VINVAL

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TechnoGIN3: a generic tool for analysing cropping systems

Application of prototype for West-African conditions within the VINVAL project

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Research Report 2004-03

Impact of changing land cover on the production and ecological functions of vegetation in inland valleys in West Africa

Due to several reasons, food shortage problems are a major issue in sub-Saharan Africa. In attempts to solve the shortages considerable effort has been devoted to strategies for increasing agricultural production. This is being achieved by an expansion of cultivated area, as well as by higher productivity per unit. The need for new agricultural land has been a strong argument for the extensive clearing of natural vegetation. This has resulted in widespread environmental degradation. As this is now resulting in serious constraints to sustainable development, there is clearly a need to develop an integrated approach towards land use planning involving and balancing both agricultural production objectives and environmental concerns.

Overall Objective:

The overall objective of the project is to develop a tool for integrated land use planning at watershed scale that contributes to improve sustainable agricultural production systems in inland valleys in West Africa. Inland valleys are the upstream areas of drainage systems. This tool will take into account the balance between production and protection objectives and will assist in making informed decisions on allocating land use activities of small holder farmers across the watershed on both agricultural and natural land. Natural land is here defined as all land that is covered by natural and fallow vegetation. Such decisions are based on knowledge of the productive value of these land use activities and their impact on ecological functions.

Specific Objectives:

- Quantify the production, regulation (water, sediment and nutrient flows) and bio-diversity functions of natural and agricultural ecosystems at farm and watershed scale in three inland valleys in Ghana and Burkina Faso with distinct different land use intensities.
- Assess the economic importance of the tradeoffs and complementarities between natural and agricultural ecosystems and the different functions they provide.
- Develop a GIS-based tool for integrated, multifunctional watershed-level land use planning for use by extension services and planners. This tool will support the analysis of the

impact of different land use development scenarios on the ecological and production functions. The tool can be used in the decision-making process of land development.

Duration

This project will run from 2001 until 2005.

Location

The project will work in selected inland valleys of West Africa, where land cover ranges from almost natural to intensive agricultural production. The selected inland valleys are located in Ghana (Ashanti Region) and Burkina Faso (Kompienga).

The Participants

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The project outputs are organised in the following report series:

- **WP = Working Paper**

In these reports the most important results of the project activities are presented. These reports have the status of working papers of which some will be published in scientific journals.

- **MR = Mission reports**

These reports present the activities undertaken during missions of the European project partners to China and Vietnam.

- **PM = Project Management reports**

These reports contain information about two important issues, the progress of the VINVAL project and accounts of the official project workshops.

RDA team:

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Contents

1 Introduction

Agricultural research in Africa and Asia is increasingly challenged by the search for land use options that best match multiple development objectives of rural societies (i.e. increased income, employment, improved natural resource use efficiency, food security, reduced environmental pollution). This calls, among others, for effective tools for resource use analysis at different integration levels. Since the 1980s, the method of interactive multiple goal linear programming (IMGLP) has been proposed for an integrated analysis of resource use at regional or farm level (De Wit et al., 1988). This method has been applied in various land use studies (Rabbinge & Van Latesteijn, 1998; Bouman et al., 1999). Key components in frameworks using this approach are: (1) databases on biophysical and socio-economic resources and development targets; (2) description of inputs and outputs of all promising production activities and techniques; (3) multiple criteria decision method (optimisation); and (4) sets of goal variables (representing specific objectives and constraints).

Within the IRMLA-project, TechnoGIN-3 has been developed for quantifying inputs and outputs (see component 2 above) of main current and future-oriented production activities (i.e. cropping systems) in regions in the Philippines, P.R. China and Vietnam. TechnoGIN stands for Technical coefficient generator for Ilocos Norte province, Philippines, as it was originally developed for this province. TechnoGIN is a technical coefficient generator (TCG) and is comparable to tools that have been developed for the purpose of explorative land use analysis under multiple goals in Costa Rica and Vietnam (Hengsdijk et al., 1996; 1998; Bouman et al., 1998; Jansen, 2000).

