



An introduction to the Technical Coefficient Generator for land use systems in Tigray

Developed within the project Policies for Sustainable Land Management in the Ethiopian Highlands

H. Hengsdijk



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Abstract

This report describes a Technical Coefficient Generator (TCG) developed within the project 'Policies for Sustainable Land Management in the Ethiopian Highlands', a collaboration of the International Food policy Research Institute (IFPRI), Wageningen University and Research Centre (WUR), the International Livestock Research Institute (ILRI) and Mekelle University (MU) from Ethiopia. This TCG is a model that enables to calculate inputs and outputs (IO's) of many different types of 'alternative' land use systems for conditions prevailing in Tigray, Ethiopia. Here, 'alternative' implies that land use systems are designed to deal with natural resource depletion, and low soil and labour productivity that characterise many current land use systems in Tigray. Alternative land use systems are identified in a target-oriented way: First target outputs (e.g. yields) of land use systems are determined based on the prevailing physical conditions and objectives, and subsequently, the inputs required for realising these target outputs. The so-called *keushets* (communities) Gobo Deguat and Tegahne in Tigray have been used as case study areas for developing the TCG. The TCG enables to generate IO's of five different types of cropping and animal systems, and feed menus facilitating to link animal and cropping systems. The five systems are: (arable) cropping, bovine, goat, sheep and oxen systems.

Main features of this TCG compared to previous versions developed for other regions are:

- 1) The definition of cropping systems as rotations consisting of four crops enabling to model nutrient turn-over;
- 2) Water-limited crop yields simulated with the dynamic crop growth model WOFOST are used as target yields;
- 3) Two modules describe the nitrogen and phosphorus dynamics of cropping systems;
- 4) Calculation rules determining the nitrogen content of crop residues (quality) as function of yield level;
- 5) Calculation rules determining the yield level as function of soil and water conservation measures (bunds).

The TCG-Tigray offers a generic framework to integrate different types of land use data and knowledge required to quantify alternative land use systems in terms of inputs and outputs. Many data are based on published sources while relevant processes have been modelled using well-accepted approaches. Within the limited time horizon of the project and the data scarce environment, it was impossible to validate the model. The TCG contains probably one of the most extensive and accessible data- and knowledge bases on land use systems in Tigray. The structure of the TCG and modelling software (Excel and Visual Basic for Applications) leave ample scope for improvements with respect to the data and modelled processes. A copy of the TCG can be obtained from the author (huib.hengsdijk@wur.nl).

1. Introduction

This report is an introduction to the Technical Coefficient Generator (TCG) developed for Tigray, Ethiopia within the project ‘Policies for Sustainable Land Management in the Ethiopian Highlands’, a collaboration of the International Food policy Research Institute (IFPRI), Wageningen University and Research Centre (WUR), the International Livestock Research Institute (ILRI) and Mekelle University (MU) from Ethiopia. The project aims at identification of appropriate policy instruments stimulating the sustainable use of natural resources, alleviating poverty and improving livelihoods in Tigray. The project is loosely linked to the parallel program RESPONSE, a joint effort of IFPRI-WUR (<http://www.sls.wau.nl/mi/Response/newsletter%201.pdf>). In this long-term program with similar aims but not restricted to Tigray, research and training of local students are combined. Results realised within the research project ‘Policies for Sustainable Land Management in the Ethiopian Highlands’ are used in RESPONSE as benchmark or as direct research input.

The TCG developed with the project ‘Policies for Sustainable Land Management in the Ethiopian Highlands’ enables to calculate inputs and outputs (IO’s) of a great number of different types of ‘alternative’ land use systems geared towards prevailing conditions in Tigray. Here, ‘alternative’ implies that land use systems are designed to deal with natural resource depletion, and low soil and labour productivity that characterise many current land use systems in Tigray. Using local objectives and available natural resources as a starting point, new alternative land use systems are identified in a target-oriented way (Hengsdijk & Van Ittersum, 2002). This means that first target outputs (yields) of land use systems are determined based on the prevailing physical conditions and objectives, and subsequently, the inputs required for realising these target outputs. Here, a land use system is defined as a land use type and a well-defined physical environment that is uniquely characterised by its inputs and outputs, and possibly land improvements such as irrigation. A land use type is a combination of a crop or animal type and production technique (e.g. the use of inputs). The physical environment is defined as a physical area of land that is uniform in its climate and soil characteristics. Inputs and outputs of land use systems are expressed per hectare per year.

The TCG developed within this project is a model that helps to structure basic biophysical data and knowledge on land use, and to design and quantify inputs and outputs of alternative land use systems (Hengsdijk *et al.*, 1999). It consists of different types of data sets and calculation rules to quantify various processes underlying input-output relationships. Land use systems are quantitatively characterised with these input-output relationships. The so-called *keushets* (communities) Gobo Deguat (13°40’N, 39°25’E) and Tegahne (13°45’N, 37°41’E) in Tigray have been used as case study areas for developing the TCG. The TCG enables to generate IO’s of five different types of cropping and animal systems, and feed menus linking animal and cropping systems. The five systems are: (arable) cropping, bovine, goat, sheep and oxen systems.

The structure of the TCG-Tigray, calculation rules and organisation of data are largely based on three TCGs developed for Mali (Hengsdijk *et al.*, 1996) and Costa Rica (Hengsdijk *et al.*, 1998; Hengsdijk, 1999). Due to biophysical differences, new research questions and available data, important changes were made with respect to these existing TCGs. This document describes the differences and adjustments that have been made with respect to the earlier developed TCGs. The main differences can be grouped according to differences in file structure and organisation, the type and definition of land use systems, and applied calculation rules. As major changes only occurred with respect to the modelling of annual cropping systems, only related aspects get attention in this document.

Major changes with respect to the calculation rules in the TCG-Tigray include the incorporation of land use systems defined as a four-year crop rotation, water-limited crop yields simulated with the dynamic crop growth model WOFOST (section 4.1) and two modules describing the nitrogen and phosphorus dynamics of land use systems (section 4.2.2). The nitrogen module is based on Wolf & Van Keulen, 1989) and the phosphorus module on Wolf *et al.* (1987). Both modules operate independent of the TCG, i.e. they only estimate nutrient dynamics of land use systems based on target yields but do not calculate the dynamics in other inputs and outputs. The conventional, static approach to estimate

nutrient requirements of land use systems (section 4.2.1) is extended with calculation rules to determine the nitrogen content of crop residues (quality) as function of yield level. In a previous TCG version, the quality of crop residues was fixed for all yield levels (Hengsdijk *et al.*, 1996). Also the erosion module went through a major revision (section 4.3). Labour and implement requirements have been adjusted to operations related to the prevailing conditions in Tigray, such as construction and maintenance of bunds (section 4.4).

1.1 Installation of the TCG

Preferably, Excel should be configured in manual calculation mode while recalculation before saving should be switched off. The generation of cropping systems contains circular calculations, which the automatic and manual calculation mode of Excel cannot handle very well. A special macro has been written to recalculate worksheets of cropping systems (section 2.2.2). In the Tools menu of Excel, under Options in the Calculation tab, the required mode can be set.

The TCG for Tigray exists of the following files:

ANN_RESULT.XLS	IO's of arable cropping systems are written to this output file
CLIMATE.XLS	Rainfall data
COW_RESULT.XLS	IO's of bovine animal systems are written to this output file
CROPA_BASE.XLS	Basic annual crop data and yield data simulated with WOFOST
GOT_RESULT.XLS	IO's of goat animal systems are written to this output file
IO_ANN.XLS	IO's of arable cropping systems are generated in this file
IO_COW.XLS	IO's of bovine animal systems are generated in this file
IO_GOT.XLS	IO's of goat animal systems are generated in this file
IO_MEN.XLS	IO's of animal menus are generated in this file
IO_OXE.XLS	IO's of oxen systems are generated in this file
IO_SHP.XLS	IO's of sheep systems are generated in this file
LIST.XLS	Definition criteria of all types of land use systems and visual basic modules
MEN_RESULT.XLS	Animal menus are written to this output file
OXE_RESULT.XLS	IO's of oxen systems are written to this output file
SHP_RESULT.XLS	IO's of sheep systems are written to this output file
SOIL.XLS	Soil data

These files must be copied to a new directory on the hard disk C, for example, C:\TCG. When opening the file LIST.XLS for the first time, Excel may pop up with a message box indicating that the workbook contains macros. To enable the TCG work properly, the option 'Enable macro's' should be clicked. This Excel warning message can be turned off permanently in old Excel versions by selecting the Tools menu, click Options, and click the General tab. Subsequently, deselect the macro virus protection box. In new Excel versions, Macro must be selected in the Tools menu, and subsequently, the security level must be set to Low under the option Security.

When LIST.XLS has been opened as described, a dialogue box will appear asking to type the directory in which the TCG files are stored. After filling out the dialogue box, the directory will be stored in LIST.XLS and the TCG is ready to be used. At any moment the directory can be changed manually by pressing at the same time the keys [Ctrl+d] and the same dialogue box will appear to change the location of the files.

1.2 Starting the TCG

After the steps described in section 1.1, the TCG is ready to be used. A dialogue box will welcome you and tells you what type of action to perform. A next time you want to use the TCG, just open LIST.XLS and the welcome box will appear straight away (so, without the directory dialogue box described in section 1.1). The welcome box tells to press [Ctrl+t]. This will open a new box with 8 options (Fig. 1.1):

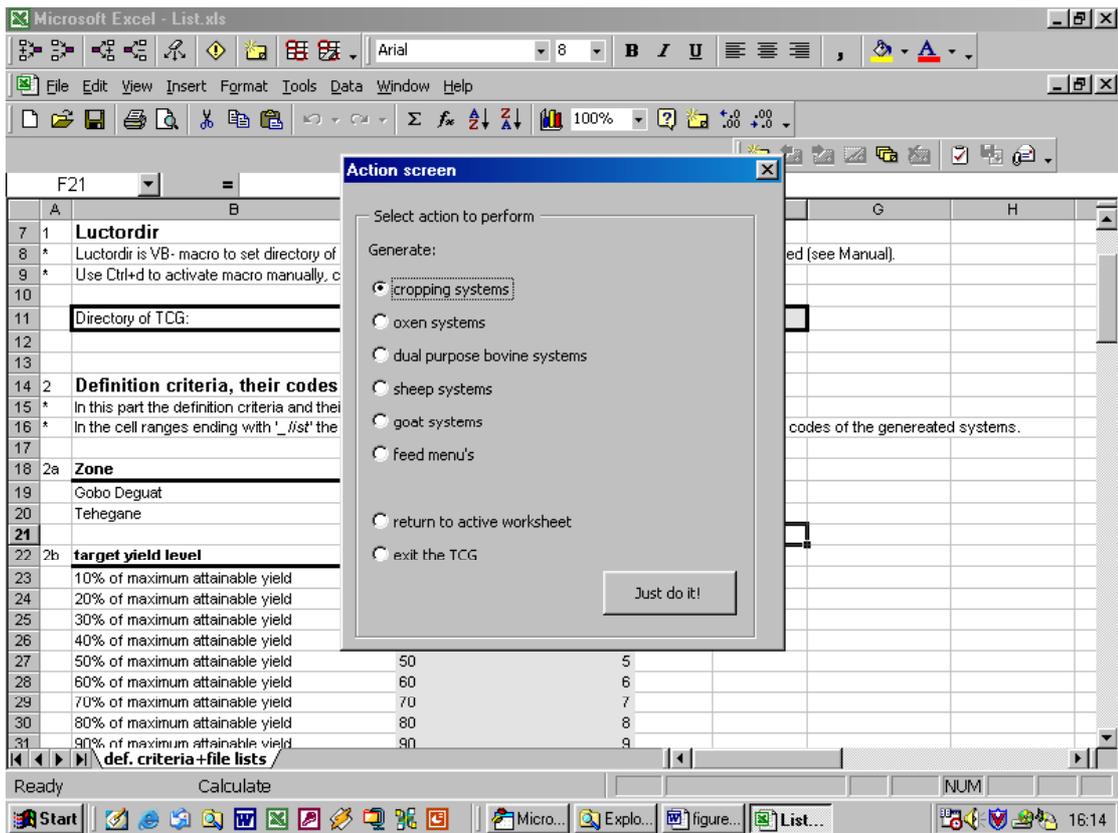


Figure 1.1. Dialogue box with the option buttons to select land use systems for which IO's can be generated. On the background a part of LIST.XLS in which the dialogue box is activated.

