineral fertilisers & total N losses

Recovery fractions

The recovery fractions for mineral fertilisers are calculated as 1 minus the loss fractions of the different nutrients, and are corrected with three different correction fractions, taking into account the differences between technologies, yields and crops. The technology related correction factors (EffN_tec, EffP_tec, and EffK_tec) are defined per technology level. These factors are defined in the Technology sheet, assuming different fertiliser application efficiencies for different production techniques (single or split application, timing and balancing of applications). The yield related efficiencies reflect the increasing inefficiencies at high fertiliser applications. The yield related correction factors for N, P and K recovery (EffN_yld,(crp), EffP_yld(crp), and EffK_yld(crp), respectively) are set to 1 in fallow seasons. The crop related efficiencies (Eff_crp) take the differences in rooting, crop cover and other characteristics of the crops that influence the nutrient uptake efficiencies into account. For fallow seasons, the crop efficiency correction factor is 1.

```
' Correction factor of nutrient recovery for crop
Eff_crp = Iif(crop(crp) = 0, 1, _
              CropSheet.Cells(4 + crop(crp), 77))
If crop(crp) = 0 Then EffN_yld(crp) = 1: _
                      EffP_yld(crp) = 1: _
                      EffK_yld(crp) = 1
frN_rec = (1 - frN_den - frN_vol - frN_lch) * _
            EffN_tec * Eff_crp * EffN_yld(crp)
frP_rec = (1 - frP_fix) * EffP_tec * Eff_crp * _
            EffP_yld(crp)
frK_rec = (1 - frK_fix - frK_lch) * EffK_tec * _
            Eff_crp * EffK_yld(crp)
```

Correction factor of nutrient recovery for mineralized nutrients

The correction factor for the recovery of mineralized nutrients is related to the nitrogen content of the crop residues of the previous crop. The parameters are set to 1.2 for a_min and 1.0 for b_min. This means (see formula below) that the correction factor is 0.2 at 0% N in the crop residues and increases towards an asymptote of 1.2.

```
b_min = Range("b_min")
a_min = Range("a_min")
Eff_min = a_min - Exp(-b_min * frN_ss(pcrp))
```

Fertilisers

For calculating fertiliser requirements, the nutrient losses from the inorganic nutrient pool by crop uptake, run-off and immobilisation are summed and divided by the fertiliser recovery fraction. From this the mineralized nutrient flow, multiplied by the correction factor for mineralized nutrients and corrected for the technology related efficiency (which only applies to the efficiencies of fertilisers), is subtracted. The other nutrient inflows to the inorganic nutrient pool (irrigation, wet and dry deposition, non-symbiotic N fixation, capillary rise, ash deposition, run-on) are also corrected for the technology related correction factor and subtracted from the fertiliser requirements.

```
N_fert(crp) = (N_upt + N_rof + N_imm) / frN_rec - _
      (N_irr + N_dep + N_fix + N_cap + N_ash + N_ron + _
       N_min * Eff_min) / EffN_tec
P_fert(crp) = (P_upt + P_rof + P_imm) / frP_rec - _
      (P_irr + P_dep + P_dis + P_cap + P_ash + P_ron + _
       P_min * Eff_min) / EffP_tec
K_fert(crp) = (K_upt + K_rof + K_imm) / frK_rec - _
      (K_irr + K_dep + K_dis + K_cap + K_ash + K_ron + _
       K_min * Eff_min) / EffK_tec
```

If the fertiliser requirements are negative, then these values are corrected for nutrient recovery and are treated as the seasonal gain of nutrients to the system.

```
If N_fert(crp) < 0 Then N_fert(crp) = N_fert(crp) * frN_rec
If P_fert(crp) < 0 Then P_fert(crp) = P_fert(crp) * frP_rec
If K_fert(crp) < 0 Then K_fert(crp) = K_fert(crp) * frK_rec
```

Total nitrogen leaching and gaseous nitrogen losses

The total loss of N through leaching and gaseous losses is calculated per season by summing all the known flows in and out the inorganic N pool. The fraction of this that is leached is the leaching fraction, divided by the sum of the leaching, volatilisation and denitrification fractions. The fraction gaseous losses is the sum of the denitrification and volatilisation loss fractions, divided by the sum of the leaching, volatilisation and denitrification fractions

```
N_lch(crp) = (N_fert(crp) + N_irr + N_dep + N_fix + N_cap + N_ash + _
              N_ron + N_min - N_upt - N_rof - N_imm) * _
              frN_lch / (frN_lch + frN_den + frN_vol)
N_gas(crp) = (N_fert(crp) + N_irr + N_dep + N_fix + N_cap + N_ash + _
              N_ron + N_min - N_upt - N_rof - N_imm) * _
             (frN_den + frN_vol) / (frN_lch + frN_den + frN_vol)
```

2.5 Yield related efficiencies

Within the first crp-loop (Section 2.1), the yield related nutrient, biocides and water use efficiency factors are calculated by interpolating the yield related efficiency factors at several reference yields (fractions of maximum yields), read from the Efficiency sheet. The underlying concept of this relationship is that input use efficiencies decrease with high application rates. The factors for nutrients are correction factors for calculating the nutrient recovery fractions, so higher values mean higher efficiencies. The factors for biocides and water are fractions of the amount of biocides used and of the crop evapotranspiration, respectively, so higher values mean lower efficiencies. The Yield related efficiency form is activated in the main sheet that appears after opening the TechnoGIN Excel file, in order to change the classes and values (Section 4.9). Two to five reference yields can be chosen to describe the relation between yield and nutrient recovery efficiency. Table 4 shows an example of yield related efficiencies with 5 reference yields. The efficiency factors for nutrients are multiplied by the recovery fractions as calculated in paragraph 2.4.7, so lower nutrient recovery efficiencies are expected at yields above 50% of the maximum yield. The efficiency factors for biocides are multiplied by the biocide use as defined in the crop sheet, which was derived from farm survey analysis. The efficiency factor for water is multiplied by the crop evapotranspiration.

Table 4. Yield related efficiency factors with 5 reference yields (% of maximum yields). The correction factors for N, P and K are multiplied by the recovery fractions of N, P and K, respectively. The correction factors for biocides are multiplied by the biocide use as defined in the crop sheet. The correction factors for water are multiplied by the crop evapotranspiration

Yield:	**Nitrogen**	**Phosphorus**	**Potassium**	**Pesticide**	**Fungicide**	**Herbicide**	**Water**
100%	0.6	0.6	0.6	1.2	1.2	1.2	1.2
75%	0.9	0.9	0.9	1.1	1.1	1.1	1.1
50%	1.0	1.0	1.0	1.0	1.0	1.0	1.0
25%	1.0	1.0	1.0	1.0	1.0	1.0	1.0
0%	1.0	1.0	1.0	1.0	1.0	1.0	1.0

```
' Read reference yield fractions from the efficiency sheet:
Reff(1) = EffSheet.Cells(8, 2)
Reff(2) = EffSheet.Cells(9, 2)
Reff(3) = EffSheet.Cells(10, 2)
Reff(4) = EffSheet.Cells(11, 2)
Reff(5) = EffSheet.Cells(12, 2)
' Calculate the yield fraction, related to maximum yield:
yldfrac = yield(crp) / pot_yld
For i = 1 To 5
   If Reff(i) < yldfrac Then GoTo ReffFound
Next
ReffFound:
' Interpolation for the different resources:
kx1 = Reff(i)
kx2 = Reff(i - 1)
For o = 3 To 11
   If o = 6 Or o = 10 Then GoTo SkipCol
   ky1 = EffSheet.Cells(7 + i, o)
   ky2 = EffSheet.Cells(7 + i - 1, o)
   resy(o) = (yldfrac * (ky2 - ky1) / (kx2 - kx1)) + _
             (ky1 - kx1 * (ky2 - ky1) / (kx2 - kx1))
SkipCol:
Next
' Assign interpolated efficiencies to the keywords:
EffN_yld(crp) = resy(3)
EffP_yld(crp) = resy(4)
EffK_yld(crp) = resy(5)
Pest_Eff(crp) = resy(7)
Fung_Eff(crp) = resy(8)
Herb_Eff(crp) = resy(9)
Water_Eff(crp) = resy(11)
```

2.6 The Dekad Loops

2.6.1 Introduction

The crop evapotranspiration, and the labour requirements are calculated per dekad. Therefore, a loop is introduced in the macro that runs the integer d (for dekad) from 1 to 36 (there are 36 dekads in a year). In this loop the data that are available per dekad in the sheets are read. To adjust cropping calendars starting at d > 1 and ending at d > 36 another integer is introduced that represents the real dekad (reald). The reald is set to the number of the first dekad that is read in the LUT sheet (columns M, N and O), plus d minus one. When reald becomes higher than 36, it is reduced by 36. For the macro to know when the harvesting labour should be calculated, the last dekad of the cropping season is calculated by adding the crop duration (divided by 10, because it is stored in days) to the first dekad, minus one. If this yields a number greater than 36, it will be reduced by 36. The Boolean “nolabour” is set to False and changes to True when the harvesting labour has been calculated. This way the macro assures that no calculated data will be overwritten in the “labour(reald)” and “cropfactor(reald)” arrays.

```
firstdec     = LUTSheet.Cells(4 + lutnr, 12 + crp)
cropduration = CropSheet.Cells(4 + crop(crp), 23)
lastdec      = firstdec + (cropduration / 10) - 1
If lastdec > 36 Then lastdec = lastdec - 36
nolabour = False ' no more labour is not true
d = 0
For d = 1 To 36
  reald = firstdec + d - 1
  If reald > 36 Then reald = reald - 36
```

2.6.2 Crop coefficients (K_c)

Crop evapotranspiration is calculated by multiplying reference evapotranspiration with crop coefficients (Doorenbos & Pruitt, 1977). When the first crop is being evaluated (crp = 1), the macro sets all zero values to one, assuming fallow the rest of the year. When there is a second and/or a third crop, only K_c values higher than zero will overwrite the earlier assumed fallow values in the kc(reald) array. The crop coefficient is then multiplied by the water use efficiency.

```
' crop coefficient
kcd = CropSheet.Cells(4 + crop(crp), 23 + d)
If crp = 1 Then If kcd = 0 Then kc(reald) = 1
If kcd > 0 Then kc(reald) = kcd
kc(reald) = kc(reald) * Water_Eff(crp)
```

2.6.3 Labour

When the real dekad (reald) equals the last dekad (lastdec) then the harvesting labour is calculated by multiplying the standard labour requirements for harvesting (man-day per ton; harvestlabourperton) with the target yield. The wage rate (Philippine Pesos per day; WageRate; see Fig. 7 for exchange rates) is set to the harvesting wage rate that is stored in the Labour sheet. In the first two dekads (when d equals 1 or 2), the wage rate is set to the land preparation wage rate and the labour requirement in man-days per dekad (labour(reald)) is retrieved from the land preparation labour column in the Crop sheet. When d equals 3 (in the 3rd dekad), the wage rate is set to the crop establishment wage rate and the labour requirement is retrieved from the crop establishment labour column. When d is between 4 and one before the last dekad, the wage rate is set to the crop management wage rate and the labour requirements are retrieved from the crop management labour column (column 62 of the Crop sheet).

```
    If nolabour = False Then ' there is still labour for this crop
      If reald = lastdec Then
        harvestlabourperton = CropSheet.Cells(4 + crop(crp), 63)
        labour(reald) = yield(crp) * harvestlabourperton
        WageRate = LabourSheet.Range("HarvestingWage")
        nolabour = True ' no more labour after harvest for this crop
      ElseIf d < 3 Then
        WageRate = LabourSheet.Range("LandPreperationWage")
        labour(reald) = CropSheet.Cells(4 + crop(crp), 60)
      ElseIf d = 3 Then
        WageRate = LabourSheet.Range("CropEstablishmentWage")
        labour(reald) = CropSheet.Cells(4 + crop(crp), 61)
      ElseIf d > 3 Then
        WageRate = LabourSheet.Range("CropManagementWage")
        labour(reald) = CropSheet.Cells(4 + crop(crp), 62)
      End If
      LabourCost(reald) = WageRate * labour(reald)
    End If
  Next
  '
```

