

TechnoGIN Quick start tutorial

EU version for long-term rotations

Version 2.1

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1 Introduction

TechnoGIN is a generator of input-output relationships or so-called technical coefficients of cropping systems. Originally, it was designed for providing input to a land use scenario studies of Ilocos Norte Province, Philippines, only; however, in the framework of the IRMLA project it has been made more flexible (Ponsioen et al., 2006), so it can be applied to all sort of study sites in subtropical and tropical regions. ***This model version is made suitable for temperate climates with rotations over many years, replacing the one-year rotations in the original TechnoGIN.***

The outputs of TechnoGIN are the specified target yields and the inputs are, for example, the amounts of labour, fertilisers etc. to attain these yields. The input-output relationships are used in linear programming models for optimizing land use in a region or a farm. However, TechnoGIN results can also be used directly, for example, for cost-benefit and environmental performance analysis of various cropping systems.

When specifying the main input-output relationships of cropping systems for a new study region, the resulting numbers of relationships may become quite large. Combining land use types (i.e. crop rotations), land units, and technology levels may easily result in hundreds of combinations, for which the input-output relationships should be determined. This indicates the need for a standardized procedure to collect input data in a consistent way and to perform calculations for generating input-output relationships in a reproducible manner. As the number of input data is large and collection of data from literature and statistics and their interpretation and translation into input data is often complicated and time-consuming, this Quick-start tutorial is meant to support the input data collection for and use of TechnoGIN.

2 First overview before Starting

2.1 Reader's guide

This tutorial gives an overview on how to compile input data and to produce a set of input-output relationships for a region. First, starting from the main menu of TechnoGIN, an overview is given of the main options of TechnoGIN (Section 2.2). Next, a detailed overview is given of the input data required for using TechnoGIN (Section 3). It is indicated which input data can be considered as constant and which data should be calibrated for new situations, how the input data can be collected and sometimes how the input data are used in TechnoGIN. Finally, the contents of the output data sets are described (Section 4).

When starting TechnoGIN, use the most recent EXCEL-model (TechnoGIN_EU_v???.xlsm, where ??? indicates the version number) together with the available data files: TechnoGIN-Test_EU_v???.xlsx (i.e. base file for an example EU region) or one of the other data files for an EU region. More documentation is available: TechnoGIN_EU.html Helpfile, the report by Ponsioen et al. from 2003 (see TechnoGIN-03-03-2003.doc, indicated by DOC) with the description of the main modelled processes (model status of March 2003 exclusive the later model changes), an article about TechnoGIN and its application by Ponsioen et al., 2006 (TechnoGIN-article.pdf) and README.txt (i.e. READ) with advice on TechnoGIN installation. Reference to this documentation is made in the following by using the above-mentioned abbreviations.

If applying TechnoGIN for the first time, it is useful to do the exercises in this Quick start tutorial (Sections 3 and 4) and possibly too the 'Getting started' (Section 1) and the exercises (Section 2) in Appendix IV of DOC. This consists of: a) first introduction to TechnoGIN; b) selection of a Land use type (LUT= crop rotation), Land Management Unit (LMU= landscape/soil unit) and technology level; c) specification of target yield levels (outputs); d) explanation of TechnoGIN results; e) explanation of data bases; f) exercise in adding new crops and LUTs.

Note that DOC does not completely correspond with the current version of TechnoGIN for temperate conditions.

It is advised to go through this tutorial completely, before starting to work with TechnoGIN and compiling input data sets for its use. In this way, you will get acquainted with the complete structure and procedures of TechnoGIN and with its complex connections (e.g. between input data in different sheets). If you have any problems with or remarks about the use of TechnoGIN or about this tutorial, please contact

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2.2 Getting started

1. Open TechnoGIN_EU_v???.xslm (where ??? indicates Enable the macro (see READ about Macro if problems occur). If you see: 'Compile error. Can't find project or library'. See Annex A to solve this problem.
2. In the main menu (TechnoGIN sheet): choose 'change data base file': TechnoGIN-Test_EU_2.9-new data-Base.xlsx. This file contains data for almost all crop types in Europe and mainly mono-crop rotations for an example region in Europe. This file can be used as a starting point for compiling a data file for TechnoGIN for your study region. Note that data files are available for fourteen regions over Europe (from Sweden and Denmark to Spain and Italy).
3. In the main menu: choose 'Select LUTs, LMUs, target yields, technology levels & run the model'. With this button the LUTs and LMUs can be selected, for which inputs and outputs need to be generated. In addition, default target yields and technology levels as defined in the database file, can be adjusted.
4. In the main menu: choose 'Yield related efficiencies'. Here, you can define to what extent the efficiency of the use of major inputs in crop production changes with the yield level. In the standard data set, the recovery fractions of applied fertiliser nitrogen, phosphorus and potassium are assumed to be independent of the relative yield level (i.e. relative to reference or maximal yield level), the biocide application is assumed to be independent of the relative yield level too except for very low yield levels, and the water use by evapo-transpiration is assumed to be completely independent of the relative yield level. Note that the standard values (e.g. evapotranspiration or biocide use as specified per crop type in Crop sheet) are used, if all values are set to 1.0. In that case, nutrient, water and biocide use are independent of the yield level. Note that these yield-related efficiencies are applied to all LUT-LMU-Technology combinations.
5. In the main menu: choose 'Cropping calendar'. For the different LUT's or crop rotations the growing seasons inclusive land preparation and harvesting are indicated in the form. The seasons are generally dark green, but red if there is an overlap between subsequent crops. If such overlap does occur for a selected LUT, the TechnoGIN run is stopped and the overlap is shown. In the Crop data sheet (see Section 3), the total cultivation period of winter wheat was set to 300 days (30 decades). If the start date is changed in the LUT sheet, you can see that also the end date is automatically changed in the form. In the original TechnoGIN for (sub)tropical conditions, the maximum cultivation period of a LUT is one year. In this TechnoGIN for temperate climates (e.g. Europe), the maximum cultivation period (with crop rotations of maximally 15 crops) is 8 years (i.e. 288 decades). If overlap between subsequent crops in a crop rotation (i.e. LUT) does occur, the

start dates for the crops in the LUT sheet should be changed and/or the length of the cultivation periods as defined in the Crop sheet, should be shortened.

6. In the main menu, the button ‘Nutrient flow diagram’ can be activated after running TechnoGIN, to view a diagram showing the nutrient cycling in the selected LUT-LMU-Technology combination, both for nitrogen, phosphorus and potassium. All nutrient inputs from fertiliser, precipitation, etc., the nutrient recycling in the soil, and all nutrient losses are indicated.

Two different systems can be chosen: **1. current system; 2. future system**, as described in the following. The choice for a future system can be made as follows: in the main menu, choose ‘select LUTs, LMUs, target yields, technology levels etc.’ and go to the Technology form with the choice of technology level. Here, you can specify technology-related correction factors for water, nutrients, labour, etc. and you can also select current or future systems.