Click on one of the option buttons on the left of the dialogue box and click subsequently on the command button 'just do it' and the TCG will open all files required to generate IO's of the requested systems. If you want to switch from one system to another system, the TCG will close automatically the files not any longer required and open the new files required for generating IO's of the desired systems. This dialogue box need also to be activated for exiting the TCG. When exiting the TCG or changing the type of systems to be generated, Excel will ask to save any changes made to the files. You can ignore changes by choosing 'no' or choose 'yes' when you want to save changes made to files.

After the files are opened a new dialogue box will appear telling to press [Ctrl+s] to generate automatically land use systems using dialogue boxes with well-defined definition criteria, or to select first the inputs and outputs that need to be generated (section 1.3). If you press 'no', the content of the opened files can be reviewed or changed. At a later stage [Ctrl+s] can be pressed to start generating the IO's. After pressing [Ctrl+s] the dialogue boxes with definition criteria relevant for the specific land use system will appear one by one. The check boxes of the dialogue boxes have to be ticked to activate them (Fig. 1.2). This procedure is called the 'automatic' generation of IO's. After the last dialogue box with check boxes, the TCG will automatically generate all possible combinations of (selected) options and write the IO's to the output file of the system (Table 1.1). The TCG will pop up with a message box when it is ready with the calculations. This message box also shows the time required to generate the systems. The generated IO's can be viewed and analysed in the relevant output file and, for example, used as input for other types of models (e.g. Bouman *et al.*, 1998, 1999).

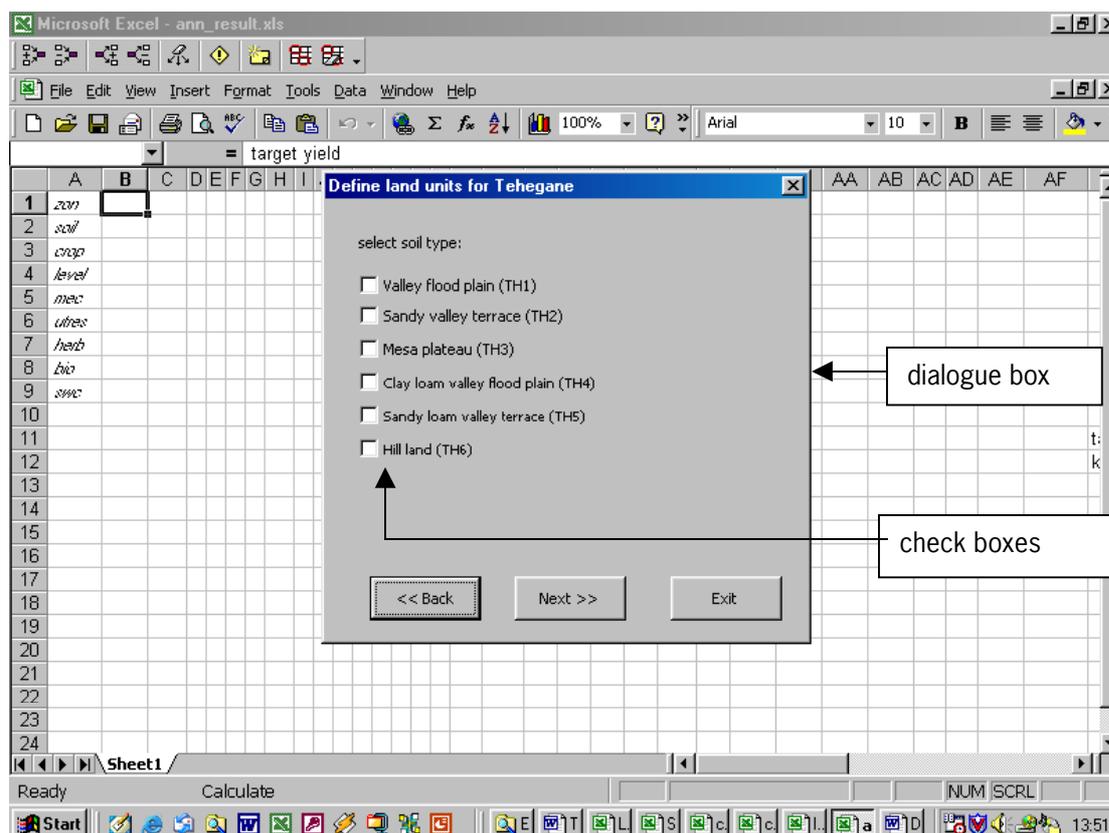


Figure 1.2. Dialogue box for selecting the soil types with check boxes. On the background ANN_RESULT.XLS in which the selected options for each definition criterion are recorded for cropping systems.

All definition criteria represented in individual message boxes can also be found in the IO-files (section 1.1.), for example, in IO_ANN.XLS[criteria]. Here, crop and management options for each criterion can be changed manually by inputting the corresponding number of the options in the green coloured cells and, subsequently, pressing [Ctrl+r] (Fig. 1.3). For other systems, the definition criteria are clearly indicated near the top of the corresponding IO-file. The options and their corresponding number for all definition criteria can be found in LIST.XLS (Fig. 1.4) but are also given in comments of the green cells (Fig. 1.3). Excel comments are indicated with a red dot in the right corner of cells. This method of defining systems is the so-called 'manual' generation of land use systems. The manual mode is required to define cropping systems consisting of different crops and crop residue strategies. The LP model used within the project 'Policies for Sustainable Land Management in the Ethiopian Highlands' for which IO's were calculated did not require crop rotations with different crops. Therefore, in the 'automatic' generation procedure activated with pressing <Ctrl+s>, selected crop and crop residue options are automatically inputted for all four crops in a rotation. IO's calculated in the manual mode can be viewed in IO_ANN.XLS[IO].

criteria	codes	input
zone	TG	1
soil type	TG1	1
crop type 1	TD	5
crop type 2	TD	5
crop type 3	TD	5
crop type 4	TD	5
yield level	100	10
mechanisation level	HM	1
residue use crop 1	STA	3
residue use crop 2	STA	3
residue use crop 3	STA	3
residue use crop 4	STA	3
weed control	HH	1
disease control method	HB	1
soil and water conservation	BUN	1

criteria	codes	input
intensity	IN	
year of sowing	av	
sowing date (julian day nr.)	197	
include labour requirements for bund construction in total labour requirements	no	
nutrient requirements covered by manure or fertilisers?	fertiliser	
assume 25 or 15% reduction in runoff by bunds (resulting in higher water-limited yields)	25	
fixed or dynamic recovery fraction (only for dynamic nutrient approach)?	no	
iterative calculations for nutrient balances, i.e. residual nutrients from crop 4 available in crop 1	yes	

Figure 1.3. The worksheet IO_ANN.XLS[*criteria*] in which cropping systems can be defined in manual mode (see text).

type of soil (Gobo Deguat)	soilTG_list	number
sandstone-sandy loam-bottom.terrace	TG1	1
sandstone-sand-valley.terrace	TG2	2
basalt-loamy sand-plateau	TG3	3
basalt-sandy clay loam-hilland	TG4	4
sandstone-sandy loam-midslope	TG5	5

type of soil (Teghane)	soilTH_list	number
sandstone-valley-flood plain	TH1	1
claye sandstone-valley-terrace	TH2	2
sandstone-plateau-mesa	TH3	3
claye sandstone-valley-mesa	TH4	4
sandstone-valley-terrace	TH5	5
sanstone-hill land-hill	TH6	6

type of annual crop	annual_crop_list	number
Hordeum vulgare - barley	HV	1
Pennisetum glaucum - millet	PG	2
Phaseolus vulgaris - pulses	PV	3
Sorghum vulgare - sorghum	SV	4
Triticum durum - wheat	TD	5

mechanisation level	mec_list	number
high mechanisation level	HM	1

Figure 1.4. Part of LIST.XLS in which the definition criteria and their options of all land use systems are listed including their corresponding number which need to be inputted in dedicated cell ranges of the calculation files, such as IO_ANN.XLS[*criteria*] shown in Fig. 1.3.

1.3 Generated inputs and outputs of cropping systems

Land use systems can be characterised by a great number of IO's. However, for many analyses and studies a selection of IO's is sufficient. Therefore, a macro is included to select first the required inputs and outputs of cropping systems before generating them. This macro can be activated by pressing [Ctrl+W] and is only operational for the automatic generation procedure. Most IO's are average values of four seasons, such as the nutrient requirements, which can be different among years due to nutrient turn-over (section 4.2.1).

For crop rotations consisting of different crops and/or crop residue strategies a complete list of IO's is available in IO_ANN.XLS[IO]. The IO's of each cropping year are listed. As these systems cannot be generated automatically, no special IO interface is available.

The automatically generated IO's are written to the output files in the same format for all types of systems. The first lines show the selected options, one row per definition criterion. At row 13, the generated IO's are written: In the first column a number keeps track of the generated systems, followed by columns with numbers corresponding with the selected options, followed by columns with option codes as shown in LIST.XLS, and after the cells containing 'VALUES:' the IO's are written. At the top of each column, the description or code of IO is given (Fig. 1.5).

At row 10 in the IO-file, two numbers indicate the total number of selected systems (in column C) and the total number of feasible systems (in column B). The latter can be smaller than the first, as the TCG automatically skips, for example, selected but infeasible crop-soil combinations in its calculation procedure.

