SAMARA V2.1

SweetFuel Modeling Training Workshop

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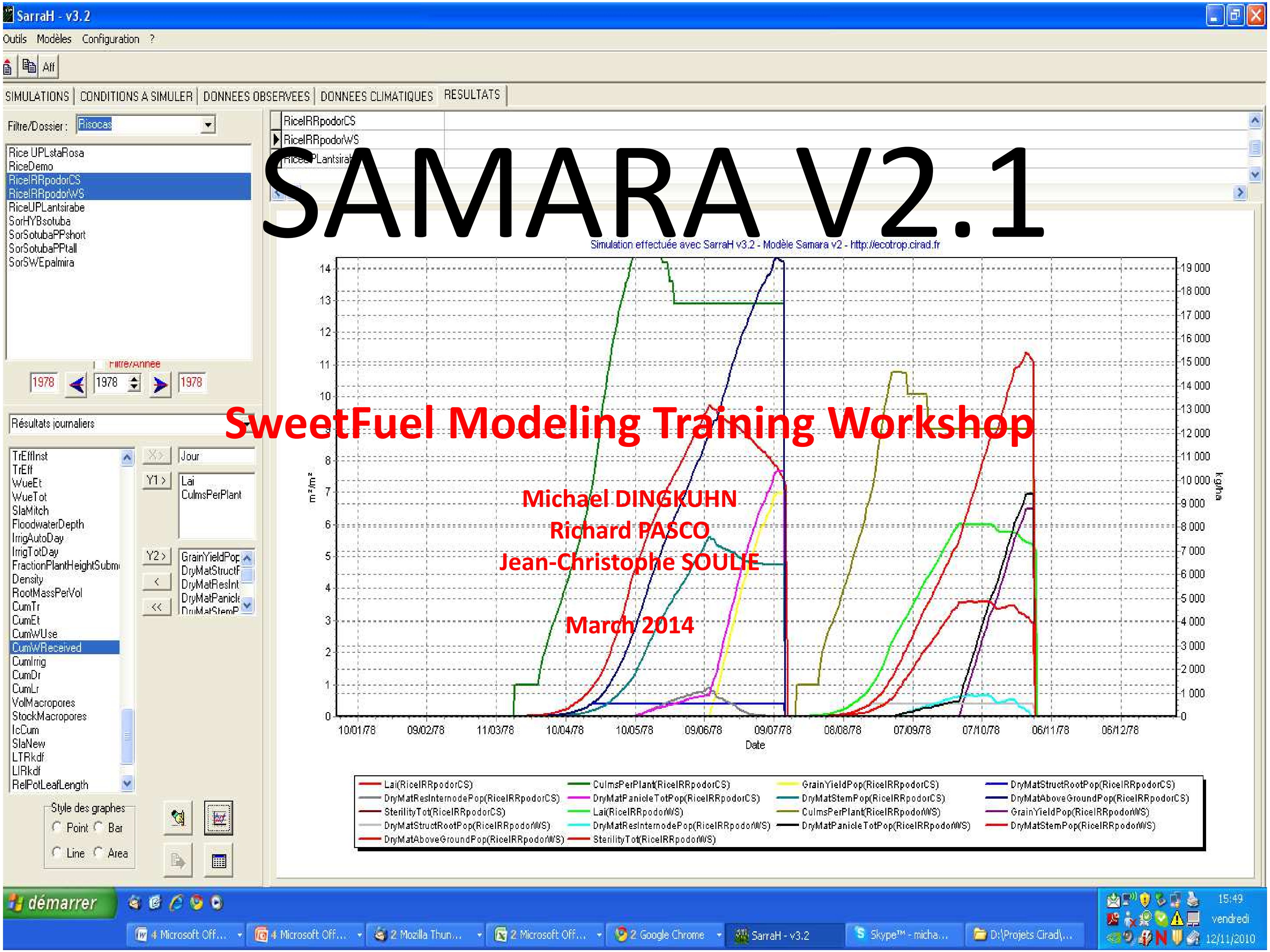


Course Objectives

- Familiarization with SAMARA crop model
  - Theory, User interface
  - Hands-on applications
- Specificities for sorghum
  - Photoperiodism
  - FFF (Food/Feed/Fuel: grain, biomass, NSC)
- Virtual experiments with Ideotypes
  - Phenology, tallness
  - Trade-offs grain vs biomass vs NSC traits
  - Cultural practices: Population density
  - Environments: Sowing dates, Drought

Part 1
General concepts

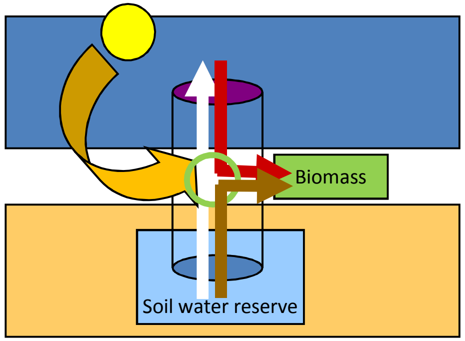
SAMARA in a Nutshell

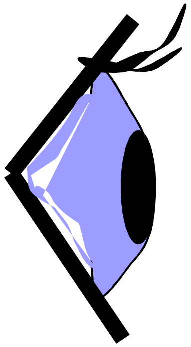
- For GxExM & ideotype exploration
- Rice (upl, rf-LL, irrig), sorghum (grain, sweet, biomass types), millet…
- Mono-crop
- Deterministic crop model, daily time step, point model
- Pop' scale (by extension of detailed simulation of individual plant)
- Biology: Emphasis on adaptive plasticity
  - Phenotypic plasticity at organ level (from EcoMeristem)
  - Inter-organ competition (*Ic*) drives tillering, NSC reserves, senescence…
  - Source- or sink-limited growth => 'bold' or 'cautious' plant types
  - Self-adjusting system thru trophic feedbacks on phenology and morphology
- Agronomy: Emphasis on water
  - Water management (many options)
  - Water balance, WUE at various scales
  - Stresses: Drought, water logging, submergence; thermal stresses
  - Transplanting

SAMARA: What’s New?

- Inherited from SARRAH
  - ECOTROP Platform and interface adapted from SARRAH
  - Water balance for upland from SARRAH
  - Big-leaf canopy concept & Lambert-Beer from SARRAH
  - Basic phenology from SARRAH, incl. IMPATIENCE (PPism)
- New
  - « Lights » version of EcoMeristem
    - Supply & Demand driven growth
    - Ic as supply/demand internal signal driving organogenetic adjustments & senescence
    - Some morphological detail (tillers, phyllochron, organ size, plant height…)
    - Reserve management (storage, mobilization)
  - Lowland water balance (aquatic)
    - Bunding, water logging, flooding, water management; alternate wetting/drying and rainfed-LL can be simulated
  - Stress responses
    - Leaf rolling, leaf & tiller senescence, sterility (cold, heat, drought); water logging; submergence
  - Potential root growth is a function of explorable soil volume per plant

Demand driven growth:
Need to model meristem behaviour





Plumbing of a system of reservoirs & conduits:

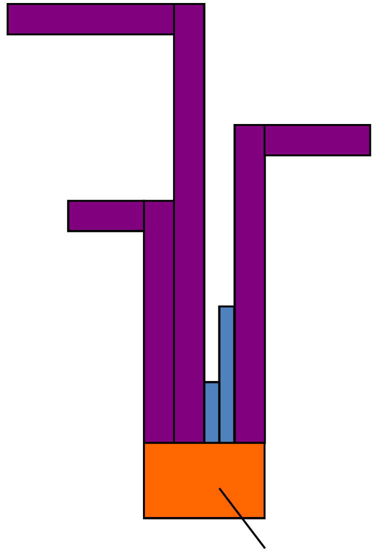
- Capture (PAR, H20)
- Conversion
- Partitioning

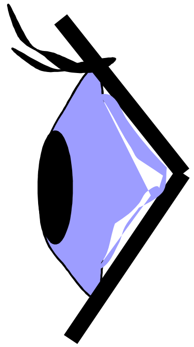
Agronomic angle:

Supply (assimilation) driven system

Architectural models:

- Genesis of topological structure
- Body plan, phystomer succession, metamorphoses
- Filling of compartments





Meristem → main site of **gene** action

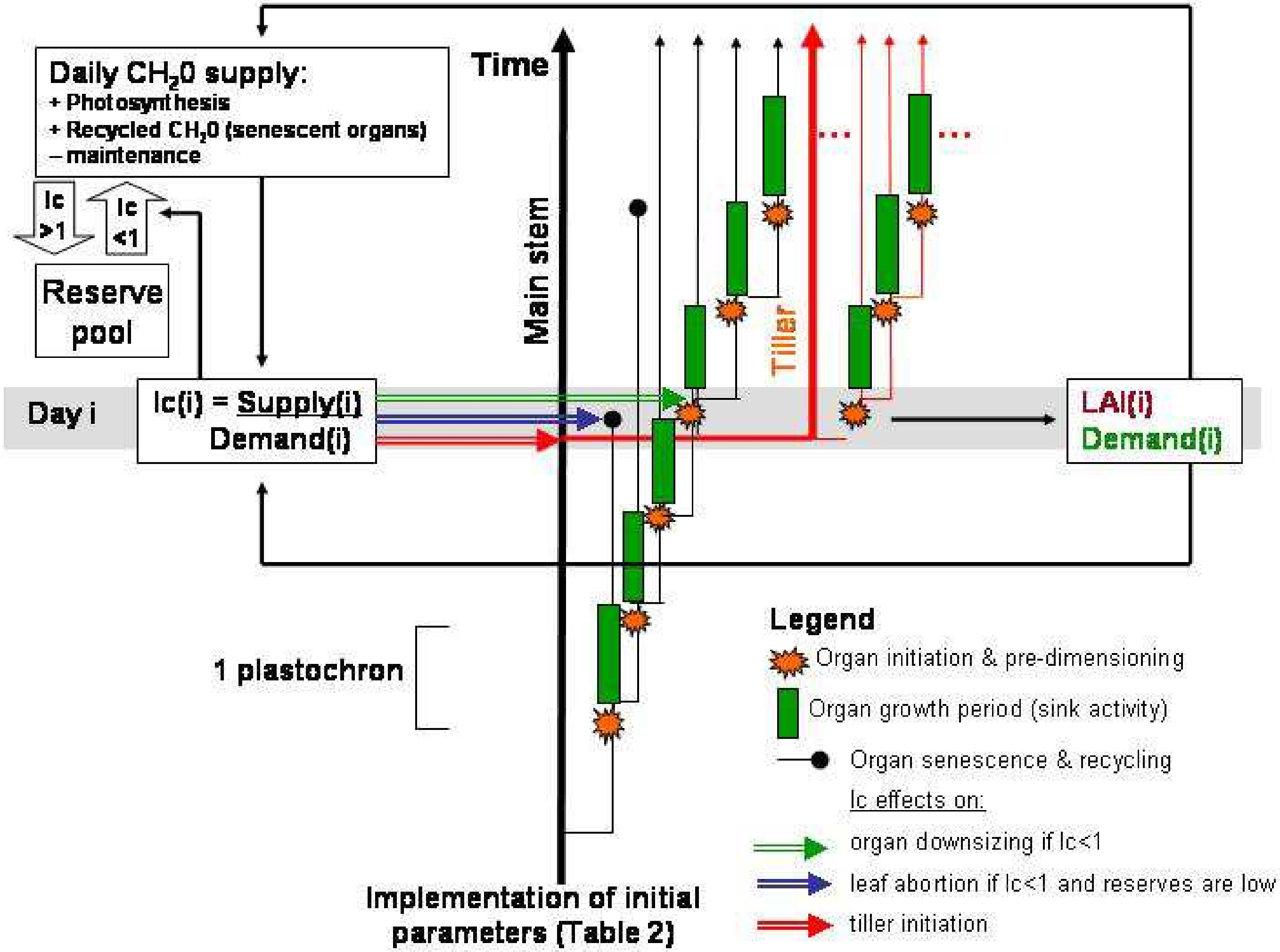
Botanical angle:

Demand (organogenesis) driven system

SAMARA: Hybrid Concept

- Organogenesis: simplified to represent only trophic demand functions
- Plasticity of organogenesis thru resource & stress feedbacks
- Economics approach (supply-demand interactions)
- Emphasis on light, water and agronomy (cultural practices at plot scale)
- Emphasis on morpho-physiological tradeoffs

EcoMeristem, model of phenotypic plasticity



Ic **= Index of internal Competition = state variable = proxy for sugar signaling**

SAMARA vs. EcoMeristem

AGRONOMY, BREEDING SUPPORT

PHENOTYPING, TRAIT DISSECTION

Common features

- Phenotypic plasticity (GxE of tillering, leaf senescence, plant height…)
- Competition for carbon resources, transitory reserve management
- Drought responses

Polyvalent water balance

- Upland, RF lowland, irrigated
- - Water excess or deficit, submergence/logging stresses

Cultural practices

- direct seeding / transplanting
- Pop. density in nursery & field
- Bunding, drainage options
- Water saving irrigation