In **future systems**, the target yield is specified by the user and determines the nutrient uptake by the crop (as calculated with the QUEFTS system (Janssen et al., 1990)). In this system, the fertiliser requirements are calculated from crop’s nutrient uptake minus natural nutrient supply, divided by the recovery fraction of applied fertilisers.

In the **current systems**, the actual fertiliser nutrient applications are entered and are not calculated. These nutrient (NPK) applications are specified for each crop type-LMU combinations in the Crop sheet (columns far to the right). If no data are specified, a zero application is assumed. For more information on nutrient inputs and on the applied method for calculating nutrient uptake, nutrient recycling and fertiliser nutrient requirements, see Section 3 no. **10**.

7. In the main menu: choose ‘QUEFTS’. For a crop type, e.g. Winter wheat, you can see the result of the crop’s nutrient uptake calculation with QUEFTS. If you specify a target yield, e.g. 6 ton grains (air dry, 84% dry matter), the nutrient uptake is calculated (by clicking on button ‘QUEFTS run’) for a dry matter grain yield of 5040 kg/ha and for the yield/nutrient uptake ratios. The used ratio, indicated as internal efficiency, is in-between the minimum and maximum values for the yield/nutrient uptake ratios (e.g. 24 and 71 kg grain dry matter yield/kg N uptake) and becomes lower, if the yield is approaching the maximal possible grain yield (e.g. 10000 kg grain-dry matter/ha, in Crop sheet). The maximal and minimal yield/nutrient uptake ratios are calculated from respectively, the minimal and maximal N/P/K concentrations in grains and crop residues and the harvest index (all specified in Crop sheet), as described in DOC p. 16 for Ranges. For more information on the QUEFTS calculations, see DOC p. 14-16.

8. In the main menu: choose ‘change database file’ to select a new database file for the calculation of input and output coefficients of another region (as indicated on the screen). Next, the new database file can be opened by the ‘open database file’ command. The old file will not be closed automatically.

9. In the main menu: choose ‘export output’ to save the output in a new output file. You may ‘save the output in Excel files’, or ‘save the output in PRN-files’ for

GAMS linear programming models for optimizing land use in a region or a farm, or save the output ' to a MS-Access file to be used for FSSIM' for use in the the FSSIM farm optimization model.

10. In the main menu: choose 'Help file' to get additional information on TechnoGIN. In addition to this help file, help buttons are often indicated with information, for example, when you are selecting LUTs and LMUs. The 'Help file' gives initial information about how to get started with TechnoGIN, some possible problems, the structure of TechnoGIN, and an overview of the data sheets with input data, the calculation macros, and the output data sheets. For each data sheet, the included data and parameters, their descriptions and their units are given.
11. In the main menu: choose 'Quickstart manual' to open this manual.

2.3 Main changes in this TechnoGIN version for temperate conditions (e.g. EU) vs. the original one

The original model version of TechnoGIN has been developed for Philippines (see DOC) and applied to many (sub)tropical regions in China, Vietnam and Philippines within the IRMLA project (Roetter et al., 2007). The current model version is meant for temperate climate (e.g. Europe). The main difference is related to the LUTs or crop rotations. For the (sub)tropics the LUTs are assumed to consist of one, two or three crops within one year. Hence, all the calculations per LUT-LMU-Technology combination are done for one year. For the current model version we have included crop rotations over longer periods (maximally over eight years).

The main differences in the current TechnoGIN compared to the original model version are:

1. LUTs for maximally 15 crops in a rotation and 8 years (i.e. 96 months and 288 decades);
2. Results for fertiliser demands, nutrient losses, and biocide emissions are given both as the amounts per crop cultivation (and thus not per year) and as total amounts for the total duration of the crop rotation;
3. The calculated costs for fertilisers, seed, labour etc. and the gross and net returns are given as totals for the total duration of the crop rotation (and thus not per year).

3 Compilation of data set for a new region

In the following an overview is given of the main input data sets. It is indicated which data can initially be kept the same, and which data should always be based on site-specific data. Crops can be cultivated in different ways: more or less mechanized technologies with lower or higher labour requirements, more or less environment-friendly technologies with less or more biocide-use, more or less efficient fertiliser nutrient application, etc. These relative factors of input use are specified in the Technology sheet (see below: no. 8). However, there are sometimes combinations of LUTs-LMUs-Tech, for which the differences in input use cannot be specified. For example, the labour requirements for land preparation on LMUs with clay texture are double those with sandy texture. Such differentiation in input use can only be included by specifying different crops in the Crop sheet (see below: no. 3), such as, for example, first, 'wheat on sand' and 'wheat on clay' with different labour requirements, second, wheat with different technologies (e.g. labour intensive, more animal use, or mechanized) and third, wheat with improved management and thus higher recovery fraction of applied fertiliser nutrients. Note that this approach (i.e. subdivision of a crop type or perhaps a LMU for different soil nutrient supplies) is more flexible and easier to control than using the Technology sheet (see below no. 8), which specifies correction factors for all LUT-LMU combinations for a technology level.

For the compilation of a data set for a new region, a large number of Excel-sheets with input data are filled as described in the following:

1. Copy the file 'TechnoGIN-Test_EU_2.9-new data-Base.xlsx' to a new file 'Technogin-YourRegion.xlsx' using Windows Explorer. This copy of the data base file can now be changed freely. Data sets for, for example, missing LUTs can be copied from the other data base files.
2. In the main menu: choose 'Change data base': 'TechnoGIN-Your Region.xlsx' and next 'Open data base file'.

3. Crop sheet:

In this sheet, specific crop data should be entered for rotations in the LUT-sheet (see no. 4). Based on these LUTs, for example, the crops are wheat, maize, soyabean, potato, etc. For the crops a large amount of information should be given, of which one part is generic and can be used in most situations (as indicated by **Constant**) and another part depends on local conditions and should be based on local information (i.e. collection of experimental and statistical information) (**Variable**). To include a new crop type, one line for a crop should be copied to a line below the other crops and given a following number. Next, the data should be adapted to the new crop type. The procedure to make a new crop in the Crop sheet is described in exercise 2.3 in DOC p. IV-7.

For one crop the list of data (i.e. one line) consists of (from left to right in the sheet) :