Year	Soil	Crop	Residue	Management	...	target yield kg/ha	nitrogen lo: kg/ha	phosphoru kg/ha	potas kg/ha
1	200	TG				844.9	0.178332	7.622381	3.57
2	201	TG4	TG5			844.9	6.000249	10.14513	8.48
3	1	PV	SV	TD		89.8875	4.196047	0.396298	0.65
4	4	1	4	4	4	89.8875	6.565205	0.114045	2.88
5	5	1	4	5	5	1469.693	14.13397	9.907227	4.12
6	6	1	4	5	5	1469.693	20.3757	15.18408	12.6
7	7	1	5	3	3	165.0275	5.039196	0.642689	4.85
8	8	1	5	3	3	165.0275	8.016472	1.78178	8.05
9	9	1	5	4	4	38.0375	8.791041	0.522982	4.42
10	10	1	5	4	4	38.0375	11.6107	0.159306	7.37
11	11	1	5	5	5	377.145	13.52408	1.599995	9.75
12	12	1	5	5	5	377.145	19.29829	3.597954	17.8

Figure 1.5. Illustration of generated results in ANN_RESULT.XLS.

1.4 Software

The TCG is programmed in Excel and Visual Basic for Applications. Macros in Visual Basic have been written to support various actions that have to be repeated frequently. The most important macros can be activated using short cut keys (Table 1.2). With pressing [Alt+F11] the Visual Basic modules and their macros can be viewed and adjusted (section 2.2.2). All Visual Basic modules of the TCG are stored in LIST.XLS.

Table 1.2. Most important macros and their short cut keys.

Name of macro	Description	Short cut key to activate macro
Iter	recalculate worksheets for cropping systems	Ctrl + r
start_tcg	select type of activity; control of file opening/closing	Ctrl + t
iteroption	select nutrient requirement calculation procedure with/without residual nutrients from last crop in the rotation	Ctrl + y
headprogram	activate other macros to select, combine and calculate options	Ctrl + s
luctordir	set the directory of the TCG	Ctrl + d
name_head	define required IOs of cropping systems and writes names and units of IOs to RESULT_ANN.XLS	Ctrl + w

2. File organisation, structure and conventions

2.1 File organisation and structure

The TCG-Tigray enables to generate IO's of five different types of cropping and animal systems, and feed menus linking animal and cropping systems. The five systems are: (arable) cropping, bovine, goat, sheep and oxen systems. For generation of IO's of each type of system different files are required which is taken care of by the TCG as described in section 1.2.

The files required for each system include:

cropping systems	ANN_RESULT.XLS, IO_ANN.XLS, CLIMATE.XLS, SOIL.XLS, CROPA_BASE.XLS
bovine systems	IO_COW.XLS, COW_RESULT.XLS
oxen systems	IO_OXE.XLS, OXE_RESULT.XLS
sheep systems	IO_SHP.XLS, SHP_RESULT.XLS
goat systems	IO_GOT.XLS, GOT_RESULT.XLS
menu (systems)	IO_MEN.XLS, MEN_RESULT.XLS

In LIST.XLS, which is always required for generating IO's, this list with files can be found. Only for cropping systems more than two files are required. All other systems require a calculation file and an output file in which the calculated IO's are recorded using the automatic generation procedure described in section 1.2. The four animal systems and menu's are calculated according to the method described in Hengsdijk *et al.* (1996) and Bakker *et al.* (1996). The same files and data have been used as information on animals for Tigray was lacking. As differences in Tigray and West-Africa are assumed to be relatively small, this is a practical starting point to stimulate data collection and adjustment of calculation rules aimed at the situation in Tigray. The only difference with the files described in Hengsdijk *et al.* (1996) and Bakker *et al.* (1996) is that informative text and description of calculation rules are translated from French to English as much as possible. Also the difference in cells with data and calculation rules is indicated as described in section 2.2.

Most files contain one worksheet, only two files (IO_ANN.XLS and CROPA_BASE.XLS) contain more worksheets which is indicated by the tabs at the bottom of the screen (Fig. 1.3).

IO_ANN.XLS contains the following worksheets and their content:

Criteria	Definition criteria of cropping systems, plus variables which currently have default values (sowing date, year of simulation, etc.) but can be changed manually between different TCG-runs.
Io	Inputs and outputs which are calculated in other sheets of this file are grouped.
Labour	Labour requirements in different periods and their distribution over the year (on the basis of decade of days).
Production	Simulated water-limited production levels which may be corrected for low biocide and mechanisation levels, selected production level (% of water-limited production), size of field (in case of bunds), and increased water availability due to bunds. Biomass distribution, and residue availability (field or stable) including its quality.
Timing	Calculates the timing and length of field operations within a year.
Nutrient	Calculates NPK requirements and includes dynamic N and P modules that operate independent of the other nutrient calculation rules (section 4.2.2).
Transport	Calculates transport time for product, crop residues and manure on the basis of defined transport modes (Hengsdijk <i>et al.</i> , 1996).

CROPA_BASE.XLS contains the following worksheets and their content:

basic data	crop specific data (standard labour requirements, length of field operations, biomass fractions for different crop residue strategies, nutrient contents of crop parts, N-transfer fractions for dynamic N model)
TD	simulated water limited yields of wheat and related data calculated with WOFOST
HV	simulated water limited yields of barley and related data calculated with WOFOST
PV	simulated water limited yields of pulses and related data calculated with WOFOST
SV	simulated water limited yields of sorghum and related data calculated with WOFOST
PG	simulated water limited yields of millet and related data calculated with WOFOST

The calculation files (names starting with IO) and including worksheets contain links to other files required for the retrieval of data. Table 2.1 gives an overview of file and worksheets linkages in the TCG:

Table 2.1. Overview of files and linkages to other files and worksheets.

File name	Worksheet name	Retrieves data from
IO_ANN.XLS	criteria	LIST.XLS
	io	IO_ANN.XLS[labour]; IO_ANN.XLS[nutrient]; IO_ANN.XLS[production]; IO_ANN.XLS[criteria]
	labour	CROPA_BASE.XLS[basic data]; IO_ANN.XLS[timing]; IO_ANN.XLS[production]; IO_ANN.XLS[nutrient]; IO_ANN.XLS[criteria]
	production	CROPA_BASE.XLS[basic data]; CROPA_BASE.XLS[TD]; CROPA_BASE.XLS[HV]; CROPA_BASE.XLS[PV]; CROPA_BASE.XLS[PG], CROPA_BASE.XLS[SV], IO_ANN.XLS[criteria]
	timing	CROPA_BASE.XLS[basic data]; CROPA_BASE.XLS[TD]; CROPA_BASE.XLS[HV]; CROPA_BASE.XLS[PV]; CROPA_BASE.XLS[PG], CROPA_BASE.XLS[SV], IO_ANN.XLS[criteria]
	nutrient	CROPA_BASE.XLS[basic data]; CROPA_BASE.XLS[TD]; CROPA_BASE.XLS[HV], CROPA_BASE.XLS[PV]; CROPA_BASE.XLS[PG], CROPA_BASE.XLS[SV], IO_ANN.XLS[criteria]; SOIL.XLS; CLIMATE.XLS
	transport	CROPA_BASE.XLS[basic data]; IO_ANN.XLS[criteria]
IO_COW.XLS	io_cow	LIST.XLS
IO_OXE.XLS	io_oxe	LIST.XLS
IO_SHP.XLS	io_shp	LIST.XLS
IO_GOT.XLS	io_got	LIST.XLS
IO_MEN.XLS	io_men	LIST.XLS

Especially, IO_ANN.XLS contains many linkages with other files and worksheets. Therefore, changes made to this file need to be checked carefully as wrong references may result in errors and undesired results.

2.2 Programming conventions

2.2.1 Excel

As much as possible, data have been separated from calculation rules in files and worksheets. However, this programming principle is not completely implemented due to a lack of time. In general, files starting with IO in their name only contain calculation rules and retrieve basic data from other (data) files. The animal IO-files, however, all contain data and calculation rules and also IO_ANN.XLS contains some basic data which are not retrieved from other files. To distinguish data from calculation rules and vice versa, cells with basic data are coloured light green, and cells with calculation rules or formulas retrieving data from other files (a kind of calculation rule) are coloured light yellow. Some cells are coloured light grey. They contain formulas that are not required for calculating IO's but contain information that improves interpretation of other calculation rules. Cells that are coloured purple contain important user-information for running the TCG properly.

As in previous TCG versions, almost all cells with data or calculation rules have names, so-called range names. The content of such cells can be retrieved using these names. Data retrieval (from data files) is completely based on names of parameters that refer to cell ranges. In general, data is stored in a table form. To retrieve data from a table the intersection method is applied (Hengsdijk *et al.*, 1998). The defined parameter names in a file can be viewed by pressing [F5], and can be traced by clicking one of the parameter names or typing the parameter name in the available input box. In all files, range names are written in italic and, in general, can be found just above or next to the cell(s) to which they refer. Some cell range names end with (1-4), for example, *minyld(1-4)* indicating that the four cells right of this name refer from left to right to the names *minyld1*, *minyld2*, *minyld3* and *minyld4*. Precedent and dependent cells of cell formula's can be traced by using Excel's audit toolbar.

Some cells contain comments, which are indicated with a red dot in the corner of cells. These comments contain information about the data source or instructions how to change the value of the specific cell.

2.2.2 Visual Basic macros

The TCG contains macros written in Visual Basic for Applications supporting tasks that have to be repeated frequently. The use of these macros makes the TCG easy to operate and accessible to a wide group of users. Changing the Visual Basic macros requires basic understanding of this software. It is emphasised that the TCG functions perfectly well without most Visual Basic macros but only in a 'manual' mode, i.e. inputs and outputs of land use systems can still be generated, but only one by one: definition criteria of a land use system must be changed manually in one of the worksheets (section 1.2) and recalculated with pressing [Ctrl+r] (for cropping systems) or F9-key (for other systems). Hence, without using the dialogue boxes (Fig. 1.2). By copying the generated IO's of individual land use systems to a separate file, and repeating the procedure (i.e. changing the definition criteria) many times, still a large number of land use systems can be generated.

When new definition criteria or options for existing definition criteria need to be added, relevant Visual Basic macros and dialogue boxes need to be changed accordingly. Macros are stored in so-called modules, and dialogue boxes in user forms. With pressing [Alt+F11] the Visual Basic modules and user forms can be viewed and adjusted. All Visual Basic modules and user forms of the TCG are stored in LIST.XLS. Table 2.2 gives an overview of the modules and their function. Most macros contain comments explaining their purpose and the steps that are carried out by the macro's.

Table 2.2. Overview of the modules and their content (*macros*).

