ICARDA

Science for resilient livelihoods in dry areas

Bio-economic Modeling: A Good Starting Point for Developing an Integrated Modeling Framework?

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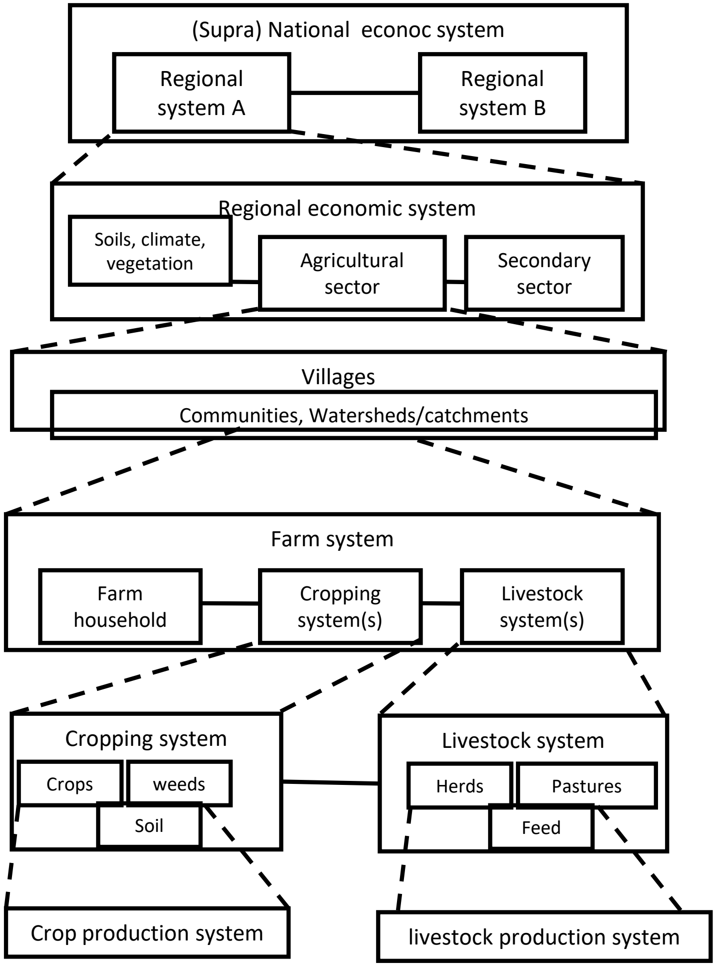
I. Systems research considerations

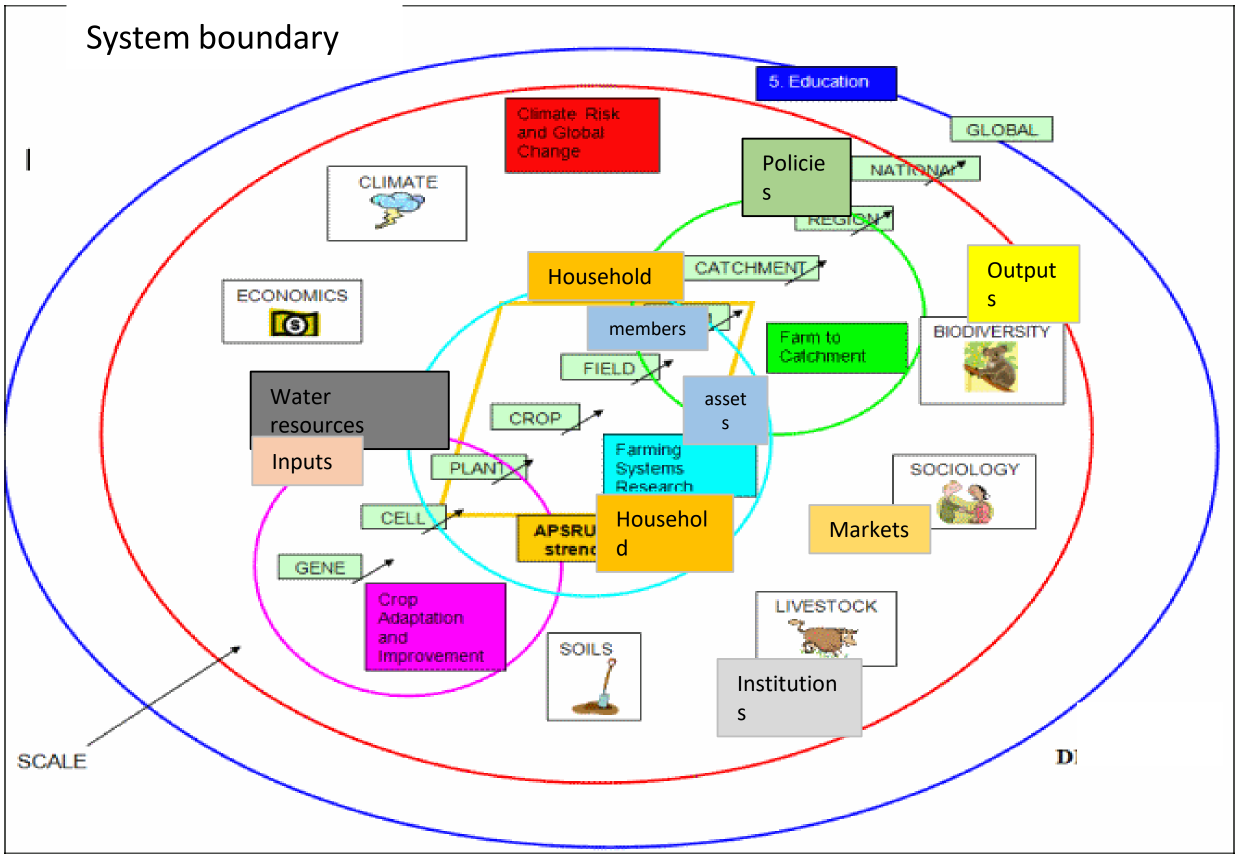
Systems are composed of sub-systems involving: Hierarchies and scales