- a.** crop number, which should correspond with numbers in the LUT-sheet;
- b.** code and full name of crop;
- c.** maximum dry matter yield (i.e. maximum yield under optimal conditions; used as maximum in nutrient uptake calculations with QUEFTS (Section 2.2, no. 7) for target yield) (**C**);
- d.** harvest index (i.e. yield/ total biomass, expressed in dry matter) (**C**);
- e.** dry matter % in yield (**C**);
- f.** fN_{fix} (fraction of nitrogen uptake supplied by symbiotic fixation; default set to 80% for leguminous crops) (**C**);
- g.** minimum and maximum nitrogen, phosphorus and potassium concentrations in economic yield and in crop residues (used in QUEFTS calculation (Section 2.2, no. 7)) (**C**);
- h.** crop family and crop product, as used in FSSIM (otherwise, not of importance with columns left empty) (**C**);
- i.** maximum air-dry yield as calculated via **c.** * 100 / **e.**;
- j.** duration of total cultivation period, inclusive time for land preparation, crop establishment and harvesting (see Section 2.2 no. 5) (**V**);
- k.** crop coefficient KC which is multiplied with the potential evapo-transpiration (for a short crop such as grass) to calculate maximum evapo-transpiration (assuming that water supply is not limiting). During fallow (i.e. outside of total cultivation period, as mentioned under **j.**), KC is set to the KC-value for fallow (=0.3, as entered in Nutrient sheet) and KC becomes 1.0 for a full-grown crop (or even slightly higher for certain crops). For e.g. potato ware with 15 decades of cultivation period, KC= 0.4 during decade 1 (e.g. 1 decade with land preparation), KC increases after decade 2 (with crop establishment, see **l.** below) to decade 8 (with $KC < 1$ as long as the light interception by the canopy is incomplete), $KC = 1$ (full-grown canopy) during decades 9 to 13, and after decade 13, KC gradually decreases due to senescence and harvest. If a new crop is entered, this time course of KC can be estimated in a similar way, based on the total cultivation period and the period with a full grown crop. If potential (reference) evapotranspiration data are not available (in LMU sheet), the maximum evapotranspiration and hence, the irrigation water requirements (which requires also precipitation data) cannot be calculated and KC is not used (**V**);
- l.** labour requirements are given for land preparation (distributed over first decades (often 1 or 2) of the defined cultivation period), for crop establishment (sowing or planting; in the decade after land preparation), for crop management (distributed over following decades minus one for harvesting), and for harvest (in last decade). See also Section 2.2 no. 5 for cropping calendar. Labour requirements are all given as total labour-days per hectare, except for the labour requirements for harvesting: labour-days per ton air dry (target) yield (**V**). Note that labour requirements for e.g. land preparation can only be differentiated between different LMUs by specifying different crop types (see beginning of Section 3). For the different technology levels (see below, no. 8 Technology sheet) different correction factors for labour requirement can be entered (due to

e.g. mechanization). In the main menu: choose 'select LUTs, LMUs, target yields, technology levels etc.' and go to the Technology form. Here, correction factors for labour input can be specified, however, these factors can also be changed in the Technology sheet;

m. other inputs for crop cultivation are specified, such as seed weight, fuel, machinery and animal hours, irrigation hours (not used!), investment (per crop) and additional costs (e.g. fertiliser costs for permanent crops and/or total irrigation costs), which are used for calculating input costs of crop production (**V**). For the various technology levels, different correction factors for inputs as fuel, machinery and animal hours, can be entered due to, for example, mechanization. This can be done in the same way (via both Technology form and Technology sheet) as described for the correction factors for Labour input (see **l.** above, but now under labels: Input cost and Relative input);

n. harvest decades: determines the distribution of labour required for harvesting (**V**);

o. land preparation decades: determines distribution of labour required for land preparation; generally set to one or two decades (**C**);

p. crop factor in the Universal Soil Loss Equation: factor might be applied for calculating nutrient loss by erosion (**C**) but generally not used;

q. recovery correction factor: recovery fraction as calculated as $(1.0 - \text{loss fractions})$, is in general similar for all crop types (factor set to 1.0) and may be varied with this factor between crops (**C**); recovery fractions are corrected by both technology (see below no. **8**), yield-related (see below: no. **9**) and these crop-related correction factors (e.g. lower recovery fraction for short-duration compared to long-duration crops);

r. soil nutrient correction factor: soil N/P/K supply as specified in LMU sheet per soil type, is in general similar for all crop types (factor set to 1.0) but may be varied with this factor between crops (**C**);

s. irrigation water: originally used for calculating nutrient input through irrigation water applications but not used anymore; these nutrient input calculations are now based on the calculated irrigation water requirements;

t. anaerobe: true for wetland rice and false for upland crops; this determines the loss fractions for nutrients in soil (as specified in Nutrient sheet) and thus the recovery fractions (**C**);

u. amounts of different types of biocides applied in kg or l per ha; the characteristics per biocide (active ingredient, persistence, toxicity) are specified in the Biocides sheet; new biocides can be added in this last sheet (**V**);

v. farm gate price of economic crop product (air-dry product) for different years in a region (**V**); for which year the prices are used in the calculation, is determined in the Technology sheet and in the Technology form (starting in the main menu: choose 'select LUTs, LMUs, target yields, technology levels, etc.' and go to Technology form) under label Currency;

w. seed costs per kg seed (**V**) for different years; for which year the prices are used in the calculation, is determined in the Technology form under label Currency;

x. current fertiliser N, P and K applications are specified for the different LMUs (**V**) and are used for reproducing the mean actual fertiliser applications and

nutrient cycling in representative field experiments or farmer's fields (note that the given applications are based on management data compiled for 14 EU regions during the SEAMLESS project); a set of applications on a new LMU can be included by copying a set from another LMU and by entering the number of the new LMU; these fertiliser applications are only used in current systems and not in future systems (see no. **8g** further on). For more information on the Crop sheet, see DOC p. 35-38 (but the Crop sheet is partly changed);

4. LUT-sheet:

When you are starting to compile a data set for a new region, the following is of importance: derive from statistics and the farm survey the crop rotations that cover about 90 % of the cropping area in the region. Later on, you can also add less important rotations. Initially it is important to concentrate on main crop rotations, land types, technology, labour requirements, etc. Land Use Types (LUTs) may exist of maximally fifteen crops over maximally 8 years, being suited for temperate climate conditions. Note that the original TechnoGIN version had maximally three crops over one year and is mainly suited for (sub-)tropical conditions.

For example, the rotations may be mono-crops as e.g. winter wheat, and may be winter wheat-grain maize, winter wheat-grain maize-potato ware etc. These rotations should be entered (if not yet available) in the LUT sheet of TechnoGIN-YourRegion.xlsx. Entering a new LUT can be done by copying a line with data for a LUT to the first free line below (see DOC, exercise 2.1 on p. IV-7 for more information on producing a new LUT). The main data in the LUT-sheet are (from left to right in the sheet):

- a. number, code and full name of LUT;
- b. crop numbers in the rotations which relate to the numbers in the crop sheet;
- c. number of crops in the LUT (i.e. rotation) with maximally 15 crops;
- d. total length (in month) of the LUT (i.e. rotation) with a maximal length of 96 months which length is calculated by TechnoGIN;
- e. fractions of crop residues that are used as fodder for the animals and are burnt (with the remainder of total fraction (=1.0) recycled to the soil as mulch);
- f. start decades of cultivation periods of crops in the rotation; the total length per LUT (see **d.** above) should be taken into account; at the start of each run the overlap of cultivation periods of subsequent crops are checked and if overlap occurs, the run stops and the errors are shown (in red) in the Cropping calendar form at the main menu;
- g. technology levels to evaluate (with maximally nine levels) which differ with respect to, for example, labour and machinery use, recovery fraction of applied fertiliser nutrients and biocide use. Start with two levels (A & B). Note that the selected target yield levels (see LUT_LY and LUT_HY sheets for respectively low and high target yields) can be identical for both technology levels but that the required inputs are different (as specified in the Technology sheet, see no. **8**);
- h. current system is set to TRUE, using the actual fertilizer applications; if set to FALSE, the LUT is a future one that is not evaluated for current conditions; see Section 2.2 point **6** for more information about current and future systems;

i. selected is set to TRUE if this LUT is selected for a run.
For more information on the LUT sheet, see DOC p. 38-39 (note that the LUT-sheet is partly changed).