Module	Macros and main function
Activate_file	<ol style="list-style-type: none"> 1. Start_TCG: sets directory to overrule default hardware settings; controls file opening/closing 2. Close_files: closes files 3. Open_files: opens files
Calculate_new iteration	<ol style="list-style-type: none"> 1. Iter: recalculation of cropping systems 1. Iteraction: select calculation method for nutrient requirements
Luctor_directory	<ol style="list-style-type: none"> 1. Luctordir: to set the directory of the TCG
Main	<ol style="list-style-type: none"> 1. Headprogram: activates other macros to select, combine and calculate options 2. Combining_crop_options: combines selected cropping options 3. Calcul_crop: calculate crop options and writes IOs to RESULT_ANN.XLS 4. Combining_cow_options: combines selected animal bovine, goat and sheep options 5. Calcul_cow: calculates animal bovine, sheep or goat options and writes IOs to RESULT_COW.XLS, RESULT_SHP.XLS or RESULT_GOT.XLS, respectively Combining_oxe_options: combines selected oxen options 6. Calcul_oxe: calculates oxen options and writes IOs to RESULT_OXE.XLS 7. Combining_men_options: combines feeds aimed at well-defined energy intake levels 8. Calcul_men: calculates menus and writes them to RESULT_MEN.XLS. 9. Delfalse: deletes all feed menus that are infeasible after generation of menus
Outputhead	<ol style="list-style-type: none"> 1. Name_head: Sets required IOs of cropping systems and writes names and units of IOs to RESULT_ANN.XLS
Processing_code1	<ol style="list-style-type: none"> 1. Startprocessing1: shows message boxes during combining of crop options
Processing_code2	<ol style="list-style-type: none"> 1. Startprocessing2: shows message box during calculation of IOs of cropping systems
Welcome	<ol style="list-style-type: none"> 1. Welcome_screen: activates welcome screen and to verify whether LIST.XLS is in default directory

2.3 Document conventions

To facilitate reading of this document the following conventions have been applied:

- File names are written in capitals, e.g. LIST.XLS.
- Worksheets as part of files are written in lower case between squared brackets immediately following the file name, e.g. IO_ANN.XLS[production].
- The alternatives of each definition criteria that can be selected by the user are written in capitals, such as FLD and refer to codes used in the TCG. In Appendix I and LIST.XLS a complete overview of the codes and their meaning is given.
- Range names used in the TCG are written in *italics*.

3. Type and definition of cropping systems

3.1 Introduction

The TCG-Tigray uses a target-oriented way to quantify inputs and outputs of all types of land use systems. First a predefined target yield level is calculated and, subsequently, the inputs are determined required for realising these target yields (Hengsdijk & Van Ittersum, 2002).

Arable cropping systems that can be generated with the TCG-Tigray differ in one important aspect with systems generated by previous TCGs: They consist of a rotation of four crops. Therefore, definition criteria of arable cropping systems encompass the definition of four crops and for each crop a separate crop residue strategy. Other selected characteristics of cropping systems are applied to all crops in the rotation. The definition criteria are described in the following sections, and their consequences for calculation rules and data retrieval from data files.

Introduction of rotations in the TCG allows to model turn-over of nutrients in crop residues and residual fertiliser and manure nutrients to the following crop. Static nitrogen transfer coefficients are used for all four crops in a rotation. The crop rotation is only operational for estimating NPK requirements of crops. Labour and other inputs are only calculated for the first crop in the rotation. However, incorporation of labour requirements for the other three crops is relatively easy. When selecting the same crop type and crop residue strategy for all four crops, - hence, a mono-culture -, a cropping system is defined that is similar with cropping systems generated by previous TCG-versions for West-Africa and Costa Rica.

Dynamic nitrogen and phosphorus modules are part of the TCG but work independent of the static part of the TCG (section 4.2.3), due to conceptual differences with the static four-year rotation in the TCG. With the dynamic nitrogen and phosphorus modules only nutrient dynamics of cropping systems can be modelled, no other inputs and outputs.

3.2 Definition criteria of cropping systems

In this chapter the definition criteria of cropping systems are described and their major characteristics, i.e. how they affect calculation rules. In Chapter 4, the most important calculation rules are described in detail and how they are affected by the definition criteria.

3.2.1 Zone

Two different zones can be selected with the dialogue boxes (section 1.2) but only one at a time. The two zones are Gobo Deguat (TG) and Tegahne (TH). The zones determine the available soil types and climate and, thus, indirectly the production potential of each zone. CLIMATE.XLS contains the annual rainfall data for both zones. Annual rainfall data are used to calculate erosion with the Universal Soil Loss Equation (section 4.3) and the amount of nutrients (NPK) that enters the system each year with precipitation.

3.2.2 Soil type

For Tegahne six soil types are identified based on a land survey carried out by Mekelle University (TH1, TH2, TH3, TH4, TH5, TH6). Soils differ mainly in presence of stones, rooting depth and slopes. The dominant soil texture is sand (Table 3.1). Soil type TH4 has a much higher soil organic

matter content than the other soils, while TH3 is located at a higher altitude than the other soils, which has been taken into account in simulating water limited yields of crops (section 4.1).

For Gobo Deguat five soil types are distinguished based on a similar land survey done by Mekelle University (TG1, TG2, TG3, TG4, TG5). Soil characteristics are similar to the soils in Tegahne and they differ mainly in the percentage of stones, rooting depth and slopes. The soils TG3 and TG4 are located about 250 m higher, and TG5 about 150 m lower than TG1 and TG2, which has been taken into account in the crop growth simulation (section 4.1).

Table 3.1. Soil characteristics of the major soil types identified in Tegabne.

Mekelle University survey code			TP1	TP2	TP4	TP5	TP6	TP7
landscape			valley	valley	plateau	valley	valley	hilland
relief	range		flood	terrace	mesa	flood	terrace	hill
	name in		plain			plain		
used soil codes in TCG	TCG		<i>TH1</i>	<i>TH2</i>	<i>TH3</i>	<i>TH4</i>	<i>TH5</i>	<i>TH6</i>
Texture								
sand	%	<i>sand</i>	73	87	80	50	67	70
loam	%	<i>loam</i>	12	10	14	24	22	15
clay	%	<i>clay</i>	14	3	6	26	11	15
stones	%	<i>stone</i>	5	40	60	5	50	40
Water holding characteristics								
Field capacity	cm ³ cm ⁻³	<i>Fc</i>	0.21	0.13	0.17	0.49	0.29	0.33
Wilting point	cm ³ cm ⁻³	<i>Wp</i>	0.02	0.02	0.08	0.08	0.05	0.03
Water content at saturation	cm ³ cm ⁻³	<i>Sat</i>	0.65	0.52	0.67	0.81	0.68	0.78
Bulk density	kg m ⁻³	<i>dens</i>	1350	1420	1620	1230	1540	1490
pH		<i>pH_{ss}</i>	7.66	7.53	7.36	6.87	7.54	7.09
Soil organic matter content	%	<i>OM</i>	1.44	1.28	1.91	5.22	1.02	0.36
Saturated hydraulic conductivity	cm day ⁻¹		16	56	82	7	11	21
Unsaturated hydraulic conductivity	cm day ⁻¹		163	225	95	28	55	84
WSA	%		11.8	17.7	29.5	22.3	15.6	10.4
Nutrient characteristics								
K exchangeable	mg 100 g ⁻¹	<i>K_{tot}</i>	5.1	4.7	6.3	5.5	2.3	4.3
N total soil	mg kg ⁻¹	<i>N_{tot}</i>	1050	1050	1100	850	910	850
fraction N turned over to next year		<i>N_{turn}</i>	0.1	0.1	0.1	0.2	0.1	0.1
fraction P turned over to next year		<i>P_{turn}</i>	0.6	0.6	0.6	0.6	0.6	0.6
P-recovery		<i>P_{rec}</i>	0.2	0.2	0.2	0.2	0.2	0.2
fraction K turned over to next year		<i>K_{turn}</i>	0.1	0.1	0.1	0.2	0.1	0.1
Data for erosion calculations								
permeability		<i>perm</i>	3	2	2	4	4	3
structure		<i>struc</i>	3	3	3	3	3	3
depth of upper soil layer	m	<i>prof_{cs}</i>	0.25	0.25	0.25	0.25	0.25	0.25
maximum length of fields	m	<i>long_{max}</i>	100	100	100	100	100	50
Rooting depth	cm	<i>depth</i>	200	64	50	200	27	31
Slope	%	<i>slope</i>	2.5	5.5	1.0	2.5	2.5	22.5
Suitability of soil types for crops (1 = suitable; 0 = not suitable)								
Hordeum vulgare – barley		<i>HV</i>	1	1	1	1	1	1
Pennisetum glaucum – millet		<i>PG</i>	0	0	0	0	0	0
Phaseolus vulgaris – pulses		<i>PV</i>	1	1	1	1	1	0
Sorghum vulgare - sorghum		<i>SV</i>	0	0	0	0	0	0
Triticum durum - wheat		<i>TD</i>	1	1	1	1	1	0

Table 3.2. Soil characteristics of the major soil types identified in Gobo Deguat. na = not available.

Survey code			GP1	GP2	GP4	GP5	GP6
landscape			valley	valley	plateau	plateau	valley
relief	range		flood	terrace	mesa	mesa	hill
	name in		plain				
	TCG		TG1	TG2	TG3	TG4	TG5
Texture							
sand	%	<i>sand</i>	75	80	54	68	79
loam	%	<i>loam</i>	16	12	17	27	16
clay	%	<i>clay</i>	9	8	29	5	5
stones	%	<i>stone</i>	0	50	15	20	20
Water holding characteristics							
Field capacity	cm ³ cm ⁻³	<i>Fc</i>	0.2	0.12	0.39	0.29	0.32
Wilting point	cm ³ cm ⁻³	<i>Wp</i>	0.02	0.02	0.08	0.08	0.05
Water content at saturation	cm ³ cm ⁻³	<i>Sat</i>	0.57	0.52	0.67	0.81	0.68
Bulk density	kg m ⁻³	<i>dens</i>	1310	1110	1390	1390	1480
pH		<i>pH_{ss}</i>	6.99	7.67	7.18	7.07	7.43
Soil organic matter content	%	<i>OM</i>	1.46	0.38	2.05	1.8	0.31
Saturated hydraulic conductivity	cm day ⁻¹		47	23	72	75	74
Unsaturated hydraulic conductivity	cm day ⁻¹		362	59	175	274	759
WSA	%		12.8	13.7	22.0	12.1	14.9
Nutrient characteristics							
P total soil	mg kg ⁻¹	<i>P_{tot}</i>	283	268	669	na	na
K exchangeable	mg 100 g ⁻¹	<i>K_{tot}</i>	7	5.5	5.1	10.6	3.5
N total soil	mg kg ⁻¹	<i>N_{tot}</i>	670	700	780	750	640
fraction N turned over to next year		<i>N_{turn}</i>	0.1	0.1	0.1	0.1	0.1
fraction P turned over to next year		<i>P_{turn}</i>	0.6	0.6	0.6	0.6	0.6
P-recovery		<i>P_{rec}</i>	0.2	0.2	0.2	0.2	0.2
fraction K turned over to next year		<i>K_{turn}</i>	0.1	0.1	0.1	0.1	0.1
Data for erosion calculations							
permeability		<i>perm</i>	2	2	4	2	2
structure		<i>struc</i>	3	3	3	3	3
depth of upper soil layer	m	<i>prof_{cs}</i>	0.25	0.25	0.25	0.25	0.10
maximum length of fields	m	<i>long_{max}</i>	100	100	100	100	100
Rooting depth	cm	<i>depth</i>	200	55	100	200	10
Slope	%	<i>slope</i>	2	40	2	2	40
Suitability of soil types for crops (1 = suitable; 0 = not suitable)							
Hordeum vulgare – barley		<i>HV</i>	1	1	1	1	1
Pennisetum glaucum – millet		<i>PG</i>	1	1	1	1	1
Phaseolus vulgaris – pulses		<i>PV</i>	1	1	1	1	1
Sorghum vulgare - sorghum		<i>SV</i>	1	1	1	1	1
Triticum durum - wheat		<i>TD</i>	1	1	1	1	1

3.2.3 Crop types

Five crops can be selected, wheat (TD), barley (HV), pulses (PV), millet (PG) and sorghum (SV). Water-limited yields of the crops have been determined with WOFOST (section 4.1). Millet and sorghum cannot be grown in Tegahne due to low temperatures. Crop rotations consisting of different crop types can only be chosen in the manual mode (section 1.2). In the automatic mode, cropping systems consisting of one crop type only are generated.