Fresco & Westphal (1988)
Exptl. Agric. 24, 399-419

… Systems research considerations (cont'd)

Scales, hierarchies, boundaries, relationships



Source: http://www.apsru.gov.au/ - with some modifications by myself

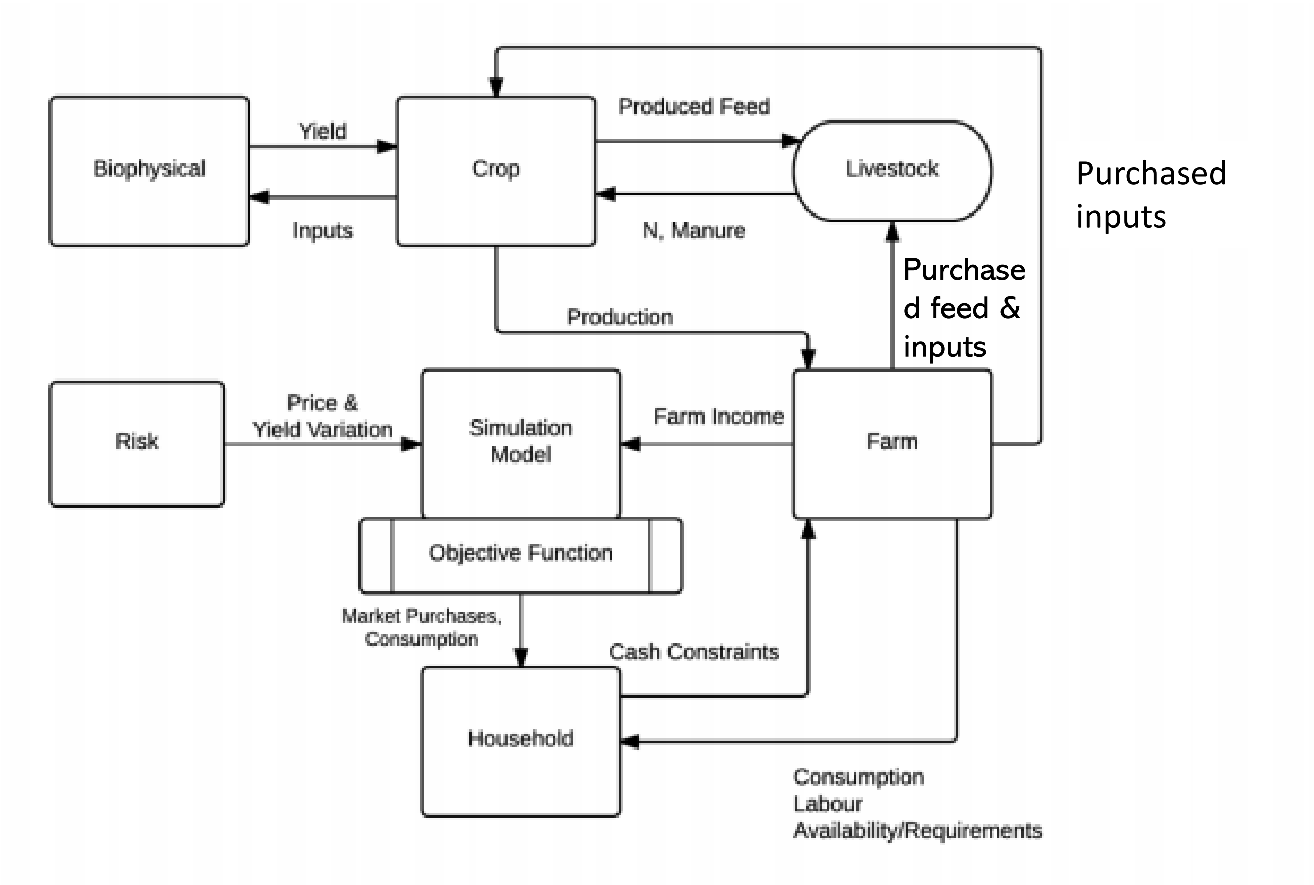
II. Systems Research: where to start?