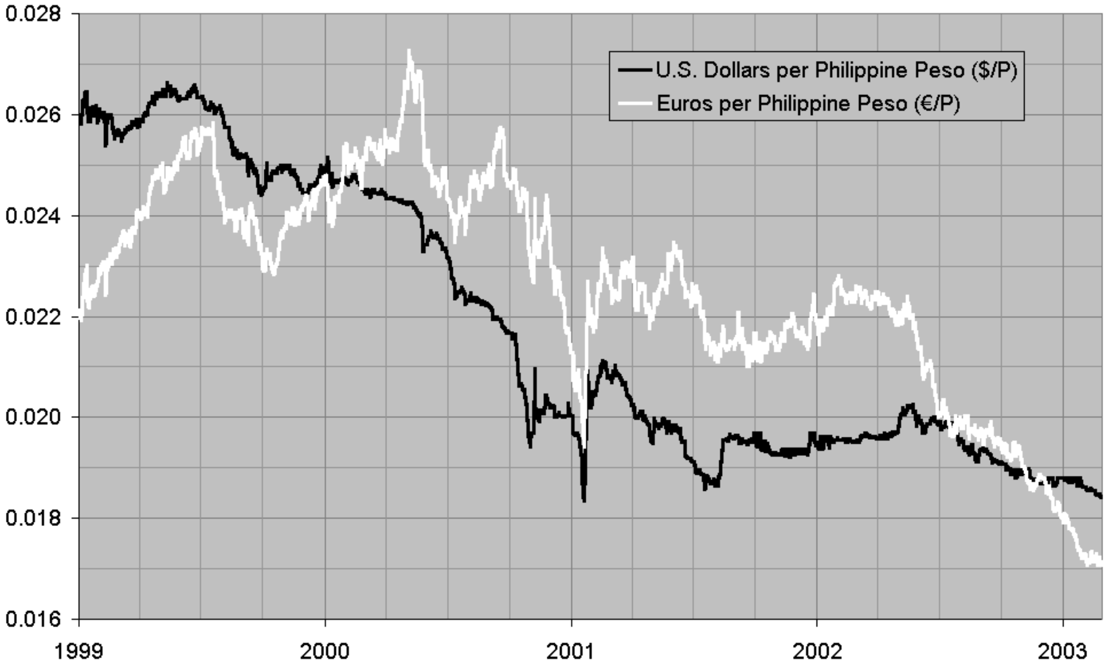


Figure 7. Exchange rates in U.S. Dollars per Philippine Peso ($/P; black line) and Euros per Philippine Peso (€/P; white line)

2.6.4 Monthly values

After the crp-loop and still within the lutnr-loop, the labour requirements are converted from dekad to monthly values by starting another dekad loop (d-loop). When d equals 3, 6, 9, 12, etc. the labour requirements of the dekads in month 1, 2, 3, 4, etc., respectively, are added.

```
  For d = 1 To 36 ' dekad
    If d = 3 * (m + 1) Then
      m = m + 1 ' month
      lab(m) = labour(d) + labour(d - 1) + labour(d - 2)
```

```
    End If
    TotLabCost = TotLabCost + LabourCost(d)
  Next
```

2.6.5 Crop evapotranspiration

A third d-loop is introduced within the lmunr-loop, because the reference evapotranspiration has to be multiplied by the crop coefficients, and its values depend on the elevation of each LMU (section 3.5). The elevation of the LMUs are read from the LMU sheet before the d-loop starts. Reference evapotranspiration classes have been defined for elevation ranges 0 – 100, 100 – 200, 200 – 300, and greater than 300 m.a.s.l. The monthly crop evapotranspiration is calculated by multiplying the crop coefficient by the reference evapotranspiration per dekad, and adding it per month.

```
d = 0
m = 0
For d = 1 To 36
 If Elevation < 100 Then
        PET = WaterSheet.Cells(4 + d, 3)
  ElseIf Elevation < 200 Then
        PET = WaterSheet.Cells(4 + d, 4)
  ElseIf Elevation < 300 Then
        PET = WaterSheet.Cells(4 + d, 5)
  Else
        PET = WaterSheet.Cells(4 + d, 6)
  End If
  If d = (m * 3) + 1 Then m = m + 1
  ETc(m) = ETc(m) + PET * kc(d)
Next
```

2.7 Farm survey data

The average seed cost, insecticide cost and use, fungicide cost and use, herbicide cost and use, fuel cost, irrigation cost, machine rent cost and farm gate prices from the farm survey for Ilocos Norte (Lansigan et al., 2000) are stored in the Crop sheet and retrieved for the selected LUTs within the macro. The amount of pesticide, fungicide and herbicide and costs are corrected for the yield and technology related pesticide, fungicide and herbicide efficiency fractions. The farm gate prices are directly multiplied by the target yield.

```
Seedcost = Seedcost + CropSheet.Cells(4 + crop(crp), 64) * _
                CropSheet.Cells(4 + crop(crp), 65)
InsectCost = InsectCost + EffPest_tec * Pest_Eff(crp) * _
                CropSheet.Cells(4 + crop(crp), 66)
Insect = Insect + EffPest_tec * Pest_Eff(crp) * _
                CropSheet.Cells(4 + crop(crp), 67)
FungiCost = FungiCost + EffFung_tec * Fung_Eff(crp) * _
                CropSheet.Cells(4 + crop(crp), 68)
Fungi = Fungi + EffFung_tec * Fung_Eff(crp) * _
                CropSheet.Cells(4 + crop(crp), 69)
HerbCost = HerbCost + EffHerb_tec * Herb_Eff(crp) * _
                CropSheet.Cells(4 + crop(crp), 70)
Herb = Herb + EffHerb_tec * Herb_Eff(crp) * _
                CropSheet.Cells(4 + crop(crp), 71)
FuelCost = FuelCost + CropSheet.Cells(4 + crop(crp), 72)
If eco = 1 Then IrrigFee = IrrigFee + CropSheet.Cells(4 + crop(crp), 73)
MachRent = MachRent + CropSheet.Cells(4 + crop(crp), 74)
FGPriceXyield = FGPriceXyield + _
CropSheet.Cells(4 + crop(crp), 75) * yield(crp) * 1000
```

2.8 Fertiliser cost model

The cost of fertiliser is calculated in an optimisation procedure using the Excel Solver (multiple integer programming or MIP) in the Fertiliser sheet. The model minimises the total cost of fertilisers, by changing the numbers of 50 kg bags of different types of fertiliser (Table 5) and keeping the differences between N, P and K in fertiliser bags and required N, P and K, respectively, positive. The number of bags must be integers and positive.

In the macro, the procedure is run by activating the Fertiliser sheet, inserting the fertiliser requirements in the cells that have names and the line that starts with solversolve. The total amounts of N, P and K in the purchased fertiliser bags, the amount of bags and total cost of the fertilisers is read from the cells with names.

```
FertSheet.Activate
lmuname = LMUSheet.Cells(4 + lmunr, 2)
Range("Fertupdate") = "Calculating for " & lutname & " in " & lmuname
Range("Nrec") = FN
Range("Prec") = FP
Range("Krec") = FK
solversolve userfinish:=True ' optimising
' output
Ntotal             = Range("Ntotal")
Ptotal             = Range("Ptotal")
Ktotal             = Range("Ktotal")
Complete           = Range("INTcom")
Ammoniumphosphate  = Range("INTamp")
Urea               = Range("INTure")
Ammoniumsulphate   = Range("INTams")
Muriate            = Range("INTmur")
Complete2          = Range("INTbal")
Ammoniumphosphate2 = Range("INTamh")
totfertcost = FertSheet.Range("totfertcost")
```

Table 5. Types of fertiliser, N, P and K concentration and price per 50 kg bag in Pesos and $ (exchange rate of December 2002)

Type of fertiliser	N	P	K	Price (2002)	
	------------- kg 100 kg^{-1} ------------			Pesos 50 kg^{-1}	$ 50 kg^{-1}
Complete 1	14	14	14	430	8.0
Ammonium-phosphate 1	16	20	00	420	7.9
Urea	46	00	00	380	7.1
Ammonium-sulphate	21	00	00	280	5.2
Muriate	00	00	60	480	9.0
Complete 2	06	09	15	550	10.3
Ammonium-phosphate 2	18	46	00	600	11.2

2.9 Preparing output

Before the lutnr-loop is started in the TechnoGIN sub-procedure, the Output sheet is cleared and the headings of the selected output groups in the Output form (section 4.6) are copied from the Output Heading sheet to the Output sheet. The grp() array is a Boolean that contains the selection of the output groups in the Output form. If the Boolean equals False, the headings are not copied, except for output group 1 (grp(1)), which contains the headings for the selected LUTs, ecoregions, technologies, LMUs, and target yields. In the second row, the selected output group headings are copied in the first column of that group. In the fourth row, the headings of the technical coefficients are copied and In the third row, the units are copied. After copying is completed, the number of headings is counted for later use.

```
OutputSheet.Activate
Range("a5").Activate
lastrow    = 4 + ActiveCell.CurrentRegion.Rows.Count
lastcolumn = ActiveCell.CurrentRegion.Columns.Count
Range(Cells(2, 1), Cells(lastrow, lastcolumn)).ClearContents
'
For groupnr = 1 To nrgroups
  If grp(groupnr) = True Then
    hdgrp = 0
    For hdgrp = 1 To 100
      If OutputHead.Cells(4 + hdgrp, groupnr * 2 - 1) <> Empty Then
        colnr = colnr + 1
        If hdgrp = 1 Then OutputSheet.Cells(2, colnr) = _
                   OutputHead.Cells(3 + hdgrp, groupnr * 2 - 1)
        OutputSheet.Cells(4, colnr) = _
             OutputHead.Cells(4 + hdgrp, groupnr * 2)
        OutputSheet.Cells(3, colnr) = _
             OutputHead.Cells(4 + hdgrp, groupnr * 2 - 1)
      End If
    Next
  End If
Next
OutputSheet.Activate
Range("A4").Select
nrout = ActiveCell.CurrentRegion.Columns.Count
```

In the lmunr-loop, the calculated technical coefficients (TCs) are temporarily stored in the array output(). The data for the first output group (land use system) will be stored in the output-array, even if the output group is not selected in the Output form. The TCs in the other output groups will only be stored in the output-array if the output group is selected in the Output form. For evapotranspiration and labour, loops are introduced to store the data per month.

```
output(1) = rownr
output(2) = lut
...
...
m = 0
For m = 1 To 12
  If grp(3) = True Then
  colnr = colnr + 1
  output(colnr) = lab(m)
End If
Next
If grp(4) = True Then
  output(colnr + 1) = FN
  output(colnr + 2) = FP
  output(colnr + 3) = FK
  output(colnr + 4) = NLeach
  output(colnr + 5) = NGass
  colnr = colnr + 5
End If
```

When all the data are stored in the output-array, they can be printed in the Output sheet.

```
For o = 1 To nrout
  OutputSheet.Cells(4 + rownr, o) = output(o)
```

```
Next
```

When all the loops (lmunr, Y, eco, t and lutnr) are finished, the user will be informed on the runtime and a question will appear if the Output sheet should be copied to a new file.

3 Databases

3.1 Introduction

The various data are arranged in different sheets in the TechnoGIN Excel file (Fig. 3 in Section 1.4). The disadvantage of using Excel sheets as databases is that it is not efficient in using computer workspace and is, therefore, relatively slow with queries. It is possible to have a link in the macro to database applications such as Microsoft Access or ASCII formatted databases. However, the advantages of having the macro and data in Excel are that it is more developer and user-friendly, and easier to access and adapt. It is also easy to edit the layout of the sheets in Excel and comments can be inserted in the cells of data that need explanation or reference to its source. In the next sections crop, land use type (LUT), and land management unit (LMU) specific data, stored in the equally named sheets, and data stored in the Water, Labour, Nutrient, Efficiency, and Technology sheets are discussed (Table 6).

Table 6. TechnoGIN data sheets

Section	Sheet name	Data
3.2	Crop	Per crop
3.3	LUT	Per land use type
3.4	LMU	Per land management unit
3.5	Water	Reference evapotranspiration
3.6	Labour	Labour cost per activity
3.7	Nutrient	Nutrient loss transfer functions
3.8	Efficiency	Yield related efficiencies
3.9	Technology	Technology related efficiencies

3.2 Crop sheet

Table 7 summarises the data that are stored in the different columns of the crop sheet. The following paragraphs describe the contents of the columns in the sequence shown in Table 7.

3.2.1 Crops and maximum yields

There are 23 crops defined in TechnoGIN, which are considered important in Ilocos Norte (Table 8). Maximum yields (potential yields at optimal weather conditions) were estimated for the different rice crops, cassava, cotton, peanut, maize, mungbean, soybean, sugarcane and tobacco by WOFOST (Boogaard et al., 1998) using weather data from Batac (MMSU, 1976-1995). For the other crops, the maximum yields were derived from statistical analysis of farm survey data (Lansigan et al., 2000), and from reported experimental data (MMSU annual research reports). The maximum yield is used in QUEFTS to define a relation between yield and nutrient uptake (which reaches a plateau at high yields). It is also used to define reference yields (fractions of the maximum yields) for describing the relation between yield and nutrient, biocide and water use efficiencies (Section 2.5).

