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Non-Point Pollution SOLutions (NPP-SOL)

Deliverable 4.2: DAHBSIM software and related handbook

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PRIMA
PARTNERSHIP FOR RESEARCH AND INNOVATION IN THE MEDITERRANEAN AREA

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DYNAMIC AGRICULTURAL HOUSEHOLD BIO-ECONOMIC SIMULATOR (DAHBSIM)

NPP-SOL

NON-POINT POLLUTION SOLUTIONS

USER HANDBOOK

CIHEAM
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INTRODUCTION

DAHBSIM IS A DYNAMIC, BIO-ECONOMIC MODEL OF AGRICULTURAL HOUSEHOLDS THAT WAS DESIGNED FOR THE PURPOSE OF ADDRESSING QUESTIONS AROUND THE BIOPHYSICAL CONSTRAINTS TO ON-FARM AGRICULTURAL PRODUCTIVITY, AND THE WHOLE-FARM IMPLICATIONS OF ALTERNATIVE STRATEGIES TO SUSTAINABLE AGRICULTURAL INTENSIFICATION.

The model links socio-economic and biophysical aspects, in order to better illustrate the environmental impacts or externalities and human welfare implications of different agricultural production practices, as they are influenced by political, economic or environmental changes.

The dynamics of the model are designed to capture long term changes in soil productivity, based on farm management decisions, which are updated on an annual basis.

The expected crop yield in future periods is based on the current year value, but each year actual crop yields are updated based on previous periods' management decisions.

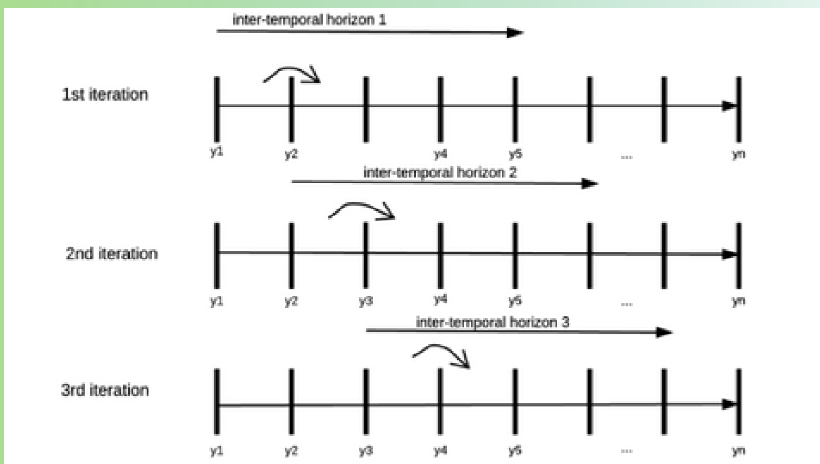
Price and yield variability in the agent's decision-making process are taken into account via the risk module.

RECURSIVE INTER-TEMPORAL OPTIMIZATION

DAHBSIM is a recursive inter-temporal model as the decision maker has usually a multi-year planning horizon. The exact number of years can be specified by the model user.
Equations are indexed over years and the decisions of farmers are optimized given a discounted utility function, the results obtained at the end of a specific simulation are used as starting values for the following one.
The yields obtained at the end of the first (inter-temporal) simulation are multiplied by the biophysical stress coefficients which increase or decrease the yields in the next (inter-temporal) simulation depending on the precedent crop and the next year's precipitations.

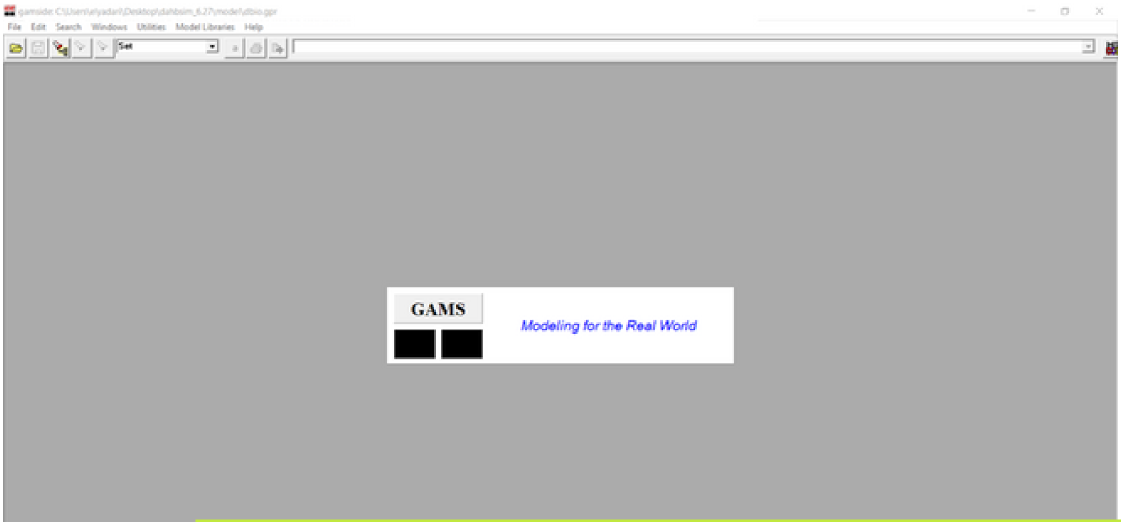
Recursive updates occur on a yearly time step in DAHBSIM., however, particular processes are accounted for on a sub-annual basis (e.g. livestock numbers, cropping activities).

The objective function is defined over a time period (the inter-temporal horizon) which can be pre-specified by the user.
The time frame over which the model operates is also pre-specified by the user. The model's objective function is run at each recursive iteration (year, in this case) and production parameters are updated each year based on the previous year's decisions.



MODELLING IN DAHBSIM

DAHBSIM IS WRITTEN IN THE GENERAL ALGEBRAIC MODELLING SYSTEM (GAMS)



OBJECTIVE FUNCTION

The model objective is the maximization of a **risk adjusted net present value** term.

$$\text{Maximize NPV} - \varphi \times \sigma$$

σ is the standard deviation of net present value

φ is a risk aversion coefficient

Net present value is defined as the present value of the future income (revenues minus costs) from crops, animal sales, external activities, plus the value of self consumption.

$$\text{NPV} = \sum_{y=1}^{n} \frac{(\text{full income} + \text{value of consumption})}{(1+i)^{y}}$$

NPV:net present value (USD hh-1 yr-1) n: number of years in the model horizon (inter temporal horizon)

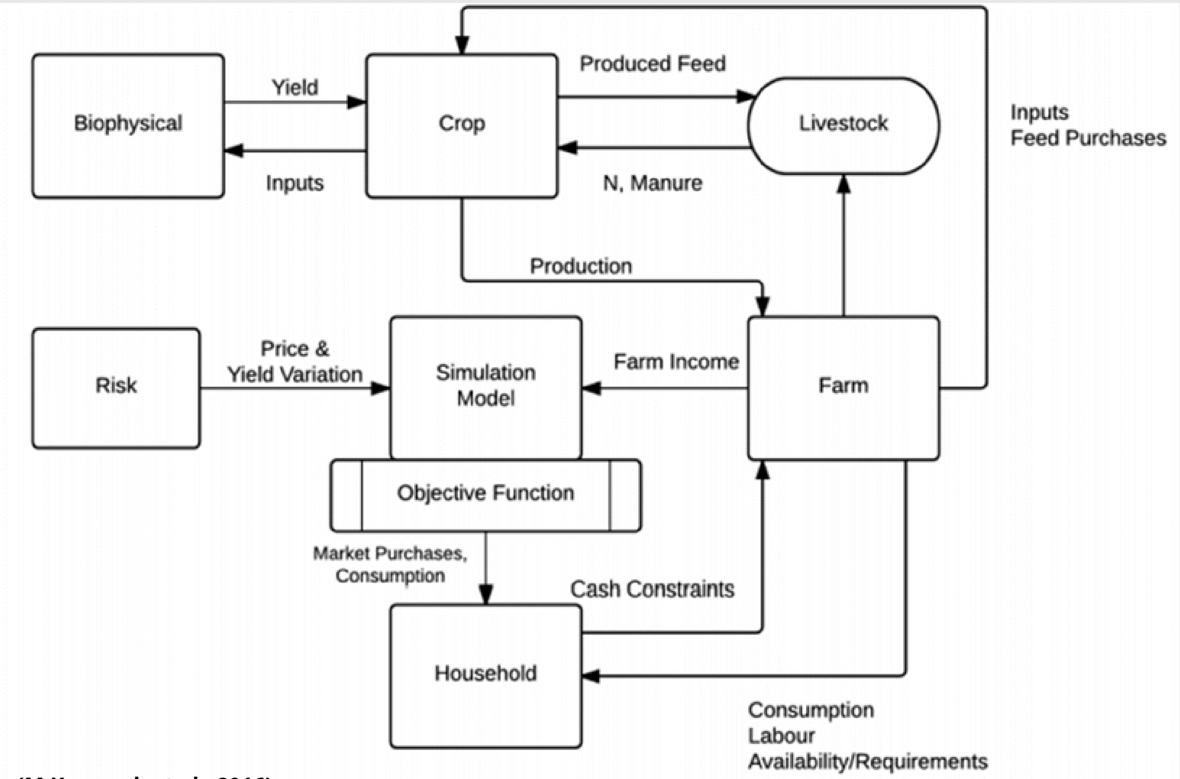
y: a specific year within the model horizon