TechnoGIN-3 is generic tool that can be applied to a large range of environmental conditions and to a large variety of cropping systems in a region. In addition to quantifying input-output relationships of main production activities, it can be used to determine the profitability and the cost-benefit ratio of these activities and their environmental pollution. For environmental conditions in West Africa, a prototype version of TechnoGIN-3 has been developed within the VINVAL project. Some preliminary results are presented in this report.

2 Methodology

TechnoGIN-3 applies a target-oriented approach. This means: a fine-tuning of inputs to realize a specified yield level under certain environmental and management conditions (Van Ittersum & Rabbinge, 1997). This approach enables us to quantify the required amount of various inputs such as labour, water, fertiliser, and their monetary values to attain yield levels in various land use systems. In addition to these yields and the related amounts of crop residues, also side effects of the production process on the resource base (such as soil nutrient depletion) and pollution of the environment (e.g. nitrate leaching, biocide exposure) can be calculated for the different land use systems. Such side effects are often expressed in sustainability indicators.

TechnoGIN-3 has initially been developed on the basis of concepts from earlier TCGs such as LUCTOR (Hengsdijk et al., 1998) and Agrotec (Jansen, 2000). The new version TechnoGIN-3 has thoroughly been re-designed and tested to become a more generic and flexible tool, applicable to an extended range of cropping systems and agro-ecological conditions in Africa and Asia. In addition, the QUEFTS model (Janssen et al., 1990; Witt et al., 1999) was incorporated to calculate the crop's nutrient uptake.

TechnoGIN-3 was programmed in Microsoft Excel with macro programming in Microsoft Visual Basic for Applications. To make the TCG and databases better manageable and accessible, TechnoGIN-3 consists of a model file and separate data base files for the different case study areas. In the model file, calculations are executed, the model interface (buttons and user forms) is integrated and model output is stored (which can be exported to a separate file for feeding the IMGLP model). TechnoGIN-3 has a user-friendly interface (Figure 1). You may select a production activity (top button of Figure 1), such as a crop rotation (i.e. LUT or land use type) on a Land Management Unit (LMU) with the yield levels that are expected for a present or future production technique. For these 'target' yield levels, TechnoGIN calculates the technical coefficients (i.e. required inputs, environmental pollution). TechnoGIN may be applied for comparing resource use efficiency, labour demand, cost/benefit ratios and environmental pollution from different crop rotations and production techniques.