Resource balances

- RUE, TE, WUE, irrig.efficiency

Detailed development biology

- Meristem-driven determination of individual organs

3D-capability

- 3D visualization
- 3D light interception

Hi-thruput phenotyping skill

- Parameter optimization tool
- Simulates single/potted plants

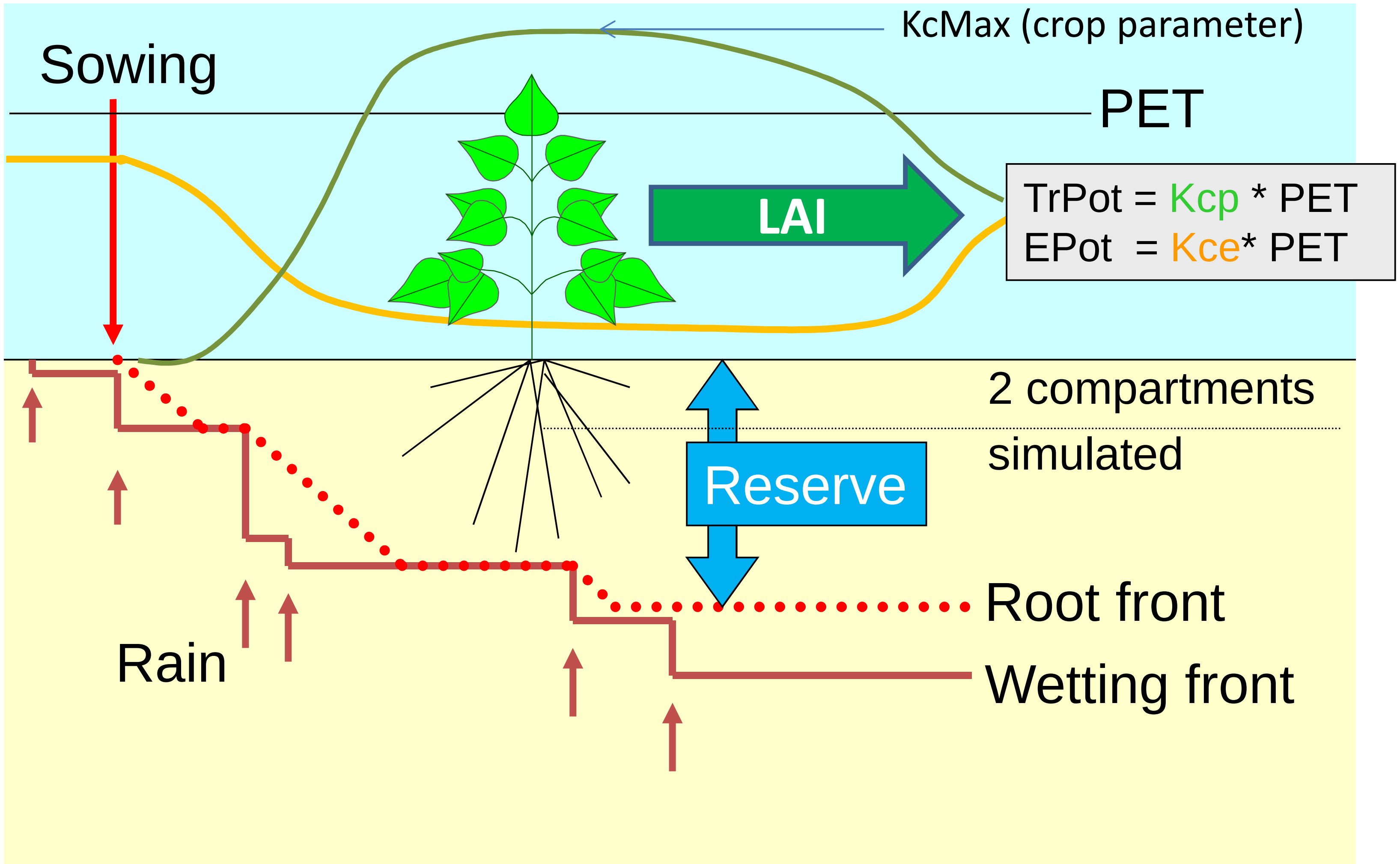
Biological significance of SAMARA paradigms

- When the plant initiates an organ, it makes a bet on resources during subsequent organ expansion
- There can be bold or conservative organogenetic behavior
- Bold plants are "resource diluters"
  - Potentially vigorous
  - Need great plasticity for adjustments (e.g., tillering & sensescence)
- Conservative plants may under-use resources
  - More transitory storage
  - End-product inhibition of photosynthesis
- **Quizz: Which is sink limited, the bold or the conservative plant?**
- *S*tem reserves are seen a a spill-over reservoir that can benefit subsequent demand such as stem elongation or grain filling
- **Quizz: Under what circumstances can the plant accumulate reserves?**

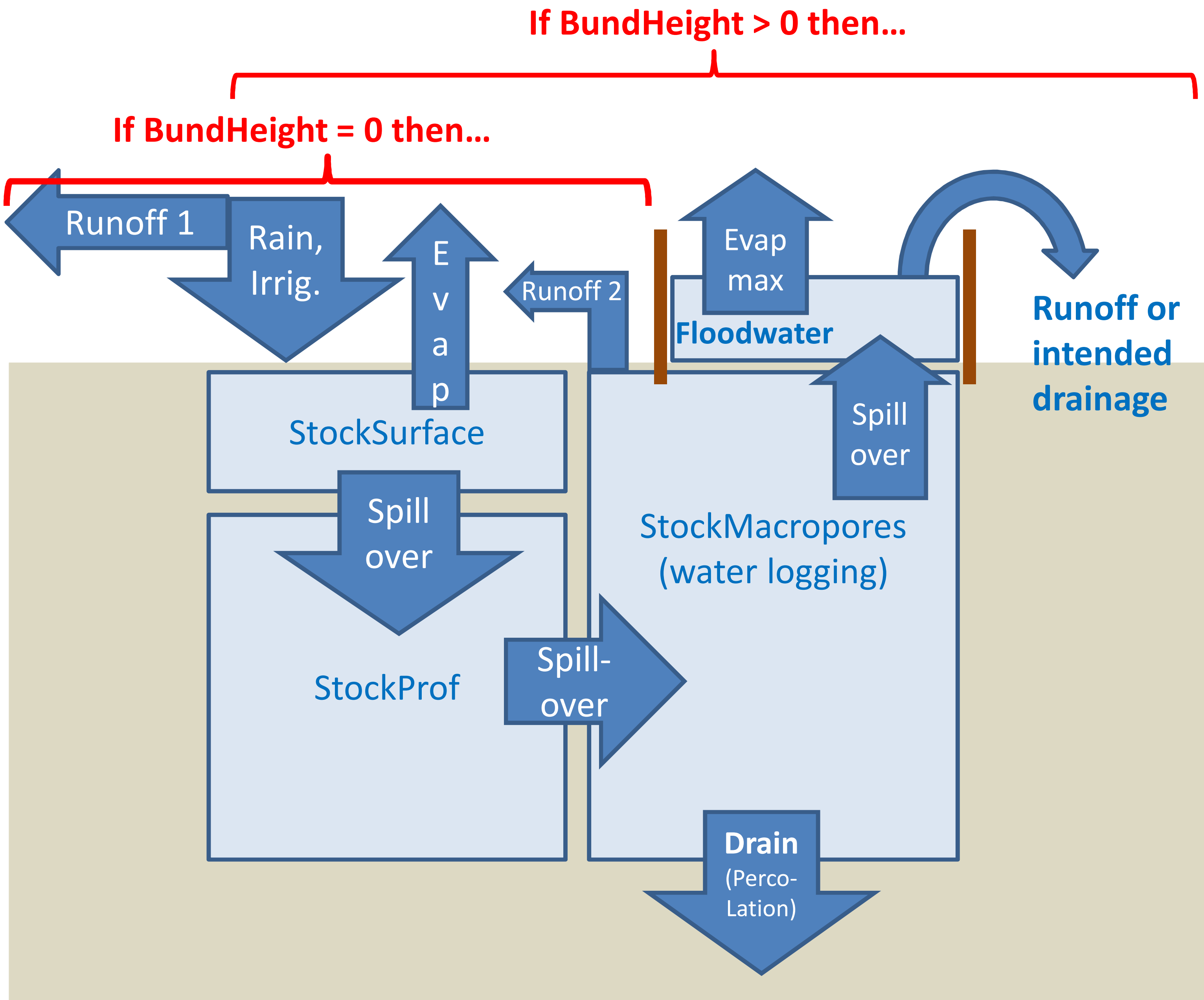
DISCUSSION

Part 2
Specific concepts

Basic water balance of SAMARA and SARRAH



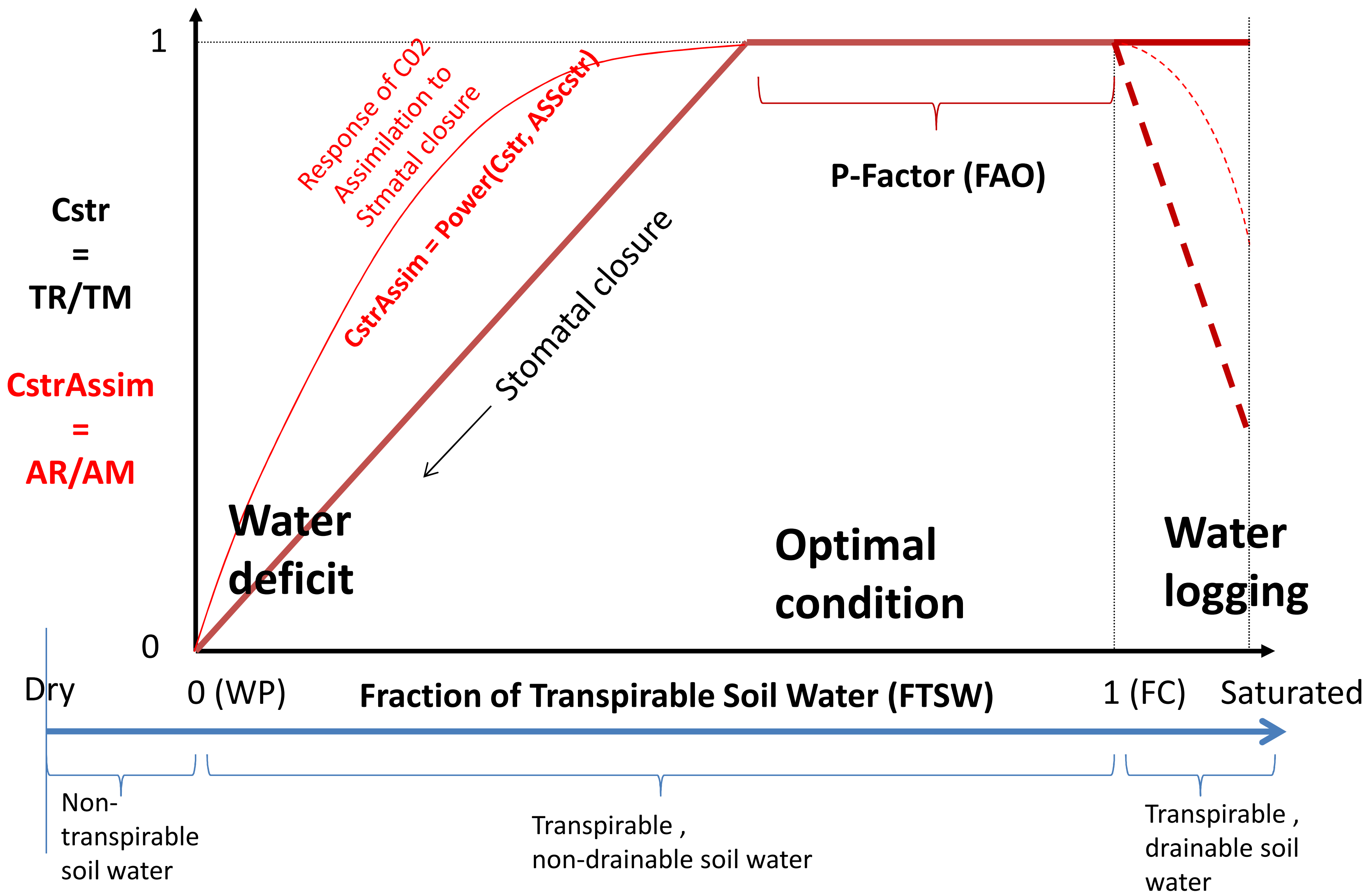
Water balance for dry, aquatic or mixed systems



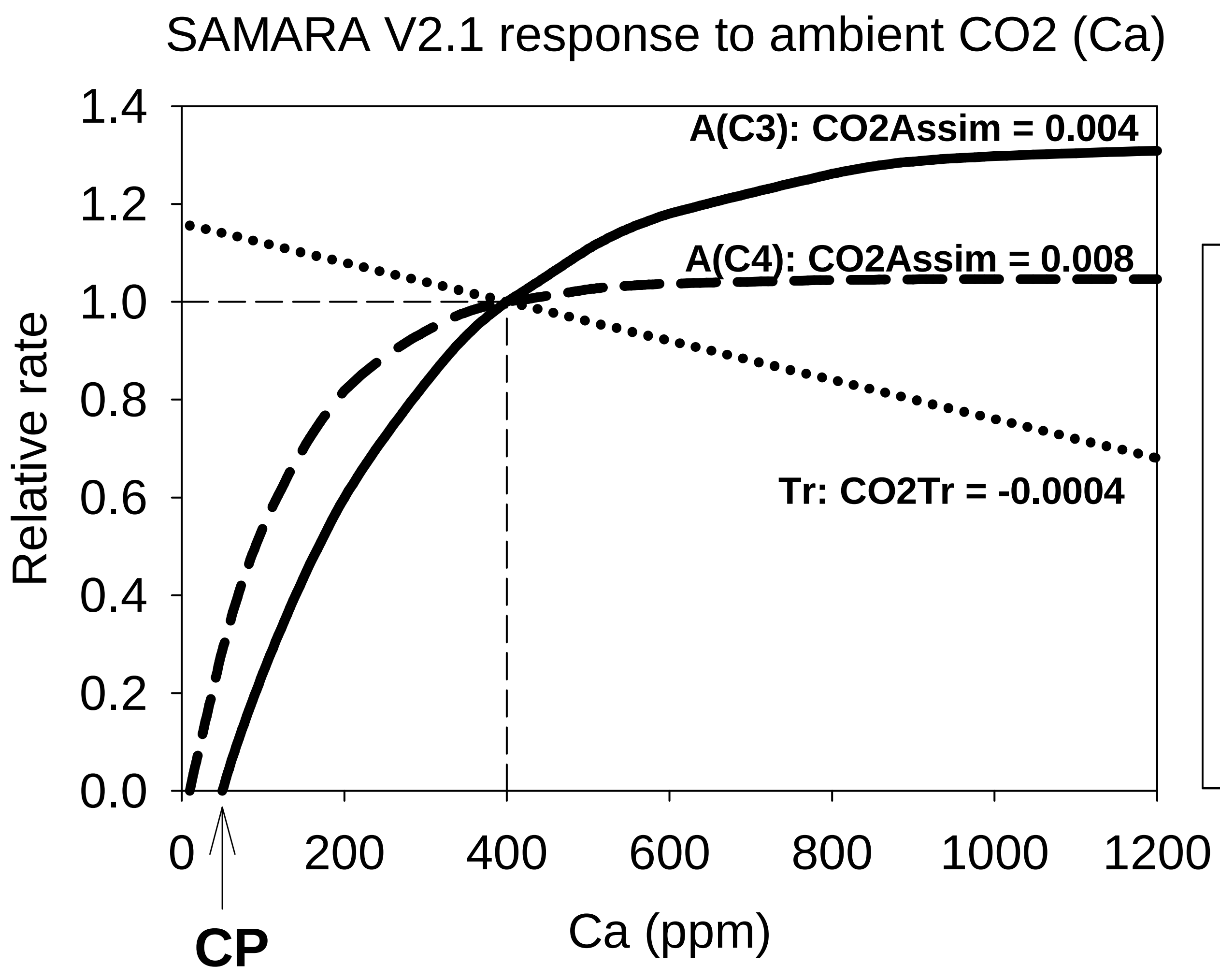
Root System

- Root front progression is fn of…
  - soil wetting front & soil depth
  - genotypic max. rates (per phase) & T
- Root assimilate demand is fn of…
  - Depth progression
  - Laterally available space
  - Genotypic max. root dw density (wt/vol)
- Actual root dw gain is demand adjusted by competition with other organs (*Ic*)
- Consequence: Partitioning to roots depends on available soil space (e.g., effect of pop density)