5. LTU_LY sheet:

The data in the LTU_LY-sheet are (from left to right in the sheet):

a. target yield levels (air dry) as specified for the first, second, third etc. crops (with maximally fifteen crops within maximally eight years) in a rotation for each LMU separately. These yields are the relatively low target yield level (in ton fresh or air-dry matter per ha), which low yields may occur under less favourable growing conditions. This may be, for example, rainfed systems and/or current technology in comparison to irrigated systems and/or future technology. Note that by choosing 'select LUTs, LMUs, target yields, technology levels etc.' in the main menu, by choosing next 'Low target yields' the yields can be seen, and by next selecting 'Change yields', low target yields can easily be changed and entered in the LUT_LY-sheet through this input-form. These target yields should be based on field experiments (note that the current yield data are based on actual yield data compiled for 14 EU regions within the SEAMLESS project).

6. LTU_HY sheet:

The data in the LTU_HY-sheet are (from left to right in the sheet):

a. target yield levels (air dry) as specified for the first, second, third etc. crops (with maximally fifteen crops within maximally eight years) in a rotation for each LMU separately. These yields are the relatively high target yield level (in ton fresh or air-dry matter per ha), which high yields may occur under favourable growing conditions. This may, for example, be irrigated systems and/or future technology. Note that by choosing 'select LUTs, LMUs, target yields, technology levels etc.' in the main menu, by choosing next 'High target yields' the yields can be seen, and by next selecting 'Change yields', high target yields can easily be changed and entered in the LUT_HY-sheet through this input-form. These target yields should be based on field experiments (note that the current data are equal to the low target yield levels times 1.2).

7. LMU sheet:

This sheet contains the characteristics of the major Land Management Units (LMUs). Entering a new LMU can be done by copying a line with data for an existing LMU to the first free line below. The main data that have to be collected for local conditions, are the natural soil supplies of nutrients, strongly affecting the calculated fertiliser requirements. The other data are less important and can be roughly estimated. The data in the LMU-sheet are (from left to right in the sheet):

- a. code and full description of LMU;
- b. lowland/upland and soil acidity: these are not used in TechnoGIN;
- c. long-term natural soil supply of nitrogen, phosphorus and potassium (in kg N, P and K per ha per crop) for equilibrium situation as based on long-term unfertilized field trials (see also Nutrient sheet no. **10c**);

- d.** maximum soil water: maximum storage of water (in mm) in the rooted top soil (between field capacity and wilting point) which is used in the water balance calculations for establishing the irrigation water requirements;
 - e.** elevation: not used in TechnoGIN; elevation is used for calculating evapo-transpiration in Penman-Monteith.xls (see **k.** below);
 - f.** slope: in- and output of nutrients by run-on and run-off may be included and depends on the slope (see Nutrient-sheet);
 - g.** Total precipitation (in mm per year): N and K leaching and denitrification loss fractions can be made partly dependent on total annual precipitation (see Nutrient sheet);
 - h.** soil texture and sand/loam/clay contents; clay content may affect the loss fractions by leaching, denitrification, volatilization and K-fixation (see Nutrient sheet);
 - i.** information on soil depth class, drainage class, parent material, soil classification, infiltration class and rate, permeability rate and bulk density can be entered but they are not used in TechnoGIN;
 - j.** monthly rainfall data (in mm): can be based on long-term climate data from nearby meteorological station, but might be left out initially;
 - k.** reference evapo-transpiration (ET, in mm) data for decades (i.e. three decades per month; potential values for well-watered full grown standard crop, like a grass canopy); they can be calculated with Penman-Monteith.xls, if required weather data (i.e. minimum and maximum temperature, irradiation or sunshine hours, vapour pressure and windspeed) are available; reference ET values are used to calculate the irrigation water requirements but might be left out initially;
 - l.** selected is set to TRUE if this LMU is selected for a run;
 - m.** rainfall data for decades (i.e. three decades per month, in mm); using the reference ET and rainfall data, the irrigation water requirements are calculated for each LMU/LUT combination in TechnoGIN.
- For more information on the LMU sheet, see DOC p. 39-40 (however, the LMU-sheet partly changed).

8. Technology sheet:

Calculations can be done for different Technology levels, which are management systems with more or less efficient use of fertilizer nutrients, more or less use of biocides, labour, machinery etc. These factors can be entered in this sheet or can be entered through the Technology form (in main menu, choose 'select LUTs, LMUs, target yields, technology levels etc.' and go to the Technology form). Note that these factors apply to all LUT-LMU combinations. The data in the sheet are (from top to bottom in the sheet) :

- a.** yield level (low or high): this indicates for each technology which target yields (low or high from respectively LUT_LY or LUT_HY sheets) are used (see no. **4g**);
- b.** relative nutrient recovery fraction (see also no. **3q**) for fertilizer N, P and K: this is multiplied with the recovery fraction (i.e. 1.0 – loss fractions from Nutrient sheet); for improved fertiliser application methods a value above 1.0 can be entered;

- c. biocide use: default values are set to 1.0; mean applications per crop type are given in Crop sheet (see above, no. **3u**); for environment friendly technologies (e.g. IPM), values lower than 1.0 can be entered;
- d. yield-loss fraction: default is 0.0 but it can be set higher for technologies with poor crop protection management;
- e. relative labour input: default is 1.0; for technologies with more or less mechanization, the labour input is less or more, respectively than the standard labour input as specified in the Crop sheet; hence, this relative labour input is then set to lower or higher values than 1.0;
- f. water use by evapo-transpiration: default is 1.0; for inefficient systems and irrigation application methods the value can be set higher than 1.0; actual water use by evapo-transpiration is equal to this technology-related correction factor times yield level-related correction factor (see no. **9c**) times KC value (see no. **3k**) times reference evapo-transpiration (see no. **7k**);
- g. current and future systems: *current* systems are mainly of interest for reproducing nutrient cycling and fluxes in representative field trials and mean farming conditions, as in these systems the actual fertiliser nutrient applications are given as inputs; in *future* systems, fertiliser requirements are outputs of the model calculations, based on crop's nutrient uptake for the target yield minus the natural nutrient supply, divided by the recovery fraction of applied fertilisers. For more information on the differences between current and future systems, see beginning of **10. Nutrient sheet**;
- h. labour costs for different operations: these costs are given in currency units per labour day and may be specified for each group of operations and type of technology, if data are available;
- i. input costs: costs of fuel, machinery rent, animal rent and irrigation (per m³);
- j. currencies used for respectively inputs and outputs and the year(s) for which the prices of inputs and outputs (i.e. product prices) apply;
- k. relative input: for technologies with more or less mechanization, the relative use (compared to the standard use as specified per crop type in the Crop sheet (see no. **3 m.**)) of fuel, machinery and animals is given;
- l. limit on fertiliser use: for each fertiliser type and technology the maximal application (kg fresh weight per year per crop per ha) can be specified.
For more information on the Technology sheet, see DOC p. 41-42 (note that the Technology-sheet is partly changed).