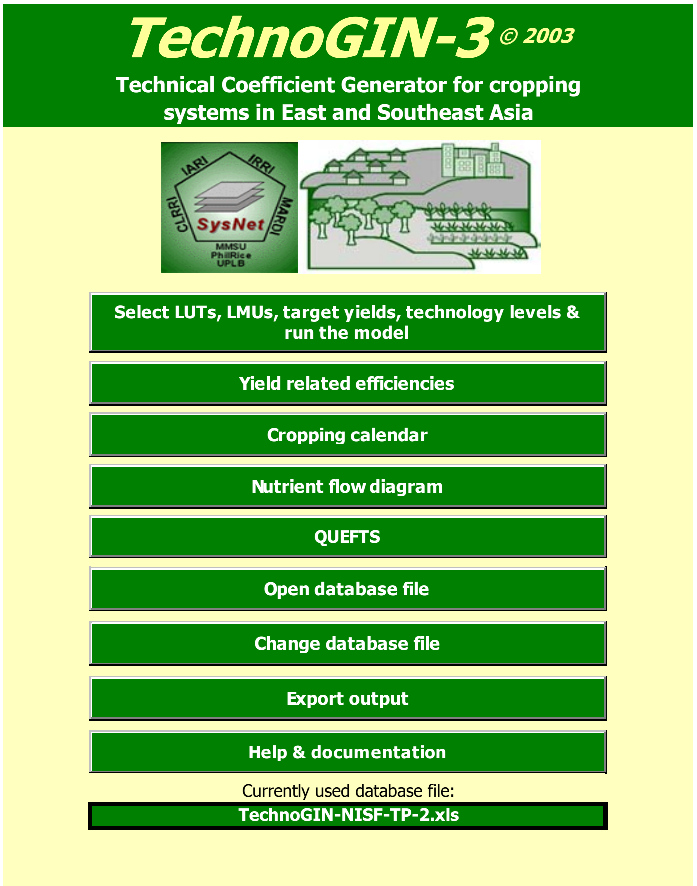

Figure 1   Main selection form of TechnoGIN-3

For each case study area a database file is produced. This file contains data bases organised in separate worksheets for respectively crops, land use types (i.e. crop rotations), land (management) units, production techniques, fertilisers, biocides, etc in that area. A simplified representation of the structure of TechnoGIN and its data bases is shown in Figure 2. An overview of the output of TechnoGIN, i.e. the technical coefficients, is also given in this figure.

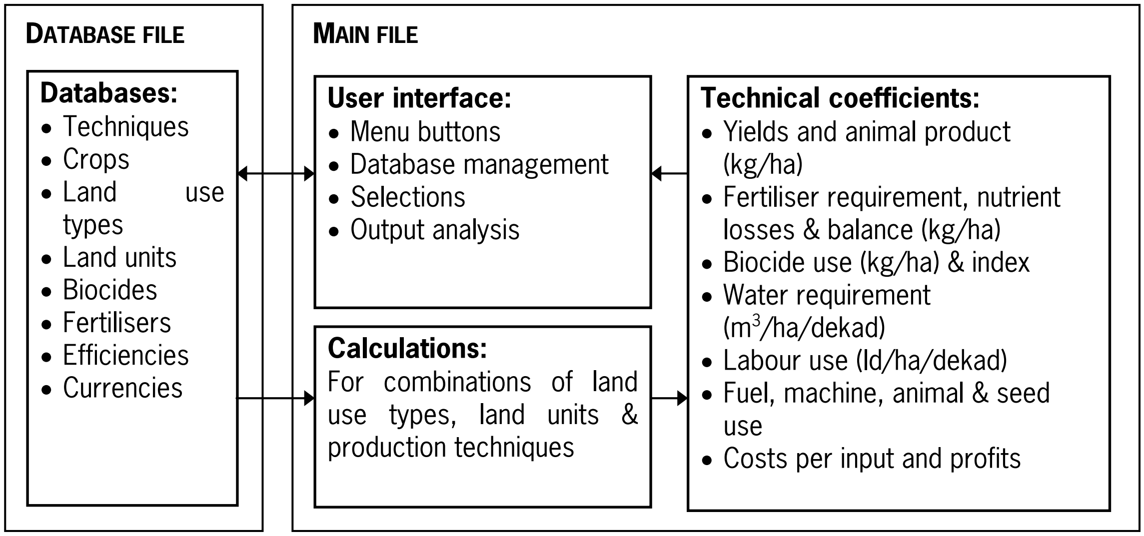

Figure 2 *Simplified representation of the structure of TechnoGIN-3 (Source: Ponsioen et al., 2003); the arrows represent flows of data*

3 Application to West African conditions

Calculations have been done for the main crop rotations or land use types (Table 1), land units (Table 2) and a number of possible future production techniques (Table 3). The target yield levels as estimated for the future under improved (i.e. low yield) and best (i.e. high yield) conditions (Table 1), can be based on results from field trials and from crop growth simulations under West African conditions.

More specific information on crops and land units as based on the local conditions in the case study areas in West Africa, should be entered later within the project. The information presented in the following, should be considered as a first start of the land use analysis and is to demonstrate the potential of TechnoGIN-3 applications for integrated land use studies.