Table 7. Contents of the crop sheet specified per column or groups of columns

Column	Contents	Unit
A – C	Crop codes and name	–
D	Maximum yield	ton per ha
E – F	Harvest index	kg per kg
G	Symbiotic N-fixation	kg per kg
H – S	N, P and K concentrations	%
T – V	Ecoregion suitability	–
W	Crop duration	days
X – BG	K_c per dekad	–
BH – BK	Labour requirements	m-d ha^{-1} (t^{-1})
BL – BW	Farm survey data	kg ha^{-1}; P ha^{-1}
BX	C factor (RUSLE)	–
BY	Recovery correction factor	–
BZ	Irrigation water	mm per ha

Table 8. List of crops defined in TechnoGIN and maximum yields in ton per ha

Nr.	Common name	Scientific name	Max. yield
			t ha^{-1}
1	Rice (1st in triple rice)	*Oryza sativa*	8.4
2	Rice (2nd in triple rice)	*Oryza sativa*	7.4
3	Rice (3rd in triple rice)	*Oryza sativa*	9.1
4	Wet season rice	*Oryza sativa*	8.3
5	Dry season rice	*Oryza sativa*	7.4
6	White corn	*Zea mays*	7.3
7	Yellow corn	*Zea mays*	7.3
8	Garlic	*Allium sativum*	10.0
9	Mungbean	*Vigna radiata*	3.1
10	Peanut	*Arachis hypogaea*	3.5
11	Tomato	*Lycopersicon esculentum*	45.0
12	Tobacco	*Nicotiana tabacum*	4.0
13	Cotton	*Gossypium hirsutum*	5.0
14	Sweet potato	*Ipomoea batatas*	25.0
15	Soybean	*Glycine max*	4.0
16	Onion	*Allium cepa*	55.0
17	Sweet pepper	*Capsicum annuum*	15.0
18	Eggplant	*Solanum melongena*	20.0
19	Vegetable (bitter gourd)	*Momordica charantia*	20.0
20	Mango	*Mangifera indica*	30.0
21	Sugarcane	*Saccharum officinarum*	15.0
22	Root crop (cassava)	*Manihot esculenta*	56.0
23	Water melon	*Citrullus vulgaris*	30.0

3.2.2 Harvest Indices

The harvest indices (HI) are estimated by data from literature, Internet sources and expert knowledge. There are two columns reserved for HI: high and low, representing differences in varieties. Currently the high HI is used. This can be changed easily to the use of the low HI, or a relation can be introduced using both values.

3.2.3 Associated N fixation

The fraction of N uptake from symbiotic N-fixing bacteria is stored in column G. For leguminous crops it is assumed to be 0.8 (Giller, 2001) and zero for other crops.

3.2.4 N, P and K concentrations

The minimum and maximum concentrations of N, P and K in the harvestable products, and crop residues of mungbean, peanut, tobacco, cotton, potato, soybean and cassava were derived from Nijhof (1987), The concentrations of garlic, onion, pepper and eggplant were derived from Knott (1967), tomato from Green et al. (1989), rice crops from Witt et al. (1999), and corn crops from C. Witt (pers. comm.). The values are used for estimating the maximum dilution and accumulation of N, P and K in QUEFTS (Section 2.3).

3.2.5 Ecoregion suitability

Not all crops are considered “promising” in every ecoregion (lowland irrigated, lowland rainfed, upland rainfed). Non-promising combinations result when biophysical requirements of the crop are not suitable to the conditions in an ecoregion. For example, double and triple rice are not promising on non-irrigated land due to water shortage. The combinations that are defined as False in the Crop sheet are disabled in the LMU selection form and, therefore, are automatically not considered.

3.2.6 Crop duration

The crop duration is partly based on data from the Bureau of Soils (1985a) and a SysNet consultative meeting with local researchers and agricultural officers (IRRI Team, 1997). The crop duration includes the time that is needed for land preparation, which is assumed to be two dekads (Section 2.6), and harvesting, which is assumed to be one dekad. This dataset should not be changed, unless the K_c values are adapted too.

3.2.7 Crop coefficient (K_c) per dekad

The crop coefficient or K_c values are based on data from the Bureau of Soils (1985a) and Doorenbos & Pruitt (1977). The first two dekads are reserved for land preparation. The remaining dekads are divided into four stages (initial, development, mid and late). The K_c values depend on the crop duration.

3.2.8 Labour requirements per activity

The average labour requirements (man-days per ha) for land preparation, crop establishment, crop management (fertiliser and biocide application, weeding and irrigation) and harvesting (+ threshing) of rice, corn, mungbean, sweet pepper and tomato are based on a farm survey (Lucas et al., 1999). Relative labour requirements (labour requirements per task divided by the total labour requirements) for land preparation (which is assumed to take place in the first two dekads), crop establishment (3^{rd} dekad), crop management (4^{th} up to the dekad before harvesting) and harvesting (last dekad) were multiplied by the total average labour requirements per crop from the farm survey by the SysNet team. Adjustments had to be made for rice, because the total labour for rice was without harvesting and threshing. The amount of labour from the last dekad (harvesting) was divided by the average yield, so it yielded labour-days per ton yield. The macro multiplies the harvesting labour per ton yield by the target yields. The labour requirement of harvesting and threshing per ton rice grain yield is calculated from Lucas et al. (1999). For crops not included in the survey by Lucas et al., assumptions for labour requirements were made, based on similarities with the monitored crops.

3.2.9 Farm survey data
The average seed, insecticide, fungicide and herbicide use (kg per ha) and cost (P per ha), fuel, irrigation and machine rent cost, and farm gate price (P per ton) per crop in the crop sheet are crop averages of data from the SysNet farm survey.

3.2.10 C factor (RUSLE)
The C factor (crop factor) for the Revised Universal Soil Loss Equation is estimated per crop as Renard et al. (1997) suggest.

3.2.11 Recovery correction factor
Per crop a correction factor for nutrient recovery is defined (paragraph 2.3.7)

3.2.12 Irrigation water
The amount of irrigation water is set per crop for calculating the nutrient inputs through irrigation.

3.3 LUT sheet

The LUT specific data are stored in the LUT sheet. Table 9 summarises the contents of the sheet. The following paragraphs describe the data shown in Table 9.

Table 9. Contents of the LUT sheet specified per column or groups of columns

Column	Contents	Data type/unit
A – C	LUT codes and name	Integer; string
D – F	Crop numbers	Integer
G – L	Crop residue strategy	Boolean
M – O	Starting dekads of crops	Dekad
P – R	Technology levels to evaluate	String
T – DE	Target yields	ton per ha
DF – EG	LUT/LMU selection	Boolean

3.3.1 Crop numbers
The crops in the LUTs are recognised in the macro by the numbers of the crops (defined in column A of the Crop sheet) in the columns D, E and F of the LUT sheet, for the first, second and third crops respectively. LUTs with only one or two crops have no value or a zero in columns E and/or F.

3.3.2 Crop residue strategy
Columns G to I contain the fractions of crop residues that are used as fodder for the first to third crop of the LUTs. Columns J to L contain the fractions of crop residues that are burnt for the first to third crop of the LUTs. The sum of the fractions per crop should be 1 or less. The remainder of the crop residues are used as fodder.

3.3.3 Starting dekads
The starting dekads of each crop in the LUTs are based on a SysNet discussion meeting (IRRI Team, 1997). In the Cropping calendar form they can be viewed as dates and can be adapted. The Cropping calendar form translates the dates into dekad numbers and writes them to columns M to O of the LUT sheet for the selected LUTs.

3.3.4 Technology levels to evaluate

Columns P to R contain the technology levels A, B, C, and/or D to evaluate per LUT and ecoregion. These can also be modified in the Technology form that appears after selecting LUTs, LMUs and target yields, before running the model. The macro reads cells that contain the technology levels and searches for the letters A, B, C and D. When the letter of a technology level is not read, the technology level is not evaluated. In Section 3.9 the definitions of the different technology levels are explained.

3.3.5 Target yields

Target yields per crop, LUT and ecoregion, as defined by the user, are optionally stored in the LUT sheet. These should always be lower than the maximum yields. Up to ten target yields (per crop, LUT and ecoregion) can be selected in the yield selection form and saved in the LUT sheet to use in future runs. The first column contains the lowest yield and the last column contains the highest yield.

Columns T to AC, AD to AM, and AN to AW contain the first, second and third crop target yields for irrigated land use types. Columns AX to BG, BH to BQ, and BR to CA contain the first, second and third crop target yields for lowland rainfed land use types. Columns CB to CK, CL to CU and CV to DE contain the first, second and third target yields for upland rainfed land use types.

3.3.6 LUT/LMU selection

The last selection of LUTs in the LUT selection form is stored in column DF of the LUT sheet. The last selection of LMUs in the LMU selection form is stored in columns DG to EG in the LUT sheet.

3.4 LMU sheet

The LMUs were identified and described by the 'Land resources evaluation project' described in Bureau of Soils (1985a and 1985b). Table 10 shows the contents of the LMU sheet, which contains data per LMU. The following paragraphs describe the data and their origin in the order of the columns as shown in Table 10.

Table 10. Contents of the LMU sheet specified per column or groups of columns

Column	Contents	Unit
A – B	Code and description	-
C	Lowland/upland	-
D – I	Chemical soil properties	variable
J – M	Elevation and slope ranges	m
N	Yearly precipitation	mm per year
O – R	Textura	%
S – T	Soil depth & drainage	-
U – V	Parent material & soil classification	-
W – Z	Infiltration, permeability & bulk density	m d^{-1}; kg dm^{-3}
AA – AL	Monthly precipitation	mm per month

3.4.1 Chemical soil properties
For each LMU chemical soil properties are defined in the LUT sheet: pH-H_2O, organic matter (%), P_{Olsen} (ppm), mineral K (ppm), base saturation point (%), cation exchange capacity (cmol per kg).

3.4.2 Elevation and slope ranges
The elevation and slope ranges were calculated per LMU with a digital elevation map (DEM).

3.4.3 Precipitation
A precipitation map was created by extrapolating yearly precipitation based on weather stations in Ilocos Norte. Extremely dry and extremely wet years are not included. The average yearly precipitation per LMU was calculated in a GIS.

3.4.4 Texture
Each LMU was assigned a texture class. From these classes the average sand, silt and clay contents were derived.

3.4.5 Soil depth and drainage classes
Soil depth and drainage classes are included in the LMU sheet, but are currently not used.

3.4.6 Parent material and soil classification
Parent material and soil classification are included in the LMU sheet, but are currently not used.

3.4.7 Infiltration, permeability & bulk density
Infiltration (m d^{-1}) is used for the RUSLE. Permeability (m d^{-1}) and bulk density (kg dm^{-3}) are currently not used.

3.4.8 Monthly precipitation
Monthly precipitation was calculated based on the average monthly distribution of six different weather stations (Dingras, 1982-1983; MMSU, Batac, 1976-2000; Buduan, Burgos, 1978-1979; Laoag City, 1970-1983; Pasui, Paoay, 1976-1983; Badoc, 1979-1983).

3.5 Water sheet

The Water sheet contains the reference evapotranspiration (ET_0) per dekad. For elevations lower than 50 meter, the reference evapotranspiration is assumed to be the evapotranspiration as estimated for rice by WOFOST (Boogaard et al., 1998) with monthly average weather data from Batac (1975-1993). Between 50 and 150 meter, the reference evapotranspiration is assumed to be the evapotranspiration as estimated for rice in the model WOFOST using the same weather data, but with lower minimum and maximum temperatures, i.e. –0.6º for every 100 meter increase in altitude. For the elevation class between 100 and 200 meters, reference evapotranspiration is estimated with the Batac temperatures reduced with 1.2º Celsius, etc.

3.6 Labour sheet

The Labour sheet contains the labour cost for labour activities (land preparation, crop establishment, crop management, and harvesting). See paragraph 2.5.3.

3.7 Nutrient sheet

The Nutrient sheet contains the parameters for the transfer functions calculating the N leaching fraction (anaerobic and aerobic conditions), denitrification fraction, N volatilisation fraction (anaerobic and aerobic conditions), P fixing fraction, K leaching fraction, K fixing fraction, efficiency of mineralized nutrients, fraction of burnt nutrients lost to the atmosphere, fraction of consumed fodder removed in animal product, wet and dry deposition (kg per ha), nitrogen fixation by free-living bacteria (kg per ha), run-off (kg per ha), run-on (kg per ha), irrigation water (kg per litre), sedimentation (kg per ha), capillary rise (kg per ha), dissolution of fixed nutrients (kg per ha), and immobilisation (kg per ha).

3.8 Efficiency sheet

The Efficiency sheet contains the yield related N, P and K, pesticide, fungicide, herbicide, and water use efficiency factors for different reference yields (Section 2.5). The number of reference yields and the efficiency factors can be changed in the Yield related efficiency form (Section 4.9).

For nutrients the yield related efficiency factor is defined as the correction factor for the recovery fractions (1 - nutrient loss factions as estimated per LMU). For biocides the yield related efficiency factor is defined as the fraction of the average biocide use (kg a.i./ha) in the farm survey. For water the yield related efficiency factor is defined as the fraction of the crop coefficient.

3.9 Technology sheet

The Technology sheet contains the technology related N, P and K, pesticide, fungicide, herbicide, and water use efficiencies for 4 different technology levels (A, B, C and D). The technology levels to be evaluated per LUT-ecoregion combination can be read in the LUT sheet. These are shown and can be modified in the Technology level form that appears after selecting LUTs, LMUs and target yields in the forms that were designed for these purposes.

The technology related efficiency factors are used as the yield related efficiency factors:

- The efficiency factors for N, P and K are multiplied by the recovery fraction as calculated in paragraph 2.4.7.
- The efficiency factors for biocides are multiplied by the biocide use as defined in the crop sheet, which was derived from farm survey analysis.
- The efficiency factor for water is multiplied by the crop evapotranspiration.