Feedback of soil water status on plant Tr & A



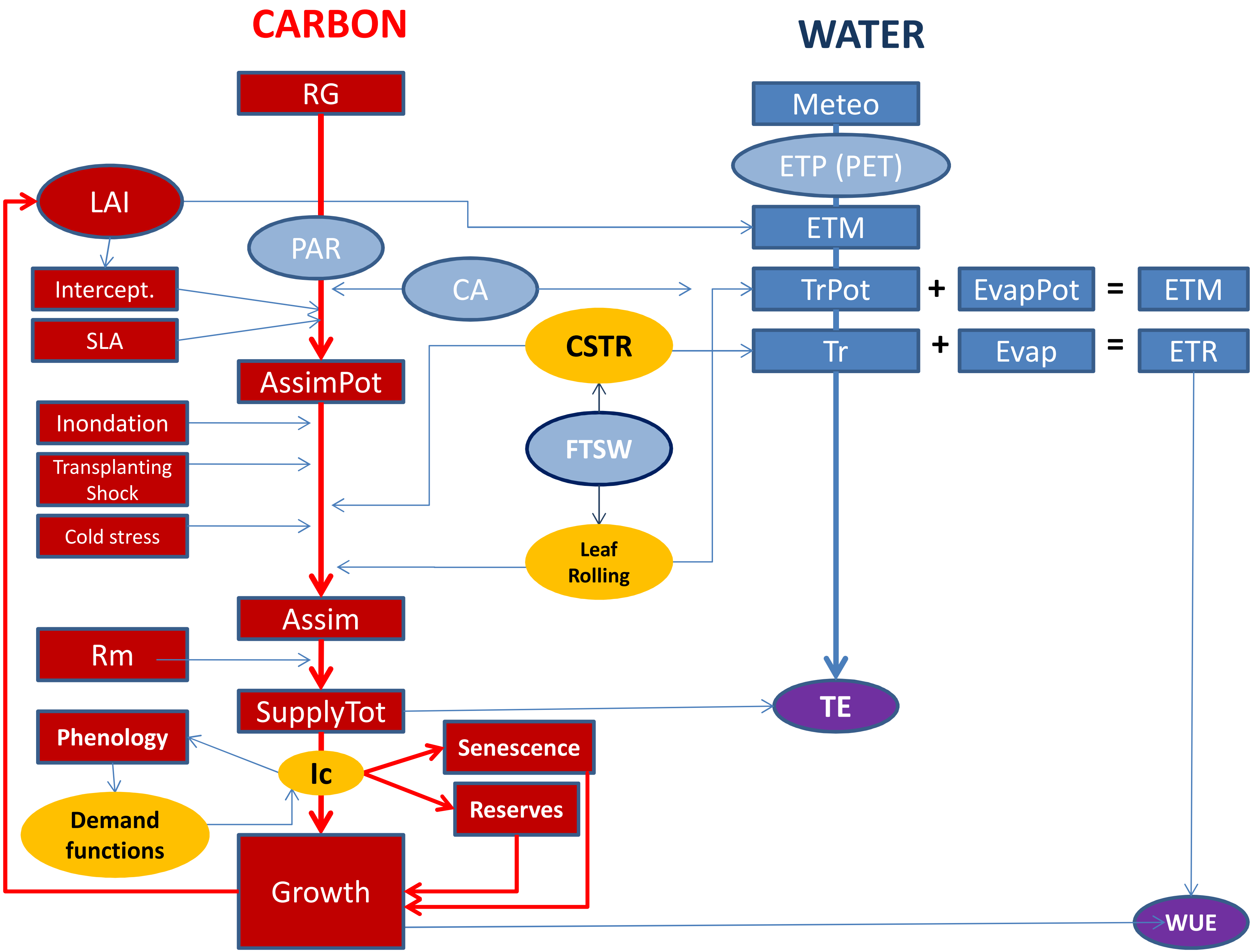
Calculation of C assimilation and RUE



Simple, similar to APSIM

3 parameters

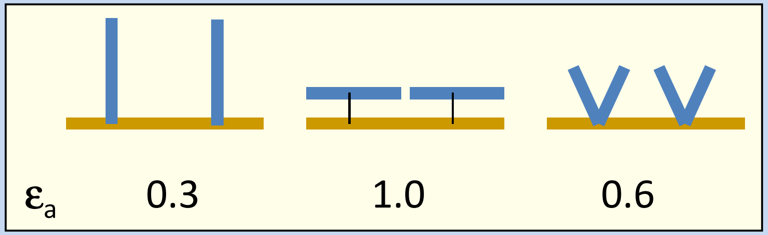
No physiological water-CO2 coupling



CARBON
WATER
RG
Meteo
ETP (PET)
LAI
ETM
PAR
CA
Intercept.
SLA
TrPot
+
EvapPot
=
ETM
CSTR
Tr
+
Evap
=
ETR
AssimPot
Inondation
FTSW
Transplanting Shock
Cold stress
Leaf Rolling
Assim
Rm
SupplyTot
TE
Phenology
Senescence
Ic
Reserves
Demand functions
Growth
WUE

Modified big-leaf approach to calculation of light interception

Lambert-Beer's law : LAI and leaf angle vs. ε_a (light interception)



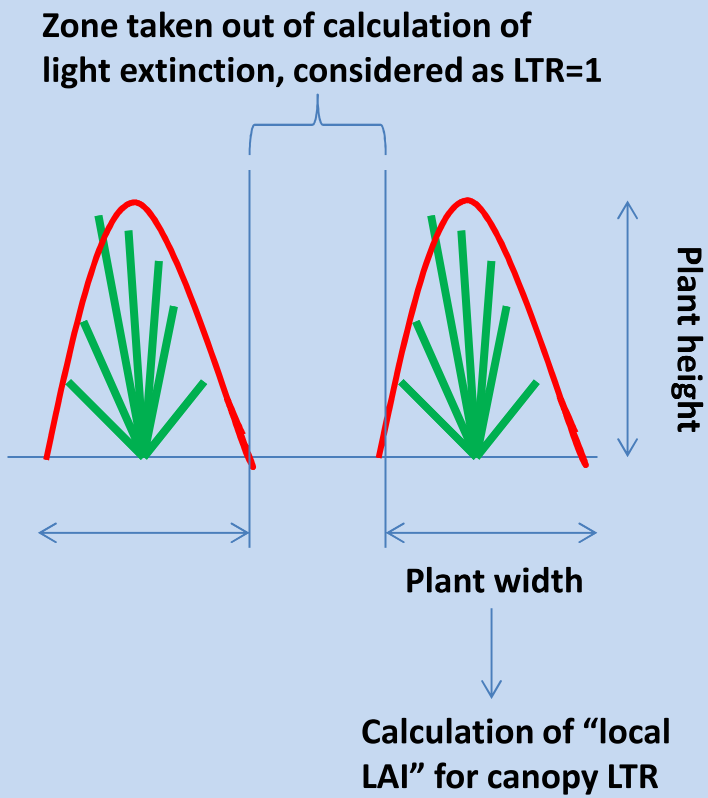
Beer's law : $\varepsilon_a = (1 - LTR) = 1 - (\exp[-Kdf * LAI])$

Therefore $Kdf = (-\ln LTR) / LAI$

$LAI = (-\ln LTR) / Kdf$

LAI	$\varepsilon_{a\ (Kdf=0.4)}$	$\varepsilon_{a\ (Kdf=0.6)}$	$\varepsilon_{a\ (Kdf=1.0)}$
1	0.33	0.45	0.64
2	0.55	0.70	0.86
4	0.80	0.91	0.98

Calculation of clumping effects



- **Growth and canopy-building processes consider organ (leaf- and tiller) number**
- **PAR interception is calculated from aggregate LA, clump dimensions and population**

Growth of a.g. organs

- Phytomer succession (phyllochron)
  - New leaves & internodes have a potential size (demand)
  - Actual size is affected by competition (*Ic*)
  - Leaf senescence is fn(*Ic*)
- Tillering
  - Tillers are produced or aborted by fn(*Ic*)
- Panicle
  - Structural mass (pre-flowering)
  - Grain (post-flowering)
  - Dimensioning of sink during pre-flowering (structure)
  - User can define rel. priority of panicle structure growth
  - Sterility fraction of spikes is fn(heat, cold & drought stress)

CH_2O Reserve Management

- Internodes and sheaths (=stem) considered as one single reservoir
- Capacity set as fraction of stem dw (*CoeffResCapacityInternodes*, 0…1)
- Simple spill-over (CoeffReserveSink=0) or active sink (>0)
- Mobilization happens when Ic<1
- Mobilization has a max. rate of *RelMobiliInternodeMax* (0…1)

Ic = Supply / Demand

- Ic is a central state variable providing for physiological feed-back among trophic and developmental processes
  - Tiller outgrowth => new sinks
  - Tiller death => sink down-sizing
  - Leaf death => additional resources: recycling
  - Panicle dimensioning => new sinks
  - Stem reserve management =>storage, mobilization

- Genotypic differences in sensitivity to Ic
  - Sink-source interaction
  - Parameters TilAbility, TilDeath, LeafDeath, …
  - « Bold » or « cautious » strategies
  - Bold types use all assimilate for fast growth but risk « overcommitting »
  - Cautious types make less biomass (unused assimilate) but avoid structural crises all demand can be accomodated)

- Difficult to calibrate (everything affects everything)
- But biologically meaningful: Growth can be supply- or demand-driven
  - Varietal differences in vigour are usually not due to photosynthesis!!!

Crop parameters/traits of SAMARA affecting drought response

Direct

- P-factor (≈ stomatal response to FTSW)
- Leaf rolling response to PET & FTSW
- Rooting depth
- Spike sterility response to drought

Indirect

- Phenology (crop duration)
- Phenology DR response to FTSW)
- Kc (maximal canopy Tr)
- TE (fixed or drought dependent)
- Tiller senescence
- Leaf senescence (e.g., Stay-green trait)
- Reserve buffer (terminal drought)

Not simulated:

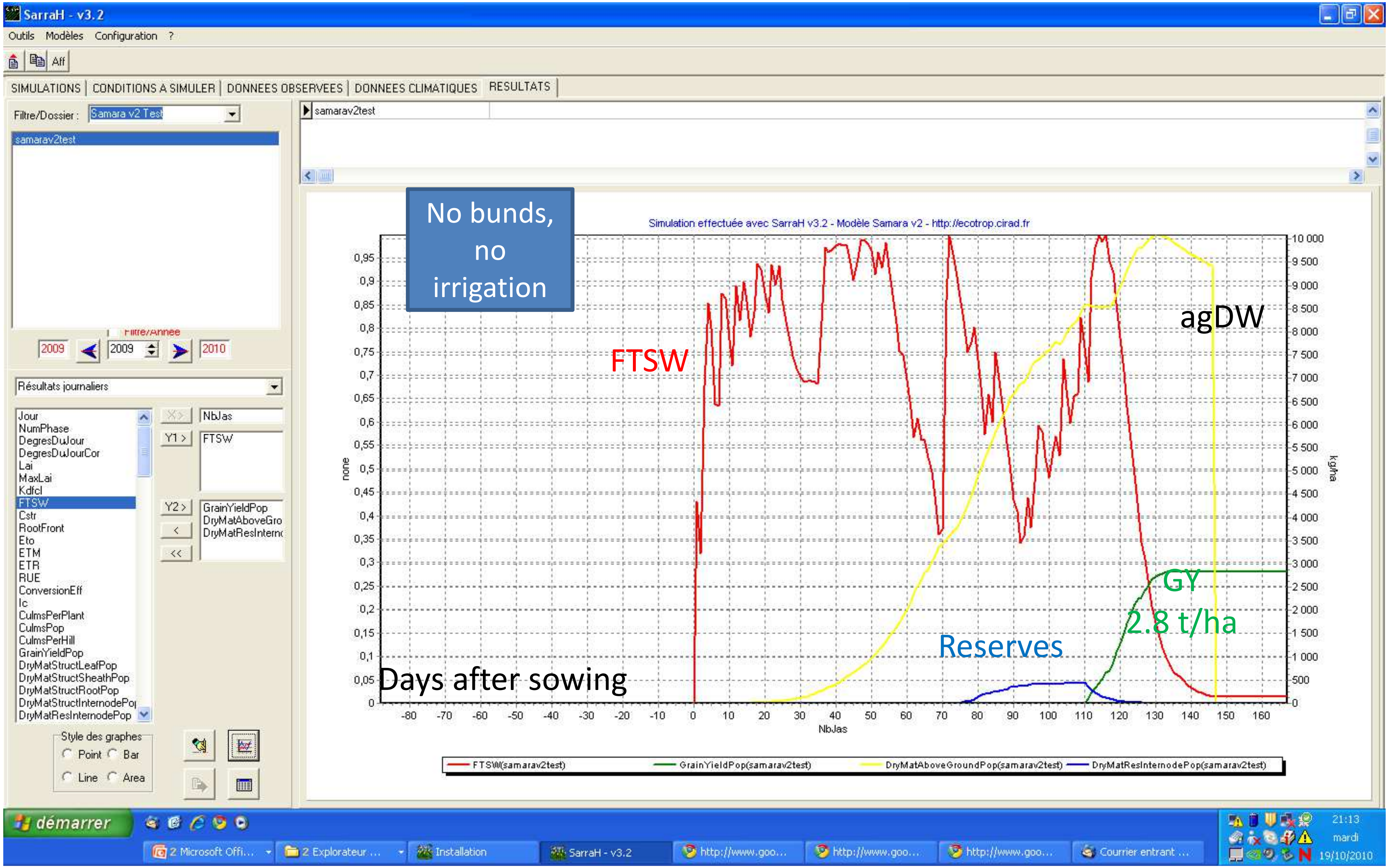
- Osmotic adjustment

DISCUSSION

Part 3
Examples of SAMARA simulation outputs

Demonstration of SAMARA:
Water management vs drought effects on yield (1)