Table 1 Main crop rotations and future target yield levels under West African conditions

Crop	Duration growing season (d)	Target yield low (ton/ha) Lowland / Terrace	Target yield high (ton/ha) Lowland / Terrace
Rice	120	4.0 / 3.0	5.0 / 4.0
Maize	120	5.0 / 4.0	6.0 / 5.0
Peanut	120	3.0 / 2.0	4.0 / 3.0
Cotton	120	3.0 / 2.0	4.0 / 3.0
Vegetable	90	4.0 / 3.0	5.0 / 4.0
Mango	360	2.0 / 1.5	3.0 / 2.5
Sorghum	120	4.0 / 3.0	5.0 / 4.0
Millet	90	2.0 / 1.5	3.0 / 2.5

Table 2 Main land units and their soil characteristics for West Africa

Land unit	Annual precipitation[1] (mm)	Maximum soil water holding capa-city (mm)	Soil N supply (kg N/ha/yr)	Soil P supply (kg P/ha/yr)	Soil K supply (kg K/ha/yr)
Lowland poor	800	100	20	3	30
Lowland moderate-rich	800	100	40	8	50
Terrace poor	800	100	20	3	30
Terrace moderate-rich	800	100	40	8	50

[1] rainfall period starting in May and ending in September

The TechnoGIN-3 calculations have been done for four different future types of production technique. Technique A is slightly improved in comparison to the actual cropping systems and has a relatively low target yield, a relatively low recovery fraction of applied fertilizer nutrients and standard input use (i.e. specified per crop type in worksheet) with respect to labour, biocides, mechanical equipment and animal use (Table 3). Technique B applies a more intensive production technique with a higher target yield level and hence higher input requirements (fertilisers, biocides, labour, etc.). Technique C applies Integrated Nutrient

Management (e.g. split nutrient application and crop- and site-specific nutrient management). This results in a higher recovery fraction of applied nutrients but consequently too in higher demands for labour, fuel and use of mechanical equipment. Technique D applies both Integrated Nutrient Management (INM) and Integrated Pest Management (IPM).Compared to technique C , the labour demand for crop management becomes even higher, but the use of biocides is strongly reduced.

Table 3 Main production techniques for actual and future cropping systems under West African conditions and their target yield levels and input use requirements

Input requirements	Actual (**A**)	Improved, high NPK (**B**)	INM (**C**) [1]	INM + IPM (**D**) [2]
Yield level[3]	Low	High	High	High
Recovery fr. applied N	40%	40%	52%	52%
Recovery fr. applied P	30%	30%	39%	39%
Recovery fr. applied K	50%	50%	65%	65%
Relative labour input for crop management	1.0	2.0	3.0	4.0
Relative biocide use	1.0	2.0	2.0	0.5
Relative fuel use	1.0	2.0	3.0	3.0
Relative machinery use	1.0	2.0	3.0	3.0
Relative animal use	1.0	1.0	0.0	0.0

[1] INM: integrated nutrient management
[2] IPM: integrated pest management
[3] Yield levels as specified in Table 1 for both low and high target levels for the different crop types

4 Results

The outputs of TechnoGIN-3 are the technical coefficients that describe the input – output relationships of crop production systems. The technical coefficients consist of:

a. evapo-transpiration and required irrigation water
b. N,P,K fertiliser requirements and emissions
c. labour demand
d. costs and use of different types of fertilisers
e. cost and use of different pesticides, herbicides and fungicides
f. costs and use of other inputs (machinery, animals, investments)
g. economic indicators
h. environmental impacts

The technical coefficients have been calculated for all combinations of crop rotation, land units and production techniques (see Section 3). Some of these results are shown in the following. Note that these results are based on first rough information for the main crop rotations, land units and possible future production techniques for West Africa. More specific and precise information is to be collected for the main cropping systems in West Africa within the VINVAL project. After this literature search and subsequent improvement of the data base worksheets for crops, land units, etc. (see Figure 2), more precise and site-specific input-output relationships can rapidly be produced with TechnoGIN-3.