- **Farm households** – a good place to start
  - Best link between the lower and upper scales
  - Households are the most influential components of any production system (as active and reactive components)
  - Households are beneficiaries/victims of the socio-economic, bio-physical and environmental changes;
  - Targets often the main subjects of any intervention
  - Results can have wide implications
    - Policy, research, development, extension, …

III. Household-level bio-economic modeling tools at ICARDA

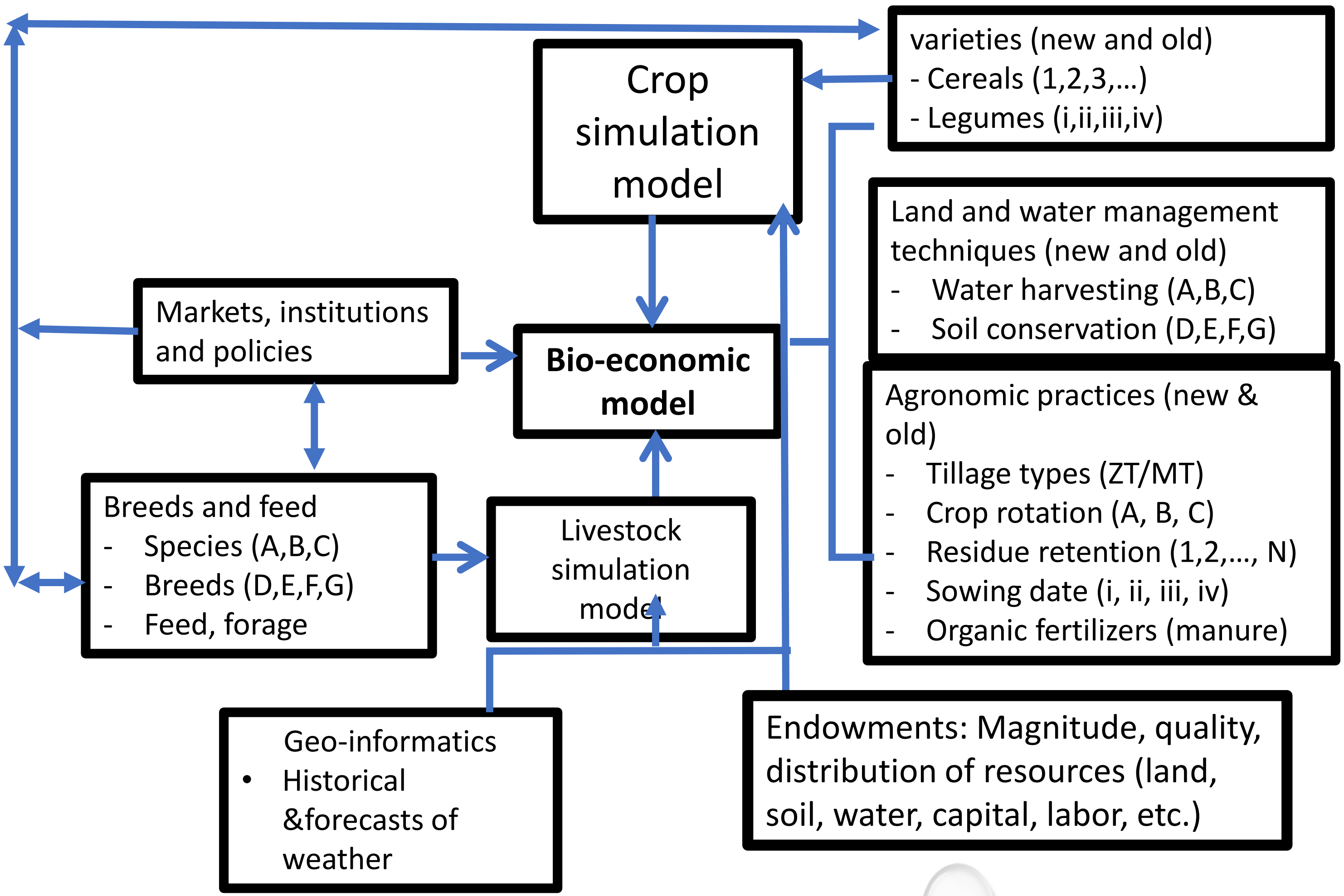
1) Dynamic stochastic model of an integrated crop-livestock household (DSM-ICLH)
2) A version of the dynamic agricultural household bio-economic simulation model (DAHBSI)- (originally developed by CEHEAM-IAMM under IFPRI's BioSight project)

Basic Structure of the DAHBSIM and DSM-ICLH models



(Flichman et al., 2014; Boussios, 2019)

Basic Structure of the DSM-ICLH models



The objective function (DAHBSIM)

A variant of the Mean-Variance Utility Function

Present value of Net Income over the entire planning horizon

Utility

$$U = NPV - \emptyset * \sigma$$

Risk aversion coefficient

Standard deviation of the
farm household net income

Production

Off farm income

Own consumption

$$NPV = \sum_{y=1}^{n} \left(\frac{CIy + OIy + VFCy}{(1+i)y} \right)$$

Discount rate

Solved Using Forward Recursion

- Objective function (DSM-ICLH)
  - A linear utility function (risk neutrality assumed)

$$V_{ti} = \underset{D_{ti}}{Max} \left[\pi_{ti}(D_{ti}) + \alpha \sum_{j} P_{tij}(D_{ti}) \times V_{t+1,j} \right], \forall t,i$$