3.2.4 Yield level

This option is incorporated to reduce the simulated water-limited yields, for example, in case these yields are too high within the time horizon of a study. With this criterion the simulated water-limited yield can be reduced stepwise down to 10% of the originally simulated yield level. More than one reduction percentage can be selected simultaneously with the dialogue boxes. Other inputs and outputs are not reduced correspondingly as the TCG incorporates various non-linear processes, for example, N-requirements and labour requirements (Hengsdijk & Van Ittersum, 2001).

3.2.5 Mechanisation level

Here, two alternatives are possible, one with only manual field operations (LM) and one in which certain operations are carried out by animal traction (HM): ploughing (field preparation), sowing with oxen, first weeding operation, transport of manure, harvested product and crop residues. In IO_ANN.XLS[transport] the mode of transport for manure, harvested product and crop residues can be defined: by men, two donkeys, a donkey cart and an oxen cart. Characteristics of these modes of transport can also be found and adjusted in this worksheet. A combination of different modes of transport can be defined. This procedure is described in more detail in Hengsdijk *et al.* (1996). In the original procedure four different combinations of transport modes (or intensities) could be defined indicated with 'ex', 'exta', 'si' and 'in'. In the TCG-Tigray this option is not any longer available. It is set in IO_ANN.XLS[criteria] to 'in' and cannot be changed. It is assumed that yield reductions may occur due to manual field preparation (LM) compared to mechanised field preparation (HM). This yield reduction is crop specific and can be defined in CROPA_BASE.XLS[basic], its default value is 15% for all crops.

3.2.6 Crop residue strategy

Three crop residue strategies can be selected, field grazing and burning (FLD), mulching (MUL), and harvesting of the residues to be used for feeding cattle in the dry period (HAR). In the field grazing option a part of the crop residues is grazed (removed) from the system and the remainder is burned. Eighty percent of the nitrogen in the crop residues is lost from the system by burning (Crutzen & Andreae, 1990). The mulch option assumes that all crop residues remain in the field as soil conservation measure (erosion protection). Contrary to the actual situation in Tigray, it is assumed that no animals pass such fields in the dry season. In CROPA_BASE.XLS[basic] fractions of crop parts (biomass) are defined that are left in the field, burned and harvested. The selected crop residue strategy determines the amount of nutrients that is returned to the field and, hence, the nutrient dynamics of the system. Also labour requirements (e.g. harvesting and distribution of crop residues) is affected by the chosen strategy.

In the manual mode, different crop residue strategies for the four crops in a rotation can be selected. In the automatic mode only one strategy is assigned per generated cropping systems (section 3.2.3).

3.2.7 Weed control

Currently, herbicides are hardly used in Tigray. A weed control option is included to explore the consequences of using herbicides. Manual weed control measures require much labour during the growing season and often is inadequate due to labour shortages. Two weed control options can be selected: only manual weeding (LH) and weed control partly with herbicides, especially in the beginning of the growing season (HH).

3.2.8 Pest and disease control

Also biocides to control pests and diseases are not commonly used in Tigray. Frequently, yield reductions occur under current conditions due to inadequate control of pests and diseases. Therefore, an option is included that uses biocides to control pests and diseases (HB). In the current version of the TCG these pests and diseases are not further specified, neither the applied type and amount of biocides. The option in which no biocides are used represents the actual situation (LB). It is assumed that the option with biocides results in a yield increase compared to the situation in which no biocides are applied. This yield reduction is crop specific and can be defined in CROPA_BASE.XLS[basic], its default value is 30% for all crops.

3.2.9 Soil and water conservation measures

Soil and water conservation measures aim at improving the water availability for crop growth and reducing soil erosion. Different soil and water conservation measures exist, most of them are based on the construction of biophysical barriers at frequent intervals to slow down run-off (Herweg & Ludi, 1999). Quantitative assessments of these soil and water conservation practices on run-off, erosion and yields are, however, scarce. Therefore, only one generic type of barrier consisting of a stone bund is included in this TCG (BUN). The option in which no stone bunds are applied is indicated with the code NUN. The introduction of stone bunds reduces erosion and consequently soil nutrient losses. However, more labour is required for construction and maintenance. As the construction of bunds require land, yields are reduced equal to the percentage of land required for construction of bunds, but at the same time yields are adjusted for the increased water availability (section 4.1).

3.3 Linking crop residues and animal systems

As in the TCG developed for Mali (Hengsdijk *et al.*, 1996) cropping and animal systems can be linked, for example, in LP-models by means of crop residues and manure production. In the previous TCG version, nitrogen concentrations of crop residues were fixed values and thus had fixed feed quality. Here, yield levels determine nitrogen concentrations of crop parts and thus the quality of crop residues for fodder purposes (section 4.2). Crop residues with high nitrogen concentrations, have a better quality than residues with low nitrogen concentrations. Different quality categories for crop residues are distinguished in IO_ANN.XLS[production] based on their nitrogen content. For crop residues six quality categories are distinguished, i.e. Q4 to Q9 that are only available in the dry season. Quality categories Q1 to Q3 are predetermined for pasture fodder available in the wet season, and quality category Q10 is predetermined for feed supplements, such as cotton cake. In theory, two quality categories can be produced by crop residues as different nitrogen concentrations for leaves and stems can be defined in CROPA_BASE.XLS[basic]. In practice, however, little information is available on nutrient concentrations in both crop parts. Therefore, the default nitrogen concentrations for both stems and leaves are kept the same.

Linking of crop residues and animal systems is similar as described in Hengsdijk *et al.* (1996). First, the amount of crop residues (expressed in dry matter) must be converted into organic matter by multiplying it with a factor 0.9. Subsequently, the amount of organic matter must be converted into digestible organic matter (DOM) by multiplying it with the percentage DOM corresponding with each feed

quality category. The percentage DOM per feed quality is given in Hengsdijk *et al.* (1996) and in IO_ANN.XLS![production].

For animal systems an amount of DOM (feed requirement) is calculated which is needed to realise the user-defined energy intake level of the animal, representing the rate of live weight gain. For bovine animal systems, for example, four energy intake levels can be selected. To fulfil higher energy intake levels, the fraction of high quality feed in the menu need to be increased.

Feed menu's can be calculated with the TCG that are geared towards realising different feed intake levels. As feeds with different qualities are available, different combinations of feeds are calculated that enable the realisation of feed intake levels. The calculated menu's express fractions of each feed quality category in a menu required to realise the specified energy intake level. Now, feed requirement of animals (expressed in DOM) can be matched using the menu's geared towards the same energy intake level as the animals, and the DOM in the various feed categories as available in crop residues.

Calculated menu's are based on annual basis and include feed (categories Q4 to Q10) available in the dry season, i.e. crop residues and feed (categories Q1 to Q3) available in the wet season, i.e. pasture fodder. The TCG does not estimate the available pasture and its quality in the wet season. Thus, to link animal systems and available feed using menu's, pasture fodder and its quality should be estimated using other methods.

4. Major calculation rule

In this chapter major calculation rules are described and the way definition criteria affect these calculation rules.

4.1 Target yields

Inputs and outputs of cropping systems are determined in a target-oriented way, i.e. first water-limited yields have been determined and, subsequently, the inputs to realise these yields (Hengsdijk & Van Ittersum, 2002). Water-limited crop yields have been calculated using the dynamic crop growth simulation model WOFOST (Boogaard *et al.*, 1998), which estimates the growth and production of annual field crops given a set of specific soil, weather and crop data. WOFOST is not an integral part of the TCG, but only results determined with WOFOST. Worksheets of CROPA_BASE.XLS indicated with the crop codes in the tabs contain results of WOFOST simulations.

Daily rainfall data have been used to simulate water-limited yields. Other climate data used for calculating water-limited yields include long term monthly averages for radiation, minimum and maximum temperature, vapour pressure, wind speed, rainfall and number of days with rainfall. The monthly climate data have been based on an available climate file for Mekelle (13°50'N, 39°48'E) in which minimum and maximum temperatures have been replaced with data from Gobo Deguat and Tegahne. As WOFOST allows to use a combination of monthly climate and daily rainfall data, daily rainfall data for the years 1999 and 2000 have been used for Tegahne, and 1972 to 1981 and 1993 to 1997 for Gobo Deguat. For both Tegahne and Gobo Deguat, different climate files have been used as the elevation of various soil types in each zone differed (section 3.2.2). The altitude of TH3 is about 150 m higher than the other soils in Tegahne, while TG3 and TG4 are located about 250 m higher and TG5 about 150 m lower than TG1 and TG2 in Gobo Deguat. Therefore, monthly average minimum and maximum temperatures associated with these soil types have been adjusted in the simulations with 0.6 °C per 100 m elevation difference to account for the differences in altitude. For each zone, also an average simulated yield is determined based on the 2 and 15 available rainfall years in Tegahne and Gobo Deguat, respectively.

Simulated yields have not been validated as suitable data were lacking. Crop data have been based on Simane *et al.* (1994) and results from unpublished breeding trials from the Institute of Agricultural Research (IAR) in Mekele. During the analysis of the WOFOST-simulation, calculated leaf area indices, harvest indices, period between emergence and anthesis and the length of the entire growing period have been carefully checked whether they were according to the limited data set available or within agronomically feasible ranges. The simulated yields show consequences of different combinations of crop type, soil type, weather and sowing date. Results are useful to illustrate general effects of selected management options. They are a first attempt to estimate the biophysical production potential and can be used as a starting point for more detailed analysis of a biophysical assessment in the RESPONSE program (Chapter 1).