4.1 Evapo-transpiration and required irrigation water

TechnoGIN-3 calculates from the maximal evapo-transpiration over the year for the specified crop rotation and from the annual rainfall distribution the required amount of irrigation water (Figure 3). This shows that in West Africa (in region with annual rainfall of 800 mm) the maximal evapo-transpiration of annual crops (such as rice) increases from crop emergence in June, is highest in July and August when the crop cover is closed, and stops at crop maturity at the end of August. The irrigation water requirements for annual crops as rice are nil, as long as the growth period just falls in the high-rainfall period during the summer. During the winter the maximum evapo-transpiration is determined by the soil evaporation (i.e. fallow land) and the actual evapo-transpiration is generally nil as no rainfall occurs.

Growth of mango trees finds place during the whole year, assuming irrigation during the dry winters. The crop cover and hence the maximal evapo-transpiration is assumed to be less than that for annual crops with a closed canopy (Figure 3). Irrigation water demand for a permanent crop as mango is strong during the dry winter period.

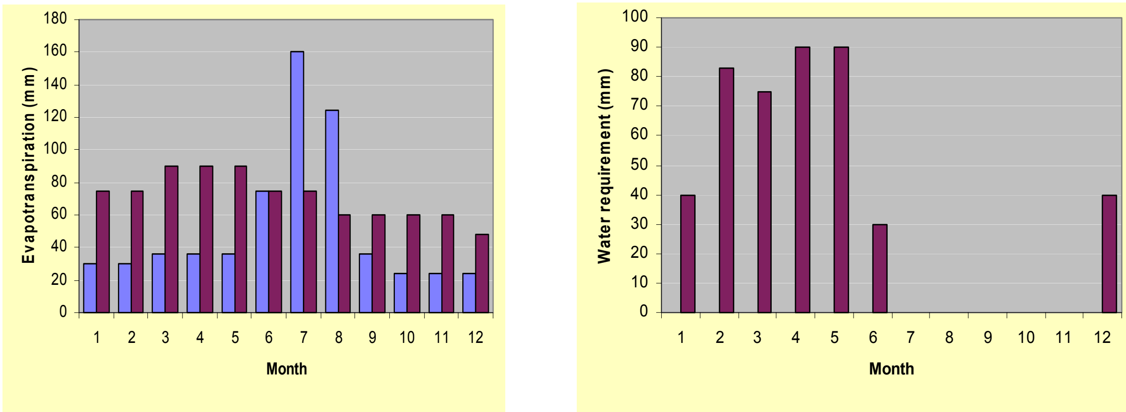

Figure 3 Maximal evapo-transpiration (left) and required amount of irrigation water (right) for rice and mango (assuming permanent growth and irrigation) cropping systems in West Africa from TechnoGIN-3 calculation. Rice= blue columns and Mango= dark-red columns.