Where,

V_{ti} = maximum expected profit in period *t* and state *i*

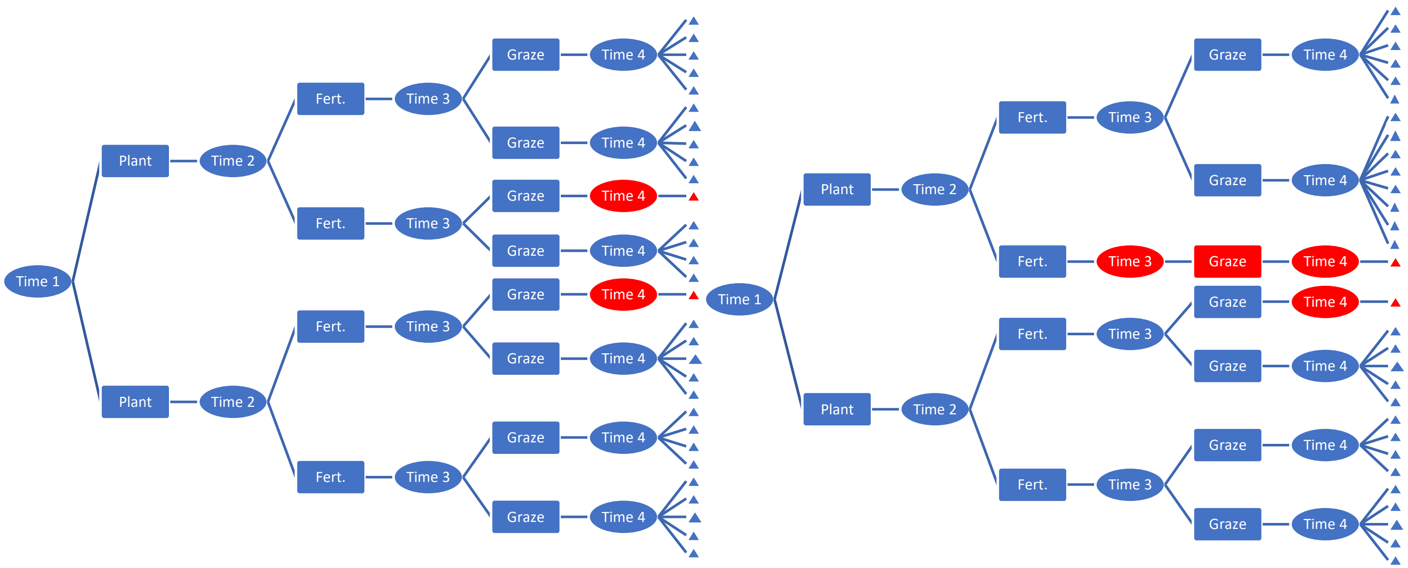
$\pi_{ti}(D_{ti})$ = Contributions of current actions to profit

D_{ti} = Set of actions in period *t* conditional on state *i*

$P_{tij}(D_{ti})$ = transition probability from state *i* to state *j*

Solved Using Backward recursion (Bellman, 1957)

- Curse of dimensionality in SDPs



…bio-economic modeling tools at ICARDA cont'd

1. Dynamic stochastic model of an integrated crop-livestock household (DSM-ICLH) – Jordan (dissertation completed, one article published and another ready for submission)

Strengths

- Intertemporal decision tool
- Stochastic with risk component - (weather only)
- Dynamic – with recourse (suitable for response farming)
- Solved using gams (compatible with most existing household models)
- Integrates crops, livestock and soils
- Captures synergies/trade-offs

…bio-economic modeling tools at ICARDA cont'd

…Dynamic stochastic model of an integrated crop-livestock household (DSM-ICLH) cont'd

Shortcomings

- Discrete data points
- Limited by curse of dimensionality (as all SDPs)
    - Uses ***outputs*** from:
        - APSIM-for crops
        - A separate infinite horizon dynamic programing (DP) model
            - For valuing slow evolving components (soils) - published
            - Solved using MATLAB
            - Deterministic livestock-unit (LU) formulation used (but linked to weather via feed)
- Integrates crops, livestock and soils
    - Limited number of enterprises (crops & livestock), species/varieties, time periods.
- Not generic
- Difficult to aggregate into higher scales (village/watershed/catchment…)

…bio-economic modeling tools at ICARDA cont’d

2. Dynamic agricultural household bio-economic simulation model (DAHBSIM) – morocco (dissertation ready; manuscript under preparation)

<u>Strengths</u>

- Intertemporal decision tool
- Stochastic
- Solved using gams (compatible with most existing household models)
- Integrates crops, livestock and soils (efforts to include trees and investment)
- Modular (with summary biophysical models imbedded in the model)
- Identifies three distinct farm household typologies
- No limits to the number of enterprises, species, time periods.
- Semi-generic (can be adapted to other contexts)
- Captures synergies/trade-offs
- Amenable to aggregation into higher scales

…bio-economic modeling tools at ICARDA cont'd

- Dynamic stochastic model of an integrated crop-livestock household (DSM-ICLH)

Shortcomings

- Uses summary biophysical models
- Recursive *but not dynamic in the true sense – recourse not very clear*
- Deterministic livestock-unit (LU) formulation used (but linked to weather via feed)
- Perennial crops, investment, consumption modules still being developed;
- Needs some more investment to exploit its full potential.