Table 11 gives an example of a set of values for technology related efficiencies. Technology A assumes an average use of most inputs (based on surveys) and a very inefficient use of N (the factor 0.7 in the table means that the N recovery is 30% less than the default fraction calculated as described in paragraph 2.4.7), simulating the actual situation. Technology B assumes an average use of all inputs, technology C assumes a slightly more efficient use of N, P and K and technology D assumes an increase in efficiency of 30% for all inputs, compared to technology B.

Table 11. Technology related efficiency factors with 4 different technologies. The correction factor for N, P and K are multiplied by the recovery fractions of N, P and K, respectively. The correction factors for biocides are multiplied by the biocide use as defined in the crop sheet. The correction factors for water is multiplied by the crop evapotranspiration

Technology	Nitrogen	Phosphorus	Potassium	Pesticide	Fungicide	Herbicide	Water
A	0.7	1.0	1.0	1.0	1.0	1.0	1.0
B	1.0	1.0	1.0	1.0	1.0	1.0	1.0
C	1.1	1.1	1.1	1.0	1.0	1.0	1.0
D	1.3	1.3	1.3	0.7	0.7	0.7	0.7

4 User Forms

4.1 Introduction

There are two types of user forms in TechnoGIN: six user forms are for selections that precede a model run, and four user forms are for database management (Table 12). The following sections describe the functions of the user form as shown in Table 12.

Table 12. The user forms and their function

Section	User form	Function
4.2	LUT selection	Selection of LUTs
4.3	LMU selection	Selection of LMUs per LUT
4.4	Yield selection	Selection of target yields
4.5	Sheet yields	Accept the target yields as defined in the LUT sheet
4.6	Technology	Selection and definition of technology levels
4.7	Output selection	Exclude the output groups from the output sheet
4.8	Cropping calendar	Modify the starting dates of the crops in the LUTs
4.9	Yield related efficiency	Modify the input use efficiency assumptions
4.10	Nutrient loss	Modify the nutrient loss fractions
4.11	QUEFTS	QUEFTS sensitivity analysis

4.2 LUT Selection form

The LUT selection form (Fig. 8a) is activated when clicking the “Select LUTs, LMUs, target yields, technology levels & run the model” button in the TechnoGIN sheet (Fig. 4). At initialisation, the LUT selection form counts the number of LUTs that are defined in the LUT sheet and calls the names of the LUTs into the list box.

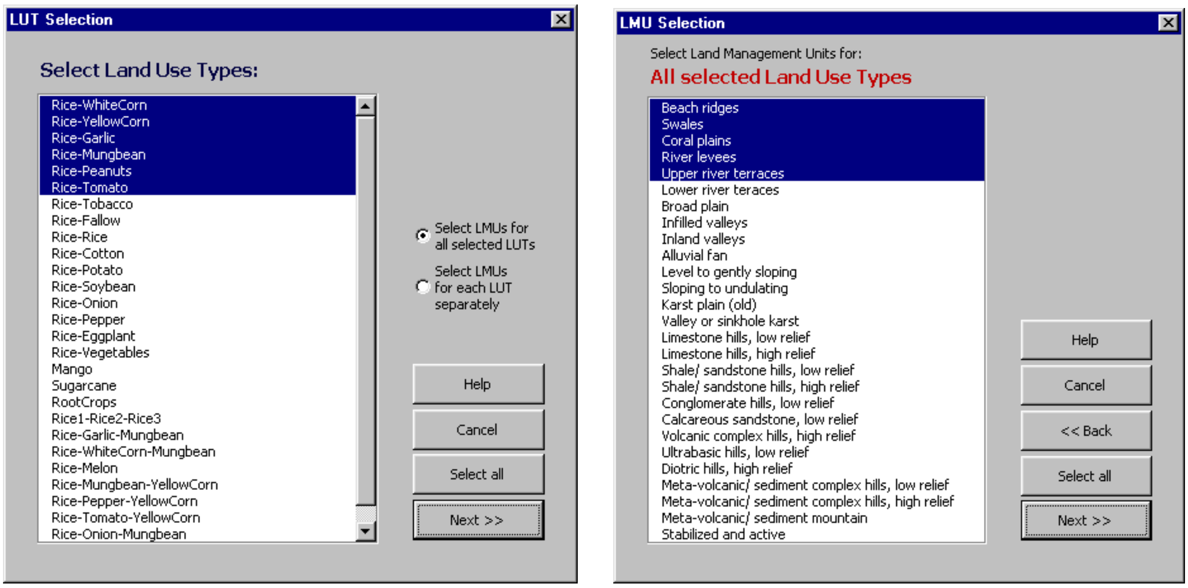
The user can select one or more LUTs by clicking the names in the list box. This will highlight the selected LUT names. Selections can be undone by clicking again. Clicking the “Select all” button will highlight all the LUT names.

The option buttons “Select LMUs for all selected LUTs”, and “Select LMUs for each LUT separately” enable the user to select different LMUs in the LMU selection form (Section 4.3), which follows after the selection of LUTs, for each selected LUT. If only one LUT is selected or when the “Select LMUs for all selected LUTs” option button is activated (default), LMUs can be selected for all selected LUTs in the LMU selection form.

After clicking the “Next >>” button, the selection is saved and the LMU selection form is activated.

4.3 LMU Selection form

The LMU selection form (Fig. 8b) is activated after selecting LUTs in the LUT selection form (Section 4.2). At initialisation, the number of LMUs in the LMU sheet are counted and the list box is filled with the names of the LMUs. In case the user activated the “Select LMUs for each LUT separately” option button in the LUT selection form, the user has to select at least one LMU (that is applicable to all crops in the LUT) for each LUT. The first LUT name appears in the top of the form. The second LUT name appears after selecting LMUs by clicking the LMU names and the “Next >>” button, and so on. If the user chose to select the same LMUs for all selected LUTs or only selected one LUT, only once LMUs have to be selected and the form will disappear after clicking the “Next >>” button (except if no valid combinations were selected). The “Select all” button can be used to select all LMUs for the LUT displayed at the top of the form or for all LUTs. Clicking the “<< Back” button enables the user to go back to the LUT selection form to change the selection of LUTs and select LMUs for the new selection of LUTs.



(a) (b)

Figure 8. The LUT selection (a) and LMU selection forms (b)

4.4 Yield selection form

The Yield selection form (Fig. 9b) is activated after the selection of LUTs and LMUs. If target yields for the selected LUT-ecoregion combinations (part of the LMUs are upland and part lowland) are available in the LUT sheet, the Sheet yields form (Fig. 9b) appears. If the user wants to select new target yields, the “Select yields” button has to be clicked to return to the Yield selection form. The Sheet yields form does not appear if no target yields are available in the LUT sheet for all selected LUT-ecoregion combinations.

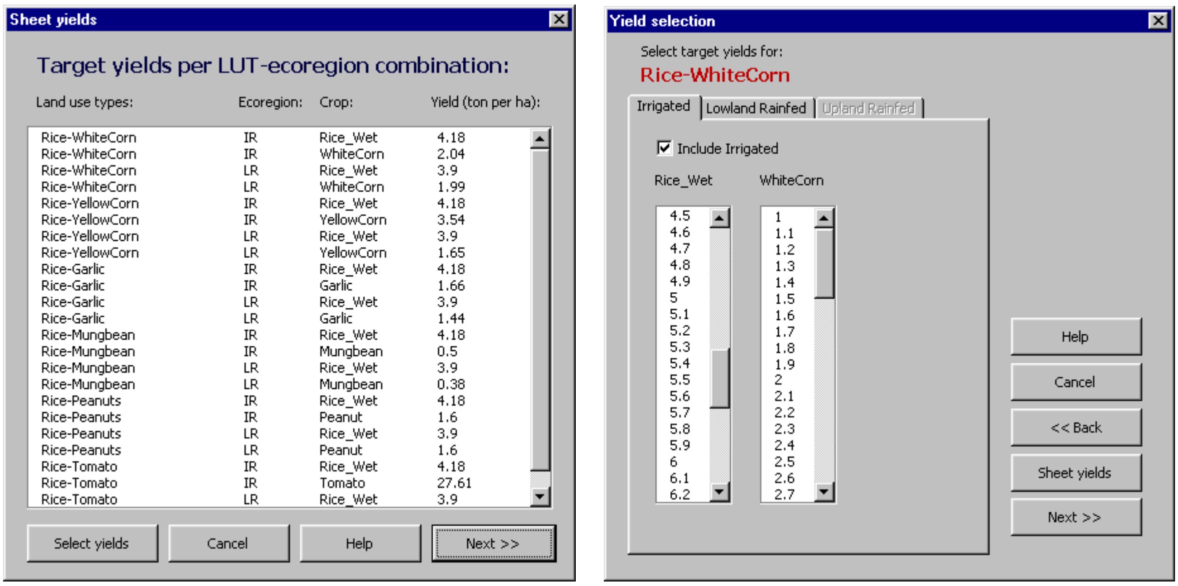
For the first selected LUT, the maximum yields are read from the Crop sheet and the list boxes of the crops are filled with numbers ranging from 1 ton per ha to the maximum yield. If no upland LMUs are selected in the LMU selection form for the LUT of which the name appears at the top of the form, the upland rainfed tab is disabled. The irrigated and lowland rainfed tabs will be disabled if no lowland LMU is selected for the LUT. If the user does not want to include the calculation for lowland rainfed or irrigated, the checkbox at the top of the page of lowland rainfed or irrigated has to be clicked.

The number of selected target yields per crop must be the same for every crop in the LUT-ecoregion combination. The first, second, third, etc., target yields from the lowest onwards are combined in the calculations. When there are no more target yields for one of the crops in the LUT, there will be no more calculations (e.g. when 5 target yields were selected for the first crop and 7 for the second crop in a LUT with two crops, only 5 different target yields are evaluated for that LUT). The maximum number of target yields to be selected per list box is 10. When target yields are selected for all the selected LUTs, the user will be asked whether the selected yields should be saved in the LUT sheet to enable the user to use them in future runs. The target yields that are stored in the LUT sheet can be called from the yield selection form by clicking the sheet yields button.

4.5 Sheet yields form

The Sheet yields form (Fig. 9a) appears after selecting LMUs for the selected LUTs in the LMU selection form if there are target yields for all selected LUT-ecoregion combinations in the LUT sheet. The Sheet yields form can also be called from the Yield selection form. The target yields that are available from the LUT sheet for all selected LUT-ecoregion combinations are displayed in the list box of the Sheet yields form.

The user either agrees with the target yields from the LUT sheet by clicking the “Next >>” button or selects new target yields by clicking the “Select yields” button, which calls the Yield selection form.



(a) (b)

Figure 9. The Sheet yields form (a) and the Yield selection form (b)

4.6 Technology level form

After accepting the target yields, the Technology level form (Fig. 10) is activated. This form shows the selected LUT-ecoregion combinations in a list box. The third column of this box shows the technology levels A, B, C and/or D that are used for each LUT-ecoregion combination. These can be changed by clicking the column of a LUT-ecoregion and by typing the letters A, B, C and/or D in the place of the existing letters. The selection can also be changed directly in columns P (irrigated), Q (lowland rainfed) and R (upland) of the LUT sheet. This is more practical for large selections. However, the selection has to be cancelled by clicking the Cancel button to be able to modify the data in the sheets and the selection procedure needs to be started again from the main sheet.

The technology related efficiency factors for nutrients, biocides, and water are shown at the bottom of the form. The values are read from the Technology sheet and can be changed in the form. Section 3.9 describes the definitions of the technology related efficiencies.

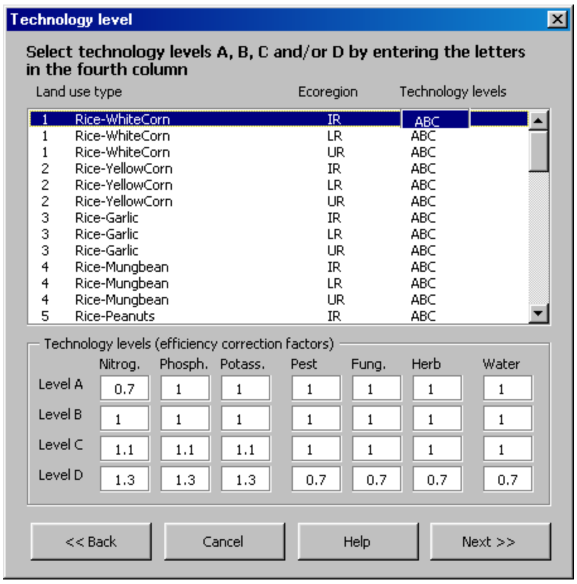


Figure 10. The Technology level form

4.7 Output Selection form

The Output selection form (Fig. 11) appears after clicking the Next button in the Technology level form. Several output groups are listed and selected. The output groups contain groups of related outputs indicated with headings and units stored in the Output headings sheet (Appendix III contains explanations of the abbreviations). To exclude an output group, the user has to click the name of that output group. By clicking the “Finish” button the selection procedure is ended and the macro for calculating the TCs for the selections is activated.