4.2 NPK fertiliser requirements and emissions

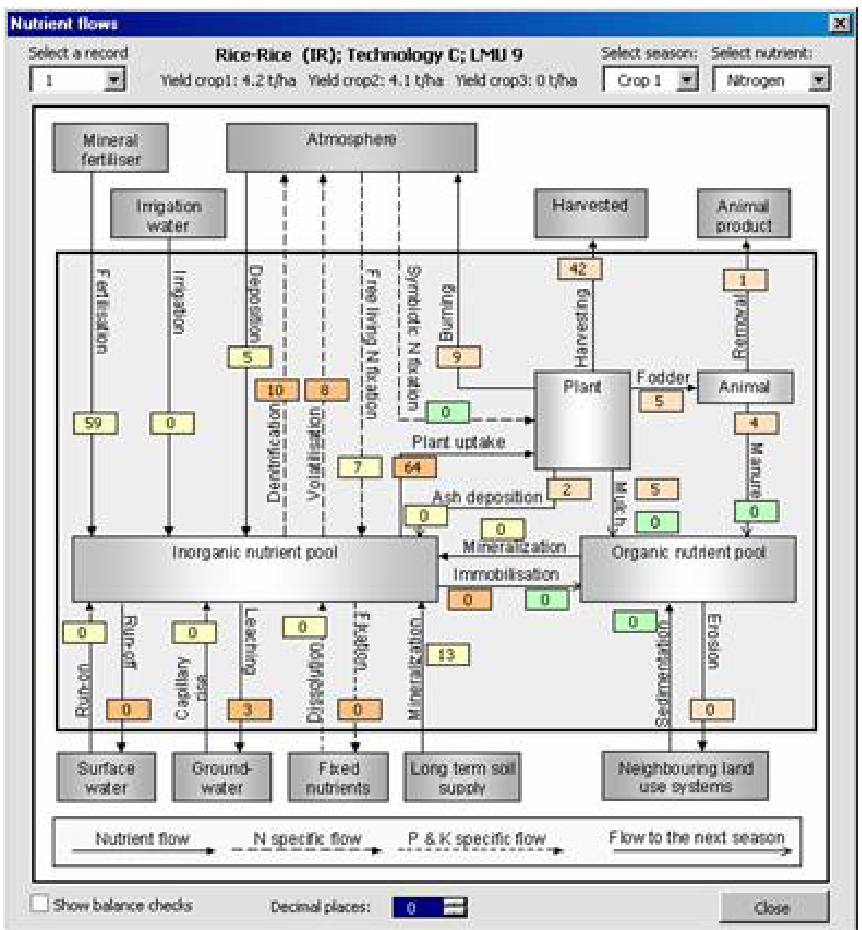

Figure 4 Diagram of nutrient pools and flows for the specified crop production system (e.g. rice with target yield of 4.2 ton/ha) from TechnoGIN-3 calculation

For the selected crop production system the flows of nitrogen, phosphorus and potassium over one year are calculated and presented by TechnoGIN-3, as shown in Figure 4. For the specified target yield level, the crop's nutrient uptake is calculated with the QUEFTS approach (Janssen et al., 1990; Witt et al., 1999). For each land unit the natural soil nutrient supply can be specified (Table 2). From this crop's nutrient uptake and the natural nutrient supply, the required amounts of fertiliser nutrients and the nutrient emissions by leaching, denitrification and volatilization are calculated.

The nitrogen and phosphorus balances have been calculated with TechnoGIN-3 for rice cropping on a poor lowland soil at production techniques A, B and C (technique D is identical to C with respect to nutrients). Technique B is a more intensified system than A with a higher target yield level (see Table 3) and hence a larger fertiliser nutrient demand (Table 4). This results in more N and P losses than for technique A. Technique C applies integrated nutrient management which results in lower fertiliser nutrient demand and in much lower nutrient losses. If technique C is applied on a moderately rich soil, the fertiliser nutrient demand and the nutrient losses are lowest. This shows that intensive crop production systems with high target yields require good soils and a very good management. Otherwise, strong nutrient losses and emissions may occur.

Table 4 Main nitrogen and phosphorus inputs and outputs (kg N and P per ha) for rice cropping on a poor lowland soil at production techniques A, B and C and for rice cropping on a moderately rich lowland soil at production technique C

Input/output	Techn. A Poor soil	Techn. B Poor soil	Techn. C Poor soil	Techn. C Moderate rich soil
Crop N uptake	73	92	92	92
N losses[3]	65	93	57	39
N fertiliser[1]	93	135	99	61
Biol. N-fixation	10	10	10	10
Soil-N supply	20	20	20	40
N-recycling[2]	15	19	19	19
Crop P uptake	10	12	12	12
P losses[3]	15	21	14	6
P fertiliser[1]	20	28	21	8
Soil P supply	3	3	3	8
P recycling[2]	2	2	2	2