THANK YOU

Some results from DSP-ICLH: Simulated results on Various indicators

		Scenarios Varying Area and Livestock Units						
Endowments	**Base**	**#1**	**#2**	**#3**	**#4**		**#5**	
Area *(hectares)*	2	2	2	4	5		8	
Livestock Units	2	1	3	2	2		2	
Financial Results								
Mean *(JD)*	1145	-850	2668	2708	3192		4509	
Minimum *(JD)*	-1890	-3203	-465	-2193	-2148		-2935	
Maximum *(JD)*	1795	-175	3370	4034	4775		6769	
Soil Results (*mean levels*)								
ESW *(mm.)*	86.5	86.6	86.5	86.6	86.5		86.3	
NO_3 *(kg. /ha.)*	15.1	15.2	15.1	15.2	14.9		13.7	
SOM *(kg. /ha.)*	1530	1506	1538	1510	1413		1045	
Planting Choices (*hectares*)								
Dec	**Dec** Barley	**Dec** Barley	**Dec** Barley	**Dec** Barley	**Dec** Barley	Wheat	**Dec** Barley	Wheat
<100	2	2	2	4	4.33	0.67	2.64	5.36
>100	2	2	2	4	5	0	8	0

Notes: Base indicates the main results. The numbered scenarios (#1 through #5) are the results varying the household's area and livestock units owned. Financial results include all financial related outcomes at the end of the year, including the value of the livestock units. Acronyms: ESW- Extractable Soil Water, NO_3- Nitrates, SOM- Surface Organic Material. Planting choices indicate the optimal choice for the stochastic weather states. For example, in the base scenario the farmer plants all 2 hectares of their land to barley in December unconditional of weather. In the scenario with 8 hectares and 2 livestock units, the farmer plants all their land to barley if rainfall was above 100 mm in December. If rainfall was less than 100 mm, they plant 2.64 hectares to barley and the remaining 5.36 ha. to wheat (All planting occurs in December). All optimal planting choices selected the barley (Rum variety) or wheat with 100kg/ha of DAP and a 40 kg/ha top-dressing of Urea. JD indicates the local currency, the Jordanian Dinar.

Some results from DSP-ICLH: Simulated results on soil quality

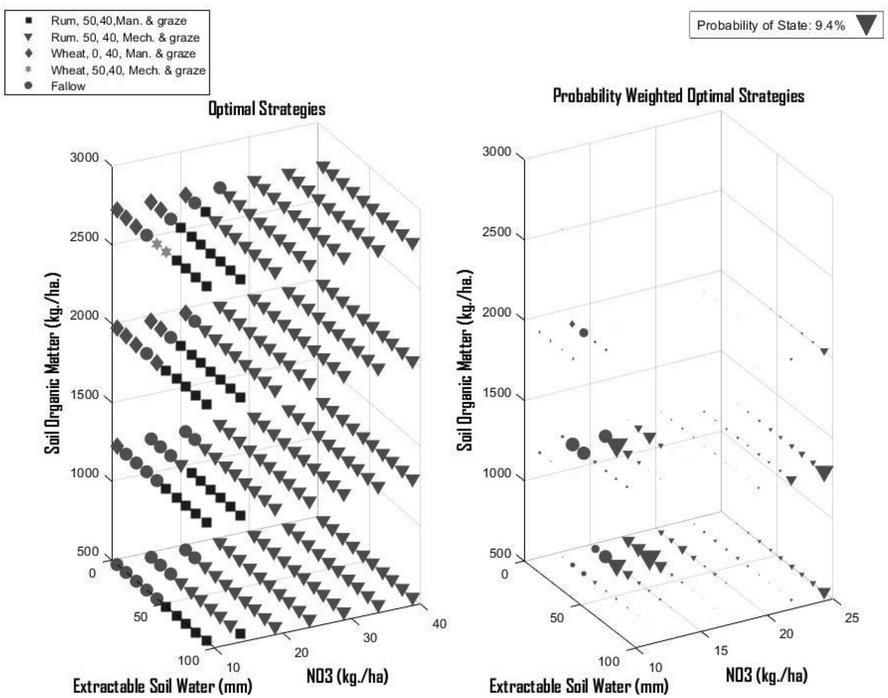


Fig. DP Results with Unconditional Choices

Note: The axes of each graph are the soil attribute levels: Extractable Soil Water and NO3 are represented on the horizontal axes, and Surface Organic Matter is on the vertical axis. On the left-hand figure, each shape represents the optimal choice of crop (Rum, Wheat, or Fallow), the fertilizer application at planting (0 or 50 kg/ha of DAP), the rate of application of top-dressed urea 60 days after planting (0 or 40 kg/ha) and the harvest technology (Manual or Mechanical) for each discrete soil state. The right-hand figure represents the same choices, however, the size of each shape indicates the steady-state probability for each state. The optimal management choice for each state is again denoted by shape. The legend indicates all management choices for the respective shape. The ordering of the quadruple indicating the management choice in the legend is: crop type, fertilizer level at planting, top-dressing, and harvesting choice. E.g. Rum, 50, 40, Man. (for Manual) indicates planting the barley variety Rum with 50 kg/ha of DAP at planting, top-dressing with 40 kg/ha of Urea 60 days after planting, and manual harvesting followed by grazing. *Source*: Results of DP.