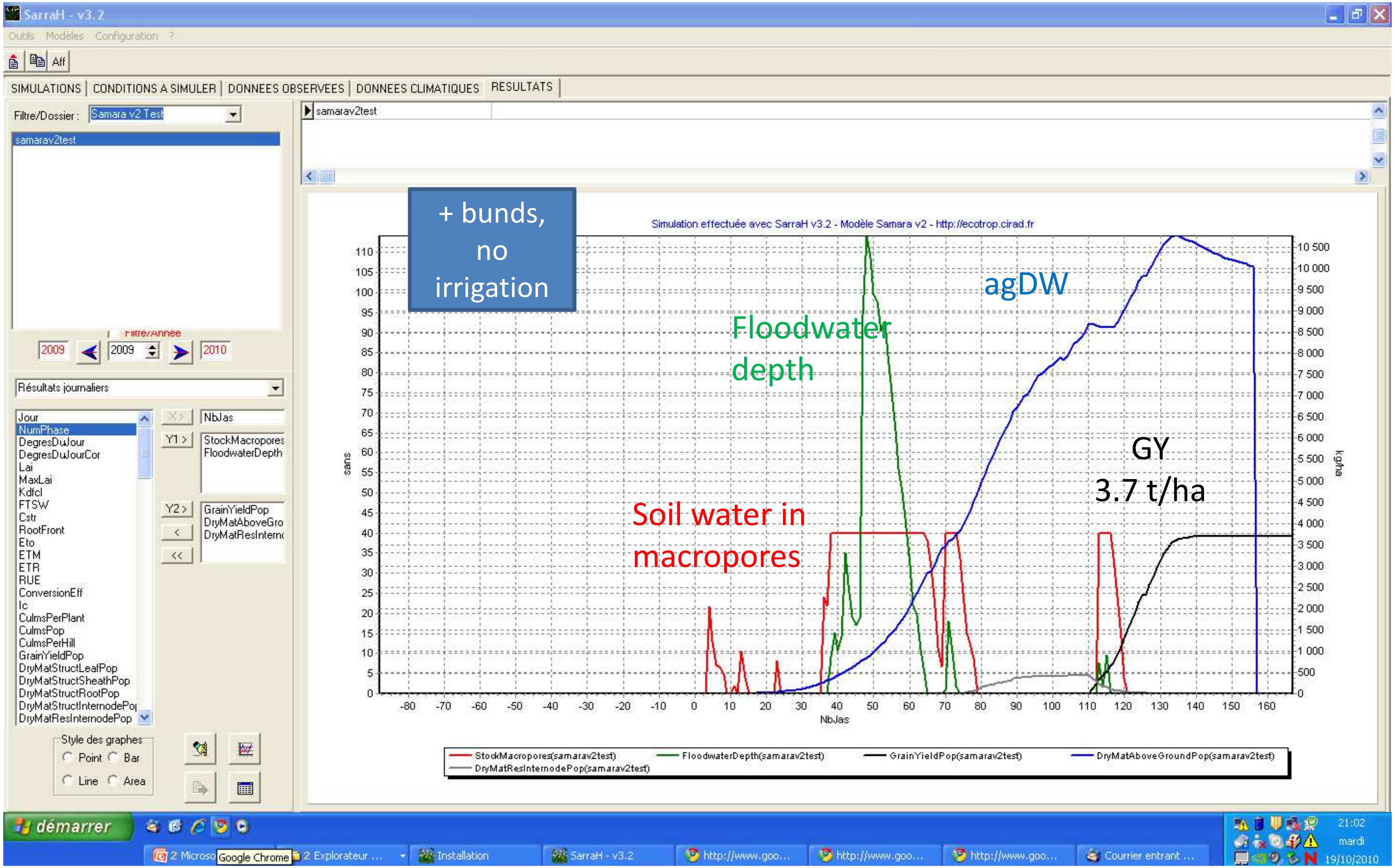
Upland condition (Madagascar highlands, 770 mm rain during crop cycle)



Demonstration of SAMARA:

Water management vs drought effects on yield (2)

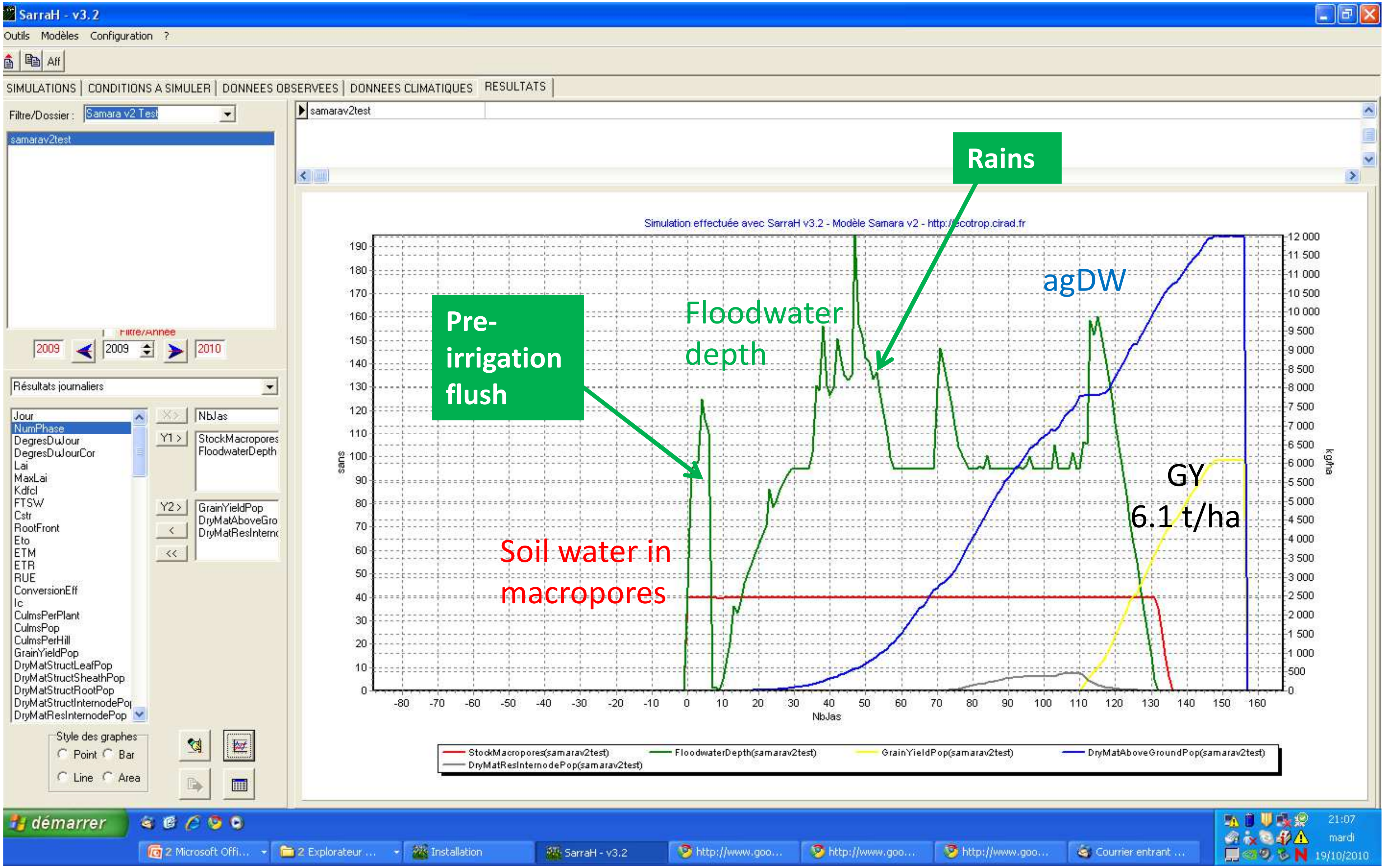
bunded-rainfed – the yield benefits from reducing runoff (770 mm)

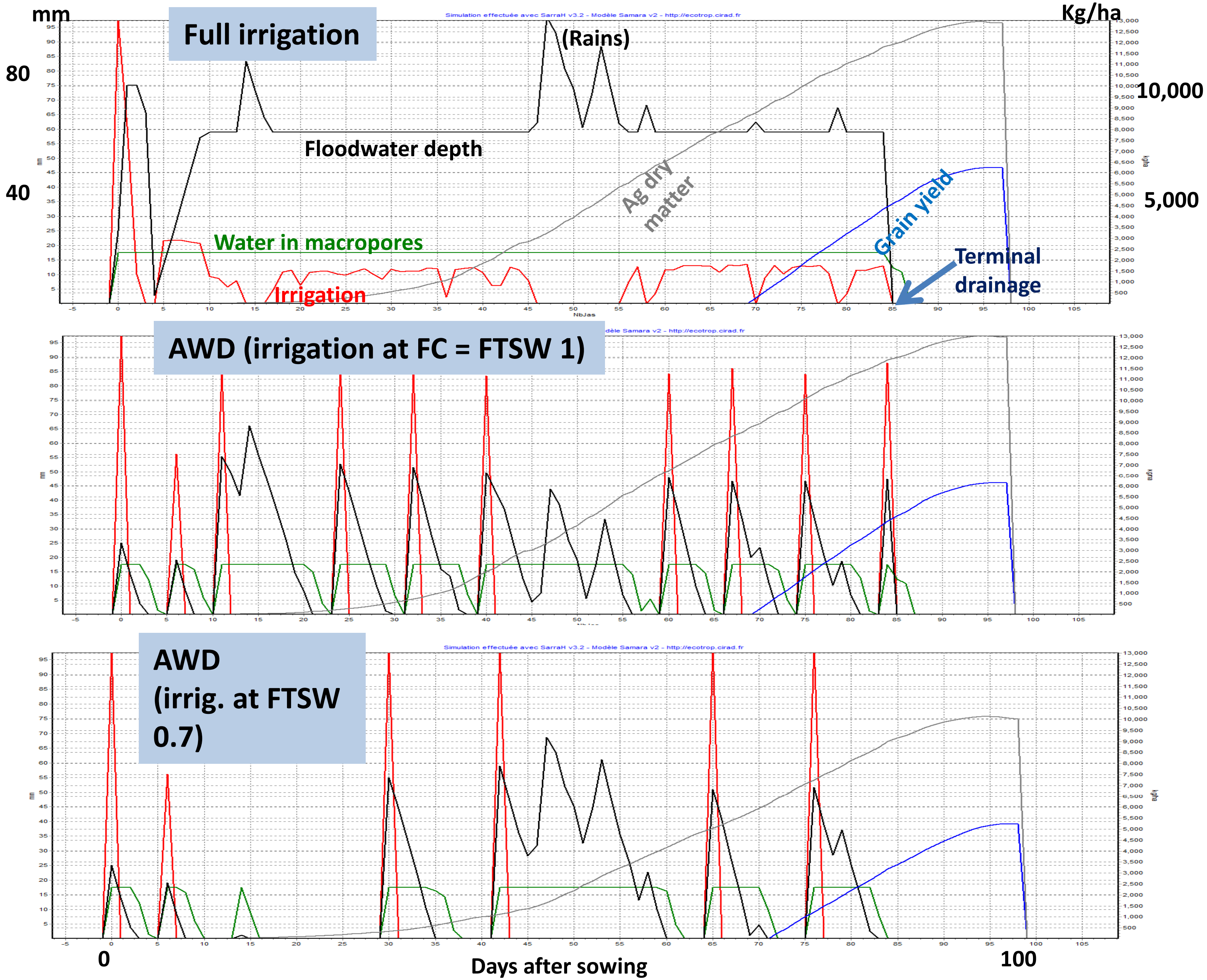


Demonstration of SAMARA:

Water management vs drought effects on yield (3)

bunded-irrigated – the yield benefits of an extra 550 mm water (1220 mm)