i: the discount rate (default value: 0.04)

full income: off farm income+ revenues -costs for crop and livestock production, (USD hh-1 yr-1)

value of food consumption: the value of food consumed from on-farm production (USD hh-1 yr-1)

MODULARITY OF DAHBSIM



(M.Komarek et al., 2016)

THE DESIGN OF DAHBSIM MODEL ALLOWS TO RUN A FULL HOUSEHOLD MODEL, INCLUDING BOTH PRODUCTION AND CONSUMPTION, AS WELL AS A PRODUCTION MODEL ONLY, WHERE THE BIOPHYSICAL INTERACTIONS BETWEEN THE ON FARM LIVESTOCK AND RELEVANT INTERACTIONS WITH SOIL AND CROPS ARE ALSO TAKEN INTE ACCOUNT.

THE DAHBSIM MODELLING APPROACH RELIES ON THE MODULARITY OF DIFFERENT SUB COMPONENTS, WHICH ARE THEN INTEGRATED INTO A LARGER GLOBAL MODEL. VARIABLES THAT ARE DEFINED IN SPECIFIC MODULES CAN ACT AS VARIABLES OR PARAMETERS IN OTHER MODULES. IN THE FOLLOWING A SUMMARY DESCRIPTION OF THE MODULES.

DAHBSIM MODULES

1 CROP MODULE

- The crop module enables the simulation of different type of crops, both yearly and multi-year crops, and crop rotations via a single set of parameters.
- It integrates key **biophysical components** representing the constraints that farmers face in on-farm productivity (captured by DAHBSIM's biophysical module, see the next section) as well as crop characteristics, cropping system management options & constraints including land allocation, crop rotation, cultivar, irrigation and nitrogen fertilization.
- It summarizes the dynamics of soil water, nitrogen budgets, and their influence on crop yields. The nitrogen budgets encompass options for crop residue production, decomposition, and livestock manure. A versatile crop simulator accommodates different crops and rotations using a unified set of parameters, considering factors like precipitation, soil properties, and crop management options.
- Unstressed (potential) yield based on crop potential evapotranspiration is first determined, then yield is adjusted to water and nitrogen limitations as follows:

> The module uses the logic of Doorenbos and Kassam (1979) to calculate water-limited yields:

$$(1-Yw/Ym)=Ky(1-ETa/ETm)$$

where: Yw: water-limited yield (kg/ha)

Ym: maximum yield (kg/ha)

Ky: yield response factor

(K=1 if yield reduction is directly proportional to reduced water use, K > 1 if crop response is sensitive to water deficits and, K < 1 if crop is more tolerant to water deficit)

ETa:actual evapotranspiration (mm/day)

ETm: maximum evapotranspiration (mm/day)

> And the logic of Godwin et al. (1991) to calculate nitrogen-limited yield:

$$Yn=Yw[1-(NCcrit-NCONCa)/(NCcrit-NCmin)]$$

Where: Yn: nitrogen-limited yield (kg/ha)

Yw: potential growth after water limitation considerations (kg/ha)

NCcrit: plant critical nitrogen concentration (kg/ha)

NCONCa:plant nitrogen after new growth (kg/ha)

NCmin: minimum plant nitrogen concentration at which growth stops (kg/ha)

- The actual yield for the year (Ya) is taken as the minimum of the yield limited by water (Yw) and by nitrogen (Yn).

Parameter Name	Units	Description	Source File
p_cropCoef; other	nc ha^{-1}	Value of other inputs per ha	cropcoef.xlsx
p_cropCoef; nitr	kg N ha^{-1}	Nitrogen applied per ha	cropcoef.xlsx
p_cropCoef; seed	kg ha^{-1}	Seed applied per ha	cropcoef.xlsx
p_cropCoef; labour	Labour days ha^{-1}	Labour days per ha	cropcoef.xlsx
p_cropCoef; yield	kg ha^{-1}	Yield per ha	cropcoef.xlsx
p_cropCoef; straw yield	kg ha^{-1}	Straw yield per ha	cropcoef.xlsx
p_cropCoef; phyto	Phyto nc ha^{-1}	Value of phytochemicals per ha	cropcoef.xlsx
p_landReq	ha	Land requirement (growth period)	cropcoef.xlsx
p_labourReq	person-days ha^{-1}	Labour requirement (person-day per ha)	cropcoef.xlsx
p_inputReq	kg ha^{-1}, nc ha^{-1}	Direct input requirements	cropcoef.xlsx
p_cropData; area	ha	Area of crop	cropcoef.xlsx
p_cropData; yield	kg ha^{-1}	Yield per ha	cropdata.xlsx
p_cropData; yield straw	kg ha^{-1}	Straw yield per ha	cropdata.xlsx
p_cropData; seed	kg ha^{-1}	Seed applied per ha	cropdata.xlsx
p_cropData; cprd	kg ha^{-1}	Seed production per ha	cropdata.xlsx
p_cropData; labour	person-days	Person days of labour	cropdata.xlsx
p_cropData; nitrogen	kg ha^{-1}	Nitrogen applied per ha	cropdata.xlsx
p_cropData; fertilizer	nc ha^{-1}	Value of fertilizer per ha	cropdata.xlsx
p_cropData; phyto	nc ha^{-1}	Value of phytochemicals per ha	cropdata.xlsx
p_cropData; other	nc ha^{-1}	Observed baseyear data	cropdata.xlsx
p_seedData	kg	Observed seed data	cropdata.xlsx
p_perresmulch	percentage	% of crop residue production allocated to field as mulch	cropcoef.xlsx
p_residuedep	percentage	% of feed not wasted between months, then can be carried forward from month m to month m+1	cropcoef.xlsx
v0_cropYld	kg ha^{-1}	Crop yield	Determined endogenously after first iteration
v0_cactLev	ha	Observed activity level	cropdata.xlsx
v0_cropArea	ha	Observed crop area by soil type	cropdata.xlsx
v0_cropLand	ha	Observed crop land	cropdata.xlsx
v0_cactPrd	t	Observed crop activity production	cropdata.xlsx
v0_prodQuant	t	Observed crop output	cropdata.xlsx
v0_cactYld	kg ha^{-1}	Crop activity yield	cropcoef.xlsx
v0_inputUse	kg	Input use	cropdata.xlsx, cropcoef.xlsx
v0_inputCost	nc	Input cost	cropcoef.xlsx
v0_seedUse	kg	Seed use	cropdata.xlsx

PARAMETERS, VARIABLES & EQUATIONS

Variable Name	Units	Description
v_cactLev	ha	crop activity level by cp
v_cactPrd	ha	crop activity total
v_cactYld	t ha^{-1}	crop activity yield
v_prodQuant	t	production quantity
v_cropArea	ha	crop area by soil type
v_cropLand	ha	cropland used
v_cropLabour	person-days	labour used for cropping activities
v_inputUse	kg y^{-1}	input use
v_seedQuant	kg ha^{-1}	total seed quantity
v_residuesfeedm	kg m^{-1}	crop residues allocated for potential livestock feed intake or for feed balance each month
v_residuesmulch	kg y^{-1}	crop residues allocated to crops for mulch
v_residuesfeed	kg y^{-1}	crop residues allocated for potential livestock use or for feed balance
v_residuessell	kg y^{-1}	crop residues sold
v_residuessellm	kg y^{-1}	crop residues sold per month