9. Efficiency sheet:

It can be assumed that sometimes the efficiency of input use is changing with the relative yield level (with the reference yield being the potential yield for the crop type as specified in the Crop sheet (see no. **3c**)). These yield-related efficiencies can be entered in the efficiency sheet or can be entered through the yield-efficiency form (in main menu, choose 'yield-related efficiencies'). Note that these factors apply to all LUT-LMU combinations. The yield related efficiencies (see also **Section 2.2 no. 4**) relate to:

- a. fertiliser nutrient (N-P-K) applications: default is 1.0; if at high yield levels and thus high nutrient applications the recovery fractions are reduced in field experiments due to the larger risk of e.g. leaching, the efficiencies might be

reduced; for example, at 50% yield level the recovery fraction may be multiplied with 1.0, at 75% level the recovery fraction is multiplied with 0.9, and at 100% level with 0.8;

b. biocide use: standard values specified per crop type are in the Crop sheet (see no. **3u**); default is 1.0; if based on field experiments a relationship can be established between relative yield level and biocide use (e.g. more biocides required at high yield levels), the use factors may be adjusted: e.g. linear relationship like assumed here, with no biocide use at the lowest yield level (thus, 0%, 0.0, 25%, 0.5, 50%, 1.0, 100%, 1.0);

c. water use: default is 1.0; the use factors may become more than 1.0 if for example, high yield levels require more irrigation water (e.g. more percolation required to avoid risk of temporary drought or salinity); actual water use by evapo-transpiration is equal to this correction factor times technology-related correction factor (see no. **8f**) times KC value (see no. **3k**) times reference evapo-transpiration (see no. **7k**).

10. Nutrient sheet:

The data in this sheet strongly determine the nutrient inflows and losses and the nutrient cycling in the soil. In the main menu, choose 'Nutrient flow diagram' to have an overview of the calculated nutrient cycling for each selected LUT-LMU-Technology combination. This diagram shows that calculations of nutrient uptake, nutrient cycling in soil, nutrient recycling of crop residues, and fertiliser nutrient requirements are complex. Note that these calculations can be done in partly different ways for current and future systems, as described in the following.

In *future* systems, the target yield is specified by the user and determines the nutrient uptake by the crop (as calculated with the QUEFTS system). In this system, the fertiliser requirements are calculated from crop's nutrient uptake minus the natural nutrient supply, divided by the recovery fraction of applied fertilisers. The natural nutrient supplies by mainly biological fixation, runon, and P and K dissolution/mineralisation, and in precipitation are specified in the Nutrient sheet and also the loss fractions due to fixation, leaching, etc. Note that these nutrient supplies and loss fractions are used for all LUT-LMU-Technology combinations in a TechnoGIN run. For different LMUs different soil nutrient supplies may be entered in the LMU sheet, which may be based on unfertilised representative (long-term equilibrium) field trials. If this is done, the other natural nutrient supplies may be set to zero to avoid double counting.

The recovery fractions (i.e. 1.0 - loss-fractions) for applied fertiliser nutrients are corrected by technology (see above no. **8b**), yield-related (see no. **9a**) and crop-related correction factors (see no. **3q**: e.g. lower recovery fraction for short-duration crops compared to long-duration crops). The distribution of nutrient recycling from crop residues over mulch (i.e. in soil), burnt, and fodder (for animals) fractions is specified in the LUT-sheet (see no. **4e**). For more information on the nutrient cycling calculations, see DOC p. 17-26. The recovery fractions for recycled nutrients are assumed to be similar to those for applied fertiliser nutrients, except for the technology correction factor that is left out.

In *current* systems, the actual fertiliser nutrient applications are entered and not calculated. These nutrient (NPK) applications are specified for each crop type-LMU combinations in the Crop sheet (see no. **3x**). If no data are specified, a zero application is assumed. The natural soil nutrient supplies and the target yields are entered in the same way as described above for future systems. The target yield and hence, the with QUEFTS calculated crop's nutrient uptake can be based on mean yield levels from representative field experiments with similar fertiliser applications. Note that if the entered fertiliser nutrient application is low compared to the target yield level and thus the crop's nutrient uptake, the inorganic nutrient balance (see Nutrient Flow Diagram after a run for the current situation) becomes negative. This indicates that soil nutrient supply is depleted and that there is no long-term equilibrium between nutrient inputs and outputs (i.e. the cropping system is not sustainable).

The main data in the Nutrient sheet are (from top to bottom in the sheet):

a. nutrient loss fractions: for applied fertiliser nutrients to soils and also for recycled nutrients from crop residues, the loss fractions are specified in this sheet; these fractions are partly dependent on clay content of the soil and the amount of precipitation, which factors determine the risk for leaching, making them more universally valid. The total loss fraction for nitrogen is equal to the sum of the loss fractions by leaching, denitrification, and ammonia volatilization. Note that for anaerobic (in wet rice) and aerobic conditions, the loss fractions are different. The total loss fraction of potassium is the sum of the loss fractions by leaching and fixation. The recovery fraction of available nutrients for crop uptake is calculated as 1.0 minus the total loss fraction. This recovery fraction may be corrected by technology-related, yield-related and crop-related correction factors (see no. **8b**, no. **9a** and no. **3q**).

The loss fractions and the resulting recovery fractions may be checked by running a current system (see above), in which the actual fertiliser nutrient applications and the actual yield levels are specified. Another option is to derive the recovery fraction of applied nutrients from fertiliser trials and to compare this with (1.0 - total loss fraction). Finally, it is possible to leave out all loss fractions (by setting them to '0.00' in this sheet) and to use only the leaching fractions for nitrogen and potassium, which fractions are then assumed to be similar to the total loss fraction and are made identical to (1.0 – observed recovery fraction);

b. nutrient recycling data: these data generally need not to be changed, except for the fraction of consumed fodder; crop residues are partly burnt, used as fodder and applied as mulch (as specified in LUT sheet, see no. **4e**); the fractions of nutrients that are lost during nutrient recycling, are specified here, i.e. 80% of nitrogen in burnt crop residues and 50% of all nutrients in consumed residues (hence, 50% of these nutrients return as manure); recycled nutrients may be immobilized, but we assume this nutrient immobilization to be nil in the long term; efficiency of the nutrient recycling from ash, mulch and manure might vary but can be assumed to be one (i.e. no additional nutrient losses);

c. nutrient inflows: natural nutrient supplies from precipitation, biological fixation, irrigation water, sedimentation, dissolution, capillary rise, and run-on.