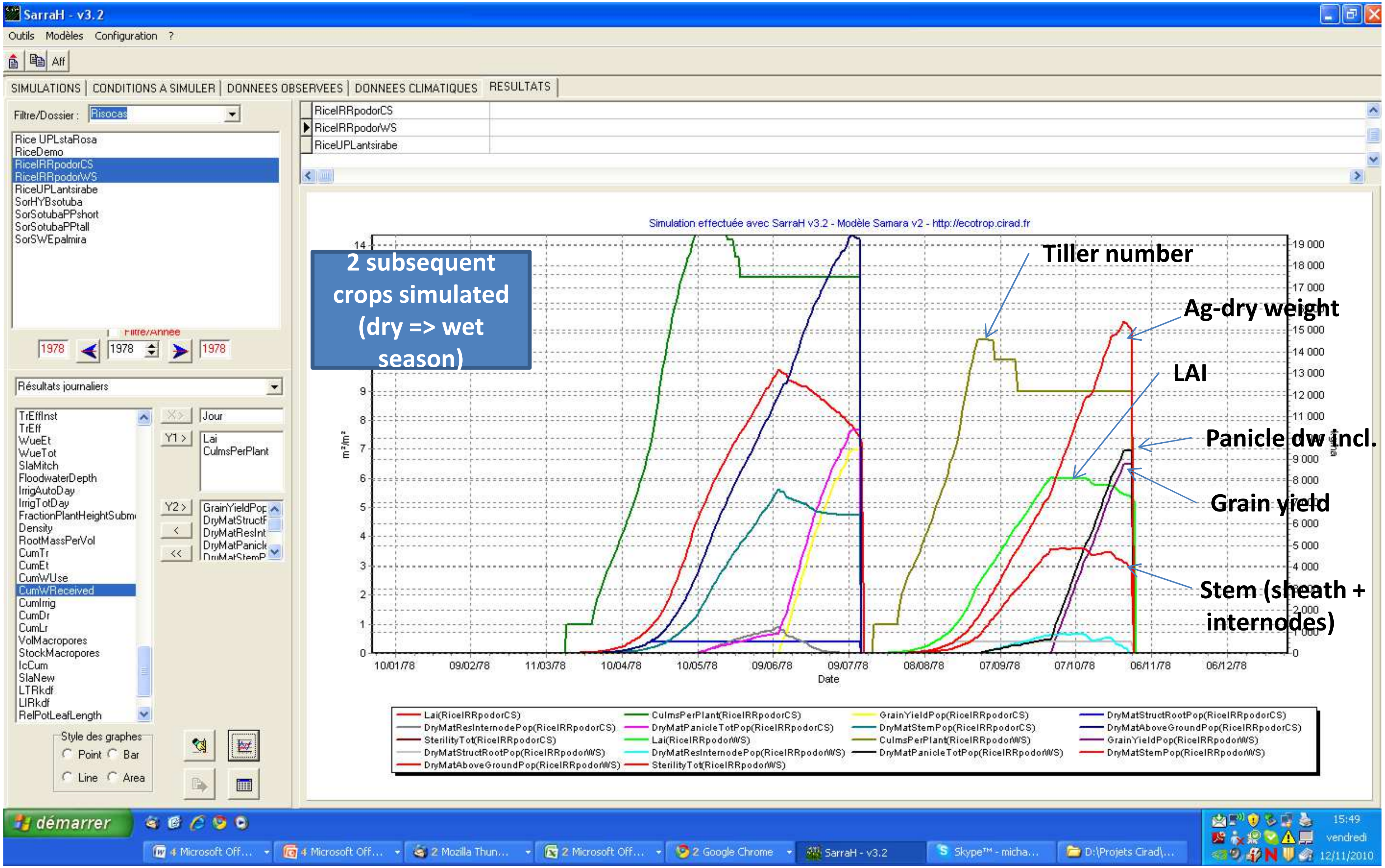




mm
Kg/ha
Full irrigation
(Rains)
80
40
10,000
5,000
Floodwater depth
Ag dry matter
Grain yield
Water in macropores
Irrigation
Terminal drainage
AWD (irrigation at FC = FTSW 1)
AWD (irrig. at FTSW 0.7)
0
Days after sowing
100

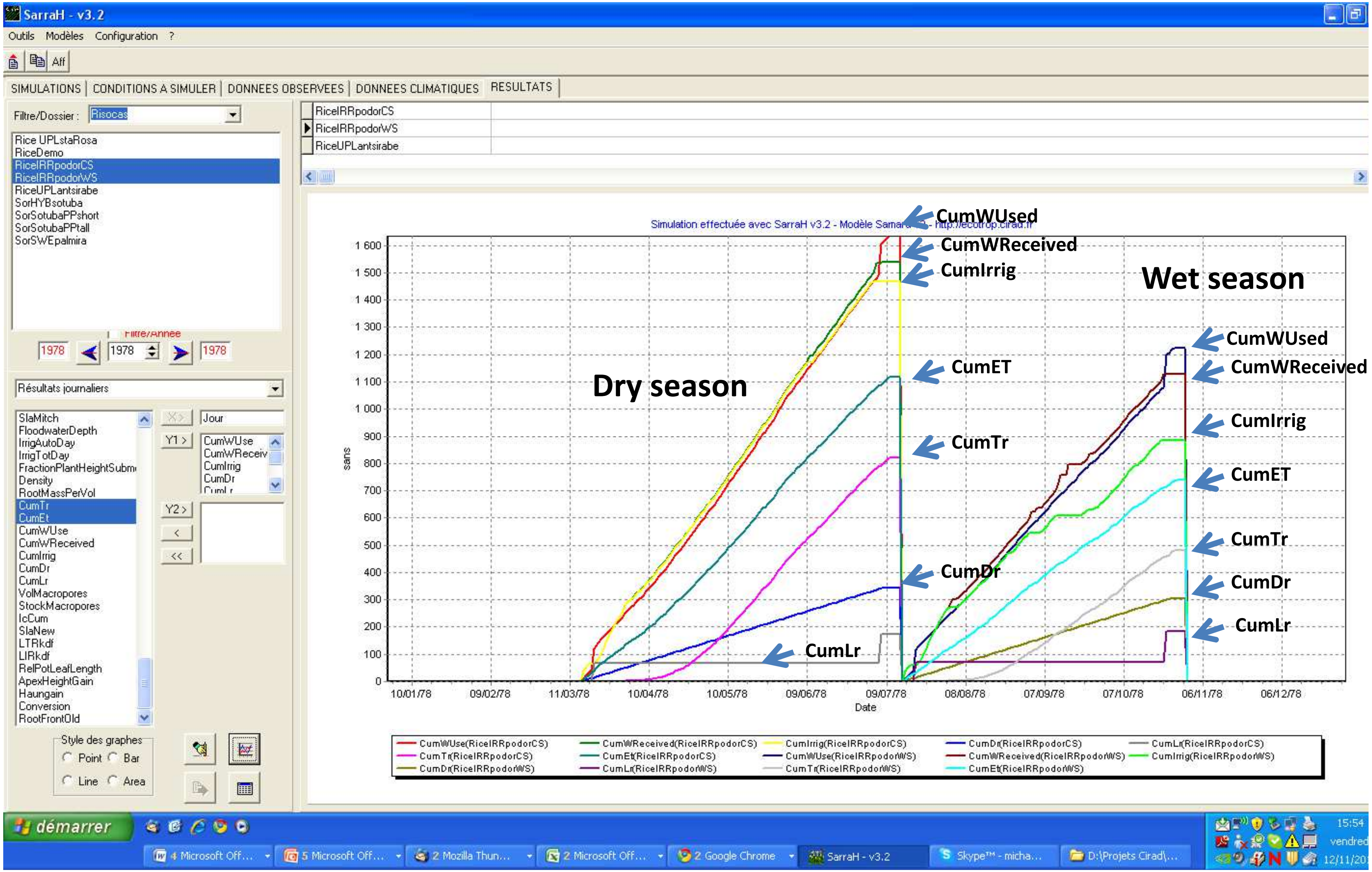
Example of simulation output (irrigated HDS & WS crop in Senegal):

Growth dynamics



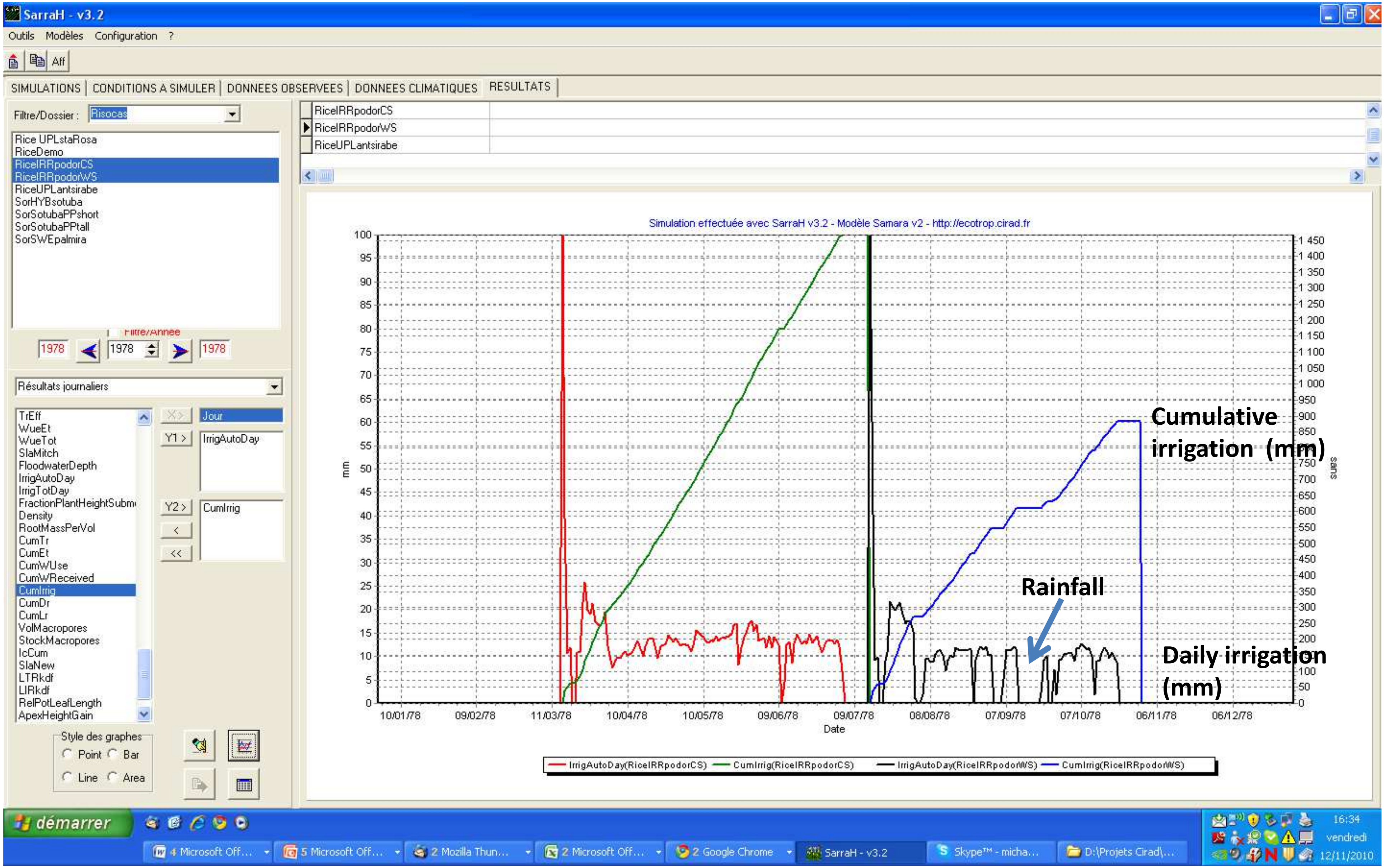
Example of simulation output (irrigated HDS & WS crop in Senegal):

Water use



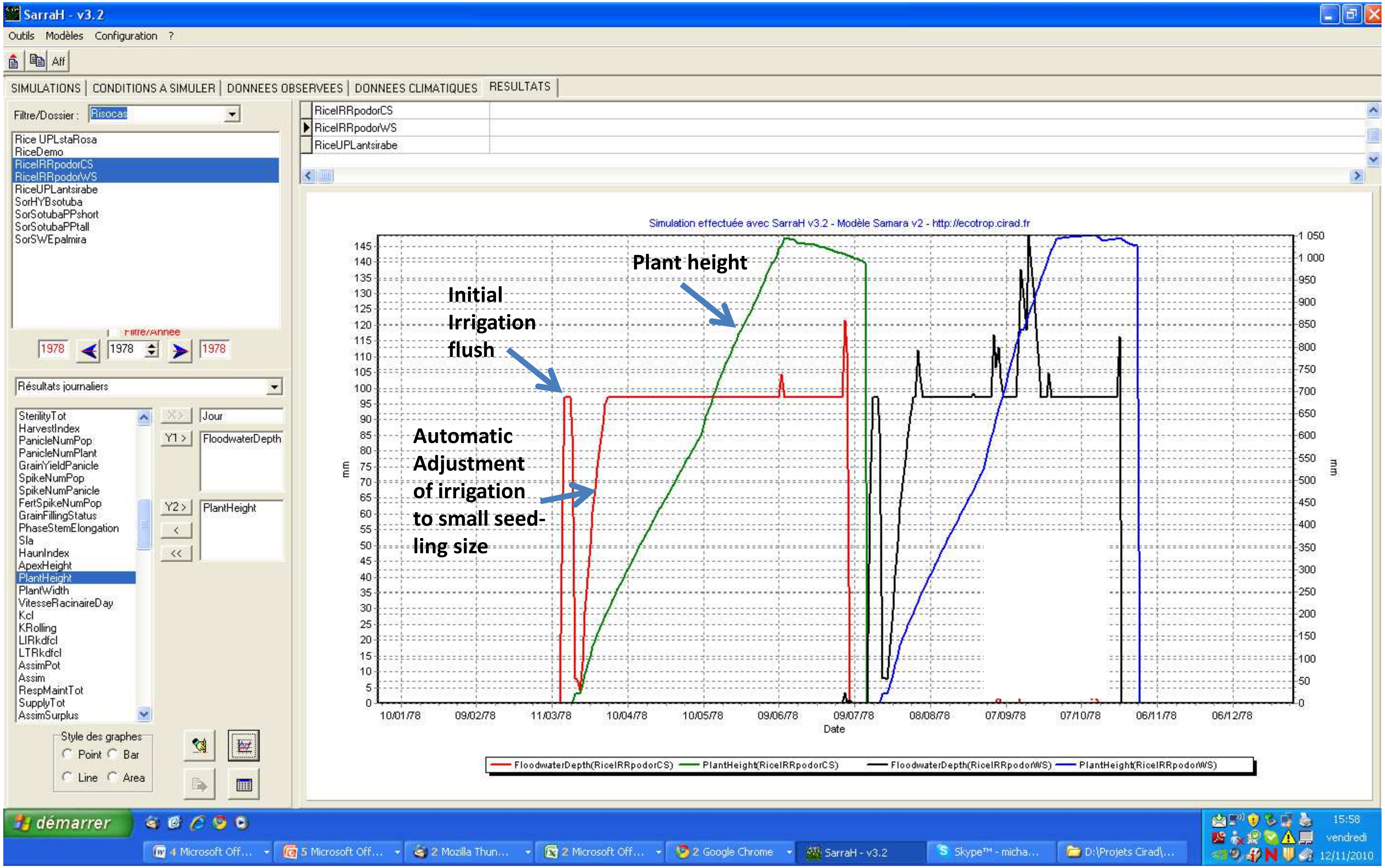
Example of simulation output (irrigated HDS & WS crop in Senegal):