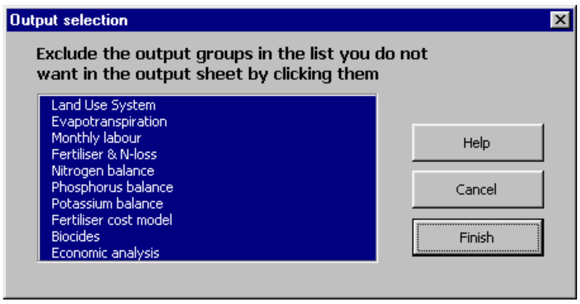


Figure 11. The Output Selection form

4.8 Cropping calendar form

The Cropping calendar form (Fig. 12) can be called from the TechnoGIN sheet. The form contains a combo box, which has a drop down list with LUT names. Selecting a LUT from this list will call the starting dekad of the crops in the selected LUT from the LUT sheet and the crop duration from the Crop sheet. These data are translated to starting and harvesting dates and displayed in the list boxes of the form.

The starting dates can be changed in the list boxes by highlighting other dates in the list boxes. The harvesting dates will automatically change, because the crop duration is fixed in the Crop sheet. These can only be changed when the K_c values per dekad in the Crop sheet are also adapted. For each date change, the Apply button has to be clicked. The Quit button will hide the Cropping calendar form.

For all crops the first two dekads are reserved for land preparation. The following dekad is for crop establishment and the last dekad is for harvesting. Hence, the actual growing period is 3 dekads less than the dates in this form (paragraph 3.2.8).

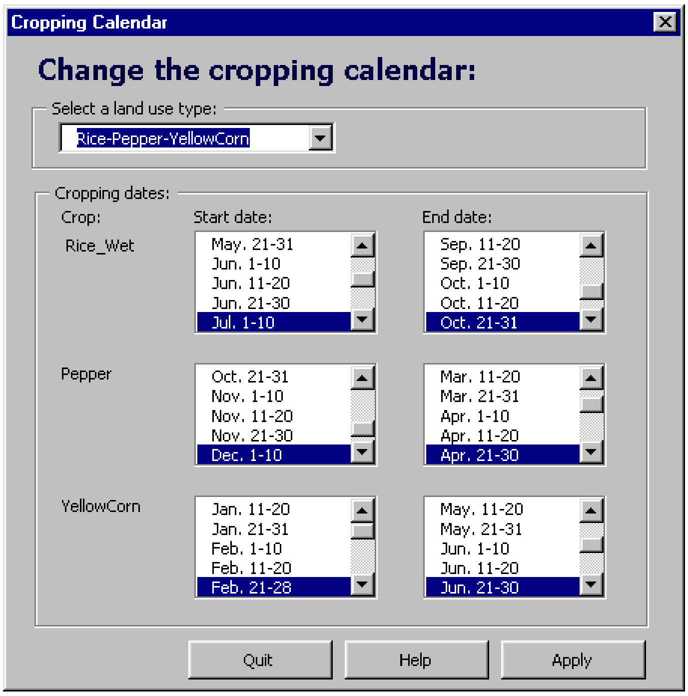


Figure 12. The Cropping calendar form with the LUT “Rice-Pepper-YellowCorn”

4.9 Yield related efficiency form

The Yield related efficiency form (Fig. 13) can be called from the TechnoGIN sheet. To specify the relation between yields and efficiency, we make use of reference yields, which are defined as fractions of the maximum yield. The relation is assumed linear between two reference yields. Two to five reference yields can be chosen to assign values for the yield related nutrient, biocide, and water use efficiency factors, by clicking the option buttons:

- 2 reference yields (0 & 100 % of maximum yield)
- 3 reference yields (0, 50 & 100 %)
- 4 reference yields (0, 33, 67 & 100 %)
- 5 reference yields (0, 25, 50, 75 & 100 %)

Definitions of the yield related efficiency factors are described in Section 3.8.

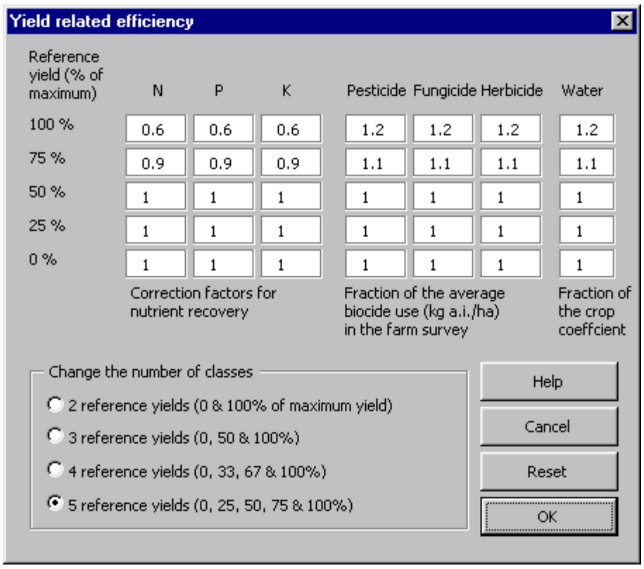


Figure 13. The Yield related efficiency form

4.10 Nutrient loss form

The Nutrient loss form (Fig. 14) is called from the TechnoGIN sheet. In this form, the parameters in the transfer functions used to calculate the nutrient recovery efficiency can be modified. The modified values are stored in the Nutrient sheet after clicking the OK button.

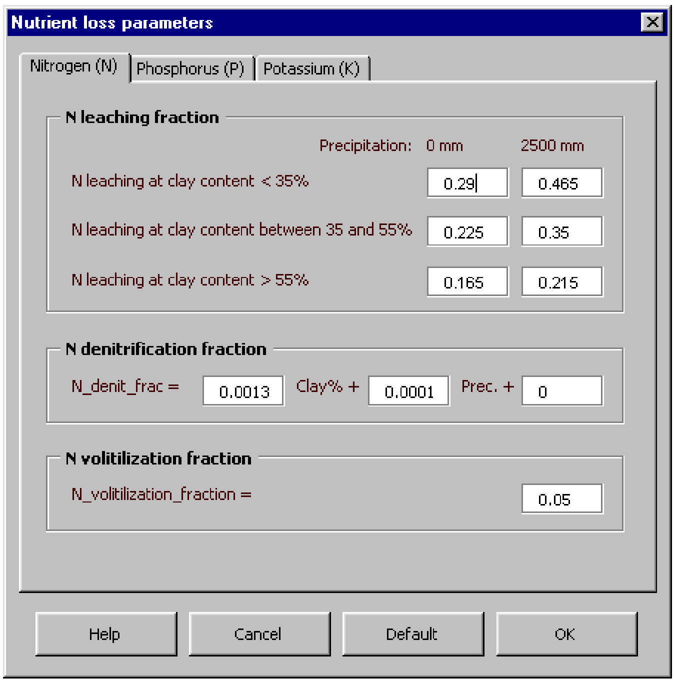


Figure 14. The Nutrient loss parameters form

4.11 QUEFTS form

In the QUEFTS form (Fig. 15), a crop can be selected to conduct a sensitivity analysis for nutrient uptake as estimated by QUEFTS at different target yields. The maximum accumulation and dilution of N, P and K are calculated for the selected crop as described in Section 2.3. They are copied to the QUEFTS sheet in the cells that are displayed in the form. Also the cells, which contain the actual internal efficiencies and the uptake of the nutrients, the maximum yield, target yield and optimised yield, are displayed in the form.

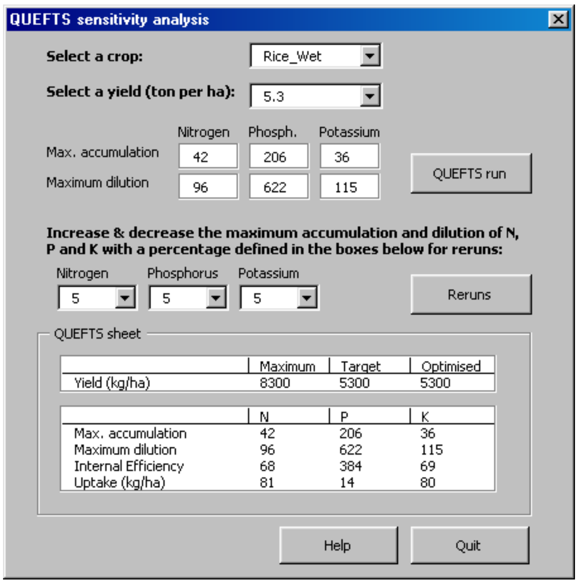


Figure 15. The Nutrient loss parameters form

In the drop down box next to “Select a crop” a crop has to be selected. This fills the drop down box directly below this box with yields from 1 ton per ha to the maximum yield as defined in the Crop sheet, with 100 kg per ha intervals. The boxes are filled with maximum dilution and accumulation of N, P and K as calculated from the data in the Crop sheet (Section 2.3). The maximum dilution and accumulation of N, P and K can be modified for evaluation. By clicking the “QUEFTS run” button, the QUEFTS model calculates the N, P and K in the plant.

In the drop down boxes below the text “Increase & decrease the maximum accumulation and dilution of N, P and K with a percentage defined in the boxes below for reruns:”, percentages can be selected for a sensitivity analysis in which the N, P and K in the plant is calculated by QUEFTS for the maximum dilution and accumulation as in the boxes above and increased and decreased by the selected percentages for 5 different target yields (20, 40, 60, 80 and 100% of maximum yield). The maximum dilution and accumulation values can be changed simultaneously for the three different nutrients or one at a time (this will be asked after clicking the “Reruns” button. Results of the sensitivity analysis are stored in the QSensitivity sheet. The graphs in the sheet give a representation of the relation between nutrient uptake at different maximum dilution and accumulation of N, P and K and yield.

5 Data quality and process knowledge

As may be observed in previous chapters, development of a technical coefficient generator (TCG) requires a lot of knowledge conveying relevant processes and data that describe these processes. Data and process descriptions are derived from different sources including field surveys, local measurements, simulation models, literature and experts. Information on the reliability of these data is often lacking, making it hard to assess their effect on the quality of the model. Although assessment of data quality is an important issue, we believe that under the current circumstances, resource management based on the presented data is still more successful than a resource management policy based on no data. TechnoGIN provides a step forward in integrating different types of data sources and making explicit which data are most lacking and which data sources cause concern. These are discussed in this chapter.

The accessibility of the functions and data in TechnoGIN has been an important goal in the development of the model in order to make the users more aware of the importance of data improvement and encourage adaptations. For this reason user forms that can be activated from the menu in the main sheet were designed for database management. The databases and model parameters are accessible in spreadsheets of a single Excel file and the calculations are accessible in the same file, via a Visual Basic (VB) macro. For example, the assumptions on yield and technology related nutrient, biocide and water use efficiencies, which are often difficult to quantify, are accessible through user forms and can also be modified directly in the spreadsheets. The functions that include the efficiency factors can also be modified in the macro by activating the VB editor while in the TechnoGIN Excel file.

The most important improvement possibilities in the water balance, nutrient cycling, soil and land characteristics, crop specific data, and economic calculations are discussed in the following sections.

5.1 Water balance

In the present version of TechnoGIN a water balance is still to be developed. As for now only the crop evapotranspiration is calculated using reference evapotranspiration calculated for Batac and extrapolated for different altitudes assuming a certain temperature decrease with altitude. Weather data from different stations in the province is needed to calculate the reference evapotranspiration in different parts of the province more accurately.

A simple water balance calculating the irrigation requirement could be developed with soil data (volumetric water content at field capacity and wilting point, which can be calculated if necessary with transfer function and texture), and monthly precipitation.

5.2 Nutrient cycling

Assumptions on yield and technology related efficiencies and parameters for calculating nutrient cycling need detailed consideration. More field data and experiments should be analysed for the calibration of these parameters. When new information about nutrient flows associated with land use systems and different (internal and external) factors is available the equations programmed in the VB macro should be adapted. Most nutrient flows are based on simple transfer functions (often based on empirical data from other parts of the world), which need little data, but are difficult to calibrate for Ilocos Norte.

An important factor in nutrient cycling is the crop residue strategy. Crucial questions concerning this matter are: How much N, P and K is taken up by the crops (minimum and maximum concentrations) and allocated to the crop residues (harvest index)? How much of this is returned to the soil via burning, mulching and fodder and when? How much of the returned N, P and K is lost and how much of this is available to the crops?

The losses of inorganic nutrients (especially from fertilisers) can be very high and are important for economic and environmental indicators. Here, different losses are related to soil and weather characteristics. Measuring these losses is difficult and expensive. Even if a lot of site-specific data are available, temporal and spatial variation affects losses, which makes the calibration of simple transfer function difficult.

The lack of clear relations and reliable data makes the model hypothetical and the outcome has to be analysed with caution. However, the resulting estimations enable us to calculate consistent and reproducible scenarios effecting economic and environmental sustainability at municipal and provincial scales, considering spatial variability at these scales. Therefore, continuous experimenting, data collection and analysis, sensitivity analysis and discussion is needed to constantly improve the nutrient relationships used in the model.