Yields have been simulated for weekly intervals starting from Julian day number 148 to 225. Just under the definition criteria in IO_ANN.XLS[criteria] (Fig. 1.3) the day number should be entered right of the cell *sdate*. The default value is 197 (July 15). Right of the cell *yr* the type of year should be filled out, for Tegahne, 1999, 1998 or av, meaning the average of both years. The latter is the default and means that the target yield used in the TCG is the average of water-limited yields of both years using the selected sowing date. Though both the sowing date and simulated year can be changed, separate runs with the TCG are required for calculating IO's of different sowing dates and years.

Simulated yields and other parameters generated by WOFOST are stored for each crop in separate worksheets of CROPA-BASE.XLS. Each simulation run is one row in the worksheets and indicated

with a variable name consisting of the crop type, soil type, rainfall year and sowing day, each separated by an underscore. For example, *bv_th1_1999_225* means barley at soil type TH1 simulated for the year 1999 and sown at Julian day 225. The columns indicate the different variables simulated by WOFOST and are explained in the worksheets and Boogaard *et al.* (1998). These variables are derived from the summary output file (in EXCEL format) generated by WOFOST.

These target yields are retrieved in IO_ANN.XLS[production] in the variable *yld_target* and if necessary corrected for any yield reductions. Four factors may reduce the simulated target yield. First, the selected target yield level (section 3.2.4), indicated with *cor_level*. Second, the selected pest and disease control (section 3.2.8) indicated with *cor_bio*. It is assumed that yield reductions are unavoidable in case biocides (LB) are not applied. The reduction percentage for *cor_bio* can be defined in CROPA_BASE.XLS[basic] for each crop separately. The third reduction percentage depends on the selected mechanisation level (section 3.2.5). Here, it is assumed that yield reductions (*cor_mec*) occur in the absence of oxen ploughing (LM). Also this reduction percentage can be defined for each crop type in CROPA_BASE.XLS[basic]. The fourth reduction percentage depends on the selected soil and water conservation. In case bunds are selected (BUN), a recommended distance between bunds is calculated based on a formula (*field_bun*) given in Nyssen *et al.* (2000a):

$$FBUN = 82.278 * S^{-0.7376}$$

In which FBUN the recommended distance between bunds (in m) and S, the slope of the soil type (in %). The recommended distance determines how many bunds per ha are required, and the size of fields for which erosion is calculated (section 4.3). Construction of bunds requires land and, therefore, reduces the size of fields. It is assumed that each bund reduces the standard field length (often 100 m, Table 3.1) with 1.5 m, i.e. 1.5%. The total number of bunds per ha is calculated and, subsequently, the area reduction (*cor_bund*) is used to correct the initial target yield. At the same time, the total length of bunds per field (*bund_m*) is determined and used for calculation of the labour requirements to construct (*bil_mm*) and maintain bunds (*main_bund*) (section 4.4).

The four reduction fractions, i.e. *cor_bund*, *cor_bio*, *cor_level* and *cor_mec*, are multiplied resulting in an average reduction percentage (*red_yld*) for adjustment of the calculated water-limited crop yields.

The purpose of bunds is to decrease run-off. However, quantitative information on the amount of run-off compared to non-bunded fields is scarce. Hence, consequences of reduced runoff on improved water-availability for crop growth are also unclear. Some sources report water-logging problems uphill of bunds reducing crop production (Herweg & Ludi, 1999). In the TCG, however, increased water availability is associated with a positive yield effect due to bunds. To estimate the yield increase due to bunds, simulations were done with barley on TG1 and TG2 with adjusted run-off fractions as compared to the original values used, i.e. 20 and 60%, respectively. TG1 and TG2 represent two contrasting soils with gentle (2-5%) and steep slopes (40%), respectively. As the reduction in run-off is unknown, 10 and 25% reduction of the original values was assumed. Based on the original and these new simulation results, four regression equations were derived indicating the yield increase assuming 10 and 25% reduction in run-off and for two soils.

For TG2 and 10% reduction in runoff:

$$YLDN = 76 + 1.081 * YLDO \quad (R^2 = 0.96)$$

For TG2 and 25% reduction in runoff:

$$YLDN = 147 + 1.134 * YLDO \quad (R^2 = 0.90)$$

For TG1 and 10% reduction in runoff:

$$YLDN = 18 + 1.008 * YLDO \quad (R^2 = 0.99)$$

For TG1 and 25% reduction in runoff:

$$YLDN = 57 + 1.015 * YLDO \quad (R^2 = 0.99)$$

In which YLDN (in kg ha⁻¹) is the adjusted yield taking into account bunds and the increased water availability, and YLDO (in kg ha⁻¹) the originally simulated yields with WOFOST given in CROPA_BASE.XLS for the different crops. These relationships have been incorporated in IO_ANN.XLS[production] and are used for all crops. The relationship for TG2 is also used for TG5 as they have similar slopes, while the relationships calculated for TG1 are used for the other soil types in Tegahne and Gobo Deguat. In IO_ANN.XLS[criteria] the decrease in runoff is user-defined, 10 or 25% in *yldbun*. The derived relationships show that the yield increase is a) higher at the steeper slopes than on the gentle slopes and b) not linear between 10 and 25 reduction in runoff. When bunds are selected as management option, yields are adjusted according to the soil type and selected decrease in runoff. In case many bunds are required (steep slopes, see before), the increase in yields due to improved water availability may not be sufficient to counterbalance the reduction in area required for bunds.

4.2 Nutrient requirements

The TCG includes two modules for calculation of nutrient requirements of cropping systems. First, a static target-oriented approach also used in other TCGs (e.g. Hengsdijk *et al.*, 1996, 1998). Starting point in this approach is that mineralisation is in equilibrium with immobilisation, and nutrient inputs should equal nutrient outputs. This approach is applied to generate different types of inputs and outputs of crop rotations. Second, the TCG contains two approaches for describing nitrogen and phosphorus dynamics based on models developed by Wolf & Van Keulen (1989) and Wolf *et al.* (1987), respectively. In both nitrogen and phosphorus modules, mineralisation and immobilisation are not any longer assumed to be in equilibrium. Though the underlying concept of these modules differ from the static approach, they are integrated in the TCG. Both modules only calculate nutrient related inputs and outputs of a crop rotation. The major features of the static and dynamic modules are highlighted in the following sections.

4.2.1 Static approach

This approach aims at a zero change in soil nutrient stocks. The amount of external nutrients required to realise this situation is calculated by the TCG for each crop in the four year rotation. External nutrients are calculated in the form of NPK fertilisers (IO_ANN.XLS[nutrient]) and manure (IO_ANN.XLS[labour]). The user can define with *nutreq* in ANN_IO.XLS[criteria] whether nutrient requirements are calculated in terms of fertiliser or manure. In case of manure, the nutrient that is most limiting determines the amount of manure required to maintain a zero soil nutrient stock. As a consequence of this approach, two nutrients are supplied in surplus.

Nutrient uptake is a function of the yield level. High nutrient concentrations are associated with high yields, and low nutrient concentrations with low yields, resulting in decreasing nutrient use efficiencies with increasing yields as shown in many experiments under *ceteris paribus* conditions (Van Keulen & Wolf, 1986). Minimum and maximum nutrient concentrations of crop parts are found in CROPA_BASE.XLS[basic]. Via linear interpolation between minimum target yields (*minyld(1-4)*) and maximum target yields (*maxyld(1-4)*) nutrient concentrations of intermediate yield levels are determined in IO_ANN.XLS[nutrient]. The maximum yield level of a crop relates to the maximum simulated yield of all simulations carried out for that particular crop and zone, while the minimum yield level is 10% of the calculated target yield corrected for various reduction factors (Chapter 3 and section 4.1).

The major differences with previous TCGs (e.g. Hengsdijk *et al.*, 1996, 1998) is the calculation of the loss fractions (i.e. nutrient recovery) and the turn-over of a part of calculated nutrient requirements of a crop to the next crop (residual nutrients): a part of nutrients applied to crop 1 is available for crop 2, etc. The turn-over is cyclical, i.e. a part of nutrients applied to crop 4 are available in crop 1. The cyclical calculations have consequences for recalculating the worksheets. The [F9] key, which is used in Excel to recalculate worksheets, does not work properly as the nutrient calculations contain circular

references. Therefore, a macro 'iter' has been written performing iterative calculations for N, P and K requirements till residual nutrients of crop 4 and inputted residual nutrients in crop 1 differ less than 1 kg. When error values appear in the cyclical calculations, e.g. due to error values in the retrieved data, the module has to be reset by activating this VB-macro 'iter' which can be activated with the short-cut keys <Ctrl+r>. This is also further explained in one of the purple message cells in the IO_ANN.XLS[nutrient]. However, the iterative calculations are time consuming. To speed up the calculation of large numbers of cropping systems a macro 'iteroption' is available to enable calculations without these iterations. This macro can be activated at the beginning of a run with <Ctrl+y> and it sets the residual nutrients (NPK) of the last crop to zero in the first crop. This simplified calculation procedure has only minor consequences for the nutrient related inputs and outputs. In general, differences between both calculation procedures are very small, i.e. less than 2 kg N or K ha⁻¹, only differences for P requirements are somewhat higher, but still less than 10 kg P ha⁻¹. In case large amounts of nutrients are transferred from one crop to the following, nutrient availability may exceed external nutrient requirements of the next crop. In these cases, external nutrient requirements of the next crop are set to zero. Particularly, for phosphorus such situations may occur as recoveries are low and temporary immobilisation rates are high. The total amount of transferred nutrients is available in the next season.

The recovery of nitrogen and potassium is based on the approach used in Hengsdijk & Van Keulen (2002): The nitrogen and potassium loss fraction, i.e. the complement of the N and K-recovery, is estimated using four simplified relationships representing four processes underlying nutrient losses, i.e. leaching, runoff, volatilisation and low crop uptake (for potassium only leaching, runoff and crop uptake). Based on the pooled data for the simulated period, relative losses as consequence of each of these processes were estimated assuming linear relationships. The underlying data have been derived from the WOFOST simulations (section 4.1). The relationship between percolated rainfall and partial loss fraction due to leaching indicates that leaching is highest at high percolation and no leaching happens at zero percolation. The relationship between runoff and partial loss fraction as consequence of the load in runoff water indicates that losses increase starting from a base runoff up to a maximum at the highest runoff simulated for each crop in Tegahne or Gobo Deguat. The relationship between the partial loss fraction due to volatilisation and rainfall indicates that from a base rainfall losses linearly increase up to a maximum at the highest rainfall in a simulated period. Partial loss fractions decrease with higher crop yields. It is assumed that at higher crop productivity losses are relatively lower as consequence of better developed rooting system (e.g. less N-leaching) and soil cover (e.g. less N-runoff). The total loss fraction has been calculated as the average of the four (three, for potassium) partial loss processes. For each simulation (crop, soil, zone, year and sowing date) loss fractions have been calculated and stored in the crop data worksheets of CROPA_BASE.XLS. The recovery fraction of phosphorus is a fixed estimated value (P_{rec}) stored in SOIL.XLS and depends on the selected soil type.