Some results from DSP-ICLH:
Simulated results on soil quality indicators

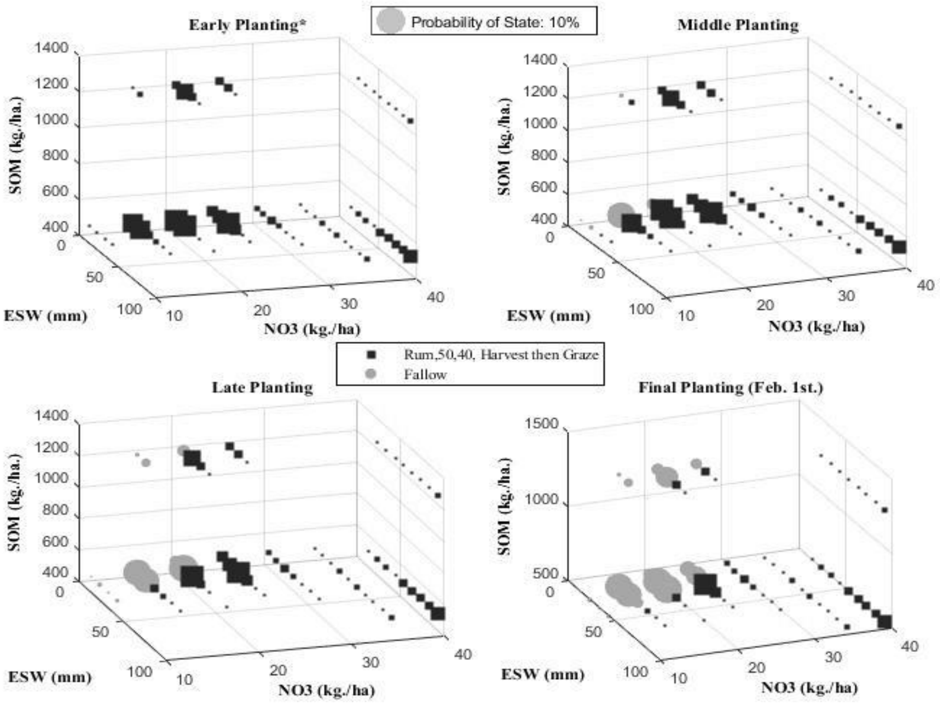


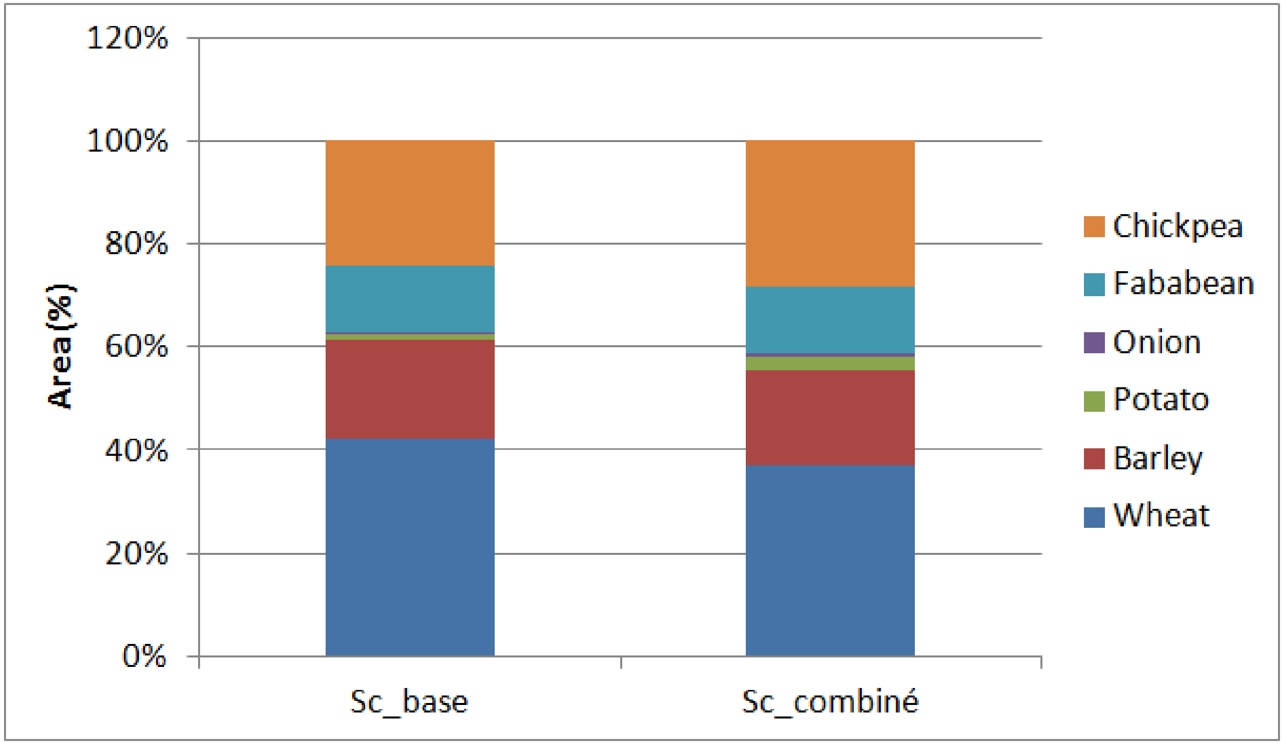
Fig.. Results with Adaptive Responses During the Year

Note: The axes of each graph are the soil attribute levels. A fourth dimension is the size of the shape, which corresponds to the probability of the recurring state in the steady-state solution. Non-recurring states are omitted. The optimal management choice for each state is denoted by its shape as in Figure 1. Each of the four graphs corresponds to the timing of the arrival of rainfall at planting. E.g., the top left graph indicates the strategies and frequency of recurrence in the steady-state solution when 100 mm of rainfall arrives during the early time window. The legend indicates all the management choices for the respective shape. Optimal harvesting choice is mechanical for all planting periods, except Early, as denoted by *. The quadruple of the management choice indicates: crop type, fertilizer level at planting, top-dressing, and harvesting choice. E.g. Rum, 50, 40, and Man. indicates planting the barley variety Rum with 50 kg/ha of DAP, top-dressing with 40 kg/ha of Urea, and manual harvesting followed by grazing. *Source*: Results of DP calculations.