5.3 Soil and land characteristics

The LMUs, which are presently used in TechnoGIN are actually too large (on average 10,000 ha) to allow averaging of different soil properties (texture, organic matter and chemical soil properties), measured at several points within each LMU. Elevation and slope ranges are also too large to average for the LMUs. Smaller land units with an average of about 2,000 ha are probably more homogenous, but defining more and smaller land units would increase the computational load for the IMGLP model considerably. Further study is needed in order to obtain the optimal land unit size for the soil and land characteristics database. The present data in the LMU sheet can be replaced or extended and will be recognised by the user forms and macro.

5.4 Crop specific data

For the crop data there should be an inventory of the varieties and their characteristics. This is quite a lot of work considering the large number of crops. The most important characteristics that should be quantified more accurately are the harvest indices, minimum and maximum concentrations of nitrogen, phosphorus and potassium in the harvestable product and in the rest of the crop. These data are used to calculate the N, P and K uptake in the QUEFTS model. Other crop characteristics that need attention are the crop duration and crop coefficients.

5.5 Pest management

Pest management is still poorly quantified in TechnoGIN. Presently, the average amount of pesticide, herbicide and fungicide use in Ilocos Norte that was calculated per crop from the farm survey data in kg active ingredients per hectare is used as default values. They can be increased or decreased by a factor that is related to yield and a factor that is related to technology. For improvement, the most important biocides should be identified per crop, so the effects of different types of biocides can be quantified more accurately, using different fractions of active ingredients, longevity and health hazard. A clear relation between yield and biocide use is very difficult to find, because many factors influence the relation, including weather factors, and complex ecological factors. However, different technologies can be defined assuming more efficient use of biocides. These should be based on findings in surveys and other sources. With a better specification of biocide use, the relation with required labour for pest management can also be quantified more accurately.

5.6 Economic indicators

Improvements in calculations for economic indicators are needed. For biocide use, the already processed data from the SysNet farm survey is used. The original data should be analysed to find relations between different types of inputs (biocides, labour), soil characteristics, weather data, crop characteristics and yield. These relations should be incorporated, and minimally processed data should be used in TechnoGIN. However, some of the processed data from the farm survey (e.g. biocide use; kg active ingredient per ha) are not realistic and can be the result of erroneous calculations or wrong information from the farmers. If the reliability of the information given by the farmers is doubtful, the interpretation and analysis of the farm survey data becomes difficult.

For labour, the differences in labour cost per labour activity (land preparation, crop establishment, crop management and harvesting) have been considered in TechnoGIN (paragraph 2.5.3), but they have not yet been quantified. Finally, it is important to record the date or period in which prices of inputs and outputs were recorded, as these are more sensitive to temporal changes than biophysical parameters.

5.7 Conclusion

Using TechnoGIN as a tool for land use studies means changing and adding data, parameters and assumptions and evaluating the output with expert knowledge and reference data. TechnoGIN is designed to easily access its data, parameters and assumptions in order to add new information and make improvements. It should be emphasised that the output needs to be carefully evaluated as it is based on many assumptions and should be interpreted accordingly. TechnoGIN can be a very useful tool for comparing possible actual and future land use systems and different strategies or technologies in terms of production, economic and environmental coefficients, taking into account many different inputs and outputs. Although the number of technical coefficients TechnoGIN can produce is vast, they can easily be managed and interpreted using graphs, statistics, geographic information systems (GIS) and optimisation models.

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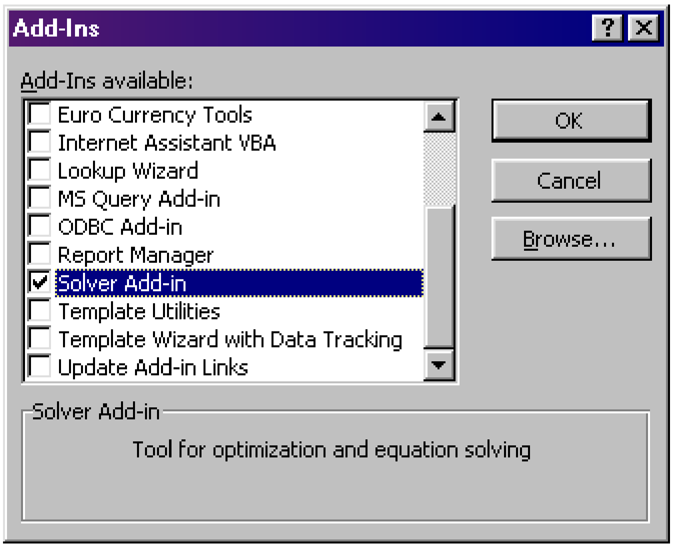
Appendix I: Installation

The TechnoGIN Excel and help files should be copied to the same directory, after checking them for viruses. When opening the Excel file, Excel might give a warning about the possible harmfulness of the macro in the file. This warning should be ignored and the macro activated.

To be able to run TechnoGIN, Microsoft Excel 97 or 2000 should be installed in the computer. The Solver add-in module should be installed and activated in Excel. To check if the Solver module is available, click the Tools menu in the menu bar of Excel to see if there is an option "Solver". If there is no Solver, install it by clicking “Add-ins…” in the Tools menu and selecting “Solver Add-in” in the available Add-Ins list that appears (see figure below). After clicking OK you might be asked to insert the Microsoft Office or MS Excel installation disk. If the “Solver Add-in” does not appear in the list MS Excel should be re-installed with the installation disk or manually by copying the Solver files “Solver.xla” and “Solver32.dll” to the directory “C:\Program Files\Microsoft Office\Office\Library\Solver\” and opening the “Add-ins” window, selecting the “Solver Add-in” (that should now appear in the list), and clicking OK. The Solver option should then be available in the Tools menu.



Appendix II: Land Management Units

Symbol	Description	Up/lowland	pH	OM	Polsen	K	BSP	CEC	Elevation		Slope		Prec	Sand	Silt	Clay	Texture
				%	ppm		%	cmol kg^{-1}	m	m	%	%	mm	%	%	%	
3	Beach ridges	Lowland	6.3	1.7	13.6	167.6	72.0	36.5	4	36	0	8	1870	40	40	20	coarse-loamy to fine-loamy
4	Swales	Lowland	7.1	2.1	6.4	174.8	91.3	47.0	5	20	0	3	1902	30	30	40	coarse-loamy to clayey
5	Coral plains	Lowland	6.8	2.5	12.2	213.3	82.0	35.3	1	20	0	3	1823	35	35	30	fine-loamy
6	River levees	Lowland	7.2	1.7	10.7	294.3	79.0	38.9	5	60	0	3	1963	35	35	30	fine-loamy
7	Upper river terraces	Lowland	7.6	1.2	5.6	247.0	94.6	75.3	5	60	0	3	1921	35	35	30	fine-loamy
8	Lower river teraces	Lowland	6.4	2.4	13.9	217.2	84.0	53.4	5	100	0	3	2037	35	35	30	fine-loamy
9	Broad plain	Lowland	7.1	2.1	10.4	252.4	88.3	71.5	5	65	0	3	1940	25	25	50	fine-loamy to clayey
16	Infilled valleys	Lowland	7.0	1.9	14.9	321.0	82.6	58.7	5	80	0	3	1893	30	30	40	coarse-loamy to clayey
17	Inland valleys	Lowland	6.6	3.0	8.0	132.0	87.9	69.5	40	120	0	3	1856	25	25	50	fine-loamy to clayey
18	Alluvial fan	Lowland	5.7	2.1	6.2	62.7	55.3	21.7	5	20	0	3	2221	40	40	20	coarse-loamy to fine-loamy
21	Level to gently sloping	Lowland	6.6	2.3	10.2	206.8	71.1	52.9	10	260	0	8	2019	25	25	50	fine-loamy to clayey
22	Sloping to undulating	Upland	6.1	2.8	15.8	266.0	78.2	62.6	5	140	8	15	2087	30	30	40	coarse-loamy to clayey
31	Karst plain (old)	Lowland	6.0	3.3	7.1	177.0	-	-	10	20	0	3	1743	35	35	30	fine-loamy
32	Valley or sinkhole karst	Lowland	6.4	4.2	11.5	127.0	63.5	43.3	5	70	0	3	1739	15	15	70	clayey
41	Limestone hills, low relief	Upland	6.2	2.1	9.9	180.3	81.2	52.3	5	260	8	15	1786	30	30	40	coarse-loamy to clayey
42	Limestone hills, high relief	Upland	6.6	3.1	7.1	123.9	74.1	45.0	6	470	15	25	1752	15	15	70	clayey
43	Shale/ sandstone hills, low relief	Upland	6.4	2.0	10.6	268.6	79.2	54.9	5	183	8	25	1903	30	30	40	coarse-loamy to clayey
44	Shale/ sandstone hills, high relief	Upland	7.0	2.0	10.3	267.8	88.0	71.9	40	500	25	40	1850	25	25	50	fine-loamy to clayey
45	Conglomerate hills, low relief	Upland	5.6	2.0	7.5	188.5	56.1	38.2	10	140	8	15	2010	30	30	40	coarse-loamy to clayey
47	Calcareous sandstone, low relief	Upland	6.2	1.8	5.4	152.1	69.2	37.2	20	230	8	15	1903	25	25	50	fine-loamy to clayey
58	Volcanic complex hills, high relief	Upland	5.3	2.8	3.7	65.8	49.4	22.4	80	300	25	60	2210	25	25	50	fine-loamy to clayey
59	Ultrabasic hills, low relief	Upland	6.0	2.4	8.8	132.2	73.4	42.5	10	206	15	25	2005	25	25	50	fine-loamy to clayey
64	Diotric hills, high relief	Upland	5.6	2.0	3.5	175.9	40.9	26.6	60	533	15	25	2300	40	40	20	coarse-loamy to fine-loamy
83	Meta-volcanic/ sediment complex hills, low relief	Upland	5.4	2.5	9.0	296.0	0.0	0.0	20	100	15	25	2185	80	10	10	sandy
84	Meta-volcanic/ sediment complex hills, high relief	Upland	6.6	1.6	4.9	248.9	78.8	73.8	40	543	40	60	2185	40	40	20	coarse-loamy to fine-loamy
91	Meta-volcanic/ sediment mountain	Upland	6.4	2.2	10.2	319.5	84.8	62.0	60	1895	40	60	2185	25	25	50	fine-loamy to clayey
97	Stabilized and active	Lowland	6.9	1.2	5.4	179.5	57.2	9.1	1	67	0	15	1885	80	10	10	sandy

Appendix III: Output headings

Explanation of symbols in the output headings

Symbol	Explanation	Unit
General		
N	Nitrogen	-
P	Phosphorus	-
K	Potassium	-
1	1st cropping season	-
2	2nd cropping season	-
3	3rd cropping season	-
Land Use System		
rownr		-
lut	Land use type	-
eco	Ecoregion	-
tech	Technology level	-
lmu	Land management unit	-
yield	Target yield	t/ha/y
Evapotranspiration		
ETc (month)	Reference evapotranspiration	mm/ha/mo
Monthly labour		
lab (month)	labour requirements	m-d/ha/mo
Fertiliser & N-loss		
fert	Fertiliser requirements	kg/ha/yr
lch	Leaching losses	kg/ha/yr
gas	Gaseous losses	kg/ha/yr
Nutrient cycling		
fert	Fertilisers	kg/ha
upt	Uptake	kg/ha
rof	Run-off	kg/ha
imm	Immobilisation	kg/ha
irr	Irrigation	kg/ha
dep	Dry and wet deposition	kg/ha
fix	Non-symbiotic fixation	kg/ha
cap	Capillary rise	kg/ha
ash	Ash deposition	kg/ha
ron	Run-on	kg/ha
min	Mineralization	kg/ha
Eff	Efficiency factor	-

Nutrient cycling (continued)		
Yld	Yield related	-
Tec	Technology related	-
Min	Mineralized nutrients	-
Prec	Precipitation	mm
Den	Denitrification	-
Vol	Volatilisation	-
Fix	Fixation	
Lch	Leaching	-
Rec	Recovery	-

Fertiliser cost model		
Fert_buy	Amount of fertilisers to buy	kg/ha/yr
Complete	Complete (14-14-14)	50kg/ha/yr
Amm.ph.	Ammonium-phosphate (16-20-00)	50kg/ha/yr
Urea	Urea (46-00-00)	50kg/ha/yr
Amm.sul.	Ammonium-sulfate (21-00-00)	50kg/ha/yr
Muriate	Muriate (00-00-60)	50kg/ha/yr
Complete2	Complete 2 (06-09-15)	50kg/ha/yr
Amm.ph.2	Ammonium-phosphate 2 (18-46-00)	50kg/ha/yr

Biocides		
Insect	Insecticides	kg a.i./ha/yr
Fungi	Fungicides	kg a.i./ha/yr
Herb	Herbicides	kg a.i./ha/yr