[1] fertiliser nutrients are calculated from the nutrient demand for the specified target yield minus the natural nutrient supply divided by the recovery fraction of applied fertiliser nutrients (see Table 3)

[2] recycling of nutrients through crop residues and manure

[3] losses through leaching, denitrification and volatilization for N and by fixation for P

4.3 Labour demand

For each crop type the amount of labour that is required for land preparation, crop establishment (sowing or planting), crop management (fertiliser application, crop protection, etc.) and harvesting, is specified in the crop data worksheet. For the specified crop rotation the labour demand over the year can be calculated with TechnoGIN-3, based on these crop data. The presented results show that the labour demand for crop management is much higher for maize with technique D (integrated nutrient and pest management) than for maize with technique A (Figure 5 left). The distribution of the labour demand over the year differs between crop types. A short-duration vegetable crop may have a higher peak in labour demand in the middle of the growing season than the rice crop (Figure 5 right). This may be of importance for the selection of cropping systems if the availability of human labour (at farm or regional scale) is a limiting factor.

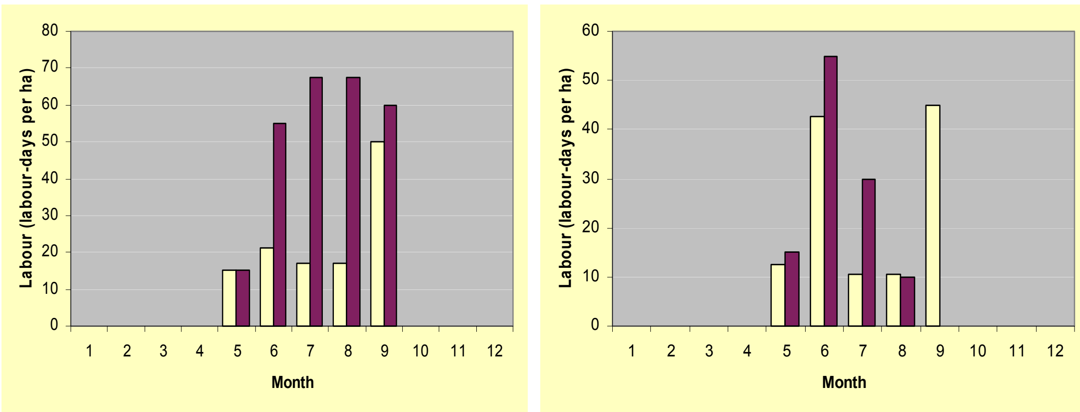

Figure 5 Labour demand over the year for maize cropping in West Africa with techniques A and D (left: A= yellow; D= dark red) and for rice and vegetable cropping with technique A (right: rice= yellow; vegetables= dark red) from TechnoGIN-3 calculation