Label	Equation
E_CROPLAND	$v\_cropLand_{hh,s,y} = \sum_{caen} v\_cropArea_{hh,caen,s,y}$
E_CROPLABOUR	$v\_cropLabour_{hh,y,m} = \sum_{caen,cp,s,tt} v\_cactLev_{hh,caen,cp,s,tt,y} \times p\_labourReq_{hh,caen,tt,m}$
E_CROPAREA_EN	$v\_cropArea(hh,caen,s,y) = \sum_{c\_c(caen,cp),tt} v\_cactLev_{hh,caen,cp,s,tt,y}$
E_ROTATION	$\sum_{c\_c(caen,cp),tt} v\_cactLev_{hh,caen,cp,s,tt,y} < v\_cropArea_{hh,cp,s,y-1} + v0\_cropArea_{hh,cp,s}$ (if y = 1)
E_CACTPRD_EN	$v\_cactPrd_{hh,caen,s,tt,y} = \sum_{c\_c(caen,cp)} v\_cactLev_{hh,caen,cp,s,tt,y} \times v\_cactYld_{hh,caen,cp,s,tt,y}$
E_CACTYLD_EN	$v\_cactYld_{hh,caen,cp,s,tt,y} = v0\_cactYld_{hh,caen,cp,s,tt}$
E_CROPPRD_CJ	$v\_prodQuant_{hh,cjen,j} = \sum_{a\_j(caen,cjen),s,tt} v\_cactPrd(hh,caen,s,tt,y)$
E_CROPPRD_CK	$v\_prodQuant_{hh,cken,y} = \sum_{a\_k(caen,cken),cp,s,tt\$c\_c(caen,cp)} v\_cactLev_{hh,caen,cp,s,tt,y} \times p\_cropcoef_{hh,caen,s,tt,'ystraw'}$
E_INPUTUSE_EN	$v\_inputUse_{hh,caen,ci,y} = \sum_{c\_c(caen,cp),s,tt} v\_cactLev_{hh,caen,cp,s,tt,y} \times p\_cropCoef_{hh,caen,s,tt,ci}$ v_inputUse(hh,caen,ci,y) = sum((c_c(caen,cp),s,tt), v_cactLev(hh,caen,cp,s,tt,y)*p_cropcoef(hh,caen,s,tt,ci))
E_SEEDUSE	$v\_seedQuant_{hh,caen,y} = v\_inputUse_{hh,caen,'seed',y}$ _seedQuant(hh,caen,y) = v_inputUse(hh,caen,'seed',y)
E_RESIDUES	$v\_residuesfeed_{hh,cken,y} + v\_residuessell_{hh,cken,y} + v\_residuesmulch_{hh,cken,y} = v\_prodQuant_{hh,cken,y}$
E_RESIDUESMULCH	$v\_residuesmulch_{hh,cken,y} = v\_prodQuant_{hh,cken,y} \times p\_perresmulch_{cken}$
E_RESIDUESFEED	$v\_residuesfeed_{hh,cken,y} = \sum_{m} v\_residuesfeedm_{hh,cken,y,m} \times flagm_{cken,m}$ v_residuesfeed(hh,cken,y)=sum(m,v_residuesfeedm(hh,cken,y,m)*flagm(cken,m))
E_RESIDUESSELL	$v\_residuessell_{hh,cken,y} = \sum_{m} v\_residuessellm_{hh,cken,y,m} \times flagm_{cken,m}$

DAHBSIM MODULES

2 BIOPHYSICAL MODULE

The biophysical model functions as a concise tool designed to estimate the impact of farm management and climate on the progression of crop yields over time. This simulation model operates on a multi-year, multi-crop, and monthly time step, offering insights into the influence of climate, soils, and management on cropping systems productivity and the environment. It provides a summary representation of soil water (including water use and drainage), nitrogen budgets (encompassing residue production and decomposition), and crop yield.

With the crop module, the model allows for the simulation of various crop types, spanning both annual and multi-year crops, as well as crop rotations using a unified set of parameters (see next table).

Simulations can cover fractions of a year or extend over several years. These processes are influenced by weather, soil properties, crop characteristics, and cropping system management options such as crop rotation, cultivar selection, irrigation, and nitrogen fertilization.

This summary model is designed for simulating crop cycles on a single land block fragment characterized by uniform soil, weather, crop rotation, and management. The crop cycle is detailed at the level of the entire plant. As mentionned previously, the core of these calculations involves determining the unstressed (potential) yield based on crop potential evapotranspiration. This potential yield is then adjusted for water and nitrogen limitations.

Consequently, in each crop cycle simulation, the actual yield for the year (Ya) is considered as the minimum of the yield limited by water (Yw) and by nitrogen (Yn).

In the following the exhaustive list of parameters for this module.

VARIABLES, PARAMETERS & EQUATIONS

Parameter Name	Units	Description
ym	t ha^{-1}	Maximum yield
p_ky	t ha^{-1}	Yield response factor specified by crop
p_hw	-	Water stress factor
p_etm	mm day^{-1}	Maximum evapotransporation
p_kc	-	Crop coefficient
p_et0	mm day^{-1}	Reference evapotransporation
p_eta_m	mm	Monthly actual evapotransporation
p_etm_m	mm	Monthly maximum evapotransporation
p_etm_t	mm	Annual maximum evapotransporation
p_eta_t	mm	Annual actual evapotransporation
p_idat;luse	-	Irrigation parameters for crops;
p_idat; nirr	-	Irrigation parameters for crops;
p_luse	-	Crop cycle - land use coefficient
p_nirr	mm $month^{-1}$	Monthly net irrigation
p_rain	mm $month^{-1}$	Monthly effective rainfall
p_meteo	mm $month^{-1}$	Monthly effective rainfall
p_asi	mm $month^{-1}$	Available soil water index
p_swd0	mm $month^{-1}$	Initial soil water depth
p_swd	mm $month^{-1}$	Actual soil water depth at sowing
p_wdf	-	Soil water depletion fraction for crop groups and Etm
p_factor	-	Actual soil water depletion fraction
p_rdm	m	Maximum rooting depth by crop
p_swa	mm m^{-1} soil depth	Soil water available by crop
p_swr	mm	Remaining soil water
p_swa_m	mm m^{-1} soil depth	Soil water available by crop
p_eta_tab	-	Table to calculate eta as function of asi and swr
p_swpar	-	Soil water parameters
p_swm	mm m^{-1} soil depth	Maximum soil water available
p_cropCoef	-	Technical coefficient (see crop module)
v0_cactYld	t ha^{-1}	Crop activity yield

VARIABLES, PARAMETERS & EQUATIONS

Parameter Name	Units	Description
p_cropCoef	-	Technical coefficient (see crop module)
p_Qfert	kg ha^{-1}	Quantity of fertilizer by activity
p_Qres	kg ha^{-1}	Quantity of residues from precedent crop
p_Qcomp	kg ha^{-1}	Quantity of compost
p_humus	kg ha^{-1}	Quantity of humus
P_Npot	kg ha^{-1}	N necessary for optimal growth
p_Nmin	kg ha^{-1}	N mineralized from humus
p_Nab	kg ha^{-1}	Current absorption of Nitrate
p_Nav	kg ha^{-1}	Available Nitrogen
p_Nini	kg ha^{-1}	Initial amount of Nitrogen
p_NI	kg ha^{-1}	N leaching (fixed at 10% of N_fert)
p_Nw	-	Coefficient of Nitrogen stress
p_Nitr	kg ha^{-1}	Total Nitrate requirements by activity
p_Nres	kg ha^{-1}	N from precedent crop residue
p_Norg	kg ha^{-1}	N from organic fertilization
p_Nfert	kg ha^{-1}	N from mineral fertilization
p_Ncomp	kg ha^{-1}	N from compost
p_Nfin	kg ha^{-1}	N at the end of the growth period
p_Hfin	%	Final amount of humus
p_Hini	%	Amount of inorganic matter (initial amount of humus)
p_Mscomp	%	Amount of biomass from compost
K3	-	Humification rate
yn	-	Parameter
v0_cactLev	ha	Crop activity level by cp
p_cropData	-	Crop Data (see crop module)
p_hini	%	Amount of inorganic matter (initial amount of humus)
K1	-	Coefficient for Nitrogen conversion
K2	-	Mineralization rate
da	kg m^{-3}	Soil bulk density
prof	m	Ploughed layer
p_MSres	%	% of dry matter from Qres
p_effr	kg of biomass	Nitrate by kg of biomass
p_Nw2	-	Coefficient of nitrogen stress
p_OrgMat	%	Amount of organic matter