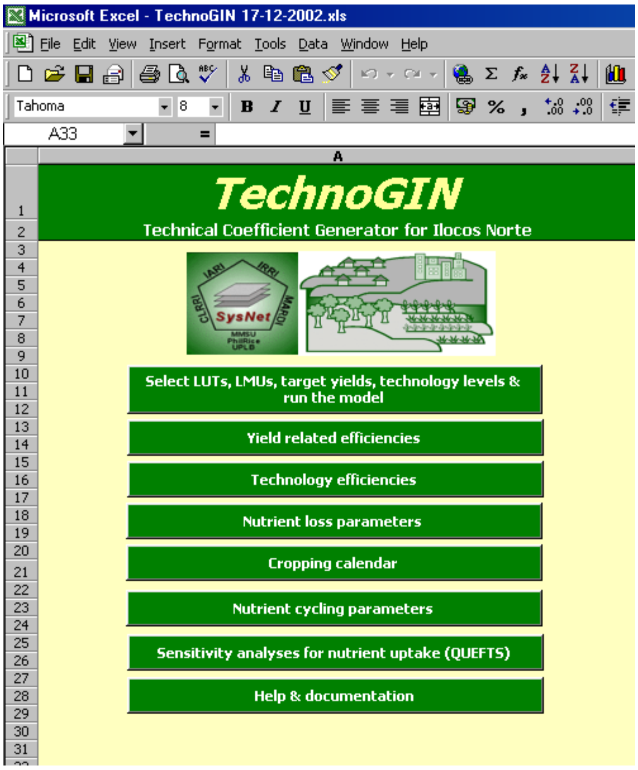
Economic analysis		
TotFertCost	Total fertiliser cost	P/ha/yr
TotLabCost	Total labour cost	P/ha/yr
Seedcost	Seed cost	P/ha/yr
InsectCost	Insecticide cost	P/ha/yr
FungiCost	Fungicide cost	P/ha/yr
HerbCost	Herbicide cost	P/ha/yr
FuelCost	Fuel cost	P/ha/yr
IrrigFee	Irrigation fee	P/ha/yr
MachRent	Machine rent	P/ha/yr
totcost	Total cost	P/ha/yr
FGPriceXyield	Income from yield	P/ha/yr
NetFarmReturn	Net farm return	P/ha/yr
NetRegReturn	Net regional return	P/ha/yr

Appendix IV: TechnoGIN exercises

The following exercises originate from the IRMLA Training Workshop, September 17-21, 2002, Beijing, China, but are adapted for some changes that were made after the workshop.

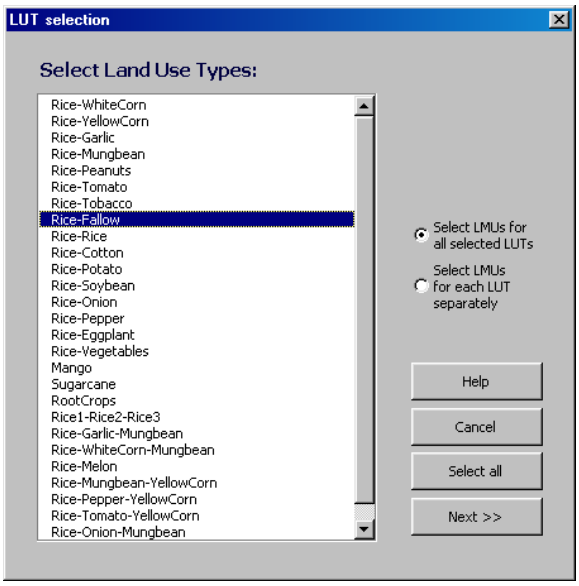
1. Getting started

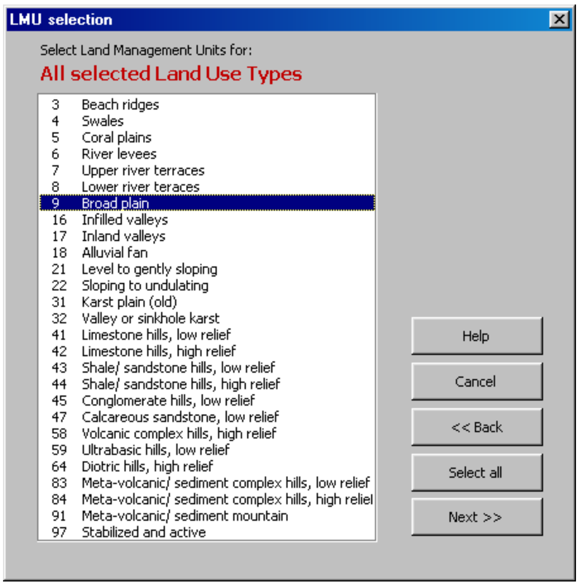
The Technical Coefficient Generator for Ilocos Norte (TechnoGIN) consists of one MS Excel file (e.g. TechnoGIN 17-12-2002.xls). As you open the file you will probably be warned about possible viruses because it contains a macro. You will have to trust the virus scanner and enable the macro. It always opens in the main sheet with the SysNet Project logo's (as it was initially developed for Ilocos Norte case study of SysNet), and a menu of buttons.



1.1 TRIAL RUN

To start, click the button "Select LUTs, LMUs, target yields, technology levels & run the model". A window appears in which you can select one or more different land use types (LUTs) that are used or could be used in the future in Ilocos Norte Province. The LUTs consist of one or more crops in one year. (Later we will look at more detailed characteristics of the LUTs.)

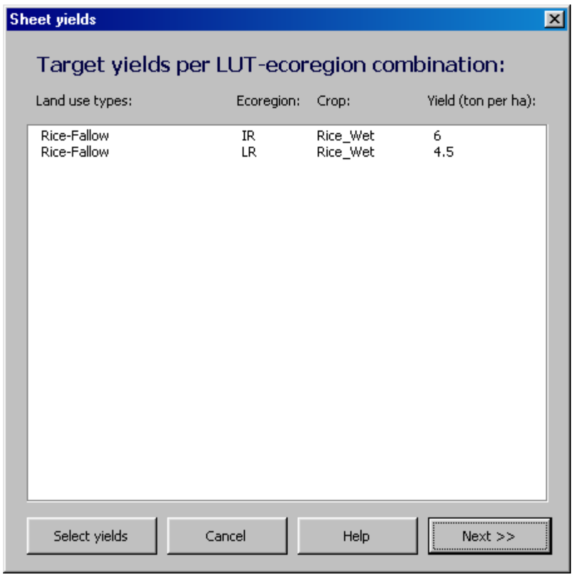


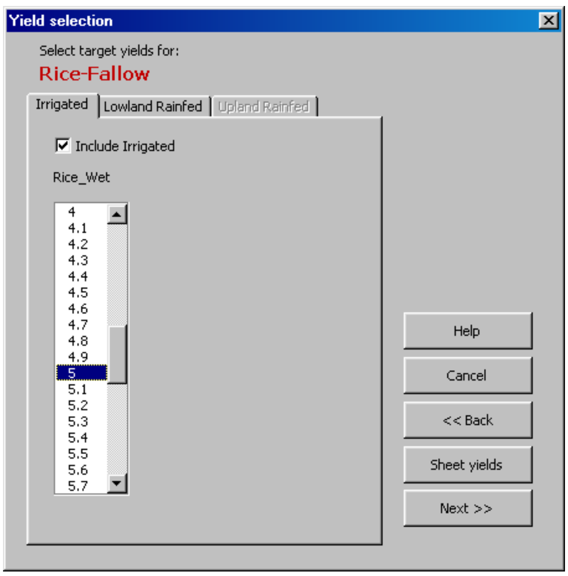


Select to begin with only "Rice-Fallow" (8th row). (You can select a LUT by clicking one time and undo the selection by clicking the LUT, that has become highlighted, again.) Click Next to continue.

A new window appears with descriptions of land management units (LMU). LMU is synonymous with land unit (LU) as used elsewhere. Note, for Ilocos Norte a distinction is made between upland and lowland LMUs. In the lowlands, a further distinction is made between irrigated and rainfed conditions, while in the uplands only rainfed conditions apply. LMUs are areas with (assumed) homogeneous landscape, soil and climate properties. (Later we will look at the LMU data.) Select a lowland LMU (no description with hills or mountains) for Rice-Fallow, for example "Broad plain". Click Next to continue.

The next window that appears shows the target yields selected in previous sessions for each crop in the selected LUTs. In case of lowland LMUs the yields can be defined for irrigated (IR) and lowland rainfed (LR). If you agree with the yields displayed, click OK to continue or if you want to select other target yields click the "Select new target yields" button. Click this button.



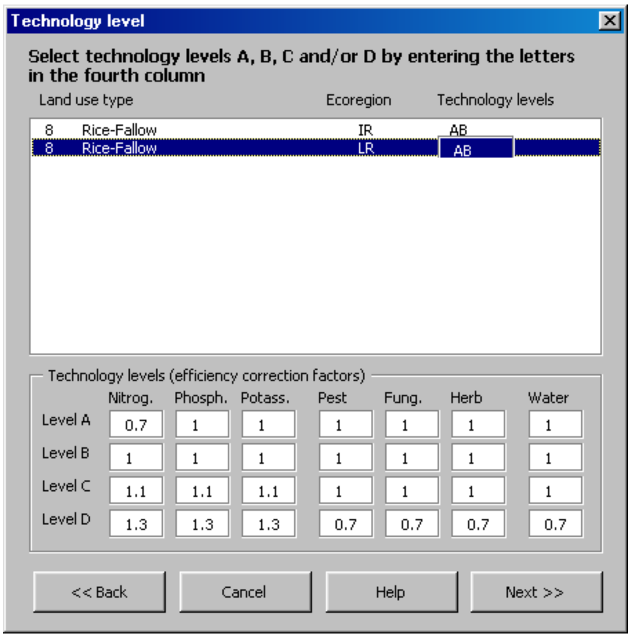


A window appears in which you can select up to 10 target yields (with an accuracy of 100 kg/ha) per crop for each LUT you selected. By clicking the tabs that say “Lowland Rainfed” you can select yields for that option. In case lowland LMUs are selected you will have to select yields in the designated tab. The irrigated or lowland rainfed options are excluded by clicking the checkboxes.

Scroll down the box under Rice_Wet in the Irrigated tab until 5 (ton/ha) appears in the range and click the 5 once so it highlights. Click the Lowland Rainfed tab and select 3 (ton/ha) in the same manner. Click Next to continue.

You will be asked to save the yields in the sheet, so you can use them again in the next runs. Click "Yes".

The next window that appears is the Technology form. Here you can select the technology levels per LUT-ecoregion combination in the upper part of the form and change the fertiliser, biocide and water use efficiency factors per technology level in the lower part. Make sure that only technology levels A and B are in the fourth column of the list box. You can change the technology related efficiency factors as you think is realistic. Click Next when you are ready to continue.



A window appears in which by default all output groups are selected. If you are only interested in some of the outputs, you can exclude one or more by clicking these groups Otherwise, click Next to include them all. Do the latter.

Your screen should be jumping up and down from sheet to sheet and numbers should be flickering. These are the Solver optimisation calculations for the QUEFTS and fertiliser modules. (Solver is a linear programming add-in module that can be installed from the MS Excel installation disk if not already done so). The other calculations and loops for the selected combinations are run by a macro, which we will have a look at later. You receive a message about the run-time (this should be about 5 to 10 seconds, depending on the processor, if longer you should close any other applications running or restart the computer to clear memory). Click OK. Finally you are asked if you want to save the output in a new file. Click "No". The Output sheet is activated.

1.2 EXPLANATION OF THE OUTPUT

There will be four rows with data. All are rice-fallow LUTs (RFa, column B, see the LUT sheet for abbreviations), and have the same LMU number (column E; for description and data see LMU sheet). In column C the "ecoregion" is stated. In Ilocos Norte we distinguish three ecoregions: IR stands for irrigated, LR for lowland rainfed and UR for upland rainfed). Column D shows the technology level A, B, C, or D (in the Technology sheet the technology related efficiency factors can be reviewed). In column F the yields for the first (wet season) crops are stated (in our LUT it is the only crop). In the irrigated case it should say 5 and the lowland rainfed 3 ton/ha/yr.

Columns I to T give the monthly evapotranspiration. These were calculated per decade (10 days for the first two decades of each month and the remaining number of days for the last) by multiplying the reference evapotranspiration, that was estimated by WOFOST with average weather data from Batac (a municipality of Ilocos Norte) and extrapolated for 4 elevation classes (see the Water sheet), by the crop coefficient (see the Crop sheet, columns X to BG). The duration of the crop is stated in column W of the Crop sheet and the starting decade in column M, N and O of the LUT sheet for the first, second and third crops respectively. Notice that the monthly

Columns U to AE of the Output sheet show the monthly labour requirements in man-day/ha/month. These are calculated from the survey data that distinguish between labour requirements for land preparation, crop establishment, crop management in man-days/ha and harvesting in man-days/ha/ton yield. These data are found in the Crop sheet, columns BH to BK. The data are divided over the decades in which the labour takes place and later the monthly totals are calculated.

The columns AG to AKJ give the nitrogen, phosphorus and potassium fertiliser requirements (N_fert, P_fert and K_fert) and nitrogen leaching (N_lch) and nitrogen gas losses (N_gas), respectively. The N, P and K fertiliser requirements, losses and availability is calculated by transfer functions (we will have a closer look at these in a later section), using soil, rainfall and crop data. The uptake is calculated by QUEFTS (see the QUEFTS sheet and columns H to S of the Crop sheet). The amounts of N, P and K required from fertilisers is calculated when the balance is negative and corrected by recovery fractions that are estimated by transfer functions (Nutrient sheet) and yield class (Efficiency sheet).