For nitrogen, phosphorus and potassium, fractions are estimated that determine how much of the calculated nutrient requirements of a crop in one season is available in the next season (crop). These fractions depend on the selected soil type and are stored in SOIL.XLS (N_{turn} , P_{turn} , K_{turn}). The 'lost' nutrients in one season (see previous paragraph), which is the differences between calculated external nutrient requirements and net requirements, is multiplied with these fractions to determine the amount of external nutrients in a crop that is turned over to the next crop.

The general equation that has been used to determine the nutrient requirements for each crop (c) in the rotation:

$$Req_c = (Tuptake_c + Erosion_c) / Rec_c - (Rain + Freefix_c + Assfix_c + Ruptake_{(c-1)} + Freq_{(c-1)}) \quad (c = 1..4)$$

In which:

Req_c = nutrient requirement of crop c

$Tuptake_c$ = total nutrient uptake crop c

$Erosion_c$ = nutrients in soil loss under crop c

Rec_c = nutrient recovery crop c

Rain = nutrients in annual precipitation

Freefix_c = nutrients fixed by free living bacteria (only for nitrogen) in crop c

Assfix_c = nutrients fixed by associated bacteria (only for nitrogen) in crop c

Ruptake_(c-1) = nutrients in the crop residues of the previous crop left in the field. If c=1, (c-1)=4

Freq_(c-1) = fraction of the nutrient requirements of the previous crop. If c=1, (c-1)=4

For leguminose, Tuptake is corrected for the amount of nitrogen fixed by rhizobacteria. The fraction nitrogen of the total uptake that is fixed by bacteria is set to 0.75 (*f_fix_N*) in CROPA_BASE.XLS[*basic*].

For phosphate and potassium the term between brackets in the equation is extended with weathering. The weathering rates (*vit_eff_K*, *vit_eff_P*) are defined in IO_ANN.XLS[*nutrient*]. Due to a lack of information on the soil P-content, default value of weathered P is set to zero.

4.2.2 Dynamic approach

Though the dynamic approach should be used independent of the rest of the TCG (section 3.1), it uses the characteristics of the cropping system as defined in IO_ANN.XLS[*criteria*], i.e. the crops, crop residue strategies, soil type, etc.. Hence, using the manual mode, nutrient dynamics of different cropping systems can be calculated. The dynamic nutrient inputs and outputs are not grouped in IO_ANN.XLS[*IO*] but must be viewed and analysed directly in IO_ANN.XLS[*nutrient*] where the dynamic approach is modelled.

In dynamic approach, two modules describe nitrogen and phosphorus dynamics while taking into account two soil nutrient pools, i.e. a stable and labile pool each with different time coefficients. Hence, soil nutrient stocks change over time, which has consequences for the nutrient availability and calculated nutrient requirements over time. This approach is fundamentally different from the approach described in the previous section in which the starting point is the equilibrium between mineralisation and immobilisation of nutrients. As the concepts are different in both approaches, it is not possible to use the same transfer coefficients (e.g. loss fractions).

Both the nitrogen and phosphorus module have not been calibrated extensively as data are lacking. However, both modules indicate the consequences of differences in crop type and productivity, soil characteristics, external nutrient source and crop residue strategy for the external nitrogen and phosphorus requirements over time. Therefore, results are illustrative for the consequences of different alternatives that can be calculated with the TCG.

The nitrogen module has been applied for a case study in West-Africa (Hengsdijk & Van Ittersum, 2003) and has been described in detail by Wolf & Van Keulen (1989) and Wolf *et al.* (1989).

The nitrogen module can be found in IO_ANN.XLS[*nutrient*] just below the static nitrogen approach. The nitrogen dynamics of a crop rotation consisting of four different crops can be modelled up to 40 year. The default values of the nitrogen transfer coefficients of crops are defined in CROPA_BASE.XLS[*basic data*].

Two alternative calculation rules have been included in the dynamic nitrogen module. First, nitrogen requirements are calculated in terms of fertiliser and manure as both may have different transfer coefficients (as defined in CROPA_BASE.XLS[*basic data*]). Differences in transfer coefficients have consequences for the nutrient dynamics of the system. Second, in case fertilisers are used, an additional alternative is included: a fixed nitrogen recovery or a dynamic recovery as function of the size of the labile N pool. For example, when the labile pool decreases with 15% in one year, the N-recovery decreases in next year's crop also with 15%. The underlying assumption is that nutrient recoveries decrease with lower soil nutrient stocks and improve with higher nutrient stocks (De Ridder & Van Keulen, 1990). A linear relationship is assumed as no other information was available on this relationship. However, it is relatively easy to include non-linear relationships. Using the current linear

relationship, a 'dynamic' nitrogen recovery fraction has no large effects on the results. The module will reach an equilibrium earlier or later than using a fixed nitrogen recovery. Cell range *FixN* in IO_ANN.XLS[*criteria*] should be set to 'yes' to activate the dynamic nitrogen recovery fraction.

The dynamic phosphorus module is based on the model described by Wolf *et al.* (1987). The phosphorus module can be found in IO_ANN.XLS[*nutrient*] just below the static phosphorus approach. The phosphorus dynamics of a crop rotation consisting of four different crops can be modelled up to 40 year. The approach in this module is similar to the one used for modelling nitrogen dynamics, also here labile and stable nutrient pools are identified which exchange phosphorus but with different rates. The dynamic phosphorus module is only implemented for calculation of required phosphate fertiliser, i.e. triple super phosphate/tsp (default) or rock phosphate, and not phosphate from manure. External phosphate sources differ in the fraction labile and stable phosphate. Although manure phosphate is not yet defined as an option it may be incorporated easily in the section fertiliser characteristics in the upper part of IO_ANN.XLS[*nutrient*]. Here, the fraction labile phosphate in manure and a range name for manure should be defined and the range name *f_labile* redefined. Subsequently, in *engrais_p* the chosen range name for manure should be entered.

4.3 Erosion

Soil erosion is one of the major processes affecting the production potential in Tigray. Various studies have been carried out investigating erosion in the highlands of Ethiopia (Eweg *et al.*, 1999; Herweg & Ludi, 1999; Nyssen *et al.*, 2000b; Nyssen *et al.*, 2001). In general, these studies are descriptive, location specific or analyse specific soil conservation measures in relation to soil loss and have not resulted in generic calculation rules enabling quantification of the soil erosion in both study areas, Tegahne and Gobo Degyat. Therefore, the generic Revised Universal Soil Loss Equation (RUSLE) (Renard *et al.*, 1996) has been applied in the TCG to quantify this process. This equation has been developed for conditions in the U.S. and its validity under other environmental conditions such as prevailing in Tigray is uncertain and even disputed (Eweg *et al.*, 1998). Therefore, the quantitative outcomes of the RUSLE-calculations should be interpreted with care but a qualitative use of RUSLE may indicate long-term differences in soil losses due to landscape, soil and crop management. Within the TCG, as much as possible parameter values have been applied that were calibrated for the situation in Tigray and which increases the confidence in the applicability for conditions prevailing in Tigray. The RUSLE is implemented in IO_ANN.XLS[*nutrient*] just above the nitrogen balances.

The RUSLE estimates soil losses on the basis of rainfall characteristics, soil properties, prevailing landscape, and soil and crop management:

$$E = R * K * C * S * L$$

In which:

E = erosion (ton ha⁻¹)

R = rainfall factor

K = erodibility factor

C = crop cover and management factor

S = slope factor

L = slope length factor

The rainfall factor (R) is based on the erosive energy of the rain drops on the soil surface and is a function of annual precipitation (Hellden, 1987):

$$R = -8.12 + 0.562 * \text{rainfall}$$

In which rainfall is the annual rainfall (mm). The erodibility factor depends on the soil texture and organic matter content. Soils with a low organic matter content and sandy texture are more susceptible to erosion and have, therefore, a higher erodibility factor (Renard *et al.*, 1996):

$$K = (0.00021 * (12-OM) * (\text{loam} * (\text{loam} + \text{sand})^{1.14} + 3.25 * (\text{struc} - 2) + 25 * (\text{perm} - 3)) / 100 * 0.1317$$

In which:

OM = soil organic matter content (%)

loam = percentage loam (%)

sand = percentage sand (%)

struc = soil structure coefficient

perm = soil permeability factor

The last two factors, stored in SOIL.XLS, are dimensionless and are estimated based on soil characteristics and soil erodibility nomographs (Renard *et al.*, 1996). The crop cover and management factors are based on the ratio of soil loss measured under specific soil and crop conditions and that under clean fallow. The cover and management factor decreases with increasing soil cover, reflecting the protective action of a biomass cover. Crops with higher soil cover due to crop architecture or higher biomass production have a smaller crop cover factor. The crop and management factor in the TCG consists of two elements, the crop biomass and the crop residues covering the soil:

$$C = C_{\text{crop}_c} * e^{(-0.00045 * (\text{straw}_c + \text{straw}_{c-1}) / 2)} + e^{(-0.0004 * \text{biomass}_c)} \quad (c = 1, \dots, 4)$$

In which:

C_{crop_c} = crop factor of the crop in year c

straw_c = amount of biomass of the crop in year c left in the field after harvest (kg ha^{-1})

straw_{c-1} = amount of biomass of the crop in year $c-1$ left in the field after harvest (kg ha^{-1})

If $c=1$, $(c-1)=4$

biomass_c = amount of biomass of the crop in year c (kg ha^{-1})

For the slope factor in the TCG two alternative calculation rules are available. The first (and default) calculation rule is based on Hellden (1987):

$$S = 0.344 + 0.0798 * \text{slope}$$

In which slope is the slope (%) of the soil type. The other option is based on Renard *et al.* (1996):

If slope < 9%: $10.8 * \sin(\pi/180 * \text{slope}) + 0.03$

If slope > 9%: $16.8 * \sin(\pi/180 * \text{slope}) - 0.5$

The user can apply one of the slope factor options by redefining the cell range *sss*.

For the slope length factor also two alternative calculation rules are available based on the same two literature sources. The default option is (Hellden, 1987):

$$L = \text{length} * 0.0101 + 0.799$$

In which length is the standard length of the field. In case soil and water conservation are part of the defined land use system, i.e. the construction of bunds, the standard field length is reduced based on the recommended field length (section 4.1). The alternative calculation rule for the slope length factor is based on Renard *et al.* (1996):

$$\text{Auxvar1} = \sin((\pi/180) * \text{slope} / 0.0896) / (3 * \sin((\pi/180) * \text{slope})^{0.8} + 0.56)$$

$$\text{Auxvar2} = \text{auxvar1} / (\text{auxvar1} + 1)$$

$$L = \text{length} / (0.3038 * 72.6)^{\text{auxvar2}}$$

In which auxvar1 and auxvar2 represent two auxiliary variables. The user can apply one of the slope length options by redefining the cell range *lll*.

The soil loss is calculated in ANN_IO.XLS[nutrient] for each crop within a rotation (*eros(1,4)*), while also the maximum value of the entire rotation is calculated (*eros*) which is used in ANN_IO.XLS[IO].