3 FARM MODULE

The farm module illustrates the interplay between cropping and livestock operations, along with the connections between on-farm and off-farm labor. The primary equations comprising this module include:

Land balance: land allocation between cropland and grassland

Labour balance: total family labour used per month cannot exceed total labour available

Supply balance: For each product and year, production should equal use (divided into self-consumption, on-farm seed use, on-farm feed use and market sales).

$$\text{prodQuant}_{hh,j,n} \leq \text{seedOnfarm}_{hh,j,n} + \text{feedOnfarm}_{hh,j,n} + \text{selfCons}_{hh,j,n} + \text{markSales}_{hh,j,n}$$

Where

j is the index for products

prodQuant is the production quantity (kg/yr)

seedOnfarm is the on-farm seed use (kg/yr)

feedOnfarm is the on-farm feed use (kg/yr)

selfCons is household self-consumption (kg/yr)

Farm income: from market sales

4 HOUSEHOLD MODULE

The household module describes the interaction between household decisions on production, consumpltion and labour. The model allocates land, labour, and cash to different crops given a set of constraints.

It includes:

Demand balance: total consumption by product and year should equal self-consumption plus market purchases.

DAHBSIM accounts for non-separability between production and consumption and calculates human food consumption using a Linear Expenditure System (LES), as used in Louhichi and Gomez y Paloma (2014).

In this system food and non-food expenditures are increasing in income and decreasing in own price.

$$p_i q_{h,i} = \gamma_{h,i} + \beta_{h,i}(y_h - \textstyle\sum_j \gamma_{h,j} p_{h,j})$$

Where:

pi is the price of good i,

qh,i is the quantity of good i consumed by household h;

yh is the household full income.

$\beta h,i$ and $\gamma h,i$ are the LES parameters

In this system $\Sigma j\ \gamma h,j\ ph,j$ is considered as the subsistence expenditure and the term $(yh - \Sigma j\ \gamma h,j\ ph,j)$ is generally interpreted as the supernumerary income.

Time allocation balance: time allocation between on-farm labour and off-farm labour

Household income: from market sales plus off-farm labour

VARIABLES, PARAMETERS & EQUATIONS

Parameter Name	Units	Description
p_hholdData; hhsize	number of people	Number of people in the household
p_hholdData; farm size	ha	Farm size
p_hholdData; labour_family	person-days	Labour availability from family
p_hholdData; labour hired	person-days	Hired labour availability
p_hholdData; labour community	person-days	Community labour availability
p_hholdData; labour total	person-days	Total labour availability
p_hholdData; aa bovine	head	Quantity of bovine animals
p_hholdData; aa chicken	head	Quantity of chickens
p_hholdData; aa goatsheep	head	Quantity of goats & sheep
p_hholdData; aa pig	head	Quantity of pigs
p_hholdData; aa other	head	Quantity of other animals
p_hholdData; hhcon_nonfood	nc yr^{-1}	Household non-food consumption
p_hholdData; inc_offfarm	nc yr^{-1}	Off farm income
p_hholdData; hh nbr	number	Number of households of this type in survey
p_consoData	kg $person^{-1}$ $year^{-1}$	Household consumption data
p_hholdNbr	Number of households	household number
p_gpridata	nc	goods prices
p_workTimeMax	days	maximum number of working days per month
p_elasIncome	-	Income elasticity
p_Frisch	-	Frisch parameter
p_goodPrice	nc kg^{-1}	Price of consumption goods
p_beta	-	Les parameter beta
p_gamma	-	Les parameter gamma
v0_hholdSize	number of people	Household size (number of members of household)
v0_hconNonfood	nc	non food consumption
v0_offFarmInc	nc	off-farm income
v0_selfcons	kg $year^{-1}$	self-consumption data
v0_hconquant	kg $year^{-1}$	Quantity consumed
v0_farmIncome	nc	farm income
v0_ConsShare	-	Budget share for LES

VARIABLES, PARAMETERS & EQUATIONS

Variable Name	Units	Description
v_offFarmInc	nc	off-farm income
v_fullIncome	nc	full income
v_offFarmInc	nc	off-farm income
v_hcon_min	kg	minimum consumption
v_hcon_nonfood	$nc\ yr^{-1}$	non food consumption
v_hiredLabour	person-days	hired labour

Label	Equation
E_TIMEBALANCE	$\text{v\_farmLabour}_{hh,y,m} < \text{p\_workTimeMax}_{hh,m} \times \text{v0\_hholdSize}_{hh} + \text{v\_hiredLabour}_{hh,y,m}$
E_MAXHIREDLABOuR	$\text{v\_hiredLabour}_{hh,y,m} < \text{p\_workTimeMax}_{hh,m} \times \text{v0\_hholdSize}_{hh}$
E_INCOMEOFF	$\text{v\_offFarmInc}_{hh,y} = \text{v0\_offFarmInc}_{hh}$
E_INCOMETOT	$\text{v\_fullIncome}_{hh,y} = \text{v\_FarmIncome}_{hh,y} = \text{v\_offFarmInc}_{hh,y}$ - sum(m,v_hiredLabour(hh,y,m)*p_buyPrice(hh,'labour'))
E_HHCON	$\text{v\_hconQuant}_{hh,gd,y} = \text{p\_gamma}_{hh,gd} + (\text{p\_beta}_{hh,gd} \times \text{v\_fullincome}_{hh,y} - \text{sum}(gd2, \text{p\_gamma}_{hh,gd2} \times \text{p\_goodprice}_{hh,gd2})/\text{p\_goodprice}_{hh,gd}$
E_CASH	$\text{v\_fullincome}_{hh,y} > \text{sum}(gd,\text{p\_goodprice}_{hh,gd} \times \text{v\_markPurch}_{hh,gd,y}$

5 LIVESTOCK MODULE

This module describes the processes that shape the livestock segment of the household and its connections with other components.

- Knowing that effective livestock feed management significantly enhances animal productivity, It focuses on how feeding decisions and opportunities impact both animal productivity and livestock numbers. The livestock module aims to discern the effects of feeding strategies on herd productivity and production, while considering the resource utilization, environmental consequences, and demographic aspects of these decisions.
- The model considers various livestock enterprises with different animal types (beef cattle, dairy cattle, goats, and sheep) and diverse outputs (milk and meat) across three intensification levels.
- The module forecasts the nutrient (protein, energy, and dry matter) requirements for different types and classes of livestock based on achieving a specified production level.
- t computes daily nutrient demands for animal maintenance, lactation, pregnancy, and growth. The module dynamically tracks herd or flock dynamics, as well as feed supply and demand balances over time in a recursive manner.

key considerations of the model:

1. For a specific type and class of animal monthly nutrient demand remains constant every month,
2. a consistent fraction of animals transitions to different classes and undergoes pregnancy every month at a uniform rate.
3. A weight to volume conversion factor for milk of 1.04 kg l−1 (USDA, 2011).
4. For dairy and beef cattle, milk has 3.5% fat and 3.5% protein (Wong et al., 1988; NRC, 2001). For sheep, milk has 4.5% protein (CSIRO, 2007), and 6.5% fat. For goats, milk 3.2% protein (CSIRO, 2007), and 6.5% fat.
5. Live weight means the average live weight of an animal in that specific age category.