The total nutrient inflow value may roughly correspond with the net nutrient uptake by crops in unfertilised long-term field trials; if the natural long-term nutrient supply is specified per LMU in the LMU-sheet (see no. 7c), these natural nutrient inflows may be set to zero to avoid double counting;

d. other nutrient losses: nutrient losses by run-off are generally set to zero, as they are incorporated in the natural long-term nutrient supply (see no. 7c), being the result of nutrient inflows (see above) minus nutrient losses;

e. recovery fraction boundaries: correction factors for the recovery fractions of applied nutrients are applied which are specified per technology, yield level and crop type (see no. 8b, no. 9a and no. 3q.); these factors may together lead to too low or too high values for the recovery fractions; hence, minimal and maximal values for the recovery fractions are given here which need not to be changed;

For more information on the nutrient inflows, recycling, and losses, see DOC p. 17-24 (note that the Nutrient sheet is partly changed);

f. water balance: KC value for evapo-transpiration (see no. 3k) from fallow land is specified here (e.g. 0.3); for wetland rice, the additional water use (compared to upland cropping) is entered here, being estimated at, for example, 60 cm in total for a cultivation period of 120 days (i.e. 50 mm per decade) due to additional water losses for puddling, flooding the fields and the resulting increase in downward water flow.

11. Biocides sheet:

The price levels per year per biocide type and the factors that determine the environmental pollution due to biocide use are specified in this sheet. In the Crop sheet, the type and amount of biocides per crop type are specified (see no. 3u). The Biocide Residue index (Pathak et al., 2001) is applied in TechnoGIN as indicator of environmental pollution. This index is calculated as follows:

$BRI = \text{Biocide (g ha}^{-1}) * \text{active ingredient fraction (kg l}^{-1} \text{ or kg kg}^{-1}) * \text{Toxicity index} *$

$\text{Persistence index} / 100$

with Toxicity index = 10, 5, 2 and 1 (i.e. converted code) for respectively, EPA/WHO toxicity classes I, II, III and IV and

$\text{Persistence index} = \text{duration (or half-time) in soil in days} / 30$ with

$1 \leq \text{Persistence Index} \leq 30$

Most values for Toxicity classes and for Duration in soil can be found on <http://ace.ace.orst.edu/info/extoxnet/pips/ghindex.html> and

http://www.pesticideinfo.org/Search_Products.jsp. Note that if part of the indexes is not known and is missing, BRI is not calculated or is underestimated.

So a rough estimate for the indexes is better than no values.

The data in the Biocides sheet are (from left to right in the sheet):

- a.** biocide code, type and description (note that the shown data are for biocides applied on main crop types on clay soils in the Netherlands (KWIND, 2009));
- b.** active ingredient in the biocide;
- c.** concentration of the active ingredient (in kg/kg or kg/l) in the biocide;
- d.** duration (or half-time, in days) of the biocide in a soil;
- e.** EPA/WHO index (i.e. toxicity class) and next, the converted code for the toxicity index;

- f. price per biocide type per year (note that the prices are for biocides applied in the Netherlands (KWIN, 2009); inflation is estimated at 3% per year).

12. Fertiliser sheet:

The composition of the applied fertilisers, the effectivity of applied nitrogen, phosphorus and potassium, and the prices per fertiliser (as dry material) are specified in this sheet. In particular in organic fertilisers as animal manure, a much larger fraction of the applied nitrogen may be lost by ammonia volatilisation or nitrogen leaching due to a possibly poor timing of N-mineralization in soil versus the time course of crop's nitrogen uptake. These losses may result in, for example, a halved effectivity for nitrogen application in organic fertilisers compared to that in inorganic fertilisers.

The data in the Fertilisers sheet are (from left to right in the sheet):

- a. fertiliser code and name;
- b. dry matter content of the fertiliser (in kg dry matter / kg fertiliser);
- c. N, P and K concentrations in fertiliser dry matter (in %; i.e., $100 * \text{kg N-P-K} / \text{kg dry fertiliser}$);
- d. Effectivity of N, P and K in applied fertiliser (i.e., ratio of available N, P or K per resp. applied N, P or K for organic fertilisers compared to that ratio for inorganic fertilisers);
- e. price per 50 kg bag of fertiliser as dry material in different years.

Note that the calculation of the type and amount of applied fertilisers is done in an optimisation procedure (for cost minimalization) using the Excel Solver, as described in DOC p. 31. This calculation, using the data as specified in this sheet, can be seen in TechnoGIN_EU_v???.xslm (where ??? indicates the version number), Fertiliser sheet.

13. Currencies sheet:

As many currencies show large exchange fluctuations over the years, the exchange rates of the Dollar versus the Euro and versus a number of other currencies (as used for input and product prices; selection of the used currency is done in the Technology sheet (see no. 8j)) can be specified here for a number of years.

4 Simple example and Output overview

We will describe here a simple example how to apply TechnoGIN and will also specify the contents of its main output files. First, use 'TechnoGIN_EU_v???.xslm' (where '???' indicates the version number) with the data file 'TechnoGIN-YourRegion.xlsx'. In the main menu choose 'Yield-related efficiencies'. Set all correction factors to 1.0, hence the relative yield level has no effect on the recovery fraction of applied nutrients, the biocide use and the water use. In the main menu, choose 'select LUTs, LMUs, target yields, technology levels etc.'. Select in LUT-form Wheat winter (Ww), in LMU-form Loam (Lo) and Sand (Sa), and in the Change yields-form enter yields of 8 and 10 tons grain yield (air dry) per ha for low and high yields on Loam and 6 and 7.5 tons grain yield per ha for low and high yields on Sand. In the Technology-form, choose technologies A and B for four combinations (with respectively, Lo and Sa). Technology A is set to Current system with low yields and Technology B is set to Future system with high yield (see **Section 3 no. 8g**). In the Technology-form, you have to check the different correction factors (see Section 3 no. 8 for related information in Technology sheet) for the two technology levels: all factors for nutrient, biocide, water and labour inputs for both Technologies A and B are set to 1.0, factors for losses are set to 0.0, for labour costs, fuel costs, machinery rent, animal rent, and irrigation the costs are set to respectively, 300 (all labour operations), 0.7, 12, 0.0, and 0.0, and for currency we use Euro (note that these data were mainly derived for The Netherlands) and as year 2010. Press 'Run TechnoGIN' button to do the calculations.

The generated output will be written to various sheets in 'TechnoGIN_EU_v???.xslm' which are discussed below.