4.4 Labour and implement requirements

Calculation of labour and implement requirements is based on Hengsdijk *et al.* (1996). In the current TCG version, these requirements are only calculated for the first crop in a rotation but they easily can be incorporated for other crops in a rotation.

Requirements are calculated per main operation period, i.e. field preparation, sowing, first maintenance, second maintenance, harvest and the rest of the season. Basic data regarding labour and oxen requirements are stored in CROPA_BASE.XLS[*basic*]. Taking into account the start of sowing, the length of the growing season and the minimum and maximum number of days required for each operation period (IO_ANN.XLS[*timing*]), the available days for each operation period are calculated and distributed over the year. The labour and implement requirements in each period divided by the available days in each period results in the labour and implement requirements per day per ha in each operation period. Subsequently, labour requirements (in mnd ha⁻¹) and oxen requirement (in oxd ha⁻¹) are expressed on a decade of days basis allowing to identify periods with labour peaks (in IO_ANN.XLS[*labour*]). These last calculations are not performed for other implements, such as carts and donkeys, but can easily be incorporated in a similar way as done for human labour and oxen requirements.

Some specific calculations regarding labour and implement requirements:

- Nutrient requirements can be met by fertilisers or manure. In ANN_IO.XLS[*criteria*] this should be defined in *nutreq*. The selected nutrient source affects labour and animal requirements as transport of manure to the field is included in the labour and animal requirement calculations, while distribution of manure in the field is labour intensive work. In addition, in an integrated regional analysis, manure requirements may have great impact on the number of animals required to produce manure.
- The number of fertiliser applications is calculated based on minimum gifts of 50 kg ha⁻¹ at a time, up to a maximum of three gifts per growing season (*Numfert(1-4)*) in ANN_IO.XLS[*labour*]. The number of applications is accounted for in calculating the labour requirements (*epa_eng_1*, *epa_eng_2* and *epa_eng_3*) during field preparation, and the first and second maintenance period. If manure is selected to cover nutrient requirements (see below), application takes place in the rest of the season.
- The most limiting nutrient determines the amount of manure that is required (section 4.2.1) to meet the calculated nutrient deficit, and hence, the amount of labour required for its application. Implicitly, two nutrients are supplied in excess while this is not taken into account in the nutrient balances.
- Labour requirements for the preparation and maintenance of bunds take into account the total length of bunds per ha. The length of bunds depends on the recommended distance between bunds, which is a function of the slope (section 4.1).
- A switch is defined in IO_ANN.XLS[*criteria*] allowing to exclude labour requirements for bund construction (*labbund*) from the labour requirements. Bund construction only has to occur once while labour requirements for maintenance of bunds have to be taken into account each year. Including the construction of bunds in each system over-estimates the labour requirements as it is a very labour intensive operation. However, it is assumed that it occurs in the rest of the growing season when labour requirements are low. Hence, consequences of bund construction at farm level may be limited.
- A pair of oxen is assumed for field operations, which is managed by one person. Single oxen ploughs exist in Tigray but are not popular (REST, 1995). Considerable differences are found in literature regarding oxen requirement for field operations, ranging from 100 to 60 oxen hours ha⁻¹ (REST, 1995). The default value is 80 oxen hours (10 oxen days ha⁻¹) and 40 man hours per ha (5 mnd ha⁻¹) for one pass including travelling time between parcels and preparation of the oxen and plough. In general, three passes are carried out during the field preparation period and one pass in the rest of the season.

5. General remarks and conclusions

The TCG-Tigray offers a generic framework to integrate different types of land use data and knowledge required to quantify alternative land use systems in terms of inputs and outputs. Many data are based on published sources (e.g. REST, 1995) while relevant processes (e.g. crop growth, erosion) have been modelled using well-accepted agro-ecological approaches as much as possible. Within the limited time horizon of the project and the data scarce environment of Tigray, it was impossible to validate the model. Researchers and other users are challenged to improve data sets and to incorporate other relationships that may better represent processes than current approaches used which, in some cases, can be typified as ‘shortcuts’. Given these limitations, users should interpret results with care. However, the model contains probably one of the most extensive and accessible data- and knowledge bases on land use systems in Tigray. The structure of the TCG and modelling software leave ample scope for improvements with respect to the data and modelled processes as long as the results (specified input or output) are stored in range names that correspond with the range names used in the generated output of the model in IO_ANN.XLS[IO].

In the following points major shortcomings of the TCG-Tigray and possibilities for improvements are briefly discussed:

- Crop growth simulations are based on combining monthly weather data with daily rainfall data for two years. Nonhebel (1993) showed the importance of accurate weather data sets for simulation purposes. Daily weather data will improve the accurateness of simulated yields, while more daily rainfall data will enable to analyse the consequences of temporal variability on yield and the agricultural development options of Tigray. Especially, in low and erratic rainfall areas such as Tigray, consequences of temporal variability may be of great importance for the livelihood of farmers and the options to improve these. One other erratic weather aspect, i.e. low temperatures, could not be dealt with in the simulations as only monthly temperature data were available. However, it is known that in certain periods of the year low temperatures affect crop growth.
- Crop parameters used in the simulation of crop yields were almost absent for Tigray. Location-specific varieties are grown in Tigray which are not well characterised by the ‘standard’ crop files in WOFOST. Some of the parameters can be determined in simple field experiments allowing to improve calibration of WOFOST.
- The livestock component in the TCG is only briefly discussed in this report as it is described in detail in Hengsdijk *et al.* (1996). It is assumed that the existing modules developed for West-Africa are a good starting point and framework for modelling livestock systems taking into account the lack of data and process-knowledge for Tigray. Probably, some of the driving variables of these modules such as mortality and fertility rate, etc. can be calibrated for the Tigray situation. The livestock modules lack an interaction between pasture and livestock, for example, animal density does not affect quantity or quality of available pasture fodder, while manure from livestock does not affect the nutrient status of pasture land and its fodder. Instead, a simplified approach based on feed menus (section 3.3) is used neglecting such interactions.
- The incorporation of a four year crop rotation in the TCG allows to study the effect of different crop sequences, such as residual nutrients. However, it was impossible to calibrate the required transfer coefficients due to a lack of data.
- Defining cropping systems as rotations has two important consequences: The number of systems that can be generated becomes very large. This was one of the reasons why rotations were not used in the project ‘Policies for Sustainable Land Management in the Ethiopian Highlands’. Therefore, the automatic generation of IO’s in the current TCG version is aimed at ‘monocultures’ only. Therefore, labour requirements are only calculated for the crop in the first year. Labour requirements of other crops in a rotation can be incorporated easily. However, the number of IO’s increases exponentially as for each year (or crop) inputs and output may differ.

- Alternative systems using herbicides and biocides can be defined. Currently, these inputs are hardly used in Tigray and, therefore, no herbicides and biocides have been specified in the TCG. Only, the labour requirements associated with their application and their potential effect on yield (biocides) has been taken into account.
- Various yield correction factors have been defined (section 4.1) to account for non-standard conditions, for example, a low mechanisation level reduces simulated yields with a well-defined percentage. These correction percentages can be user-defined and can have a positive or negative value.
- A new feature in the TCG compared to versions for other regions is the incorporation of a relationship between soil and water conservation measures (bunds) and improved water availability for crop production. Though a lot of uncertainty exists on the direction of this relationship, i.e. a positive or negative effect, here, it is assumed to be positive (section 4.1). For different soils, different relationships have determined though it is not known to what extent runoff is reduced by bunds. Two options are available, 10 and 25% less runoff. Some literature, however, point at higher reductions in runoff due to soil an water conservation measures, up to 50% (Herweg & Ludi, 1999).

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Appendix I.

Codes of options

2a	Zone	<i>zone_list</i>	number
	Gobo Deguat	TG	1
	Tehegane	TH	2
2b	target yield level	<i>level_list</i>	number
	10% of maximum attainable yield	10	1
	20% of maximum attainable yield	20	2
	30% of maximum attainable yield	30	3
	40% of maximum attainable yield	40	4
	50% of maximum attainable yield	50	5
	60% of maximum attainable yield	60	6
	70% of maximum attainable yield	70	7
	80% of maximum attainable yield	80	8
	90% of maximum attainable yield	90	9
	100% of maximum attainable yield	100	10
2c	type of soil (Gobo Deguat)	<i>soilTG_list</i>	number
	sandstone-sandy loam-bottom/terrace	TG1	1
	sandstone-sand-valley/terrace	TG2	2
	basalt-loamy sand-plateau	TG3	3
	basalt-sandy clay loam-hilland	TG4	4
	sandstone-sandy loam-midslope	TG5	5
2c	type of soil (Tegahne)	<i>soilTH_list</i>	number
	sandstone-valley-flood plain	TH1	1
	claye sandstone-valley-terrace	TH2	2
	sandstone-plateau-mesa	TH3	3
	claye sandstone-valley-mesa	TH4	4
	sandstone-valley-terrace	TH5	5
	sandstone-hill land-hill	TH6	6
2d	type of annual crop	<i>annual_crop_list</i>	number
	Hordeum vulgare - barley	HV	1
	Pennisetum glaucum - millet	PG	2
	Phaseolus vulgaris - pulses	PV	3
	Sorghum vulgare - sorghum	SV	4
	Triticium durum - wheat	TD	5
2f	mechanisation level	<i>mec_list</i>	number
	high mechanisation level	HM	1
	low mechanisation level	LM	2
2g	herbicide level	<i>herb_list</i>	number
	high herbicide level (with herbicides)	HH	1
	low herbicide level (no herbicides)	LH	2

2h	biocide level	<i>bio_list</i>	number
	high biocide level (with biocides)	HB	1
	low biocide level (no biocides)	LB	2
2i	soil and water conservation	<i>svc_list</i>	number
	soil and water conservation (bunds)	BUN	1
	no soil and water conservation	NUN	2
2i	crop residue strategy	<i>utres_list</i>	number
	field grazing/burning	FLD	1
	mulch	MUL	2
	harvesting/stable feeding	STA	3
2k	origin of oxen	<i>origin_ox_list</i>	number
	Bought	BO	1
	Herd	HD	2
2k	energy intake levels	<i>na_list</i>	number
	5% above maintenance	1.05	1
	10% above maintenance	1.1	2
	15% above maintenance	1.15	3
	20% above maintenance	1.2	4
2k	major production goal dual purpose cattle	<i>goal_list</i>	number
	meat	meat	1
	milk	milk	2
	traction	traction	3
	energy intake levels of feed in wet season	<i>na_sp_list</i>	number
	150% of maintenance	1.5	1
	175% of maintenance	1.75	2
	200% above maintenance	2	3
	energy intake levels of feed in dry season	<i>na_ss_list</i>	number
	25% of maintenance	0.25	1
	50% of maintenance	0.5	2
	75% of maintenance	0.75	3
	100% of maintenance	1	4
	125% of maintenance	1.25	5
	150% of maintenance	1.5	6
	200% of maintenance	2	7