VARIABLES, PARAMETERS & EQUATIONS

Variable	Units	Description
v_aactLev	head	Livestock numbers
v_aactLevsell	head	Livestock sales
v_aactLevbuy	head	Livestock purchases
v_aactLevslaughter	head	Livestock slaughtered
v_aactselladult	head	Adults sold not for old age
v_totallabourdemlive	person-days $month^{-1}$	Total labour demand per month for the entire herd
v_prodQmilk	l $month^{-1}$ $animal^{-1}$	Milk produced
v_prodQmeat	kg $month^{-1}$ $animal^{-1}$	Meat produced
v_feedbalance	kg	Feed carried over to next month
v_grossenergyconsumed	MJ GE hd^{-1} $month^{-1}$	Gross energy consumed per animal per month
v_eneryconsumed	MJ^{-1} hd^{-1} $month^{-1}$	Net energy consumption per animal in MJ
v_proteinconsumed	kg MP $animal^{-1}$ $month^{-1}$	Metabolisable protein consumption per animal
v_cproteinconsumed	kg CP hd^{-1} $month^{-1}$	Crude protein consumption per animal
v_fdcons	kg hd^{-1} $month^{-1}$	Amount of a specific feed consumed per animal per month
v_feedcons	kg $month^{-1}$	Total kg of a feed consumed per month
v_totalnutdem	MJ net energy hd^{-1} $month^{-1}$ and kg MP hd^{-1} $month^{-1}$	Total nutrient demand of net energy or metabolisable protein per animal per month
v_totalnutdemt	MJ net energy $month^{-1}$ and kg MP hd^{-1} $month^{-1}$	Total nutrient demand of net energy or metabolisable protein for the entire herd per month
v_DMI	kg DMI hd^{-1} $month^{-1}$	DMI per animal per month
v_residuesbuy	kg m^{-1}	kg of residue consumed from market purchases
v_nintake	kg hd^{-1} $month^{-1}$	Total nitrogen intake
v_ManureDMc	kg $month^{-1}$	Manure produced from cattle
v_ManureDMsr	kg $month^{-1}$	Manure produced from small ruminants
v_ManureDM	kg $month^{-1}$	Manure produced from all animals
v_dietprotein	kg CP kg DMI^{-1} hd^{-1} $month^{-1}$	Percentage crude protein in diet
v_nesr	kg N hd^{-1} $month^{-1}$	Total nitrogen excreted per head of small ruminant per month
v_nec	kg N hd^{-1} $month^{-1}$	Total nitrogen excreted per head of cattle per month
v_nitlivem	kg N $month^{-1}$	Nitrogen excreted from all livestock per month
v_nitlive	kg NO_3 $year^{-1}$	Total yearly nitrate excretion

Parameter Name	Units	Description	Data Source
v0_aactLev	head	initial animal activity levels	livestockdata.xlsx
p_nutcontent	MJ, %	net and gross energy content per kg feed in MJ, % metabolisable and % crude protein of feed, %dry matter of feed	livestockdata.xlsx
p_rateFert	ratio	fertility rate, young born per female adult per month	livestockdata.xlsx
p_mreprodf	head	number of males	livestockdata.xlsx
p_sexratio	ratio	birth ratio male and female	livestockdata.xlsx
p_survivalrate	%	survival rate, % of livestock that survive each year	livestockdata.xlsx
p_grad	months	months in class, used for livestock demographics	livestockdata.xlsx
p_startvalue	head	starting livestock numbers	livestockdata.xlsx
p_s	kg	starting feed balance	livestockdata.xlsx
p_labour	person-days $head^{-1}$ $month^{-1}$	labour demand for each activity in each season and intensification level across households	livestockdata.xlsx

Label	Equation
E_MILKPRODUCTION	$\text{v\_prodQmilk}_{hh.adultf.typec.inte.y.m} = \text{p\_milkprod}_{adultf.typec.inten} \times \text{v\_aactLev}_{hh.adultf.typec.inten.y.m}$
E_MEATPRODUCTION	$\text{v\_prodQmeat}_{hh.aaact.typec.inten.y.m} = \text{p\_salesw}_{aaact.typec.inten} \times \text{v\_aactLevslaughter}_{hh.aaact.typec.inten.y.m}$
E_LEGUMECONSUMPTION1	$\sum_{legumeresidues} \text{p\_nutcontent}_{\text{'metabolisableprotein'}.legumeresidues} \times \text{v\_fdcons}_{hh.aaact.typec.inten.y.m.legumeresidues} > \text{p\_fdnutrients}_{hh.aaact.typec.inten.y.m.\text{'proteinconsumptionlegumes'}}$
E_LEGUMECONSUMPTION2	$\sum_{legumeresidues} \text{p\_nutcontent}_{\text{'netenergy'}.legumeresidues} \times \text{v\_fdcons}_{hh.aaact.typec.inten.y.m.legumeresidues} = \text{p\_fdnutrients}_{hh.aaact.typec.inten.y.m.\text{'energyconsumptionlegumes'}}$
E_MAXPROTEIN	$\sum_{feedc} \text{p\_nutcontent}_{\text{'metabolisableprotein'}.feedc} \times \text{v\_fdcons}_{hh.aaact.typec.inten.y.m.feedc} < \text{p\_fdnutrients}_{hh.aaact.typec.inten.y.m.\text{'proteinconsumption''}}$
E_MAXENERGY	$\sum_{feedc} \text{p\_nutcontent}_{\text{'netenergy'}.feedc} \times \text{v\_fdcons}_{hh.aaact.typec.inten.y.m.feedc} < \text{p\_fdnutrients}_{hh.aaact.typec.inten.y.m.\text{'energyconsumption''}}$
E_FEEDING	$\text{v\_aactLev}_{hh.aaact.typec.inten.y.m} \times \text{p\_feedreq}_{nut.aaact.typec.inten.m} < \text{v\_totalnutdem}_{hh.aaact.typec.inten.nut.y.m}$
E_FEEDBAL	$\text{v\_feedbalance}_{hh.feedc.y.m-1} \times \text{p\_transferrate} + \text{v\_feedbalance}_{hh.feedc.y-1.\text{'m12'}} \times \text{p\_transferrate} + \text{p\_s}_{hh.feedc} + \text{v\_residuesfeedm}_{hh.feedc.y.m} + \text{v\_residuesbuy}_{hh.feedc.y.m} = \text{v\_feedcons}_{hh.feedc.y.m} + \text{v\_feedbalance}_{hh.feedc.y.m}$
E_ENERGYCONSUMED	$\text{v\_energyconsumed}_{hh.aaact.inten.y.m.typec} = \sum_{feedc} \text{v\_fdcons}_{hh.aaact.typec.inten.y.m.feedc} \times \text{p\_nutcontent}_{\text{'netenergy'}.feedc}$
E_PROTEINCONSUMED	$\text{v\_proteinconsumed}_{hh.aaact.inten.y.m.typec} = \sum_{feedc} \text{v\_fdcons}_{hh.aaact.typec.inten.y.m.feedc} \times \text{p\_nutcontent}_{\text{'metabolisableprotein'}.feedc.}$
E_CRPROTEINCONSUMED	$\text{v\_cproteinconsumed}_{hh.aaact.inten.y.m.typec} = \sum_{feedc} \text{v\_fdcons}_{hh.aaact.typec.inten.y.m.feedc} \times \text{p\_nutcontent}_{\text{'crudeprotein'}.feedc}$
E_GROSSENERGYCONSUMED	$\text{v\_grossenergyconsumed}_{hh.aaact.typec.inten.y.m} = \sum_{feedc} (\text{v\_fdcons}_{hh.aaact.typec.inten.y.m.feedc} \times \text{p\_nutcontent}_{\text{'grossenergy'}.feedc})/30$
E_FEEDCONS	$\text{v\_feedcons}_{hh.feedc.y.m} = \sum_{aaact.typec.inten} (\text{v\_aactLev}_{hh.aaact.typec.inten.y.m} \times \text{v\_fdcons}_{hh.aaact.typec.inten.y.m.feedc} / \text{p\_nutcontent}_{\text{'drymatter'}.feedc})$
E_FEEDCONSA	$\text{v\_DMI}_{hh.aaact.typec.inten.y.m} = \sum_{feedc} \text{v\_fdcons}_{hh.aaact.typec.inten.y.m.feedc}$
E_LABOURAA	$\sum_{aaact.typec.inten} \text{v\_aactLev}_{hh.aaact.typec.inten.y.m} \times \text{p\_labour}_{m.inten.aaact.typec} = \text{v\_totallabourdemlive}_{hh.y.m}$
E_NINTAKE	$\text{v\_nintake}_{hh.aaact.typec.inten.y.m} = \sum_{feedc} (\text{v\_fdcons}_{hh.aaact.typec.inten.y.m.feedc} \times \text{p\_nutcontent}_{\text{'grossenergy'}.feedc}/30) \times \text{v\_dietprotein}_{hh.aaact.typec.inten.y.m} \times (1/6.25) \times (1/18.45)$
E_NEC[a]	$\text{v\_nec}_{hh.aaact.\text{'dairy'}.inten.y.m} = \text{p\_nce}_{aaact.\text{'dairy'}.inten} \times (\text{v\_nintake}_{hh.aaact.\text{'dairy'}.inten.y.m} + 0.44 \times \text{v\_grossenergyconsumed}_{hh.aaact.\text{'dairy'}.inten.y.m} \times \text{p\_ca}_{aaact.sr.inten}/(1000*6.25))$
E_NESR[a]	$\text{v\_nesr}_{hh.aaact.sr.inten.y.m} = \text{p\_nce}_{aaact.sr.inten} \times (\text{v\_nintake}_{hh.aaact.sr.inten.y.m} + 0.44*\text{v\_grossenergyconsumed}_{hh.aaact.\text{'dairy'}.inten.y.m} \times \text{p\_ca}_{aact.sr.inten}) \times (1000 \times 6.25)$
E_NEC2	$\text{v\_nec}_{hh.aaact.\text{'beef''}.inten.y.m} = \text{p\_nce}_{aaact.\text{'beef'}.inten} \times (\text{v\_nintake}_{hh.aaact.\text{'beef'}.inten.y.m} + (.44 \times \text{v\_grossenergyconsumed}_{hh.aaact.\text{'dairy'}.inten.y.m} \times \text{p\_ca}_{aaact.\text{'beef'}.inten})/1000 \times 6.25 - \text{p\_nr}_{hh.aaact.\text{'beef'}.inten.y.m})$
E_NEC3	$\text{v\_nec}_{hh.aaact.sr.inten.y.m} = 0$
E_NESR2	$\text{v\_nesr}_{hh.aaact.cattle.inten.y.m} = 0$
E_NLIVEM	$\text{v\_nitlivem}_{hh.y.m} = \sum_{aaact.typec.inten} ((30*\text{v\_nec}_{hh.aaact.typec.inten.y.m} \times \text{v\_aactLev}_{hh.aaact.typec.inten.y.m}) +$
	$\text{v\_nesr}_{hh.aaact.typec.inten.y.m} \times \text{v\_aactLev}_{hh.aaact.typec.inten.y.m}))$
E_NITLIVE	$\text{v\_nitlive}_{hh.y} = \text{p\_nconv} \times \sum_{m} \text{v\_nitlivem}_{hh.y.m}$
E_DIETPROTEIN	$\text{v\_dietprotein}_{hh.aaact.inten.y.m.typec} \times \text{v\_DMI}_{hh.aaact.typec.inten.y.m} = \text{v\_cproteinconsumed}_{hh.aaact.inten.y.m.typec}$