Irrigation requirements



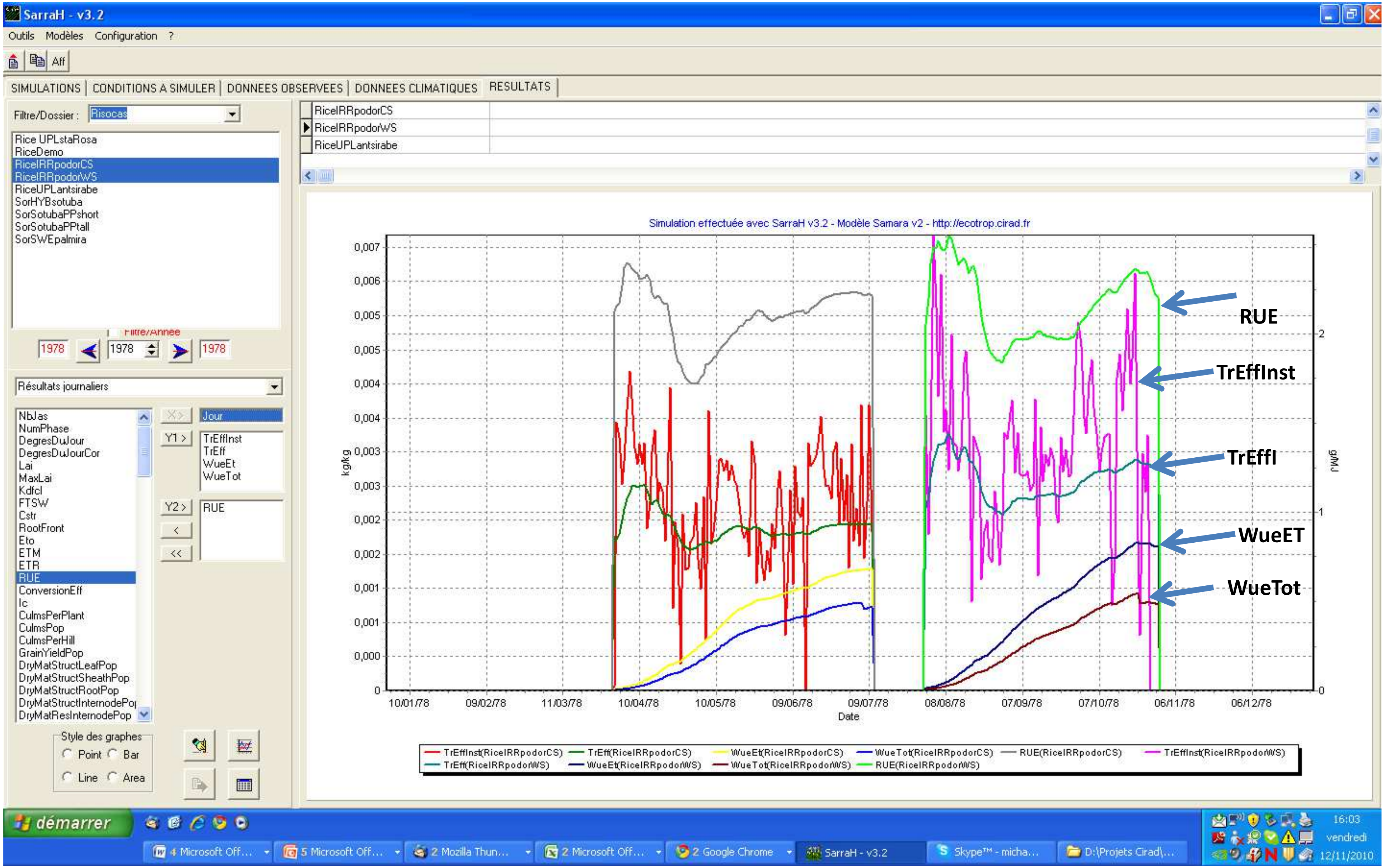
Example of simulation output (irrigated HDS & WS crop in Senegal):

Plant Height & floodwater dynamics



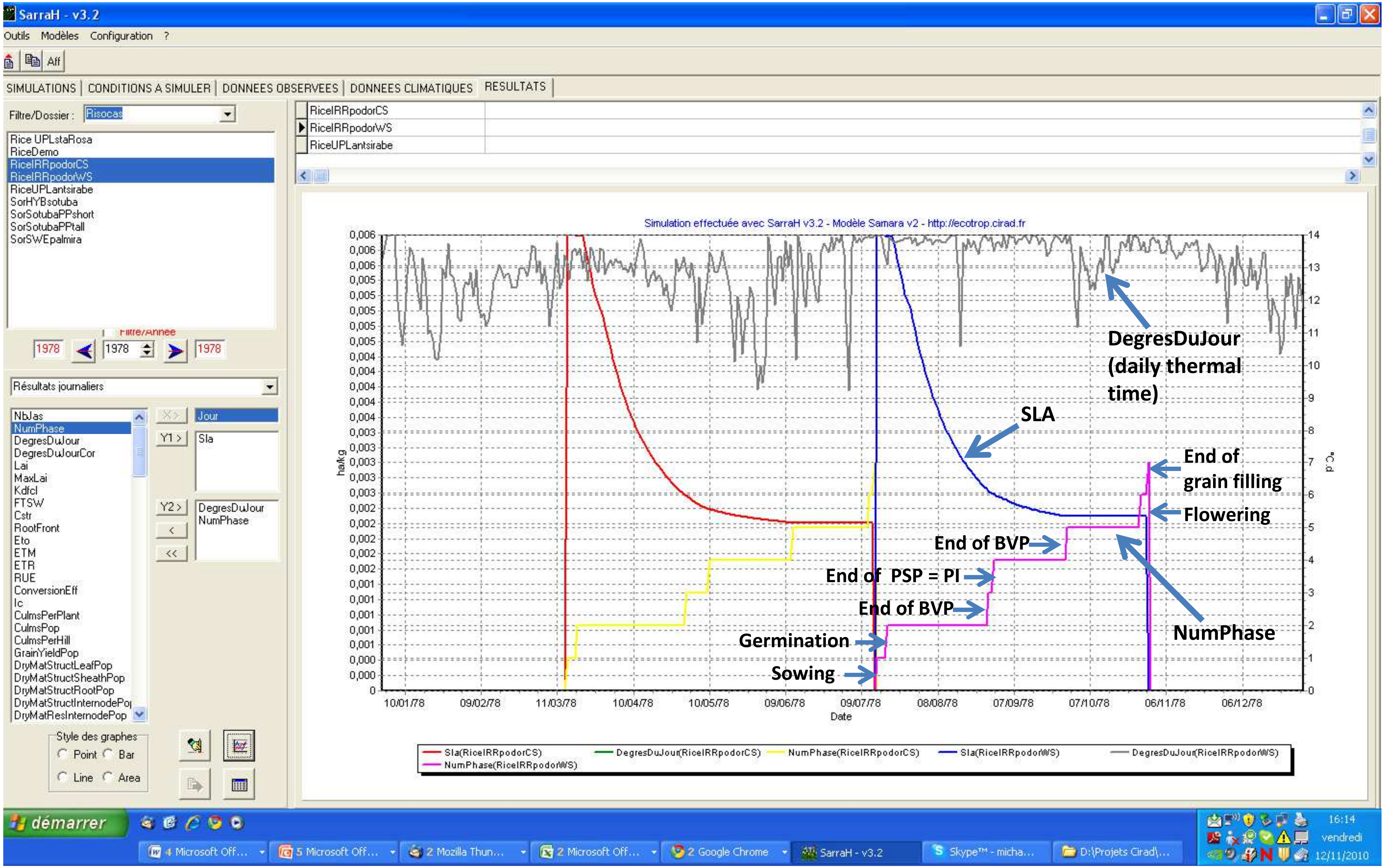
Example of simulation output (irrigated HDS & WS crop in Senegal):

Resource use efficiencies (RUE, TE, WUE)



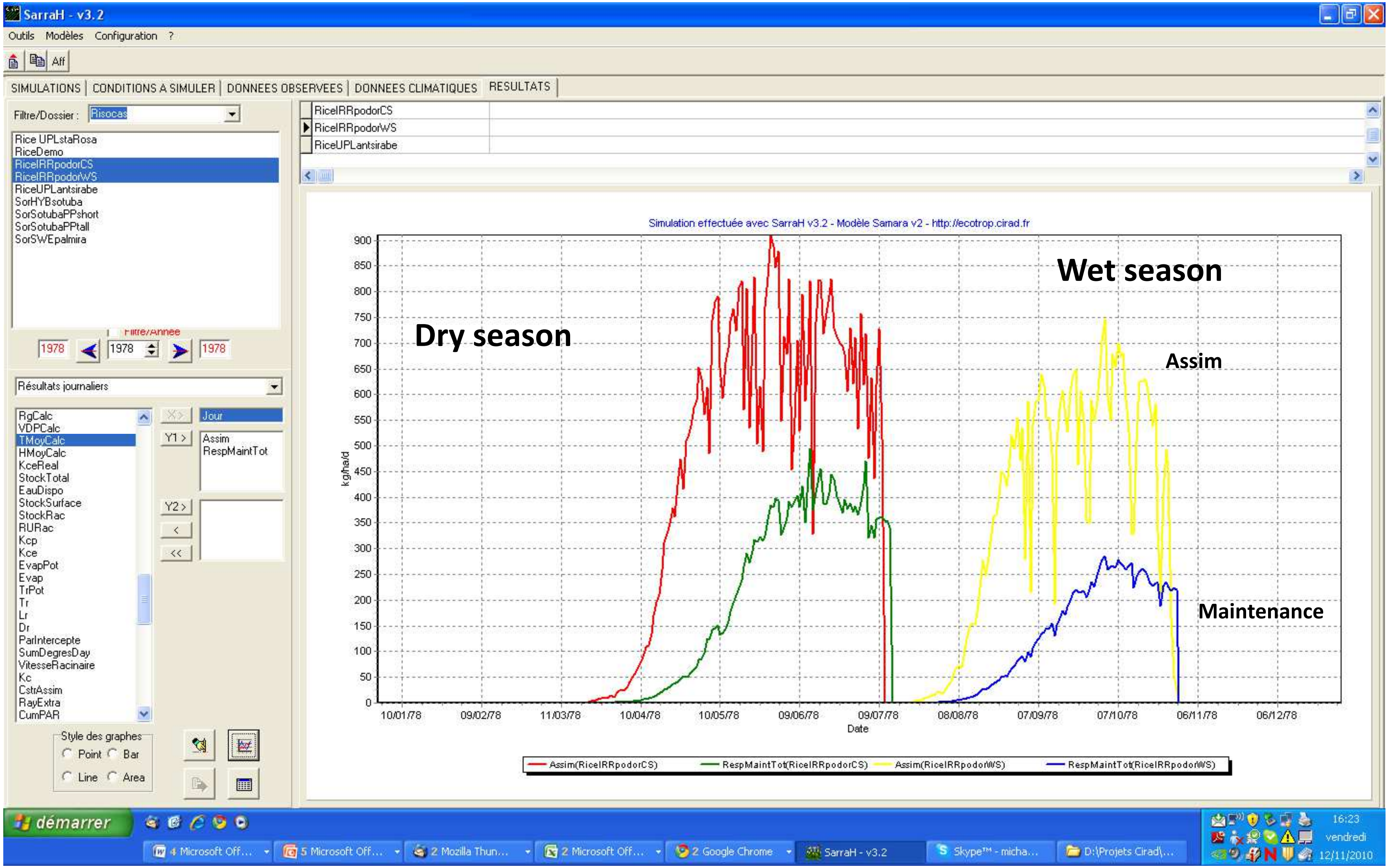
Example of simulation output (irrigated HDS & WS crop in Senegal):

SLA, Developmental phases, degree-days

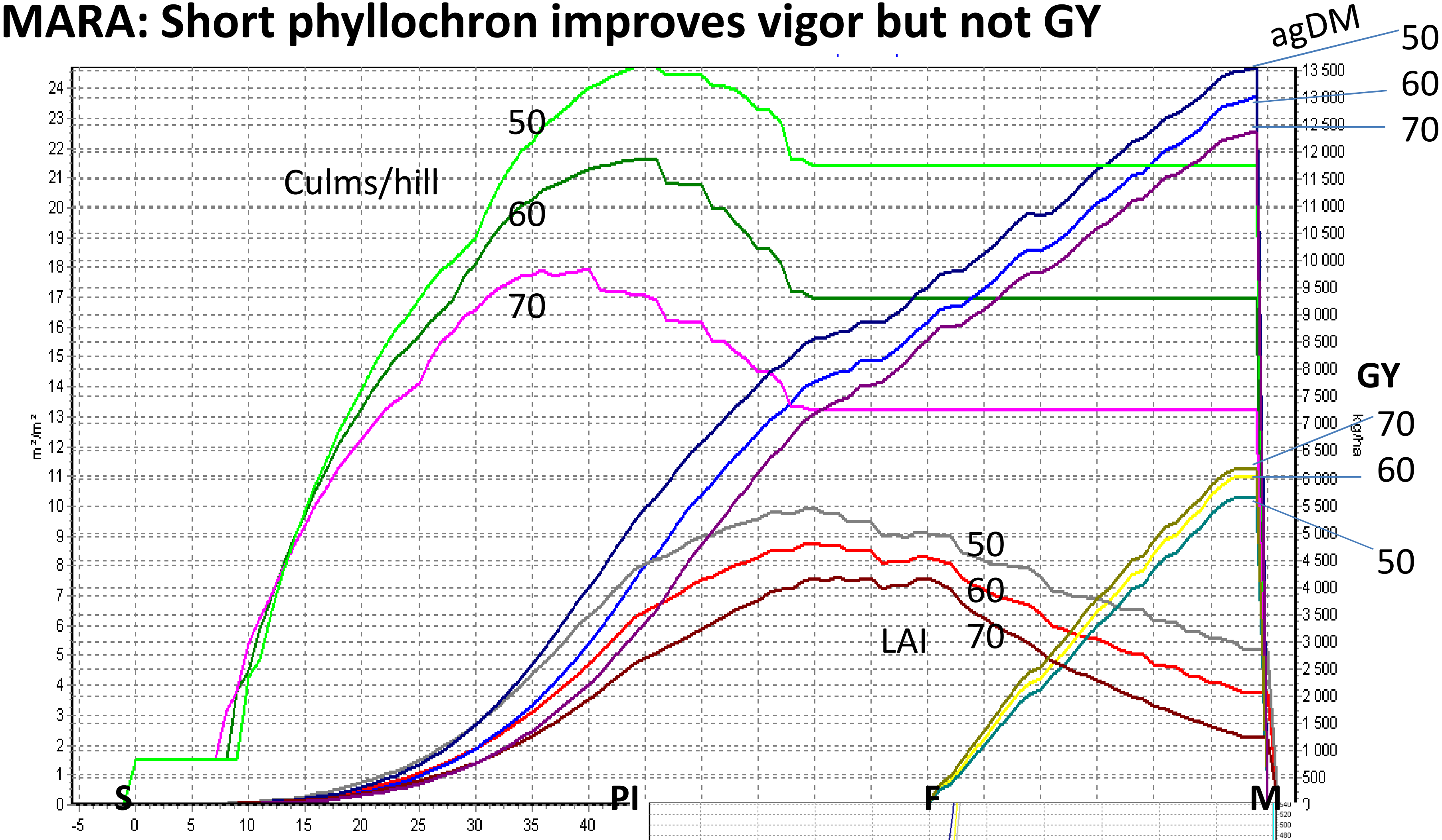


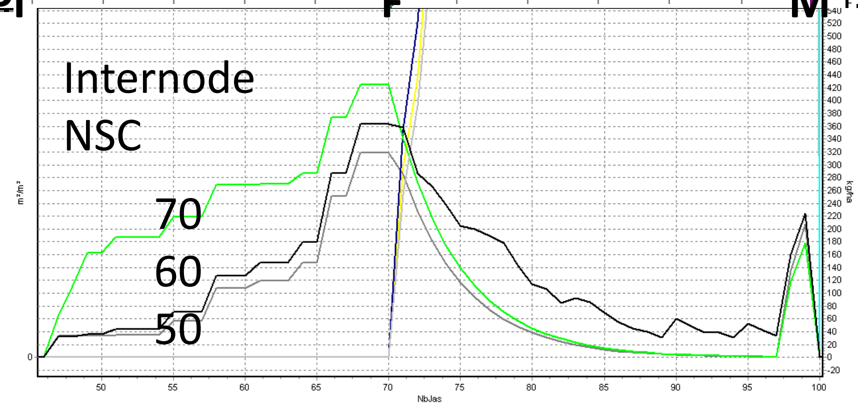
Example of simulation output (irrigated HDS & WS crop in Senegal):