The output in **OUTPUT1 sheet** of 'TechnoGIN_EU_v???.xslm' is produced for the four combinations of the monocrop of winter wheat, which are the current and the future systems (with respectively low and high yield level) and the two LMUs. This output consists of (from left to right):

- a. Codes per run for LUT, Current or future system, Technology and LMU are given and the target yields;
- b. monthly evapotranspiration values (over 24 months but for other rotations over maximally eight years) as calculated from the reference evapotranspiration (see Section 3, LMU sheet, no. **7k**) times the KC values in Crop sheet (see Section 3, no. **3k**);
- c. monthly labour requirements: labour requirements per hectare of winter wheat with 0.3 labour days for land preparation in September, 0.15 labour days for crop establishment, 0.15 labour days for crop management over the total growth period, and 0.8 and 1.0 labour-days for harvesting 8 and 10 tons per ha on the Loam soil (i.e. 8 ton per ha for low target yield on Loam soil times 0.1 labour-days per ton), as based on data in the Crop sheet for a winter wheat crop (Section 3, Crop sheet, no. **3l**); note that the crop duration of winter wheat is set here at 30 decades in total, of

which decade 1 is used for land preparation, decade 2 is used for crop establishment, decades 3-29 are used for crop management, and decade 30 is used for harvesting;

d. fertiliser nutrient applications, nutrient balances of the system and nutrient losses as calculated, are given here for the monocrop of winter wheat, but can be given separately for maximally fifteen crops in the rotation; in the current system (Technology level A) the fertiliser applications are entered in the Crop sheet for the different LMUs (Section 3 no. **3x**); in the future system (Technology level B) the fertiliser requirements are calculated in dependence of the crop's nutrient uptake, the natural soil supply and the recovery fraction of applied nutrients (see Nutrient flow diagram for more information); the nutrient balances may become positive in the current system if the target yield level is low in comparison to the fertiliser application (see N_bal1) and may become negative if the opposite applies (not here for N_bal1 but partly for P_bal1 and K_bal1); for nitrogen losses both leaching losses (see N_lch1) and losses to the air (through volatilization and denitrification, see N_gas1) are given which are dependent on the specified loss fractions (in Nutrient sheet);

e. purchase of fertilisers: with the optimization model (see Fertiliser sheet) the total amounts of fertiliser nutrients that are to be bought for the total rotation (thus for maximally 15 crops but here for only winter wheat), are calculated; these amounts are higher than the required fertiliser nutrient applications (see **d.** above), because the composition of the fertilisers is never optimal, compared to the required nutrient composition; next, for ten different types of fertiliser as specified in the Fertiliser sheet, the required fertiliser amounts (note that the amounts are not dry material for organic fertilisers) are given;

f. biocides: the total amounts of active ingredients in insecticides, fungicides and herbicides (incl. growth regulators) as applied for winter wheat cropping, are given here; these biocide amounts are given per crop and can be calculated separately for maximally 15 crops in the rotation; the biocide amounts are based on the biocide use specified per crop type in the Crop sheet (Section 3 no. **3u**); next, the Biocide Residue Index (see Section 3, Biocides sheet, no. **11** for the approach) is calculated per crop separately (maximally for 15 crops in the rotation) from the applied amount of biocides;

g. Economic analysis: from the specified input use (see Crop sheet) and the costs per unit input use (see Technology, Biocides, Fertiliser and Crop sheets) the costs of the inputs (i.e. labour, biocides, seed, fuel, machinery and animal rent, irrigation fee, and other costs which consists of both Additional and Investment (per crop) costs) are calculated; the costs of applied fertilisers have been calculated with an optimization model (see **e.** above and see Fertiliser sheet); gross return is equal to the target yields times the farm-gate prices per yield unit (in Section 3, Crop sheet, no. **3v**); net return is equal to the gross return minus the total costs; net return exclusive the labour costs is also given; these economic results are given here for the two years with one winter wheat crop, but apply to the whole rotation with maximally 15 crops in eight years;

h. Water requirements per month: these required amounts of irrigation water are calculated from the monthly actual evapo-transpiration data (i.e. equal to technology-related correction factor times yield level-related correction factor (Section 3 no. **9c**; both correction factors are set to 1.0 here) times KC value (Section 3 no. **3k**) times reference evapo-transpiration (Section 3 no. **7k**)) minus the precipitation data; note

that for uplands where irrigation water is not available and for lowlands with high groundwater tables and no need for irrigation, these required amounts of irrigation water and the costs for these water amounts are still calculated; if these irrigation water costs should not be taken into account, the costs per m³ of irrigation water should be set to zero (Section 3 no. **8i**);

i. Current fertiliser nutrient applications (also indicated in case of future systems) on the different crops (here, for one crop of winter wheat but maximally for fifteen crops) in the rotation and recovery fractions of applied fertiliser nutrients.

CHARTS sheet: the results from the OUTPUT1-sheet are shown here as charts to compare results from two LUT-LMU-Technology combinations; monthly results are presented for the duration of the rotation (e.g. 2 years here and maximally 8 years) for evapo-transpiration, irrigation water requirements, and labour demand, and totals for the whole rotation are given for the different types of costs, and for gross return, net return and net return exclusive the labour costs.

ERRORS sheet: gives possible errors in a TechnoGIN run.

Crop Calendar sheet: for the different LUTs or crop rotations the growing seasons inclusive land preparation and harvesting are shown in the form; the seasons are generally indicated as dark green, but red if there is an overlap between subsequent crops; if such overlap does occur for a selected LUT, the TechnoGIN run is stopped and the overlap is shown.

In this TechnoGIN version for temperate climates, the maximum cultivation period for crop rotations of maximally 15 crops is 8 years (i.e. 288 decades). If overlap between subsequent crops in a crop rotation (i.e. LUT) does occur, the start dates for the crops in the LUT sheet should be changed and/or the length of the cultivation periods as defined in the Crop sheet (Section 3, see no. **3j**, should be shortened.

The output in **OUTPUT2-sheet** is used to create the Nutrient flow chart (see main menu) and consists of:

a. Nitrogen balance: for the maximally 15 crops (here, only winter wheat) in the rotation, all calculated nitrogen inputs and outputs are given here; a complete overview is given in the Nutrient flow diagram; the nitrogen inputs/outputs are fertiliser N application (N_{fert}), N-inflow in irrigation water (N_{irr}), wet and dry N-deposition (N_{dep}), N-fixation by free-living bacteria (N_{fix}), symbiotic N-fixation (N_{sym}), crop's N uptake (N_{upt}), nitrogen removed in harvest (N_{har}), nitrogen lost from burnt residues (N_{bur}), nitrogen in crop residues used as fodder (N_{fod}), nitrogen removed in animals (N_{ani}), nitrogen in manure (N_{man}), nitrogen returned as ash after burning crop residues (N_{ash}), nitrogen in crop residues (N_{res}), nitrogen mineralization as a result of ploughing in (mulching) of crop residues and manure (N_{min}), nitrogen immobilization (N_{imm}), nitrogen sedimentation (N_{sed}), nitrogen lost by erosion (N_{ero}), nitrogen lost by runoff (N_{rof}), nitrogen inflow by run-on (N_{ron}), nitrogen inflow by capillary rise (N_{cap}), nitrogen losses by denitrification (N_{den}), ammonia-N volatilization (N_{vol}), nitrogen losses by leaching (N_{lch}), and long-term natural soil nitrogen supply per crop growth period (N_{soil});

b. Phosphorus balance: a complete overview is given in the Nutrient flow diagram; for phosphorus inputs/outputs, the list and shortenings are similar to those above for nitrogen; in addition, there are phosphorus fixation by the soil (P_{fix}), dissolution of phosphorus from soil (P_{dis}), and long-term natural soil phosphorus supply per crop growth period (P_{soil});

c. Potassium balance: a complete overview is given in the Nutrient flow diagram; for potassium inputs/outputs, the list and shortenings are similar to those above for nitrogen; in addition, there are potassium fixation in the soil (K_{fix}), dissolution of potassium from soil (K_{dis}), and long-term natural soil potassium supply per crop growth period (K_{soil}).