6 RISK MODULE

The risk module includes equations that employ the **mean-standard deviation** approach for risk analysis, as outlined by Hazel and Norton (1984).

We account for variations in prices and yields, both influencing decisions related to production and consumption.

Historical price and yield data are sourced from FAOStat (FAO 2016a, FAO 2016b).

An equation calculates the utility for each state of nature, or world state (WS), emerging from the price and yield variability.

The standard deviation of utility across all possible world states is computed and introduced into the objective function as a negative term, influenced by a risk aversion coefficient (refer to the objective function).

The standard deviation of net present value is defined as follows:

$$\text{StdDev} = \frac{\sqrt{\sum_{WS}(NPV - NPV_{WS})^2}}{n}$$

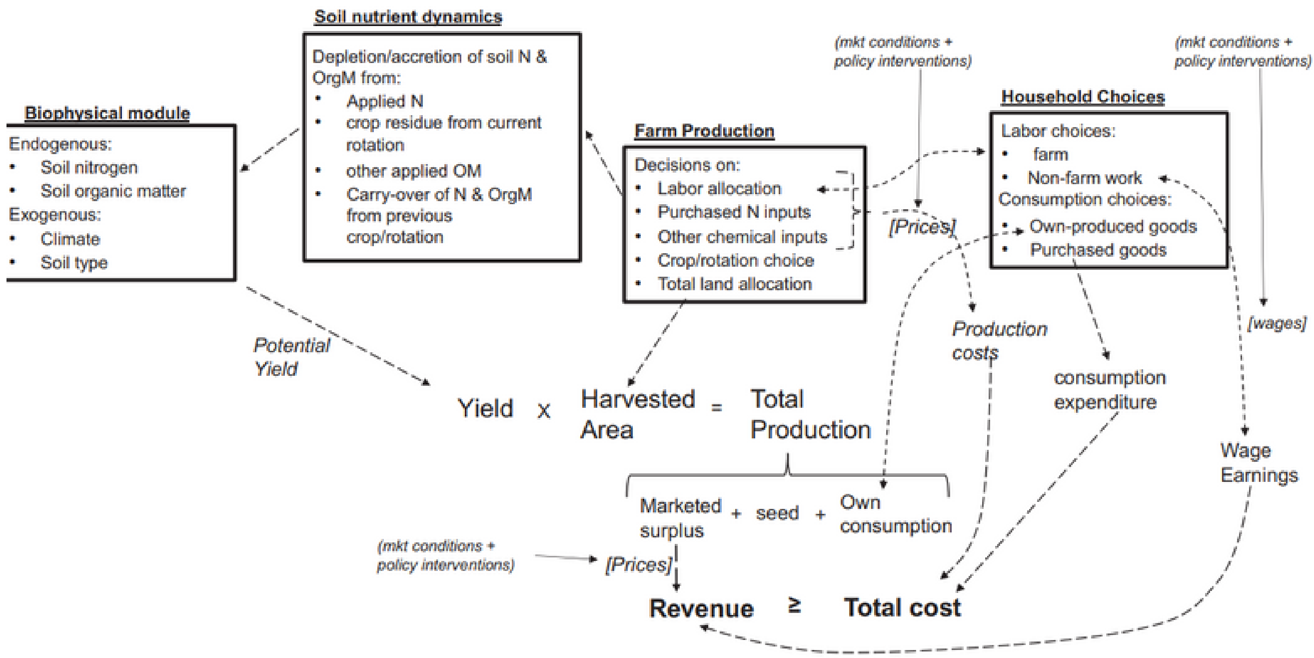
Where:

StdDev is the standard deviation

NPV is the (actual) net present value

n is the number of world states (taking a default value of 50).

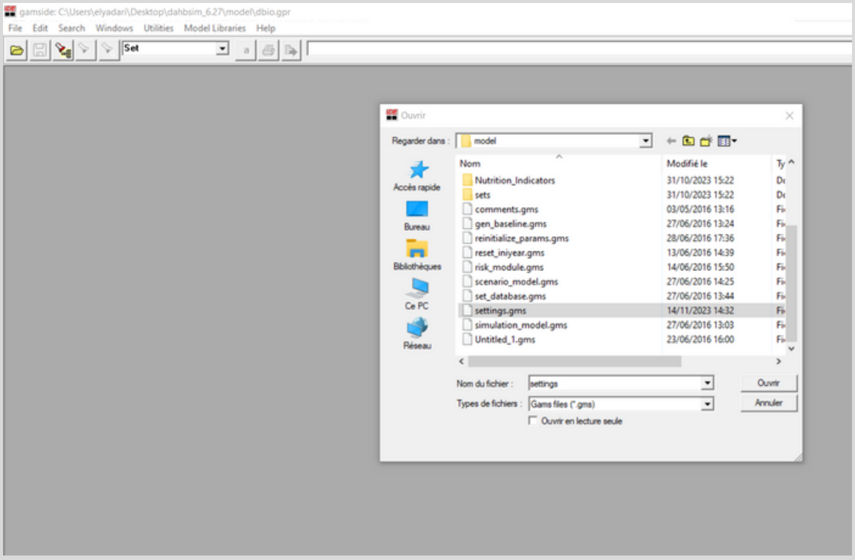
TO CONCLUDE THIS MODULAR DESCRIPTION, THE FIGURE BELOW SHOWS THE MAIN BIOPHYSICAL AND SOCIO-ECONOMIC COMPONENTS OF THE MODEL, AND THEIR LINKAGES. THE LIST OF INPUTS AND OUTPUTS THAT ALLOW THE LINKADGE BETWEEN MODULES IS IN ANNEXE.