Assimilation and Maintenance respiration



SAMARA: Short phyllochron improves vigor but not GY





SAHEL108 in WS 2010 at AfricaRice, Senegal **(source limited situation)**

Phyllochron 50 °Cd: fast-DR

Phyllochron 60 °Cd: 'normal'

Phyllochron 70 °Cd: slow-DR

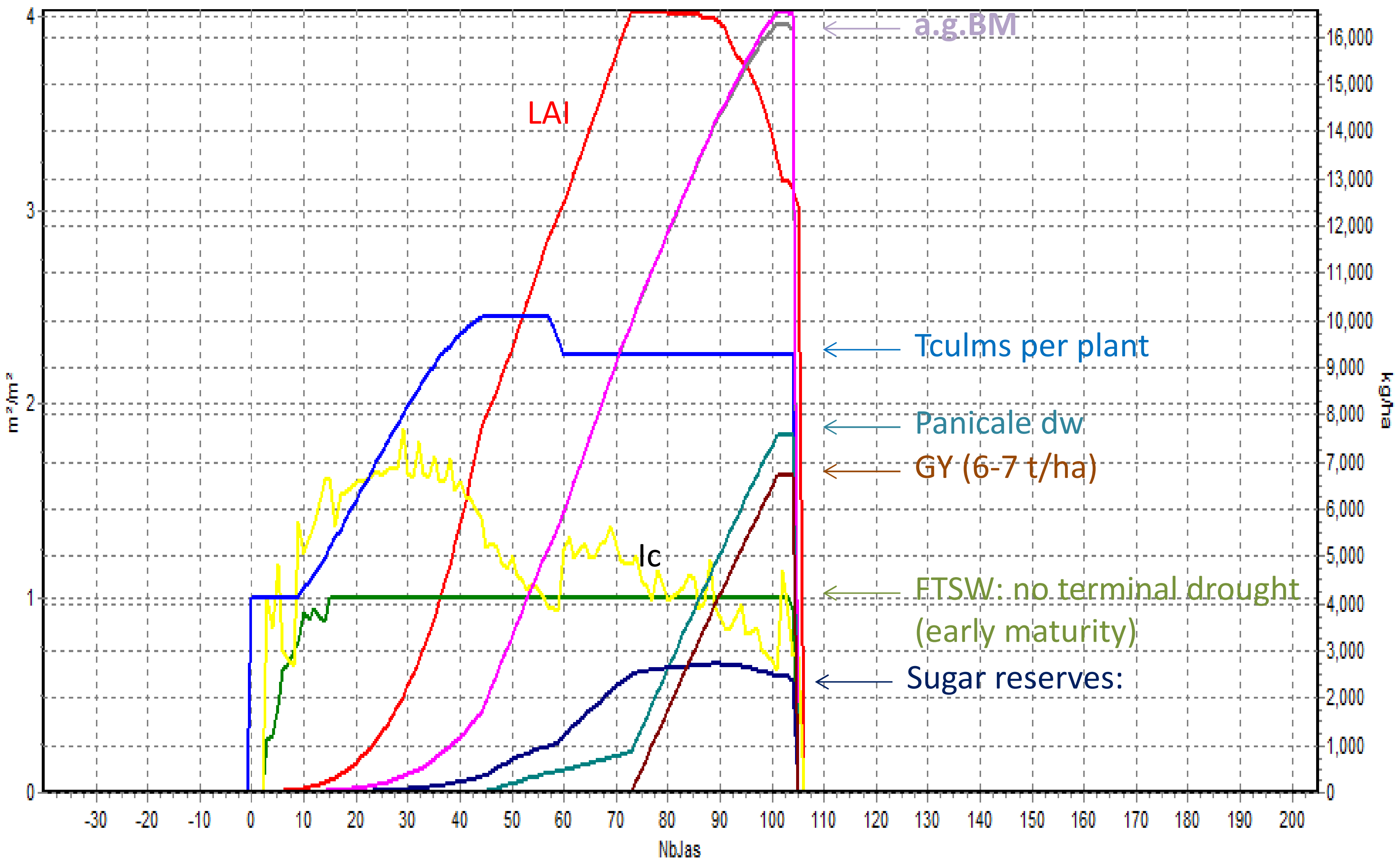
DISCUSSION

Part 4:
Virtual plant type experiments for Sorghum

- Sweet Semi-dwarf (<2m), early maturing
  - Moderate root depth (1.2m)
  - Active sink for CH2) in stems
  - No forced stay-green
- Sweet Tall (ca. 4.5m), PP-sensitive
  - Modified traits:
    - PP-sensitivity (Ppsens = 0.5 instead of 1)
    - Greater pot. Internode length (200 instead of 100 mm)
    - Deeper root system to withstand terminal drought (1500mm)
- Tall, non-sweet
  - Additional trait modified:
    - Stem reserve compartment is spill-over, not active sink (ReserveSinkStrength = 0 instead of 0.1_

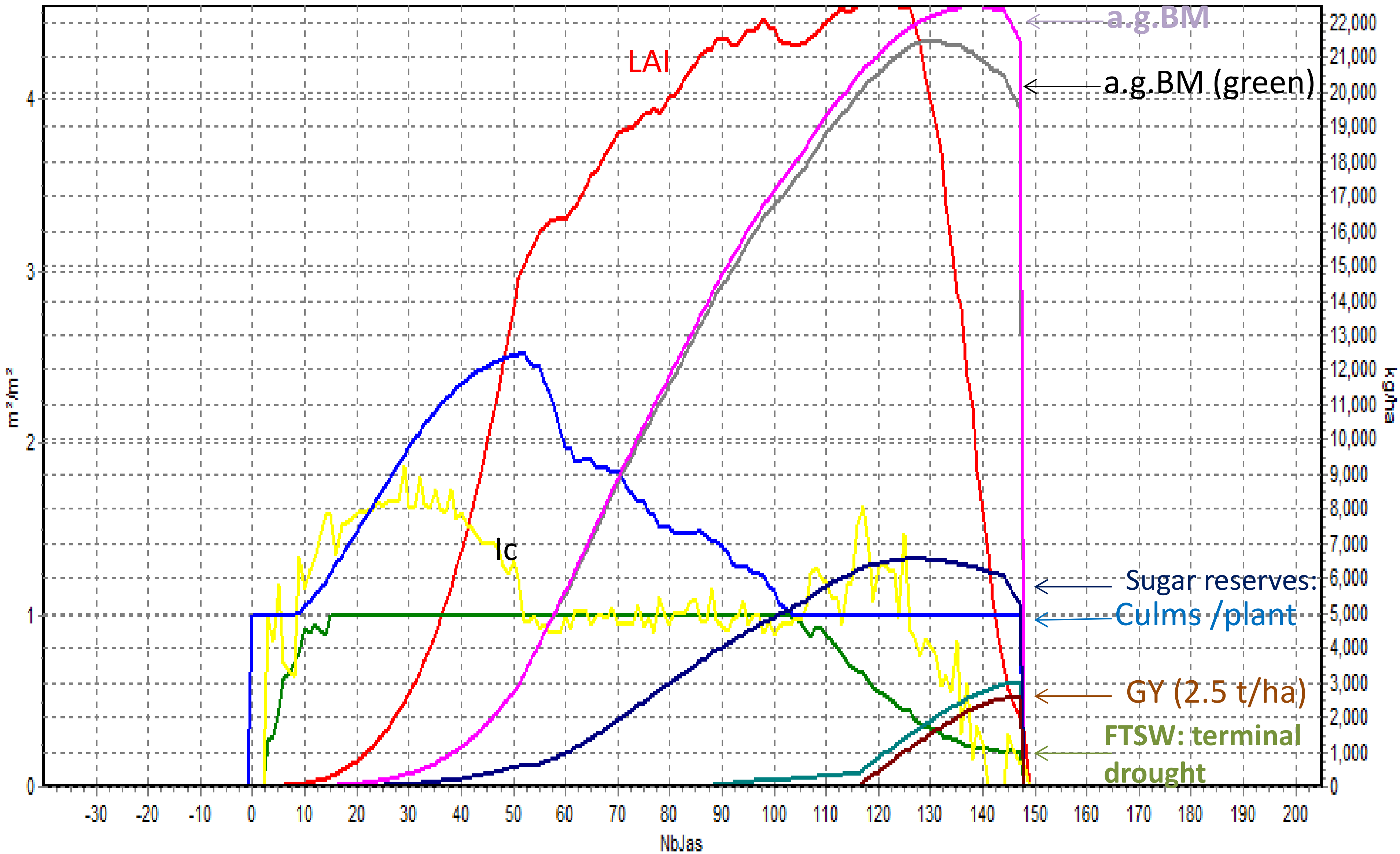
Semidwarf PP-insensitive sweet

- Early maturity (105d)
- High GY & HI
- Ca. 2.5 t/ha sugar reserves at maturity



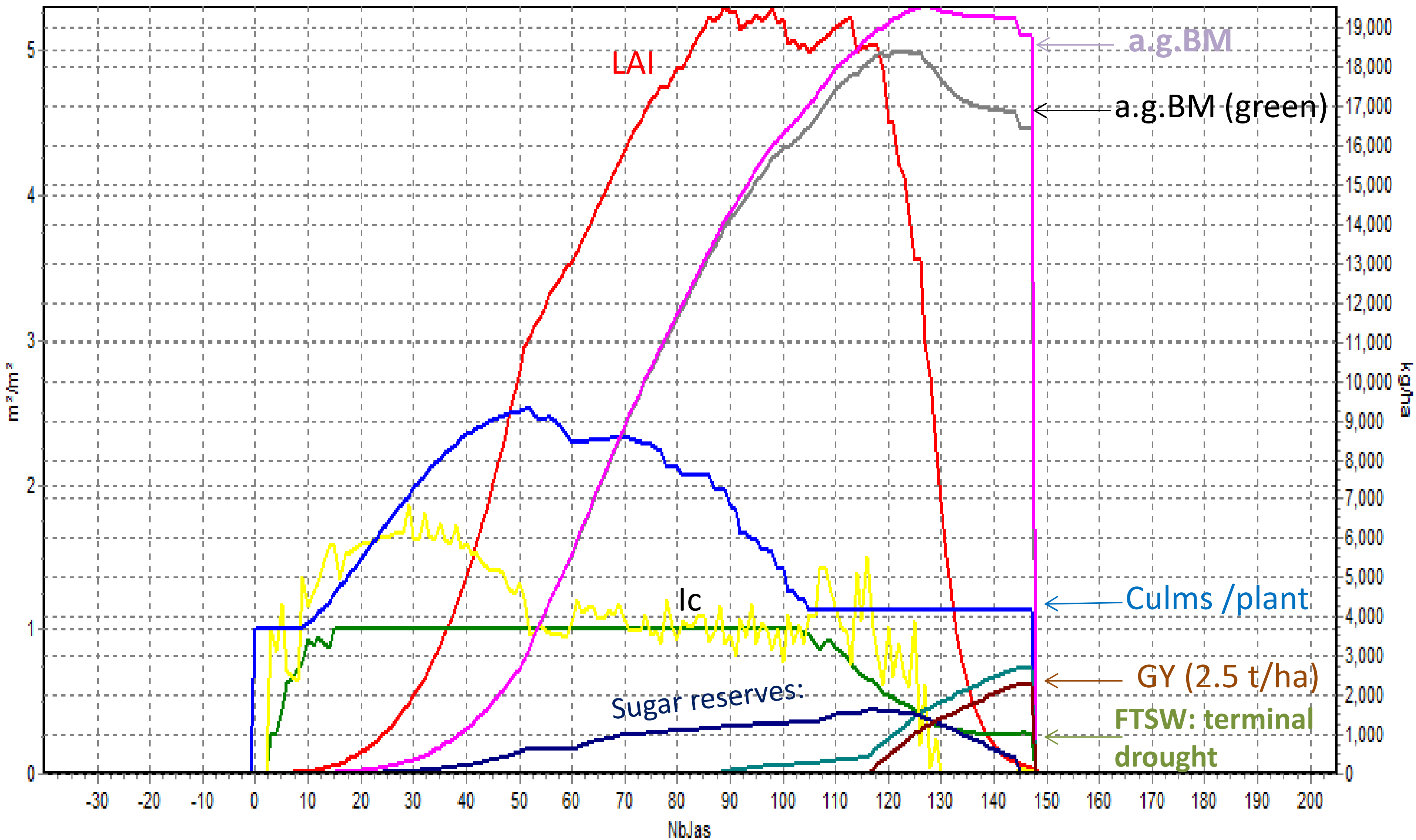
Tall PP-sensitive sweet

- Late maturity (148d)
- Low GY (half of semi-dwarf)
- High sugar reserves (twice that of semi-dwarf)
- Strong terminal senescence & tiller mortality