Note that the long-term natural soil nutrient supply is often based on long-term unfertilised field experiments and is the summary result of all the other mentioned nutrient inflows and losses; this means that if this long-term soil nutrient supply is used (entered in LMU sheet, see Section 3 no. 7c), the other nutrient inflows should generally not be used to avoid double-counting.

OUTPUT3 sheet: Data are given for 10-day periods (in total 288 dekades for a rotation of maximally 8 years) for respectively, labour demands, rainfall and irrigation water requirements.

Other output sheets (i.e. D_.. sheets): for use in other GAMS farm optimization models than FSSIM, a number of output sheets are created. For example, the D_yield sheet contains the yield data per crop for the different LMU-LUT-Technology combinations. These sheets contain the same model results as mentioned above in the two main output files (i.e. OUTPUT1 and OUTPUT2); however, these output sheets are organized in a different way, to allow direct use as input for GAMS modelling exercises.

The following sheets for GAMS are produced:

a. yield: for different crops (headings of columns) the yields (air dry) are given for the four different LMU (Lo or Sa) - LUT (Ww=winter wheat) – Technology (A or B) - Current or Future system (C or F) combinations (in rows);

b. biocost: biocide costs per crop (winter wheat in this case, but fifteen crops (S1 to S15) are maximally possible per crop rotation) for the four combinations;

c. bioindex: Biocide Residue Index for the four combinations (see Section 3, no. 11 Biocides sheet);

d. biotypes: amounts of active ingredients in the different applied biocides for the four combinations and for each crop in the rotation (maximally 15 crops --> S1 to S15);

e. fertuse: fertiliser nutrient (N-P-K) use for the four combinations and for each crop (S1 to S15) in the rotation;

f. ferttype: amounts applied (kg fresh weight of particularly organic fertilisers per ha) of the different fertilisers in the total rotation for the four combinations;

g. nloss: nitrogen losses through leaching and as gases (by denitrification and ammonia-N volatilization) for the four combinations and for maximally 15 crops (S1 to S15) in the rotation;

h. nutsurplus: results of nutrient (N-P-K) balances for the total rotation for the four combinations; the nutrient balances separately per crop are not given here but can be

found in the OUTPUT1 sheet (see above the information about the OUTPUT1 sheet at point **d.**);

- i.** animal: amounts of nutrients removed in animal products for the four combinations for the total rotation;
- j.** labuse: monthly labour demand in labour-days per ha for the four combinations over the total rotation;
- k.** labdecad: labour demand per decade in labour-days per ha for the four combinations over the total rotation;
- l.** ET= monthly actual evapo-transpiration in mm for the four combinations over the total rotation ;
- m.** watreq= monthly demand for irrigation water (= actual ET minus precipitation) in m³ per ha for the four combinations over the total rotation;
- n.** watreqdecade= demand for irrigation water (= actual ET minus precipitation) per decade in m³ per ha for the four combinations over the total rotation;
- o.** fertcost: fertiliser costs per crop for the four combinations over the total rotation (maximally 15 crops -->S1 to S15);
- p.** other: non-labour inputs such as kg seed, l fuel, hours of machinery and animal use, and m³ of irrigation water, all per ha for the four combinations and the total rotation;
- q.** profits: gross return from harvested crops, the costs for labour, biocides, fertilisers, fuel, irrigation fee, machinery and animal rent, and the investment and additional costs, and the resulting net return and net return exclusive labour costs per ha for the four combinations and the total rotation.

The **Qsensitivity sheet** can be used for calculating with the in TechnoGIN applied QUEFTS-system (Janssen et al., 1990) the nitrogen, phosphorus and potassium uptake by a specified crop type and for doing a sensitivity analysis. This can be done by choosing from the main menu 'QUEFTS' and next, selecting a crop and target yield. This sensitivity analysis may improve understanding of the QUEFTS-approach for calculating the crop's nutrient uptake (see DOC p. 14-16).

The QUEFTS sheet: This shows the last result from the optimizations (with Excel Solver) of the N, P and K uptake by the crop required for a given target yield, as calculated with the QUEFTS approach. For more information on the QUEFTS calculations, see Section 2.2 **point 7**, see DOC p. 14-16, and Janssen et al. (1990).

The Fertiliser sheet: This shows the last result of optimizing the use of the different available fertilisers to attain the required fertiliser N, P and K applications for the given Crop-LMU-Technology combination. The used input data for the available fertilisers are given in the Fertiliser sheet, as described in Section 3, no. 12. These calculations of the types and amounts of applied fertilisers are done in an optimization procedure for cost minimalization, using the Excel Solver, as described in DOC p. 31.

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Annex A SOLVER problems

November 2011

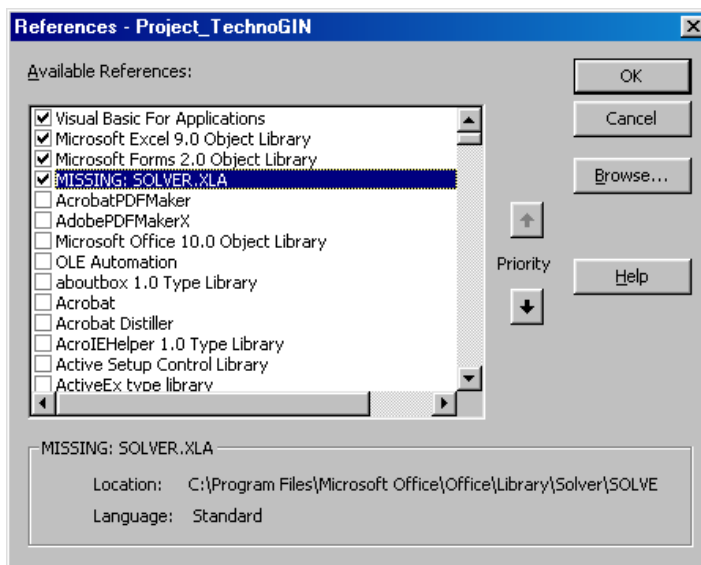
If the following message appears after starting a run, then follow the instructions below:



Click OK.

In the Excel menu select 'View', next select 'Macro', next choose 'View Macro', next choose from the list 'Edit TechnoGIN'

You are now in the Visual Basic editor menu and select 'Tools' and select 'References'. You see now a list of available references with "SOLVER.XLA" or "MISSING: SOLVER.XLA" checked:



Click the checkbox for 'MISSING: SOLVER.XLA' to remove the check and click OK. This means that the Solver is not available and should be installed.

Go to Excel by clicking in the Windows bar (on top) on 'File' and next 'Close and return to Excel'.

In the Excel menu, select 'File', select then 'Options' and next 'Add-Ins', and choose from the list of Add-ins 'Solver-add-in', and next click 'Go' and then OK for Solver Add-in.

If you go back to the Visual Basic editor and click 'Tools' in the Visual Basic editor menu and next, select 'References', you will see the list of available references. In this list the Solver (or 'SOLVER.XLA') should now be checked. You can then go back to Excel and activate the TechnoGIN sheet to start a new run.