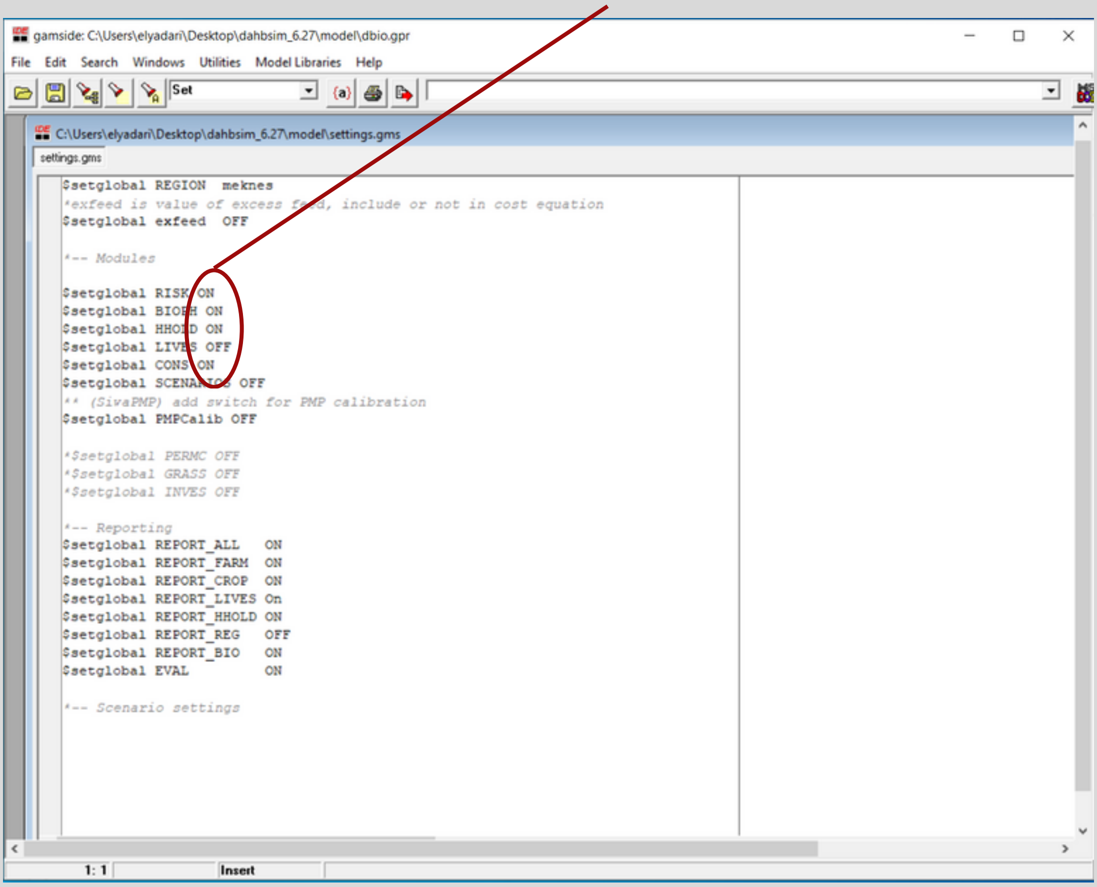
Komarek et al, 2017

RUN DAHBSIM

BEFORE RUNNING THE MODEL THE USER HAS TO SELECT THE MODULES TO ACCTIVATE IN THE FILE "SETTINGS.GMS"

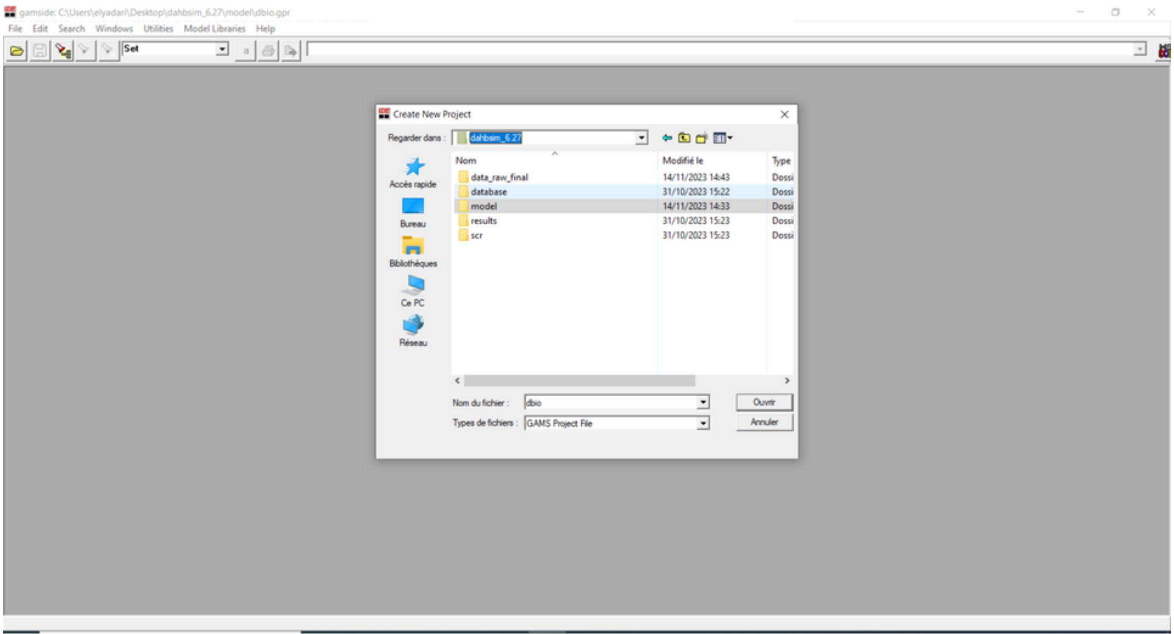


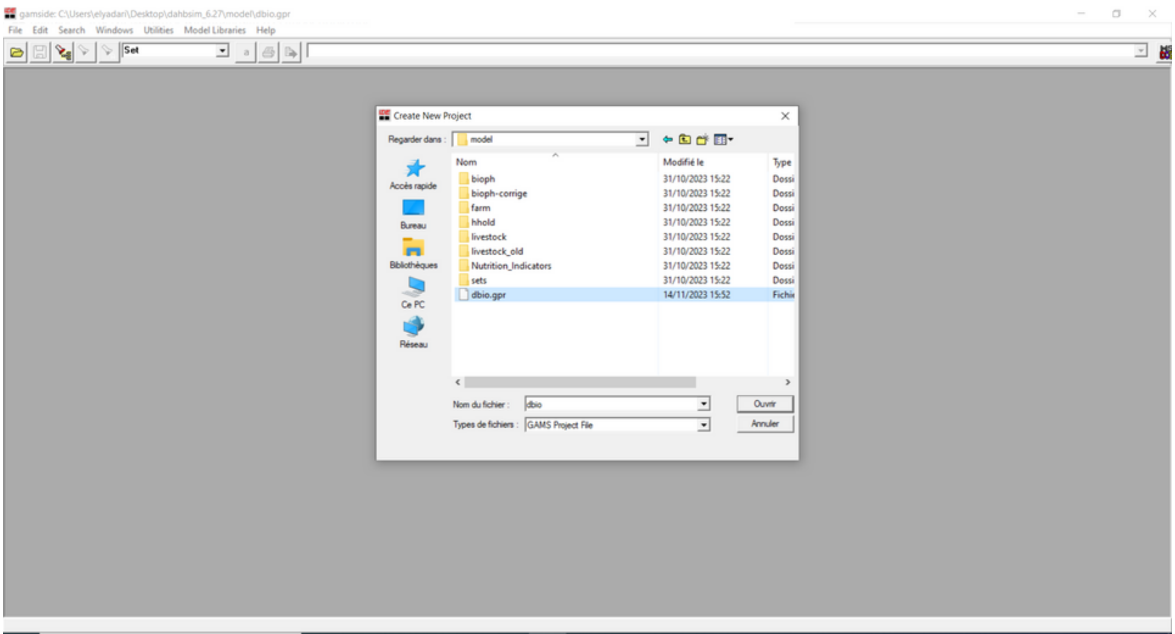
MODULES CAN BE TURNED ON OR OFF



RUN DAHBSIM

THE MODEL IS RUN USING THE FILE “GEN_BASELINE.GMS”. THIS FILE RUNS FIRST THE MODULES THAT ARE INCLUDED IN THE MODEL, AND THEN SWITCHES TO “SIMULATION_MODEL”, IN WHICH THE GLOBAL MODEL AND OBJECTIVE FUNCTION ARE DEFINED BASED ON ALL THE MODULES THAT ARE INCLUDED IN THE SETTINGS FILE. THE OBJECTIVE FUNCTION IS THEN RUN CONSECUTIVELY OVER THE YEARS OF THE RECURSIVE PERIOD.