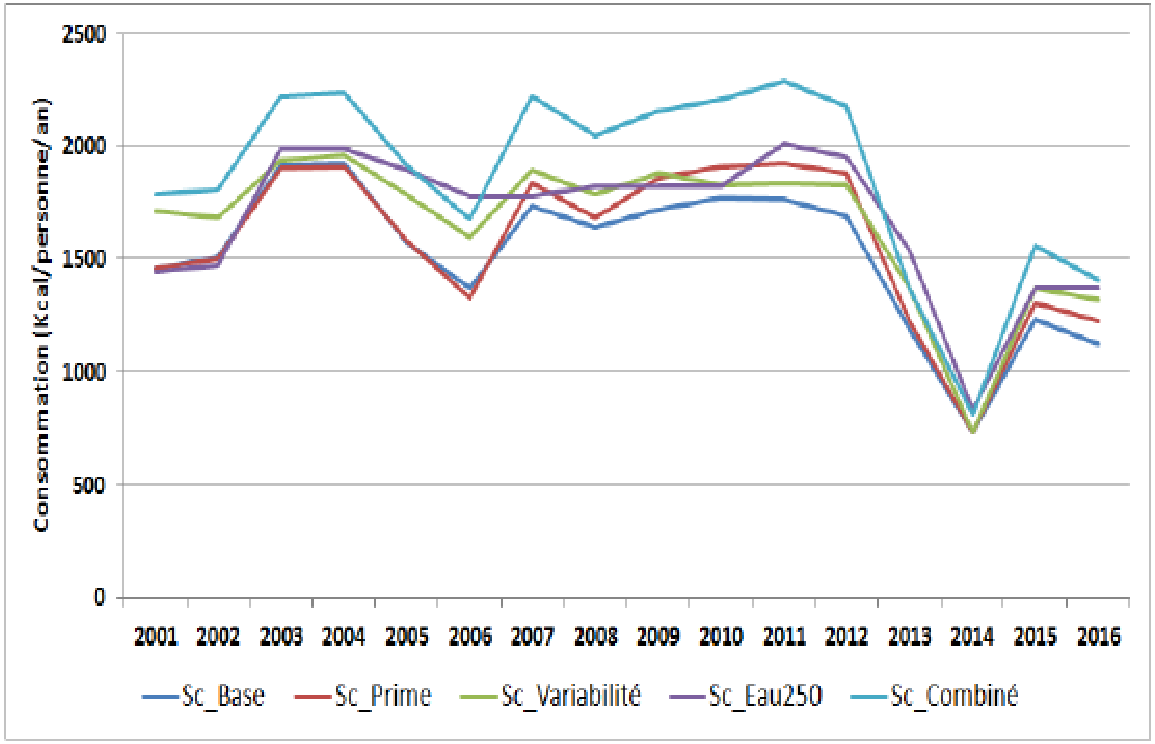
Some results from DAHBSIM-Morocco: Simulated results on Farm income

Scénario	Average farm income (dh/ha)	Difference (%)	Average consumption (Kcal/capita/day)	Difference (%)
Sc_base	7400	-	1 523	-
Sc_prime	8382	1 3	1 579	4
Sc_variabilité	8429	14	1 658	9
Sc_Eau250	8504	15	1 681	10
Sc_combiné	9407	27	1 870	22