4.4 Costs of inputs and economic indicators

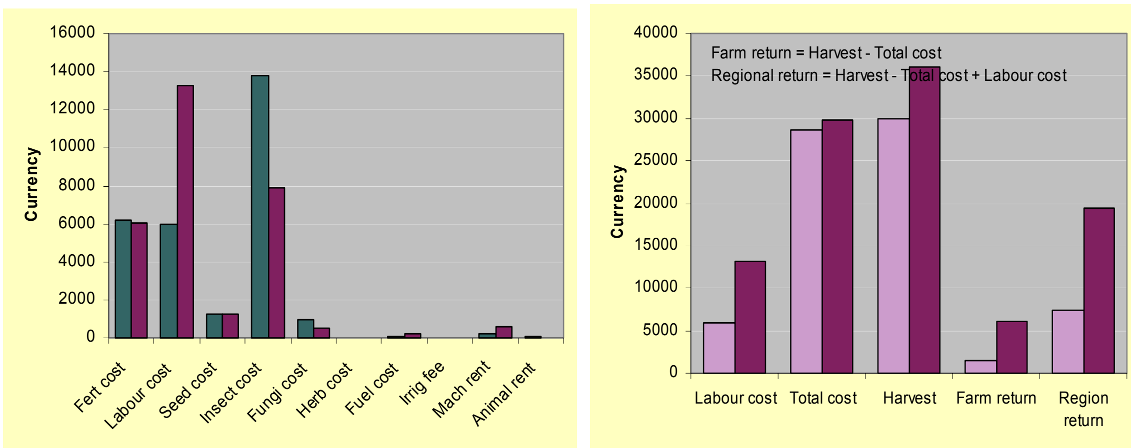

Figure 6 Costs of inputs for maize cropping with techniques A and D on a poor lowland soil in West Africa (left: green= techn. A and dark-red= techn. D) and the benefits (=harvest), farm return and region return (right: light-red= techn. A and dark-red=techn. D) from TechnoGIN-3 calculation

For the different inputs such as labour, machinery and animal use, fertilisers and biocides, the prices are specified in the data worksheets of TechnoGIN-3. From these prices and the calculated input use, the costs for the specified crop rotation can be calculated (Figure 6 left). Maize cropping with technique D with integrated nutrient and pest management requires much more labour for crop management than technique A, however, the costs for applied pesticides are much lower. For each crop product, the price is specified in the data base worksheet. The crop yields (note: higher yield for technique D than for A) times these prices give the benefits from the specified crop rotation. These benefits minus the total costs (inclusive costs for labour) give the farm return and the benefits minus the total non-labour costs give the region return (Figure 6 right). Note that actual prices for the required inputs for maize cropping and for maize grains were not available. Hence, the presented example for maize cropping in West Africa (Figure 6) is based on virtual prices. However, this example shows the potential of the TechnoGIN-3 approach.

4.5 Environmental impacts

Nutrient losses by leaching to the groundwater and nitrogen emissions to the air by denitrification and volatilization can be calculated by TechnoGIN-3, as shown above in Table 4 and in the nutrient flow diagram (Figure 4).

For each applied biocide, the persistence in the soil and the toxicity are to be specified in the data base worksheet. Based on the applied biocides in a crop rotation, the total biocide residue index is calculated with TechnoGIN-3, applying the approach by Pathak et al. (2001). This index is a rough estimate for the environmental impact of the total biocide use, and depends on total biocide use, the persistence of these biocides in the soil and their toxicity.

5 Conclusions

The first applications of TechnoGIN-3 for West Africa within the VINVAL project show that it can be a very useful tool for comparing actual and possible future land use systems and different crop production techniques. In such a comparison, the differences between production systems can be shown and analysed in terms of water use, labour demand, fertiliser nutrient requirements, resource-use efficiency, economic aspects and environmental impacts.

TechnoGIN-3 is a user-friendly tool for producing technical coefficients (i.e. inputs and outputs) for the generally large number of main crop production activities (i.e. main Crop rotation-Land unit-Production technique combinations) in a region. The number of technical coefficients that TechnoGIN-3 can produce for each production activity, is large. The large output of TechnoGIN-3 calculations can easily be managed and interpreted using graphs, statistics, geographic information systems (GIS) and optimisation models.

The quality of the TechnoGIN-3 output is always determined by the quality of the data bases for crops, land units, production techniques, etc. Hence to ensure the quality of the TechnoGIN output, used data bases should be checked on local information (e.g. farm surveys, field trials) and output need to be carefully evaluated on the basis of the applied assumptions on the agricultural production system.

This study shows the first results from application of TechnoGIN-3 to the main crop production activities that may occur in West Africa. For each of these production activities, the input-output relationships have been produced. This indicates the strong potential of TechnoGIN-3 application for integrated land use studies.

More site-specific information on crop rotations, land units and production techniques have to be collected within the VINVAL project for the case study areas in West Africa. Hence, information from farm surveys, agricultural statistics and field experiments should be collected.. Use of the site-specific information is essential to produce reliable input-output relationships for the main cropping systems in the case study areas.

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