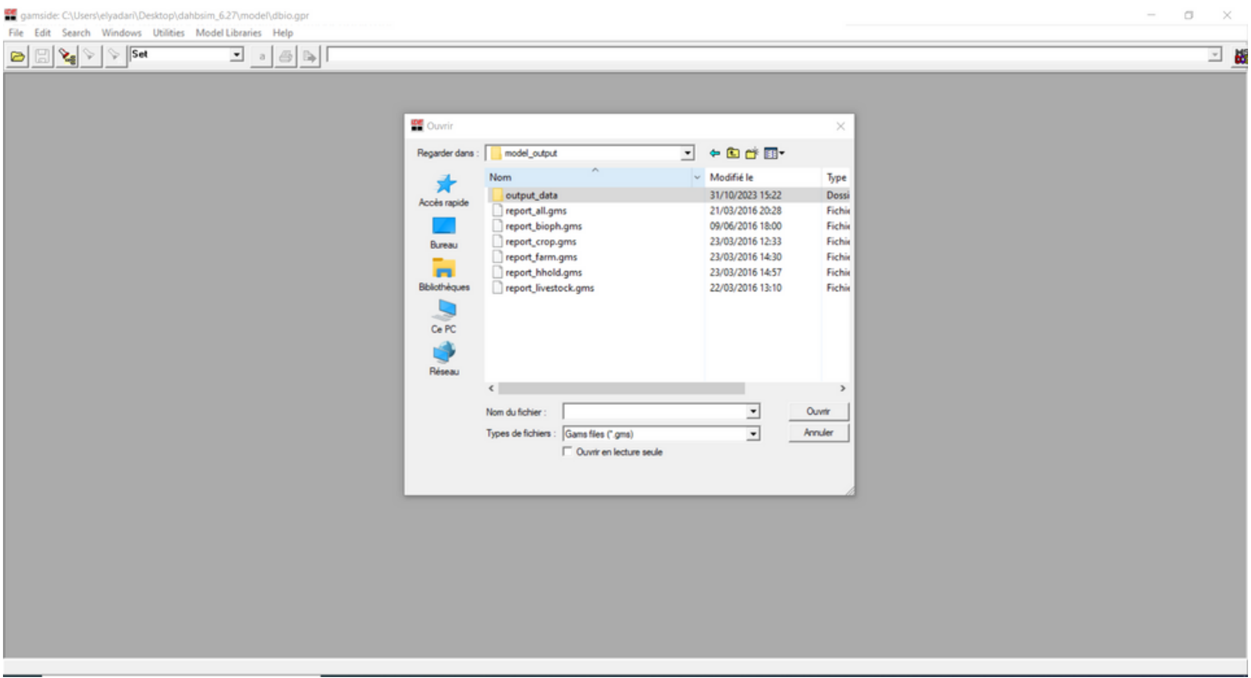




RUN DAHBSIM

AFTER EACH RECURSIVE ITERATION EXECUTED, THE RESULTS FROM THE SPECIFIC YEAR ARE SAVED IN A SERIES OF PARAMETERS, WHICH ARE THEN STORED IN THE FOLDER ‘OUTPUT_DATA’.

A SPECIFIC FILE IS CREATED FOR EACH MODULE, IN THE FORMAT OF ‘REPORT_MODULE NAME.XLS’. THESE DESCRIBE THE MODEL RESULTS OVER THE ENTIRE SPAN OF THE MODEL YEARS.



ACKNOWLEDGEMENT

THIS WORK IS BASED ON THE EXHAUSTIVE DESCRIPTION OF THE DYNAMIC AGRICULTURAL HOUSEHOLD BIO-ECONOMIC SIMULATOR MODEL (DAHBSIM) :

FLICHMAN, G., BELHOUCHETTE, H., KOMAREK, A.M., DROGUE, S., HAWKINS, J., CHENOUNE, R., HAILE, B., ROBERTS, C., MSANGI, S.. 2016. DYNAMIC AGRICULTURAL HOUSEHOLD BIO-ECONOMIC SIMULATOR (DAHBSIM) MODEL DESCRIPTION. BIOSIGHT PROJECT TECHNICAL PAPER. INTERNATIONAL FOOD POLICY RESEARCH INSTITUTE, WASHINGTON, D.C.

HTTP://EBRARY.IFPRI.ORG/CDM/REF/COLLECTION/P15738COLL2/ID/130683

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ANNEXE

List of inputs and outputs that allow the linkadge between modules

CROP MODULE

Inputs	*Outputs*
v_cactYld -- CropYields (t/ha)	v_prodQuant – Crop Production (t) v_cropLabour – Crop Labour (person-days) v_residuesfeed – Residues for Livestock Feed (kg/m) v_residuessell -- Residues Sold (kg/y) v_residuesmulch – Residues for Mulch (kg/y)

BIOPHYSICAL MODULE

NITRATE MODULE

Inputs	*Outputs*
v_nitlive – Nitrogen from livestock (kg/ha) v_residuesmulch – Mulch from residues(kg/ha) v_Nfert – Nitrogen from Fertilizer (kg/ha)	p_Nw – N stress coefficient (used for next year's yields)

WATER MODULE

Inputs	*Outputs*
p_rain – Monthly rainfall (mm/mth)	p_hw – Water Stress Coefficient (used to calculate next year's yields)

HOUSEHOLD MODULE

Inputs	*Outputs*
v_farmIncome – Farm Income v_hiredLabour – (person-days)	v_hconQuant – Household Consumption (kg/y)

FARM MODULE

The farm module contains the equations which describe the resource constraints: land, labour, supply, income/sales

Inputs

v_markSales – Market Sales of Crop and Animal Products (t)
v_animalPurch – Animal Purchases (kg)
v_ residues Bought (kg/m)
v_prodQmeat -- Meat Produced
v_prodQmilk – Milk Produced
v_seedQuant – Seed Quantity by Cropping Activity (kg/y)
v_aactLevBuy – Animal Purchases (head)
v_aactLevSell – Animal Sales (head)

Outputs

v_seedPurch – Seed Purchases by Cropping Activity (kg/y)
v_farmLabour – Farm Labour (person-days)
v_Nfert -- Nitrogen Fertilizer (kg)
v_nitlive – Nitrogen from Livestock (kg NO3/y)
v_residuesmulch – Residues (kg)
v_Self Consumption (kg/y)
v_markPurch – Market Purchases (t)
v_farmIncome
v_aactIncome – Animal Activity Income
v_cactIncome – Crop Activity Income

LIVESTOCK MODULE

Inputs

v_residuesfeedm – crop residue availability for livestock feed (kg)

Outputs

v_prodQmilk - milk production (l/m.animal)
v_prodQmeat - meat produced from slaughtered animals (kg/m. animal)
v_aactLevbuy - purchased animals (head)
v_aactLevsell - sold animals (head)
v_aactLev - animals owned by the household (head)
v_nitlive - total nitrate excretion from livestock (kg/y)
v_ManureDM - manure production (kg/m)
residuesbuy - crop residues purchased (kg/m)

RISK MODULE

The module introduces the mean-standard deviation approach for risk analysis (Hazel & Norton, 1984). Considering the variation in both prices and yields, which together influence production and consumption decisions

I***nputs***

v_inputUse – (kg/y)

v_seedPurch – (kg/y)

p_buyPrice (currency)

v_markSales – Market Sales (kg/y)

v_animalpurch – Animal Purchases

p_selPrice – Sell Price

Outputs

v_npvrd_tot – Random Net Present Value