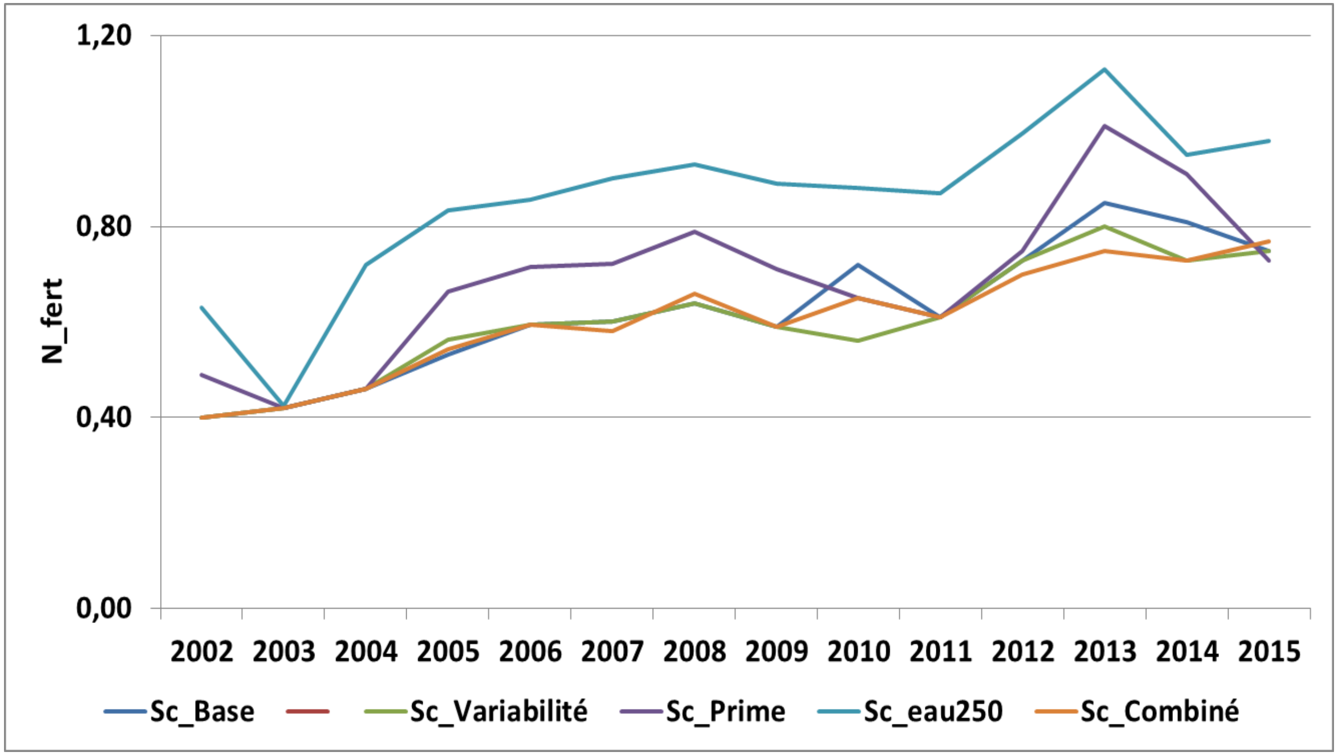
Some results from DAHBSIM-Morocco: Cropping pattern



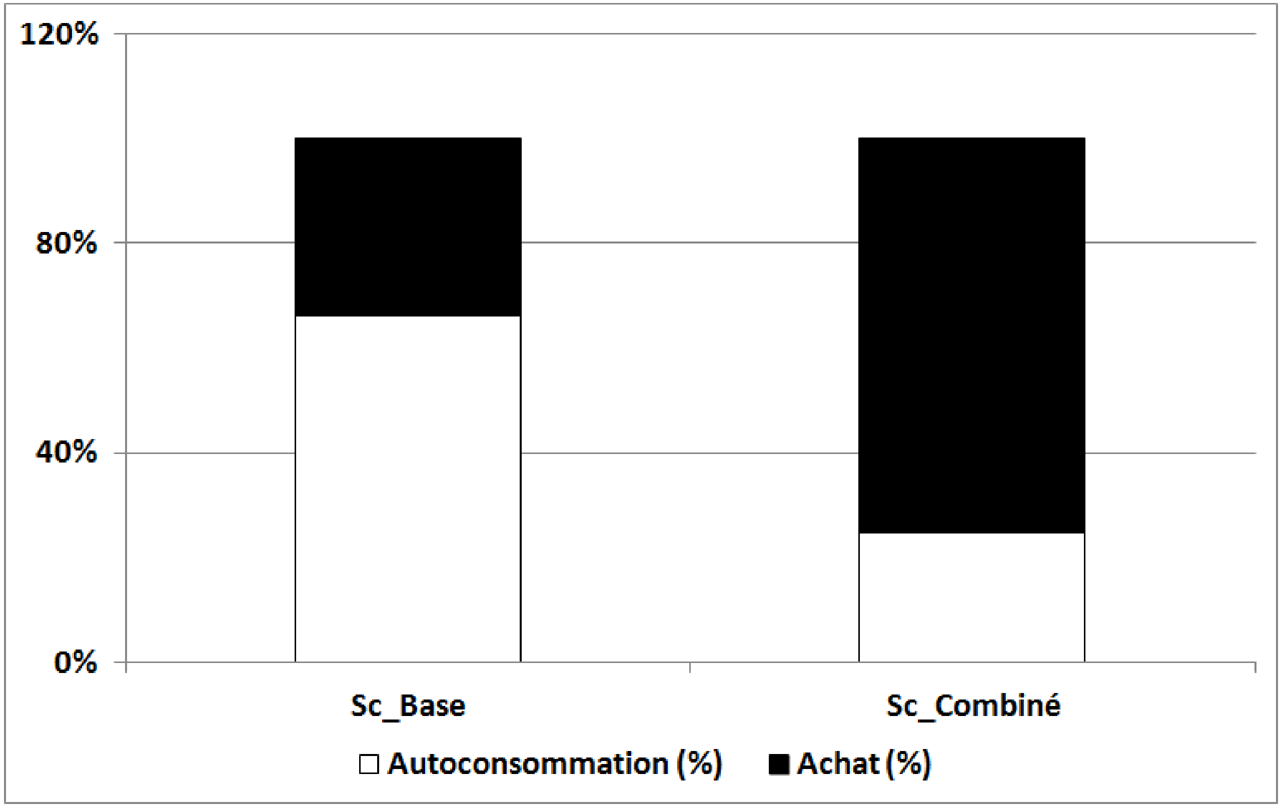
Some results from DAHBSIM-Morocco: Calorie consumption



Some results from DAHBSIM-Morocco: N_Fertilizer applicaiton



Some results from DAHBSIM-Morocco: Consumption



… Building bio-economic models Cont’d