Columns AL to GE give the N, P and K balance components.
The abbreviations in the headers are read as follows:

- N = nitrogen; P = phosphorus; K = potassium
- 1 = first cropping season; 2 = second cropping season; 3 = third cropping season
- fert = fertilisers; upt = uptake; rof = run-off; imm = immobilisation; irr = irrigation; dep = dru and wet deposition; N_fix = nitrogen fixation; cap = capillary rise; ash = ash deposition; ron = run-on; min = mineralization (all in kg/ha)
- fr = fraction; den = denitrification; vol = volatilisation; lch = leaching; rec = recovery; fix = fixation (all fractions)
- Eff = efficiency factor; yld = yield related; tec = technology related; min = mineralized nutrients; Prec = precipitation (mm)

Columns GF to GO show the available types of fertilisers and the number of 50 kg bags per ha that a linear programming model (Solver) calculates by minimising the cost and meets the recommended amounts of N, P and K, which were calculated in the nutrient balances (including QUEFTS and fertiliser recovery fraction assumptions). See the Fertiliser sheet.

Columns GP to GR contain the biocide use (insecticide, fungicide and herbicide in kg active ingredients per ha per year). These data are copied from the field survey data. A correction can be assumed for different yield classes (see the Efficiency sheet).

In columns GS to HD you can find the economic analysis in Philippine Pesos per ha per year. Most costs are copied from the field survey (see Crop sheet columns BL to BW) or by multiplying the number of man-days needed by the labour cost per man-day specified per task (see the Labour sheet). At the moment all tasks are set to P./100.

1.3 EXPLANATION OF THE DATABASES

Now you know how to select LUTs, LMUs and yields and you have seen the output and roughly from which data and how it is calculated, we have a closer look at the databases.

Activate the Crop sheet. Have a brief look at the data:

- Maximum yields (as estimated by WOFOST or guesstimated by expert knowledge) in column D (yld_max);
- Harvest indices in columns E and F (at present the high HIs are used assuming only varieties with high HIs are applied);
- Minimum and maximum weight percentages N, P and K in harvestable product and stems and straw in columns H to S which are used in the QUEFTS model;
- Ecoregion possibility in columns T to V to state whether a crop is suitable for irrigation, lowland rainfed or upland rainfed respectively;
- Duration of the crop in days in column W;
- Crop coefficient per decade in columns X to BG;
- Labour specified for land preparation, crop establishment, crop management in man-days/ha and harvesting in man-day/ha/ton in columns BH to BK;
- Other inputs and costs in columns BL to BW;
- USLE c factor in column BX

(A new crop could be added by filling in the data under the last defined crop as we will see later.)

Activate the LUT sheet. Here the LUTs are defined by filling in crop numbers as coded in the Crop sheet (column A) or 0 for fallow in columns D to E of the LUT sheet. In columns G to L the crop residue strategy is defined (fraction of crop residues used for fodder and fraction that is burnt). In columns M to O the start decades are stored. These can also be changed by selecting dates in the cropping calendar form, which can be called from the main sheet. The rest of the sheet contains the target yield stored after the runs like you did earlier.

Activate the LMU sheet. Important data in this sheet are: acidity (pH), organic matter (OM in %), P-Olsen (ppm), potassium (K in ppm), elevation range (m), permeability, precipitation (mm), slope range (%), clay content (%). To add a land unit these data need to be inserted under the last LMU. This can be a LU with any size, so these LMUs could be replaced by more detailed LUs. However, too many LUs result in many more land use systems (combined with LUTs and yields and technologies).

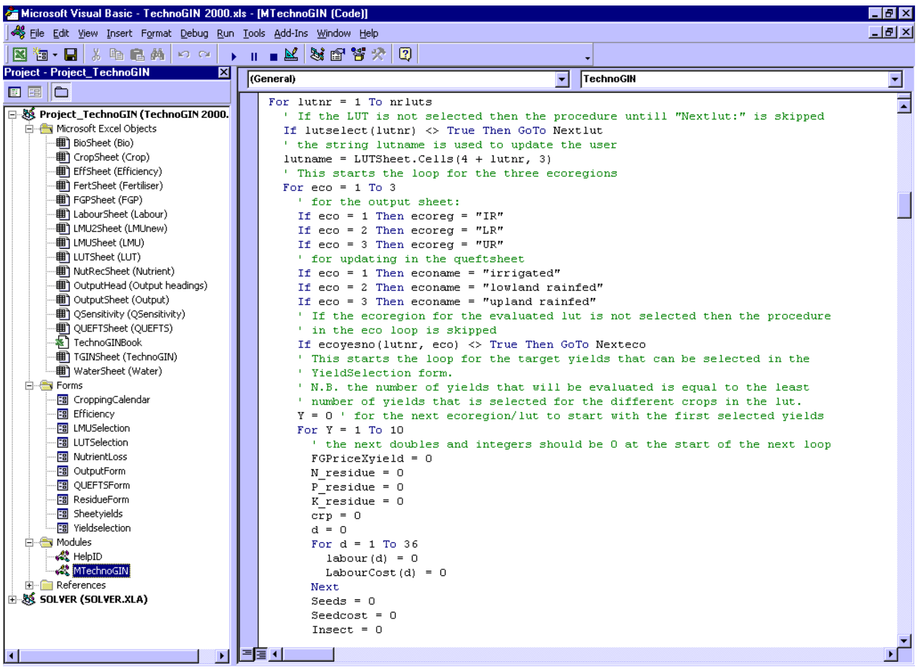
Activate the Efficiency sheet. Here are the assumptions on fertiliser, biocide and water use efficiency related to target yield class. These assumptions are based on the different levels of technology used with different target yields. One could also assume that at the highest yield class the efficiency becomes lower. We will do that later by using a form that is called from the main sheet.

Activate the Nutrient sheet. Here we find the parameters for the transfer functions calculating the nutrient losses from fertilisers. Most functions are linear and based on clay percentage and precipitation. These data still need calibration...

The Labour sheet contains labour cost in Pesos/day for 5 different tasks. The water sheet contains reference evapotranspiration as explained earlier. The Bio sheet contains active ingredient fractions and prices of biocides. The FGP sheet contains the monthly farm gate prices. The Output headings sheet contains the headings and unities per output group.

1.4 QUICK LOOK AT THE MACRO

Now you have had a look at the databases let's have a quick look at the macro by pressing Alt+F11 or Macro → Visual Basic Editor in the Tools menu. In the project explorer window on the left you can find the macros by clicking the Modules folder and MTechnoGIN. If you scroll down you will find the TechnoGIN macro under "Sub TechnoGIN()". Scrolling down further you can find the line "For lutnr = 1 to nrluts", starting the LUT loop. The line "For eco = 1 to 3" initiates the ecoregion loop, "For t = 1 to 4" the technology loop, "For Y = 1 to 10" the target yields loop, and finally "For crp = 1 to 3" the crops within the LUTs loop. Scroll further down and see if you recognise or understand any of the calculations. For full explanations and understanding of the macro refer to the documentation.



• 2. Exercises

2.1 EXERCISE RUN WITH NEW LUT

Activate the LUT sheet. Type "28" in cell A32 signifying the 28th LUT; type "RGS" in the next column and "Rice-Garlic-Soybean" in column C. Then type "4", "8" and "15" in the next three columns for the crop numbers as defined in the Crop sheet for wet season rice, garlic and soybean respectively. Then type 0.1, 0.6, 0.0, 0.4, 0.0, 0.0 in columns G to L. type AB, AB, and AB in columns P, Q and R.

Activate the main sheet (TechnoGIN) and click the button that says "Cropping calendar". Select the LUT you just defined in the box of the window that appears. You will find it as the last one in the list. The crop names will appear and boxes in which you can select starting dates. Scroll down in the start date box of rice and select "Jul. 1-10". The end date will be calculated according to the duration of the crop (column W of the Crop sheet). Select the start date of garlic directly after the end date of rice. Idem ditto for soybean after garlic. Click the "Apply" button and then "Quit". Activate the LUT sheet; (Lu) In columns M, N and O you can find 19, 31 and 10 for the new LUT as starting decades.

Activate the TechnoGIN main sheet and click the "Select LUTs, LMUs..." button. At the bottom of the box in the window that appears you will find the new LUT ("Rice-Garlic-Soybean"). Select it and click Next. Select a lowland and an upland LMU (e.g. "Lower river terraces" and "Low limestone hills") and click Next. You will have to select yields now for irrigated, lowland rainfed and upland rainfed wet season rice, garlic and soybean. Select yields for irrigated, lowland rainfed, and upland rainfed. E.g. 1.5, 3.5 and 5.5 t/ha for rice, 2, 4, and 6 t/ha for garlic and1 , 1.5 and 2.5 t/ha for soybean. Adjust the technology related efficiency factors of technologies A and B for fertiliser, biocide and water use.

2.3 EXERCISE RUN WITH NEW CROP AND LUT

The same way you created a new LUT using existing crop definitions, a new crop could be added. However, usually a lot more data is needed for doing this. In some cases, though, it might suffice to make only a few adjustments. This can be realized quickly by copying a crop and changing some data, for example, the duration and crop coefficients or harvest index and maximum yield. As an example, for garlic the duration is 150 days, but this could actually be 90 when bulbs are used to plant.

Select the Garlic row in the crop sheet (row 12, crop number 8) and copy it to the row below the last crop (row 28). Change the 8 in the first column into 24 and type 90 after "Gar" and "Garlic" ("Gar90" and "Garlic90") to distinguish it from crop 8. Change "150" in column W into "90", and delete the crop coefficients. Fill columns X to AE (the first 8 decades) with a new set of crop coefficients (à 0, 0, 0.45, 0.6, 0.85, 1, 0.8, 0.5).

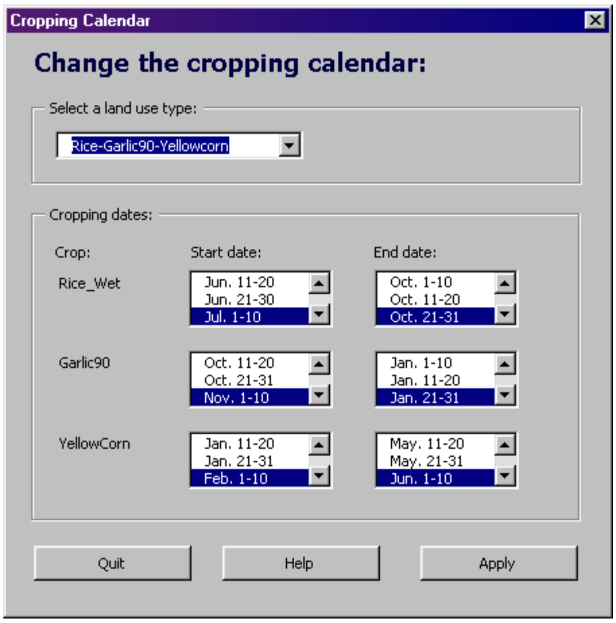
In the columns A to C and W to AE of the crop sheet, row 28 should be the following (the other columns should be equal to the data in row 12 (garlic):

A	B	C	W	X	Y	Z	AA	AB	AC	AD	AE
24	Gar90	Garlic90	90	0.00	0.00	0.45	0.60	0.85	1.00	0.80	0.50

Activate the LUT sheet and add a LUT with rice (4), garlic90 (24) and yellow corn (7). You can copy columns G to N from the previously added LUT (Section 2.3). Select the start date in the Cropping Calendar window directly after the end date of garlic90 (Feb, 1-10; see figure below).

In the columns A to O of the LUT sheet, the rows 32 and 33 should look like this:

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
28	RGS	Rice-Garlic-Soybean	4	8	15	no	yes	yes	10	1	20	19	31	10
29	RG90Y	Rice-Garlic90-Yellowcorn	4	24	7	no	yes	yes	10	1	20	19	31	4



Initiate a new run and select both new LUTs (rice-garlic-soybean, and rice-garlic90-yellowcorn) in the LUT window. After clicking OK you will be asked if you want to select the same LMUs for all selected LUTs. Click "Yes" and select any lowland LMU. Select yields for all crops in both LUTs, but exclude rainfed in both cases. Compare the results.

NOTE FROM THE FIRST AUTHOR

This introduction with exercises is intended to give you an idea of how TechnoGIN works, and will enable you to conduct some additional exercises yourself by changing and adding data and assumptions, and if required, replace these with improved data /assumptions. You have to bear in mind that the output needs to be tested as it is based on many assumptions and should be interpreted likewise. In this way it can be very useful comparing the effects of possible actual and future land use systems and different strategies or technologies, taking many different inputs and outputs - ranging from water and nutrient flows to economic indicators - into account. Although the number of technical coefficients the TCG can produce is vast, they can be interpreted using graphs, statistics, GIS and IMGLP (interactive multiple goal linear programming).

Please, send your comments on TechnoGIN by e-mail (tommie.ponsioen@wur.nl). I will be happy to receive and answer any questions in this matter.