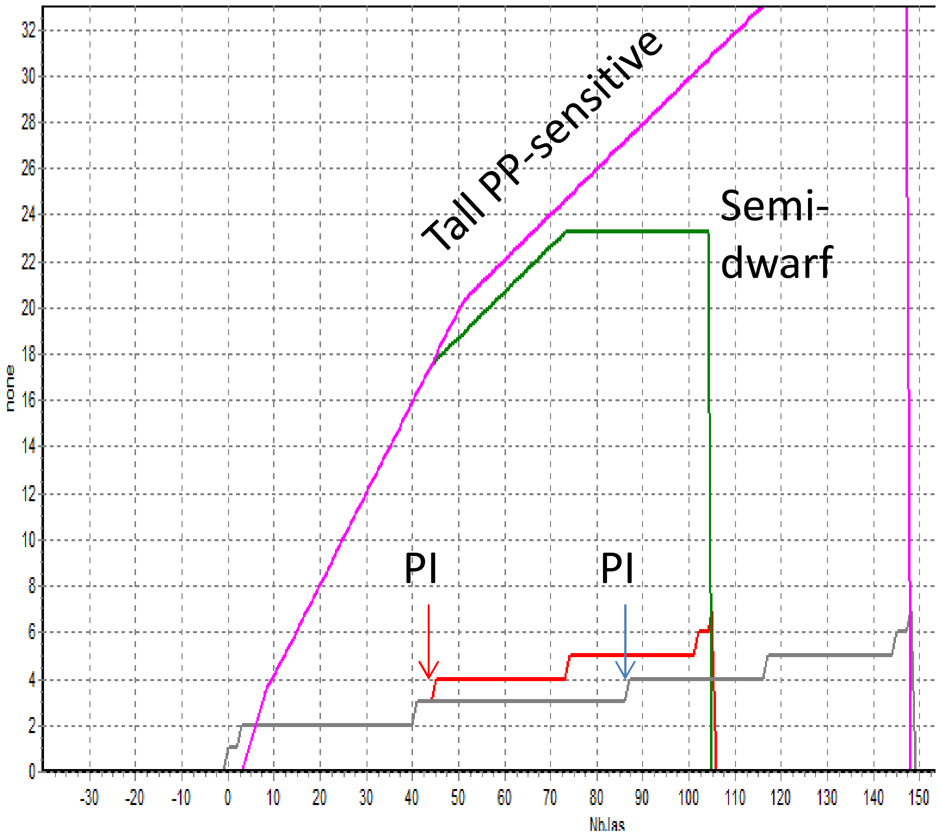
Tall PP-sensitive non-sweet

- Late maturity (148d)
- Low GY (<half of semi-dwarf)
- Allsugar reserves consumed for grain filling
- Strong terminal senescence & tiller mortality

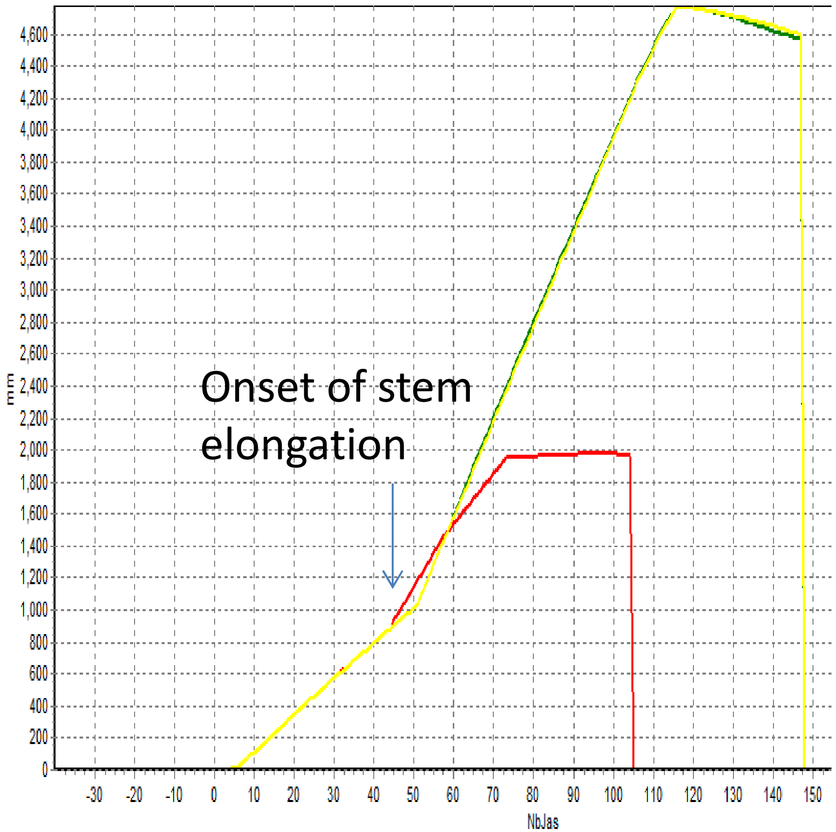


Phenology:

- Leaf number on main culm
- Duration of developmentales

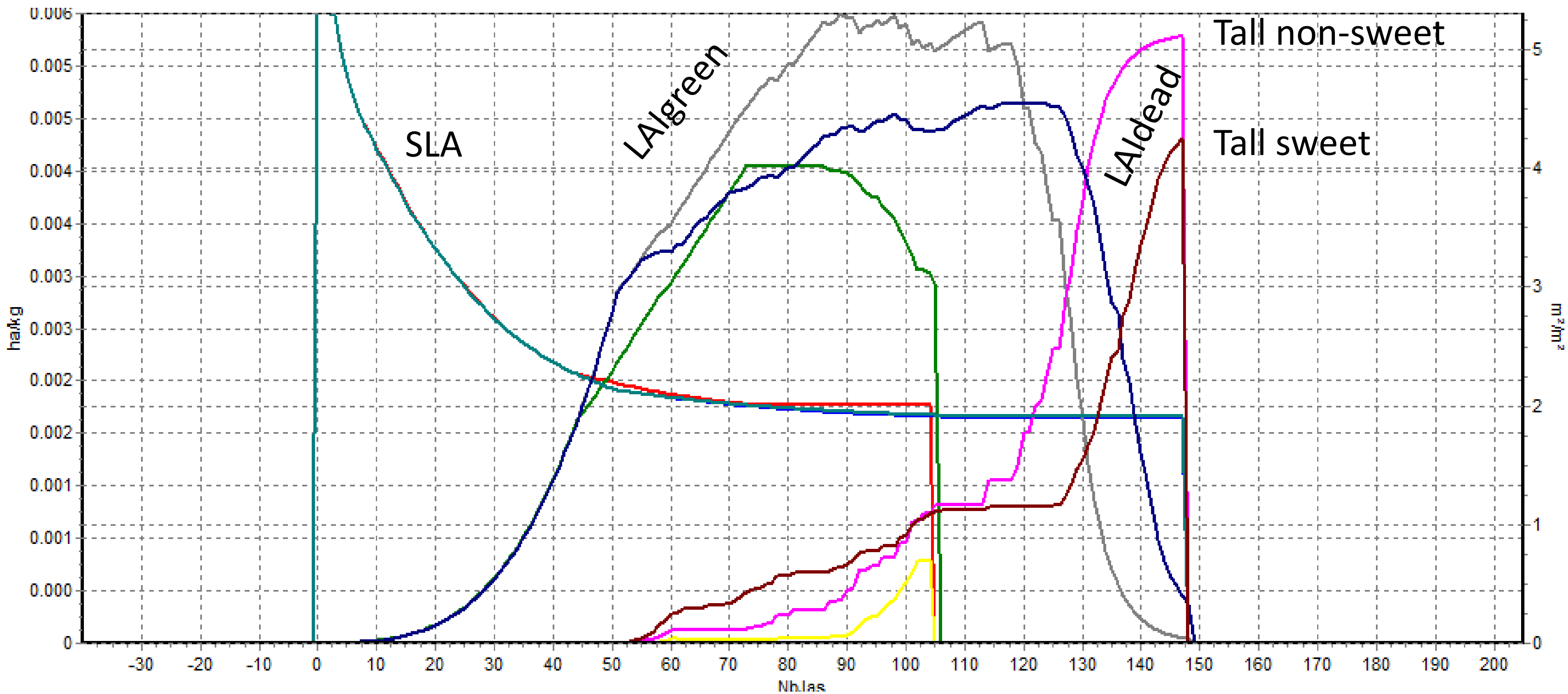


Plant Height (Canopy height)



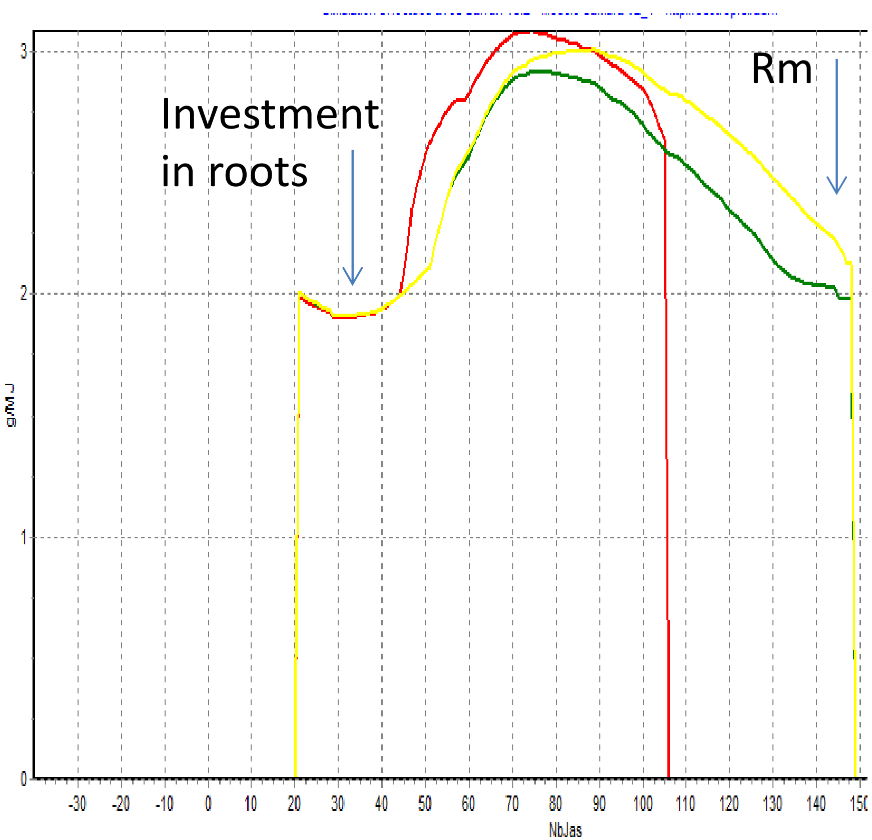
Leaf area dynamics and senescence

- ➢Tallness+PP-sensitivity increases LAI
- ➢Tallness + PP-sensitivity increases terminal senescence
- ➢Sweetness reduces LAI
- ➢Sweetness reduces terminal senescence (“stay-green”)

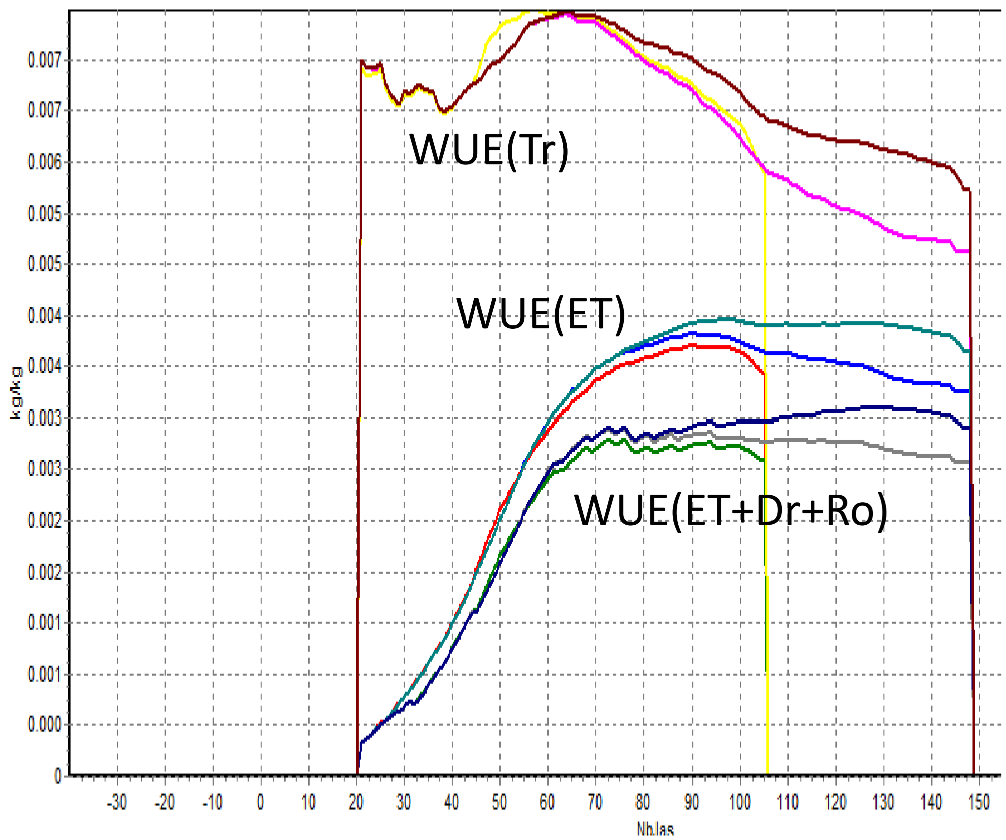


Resource use efficiencies

RUE (a.g.BM/PARi)

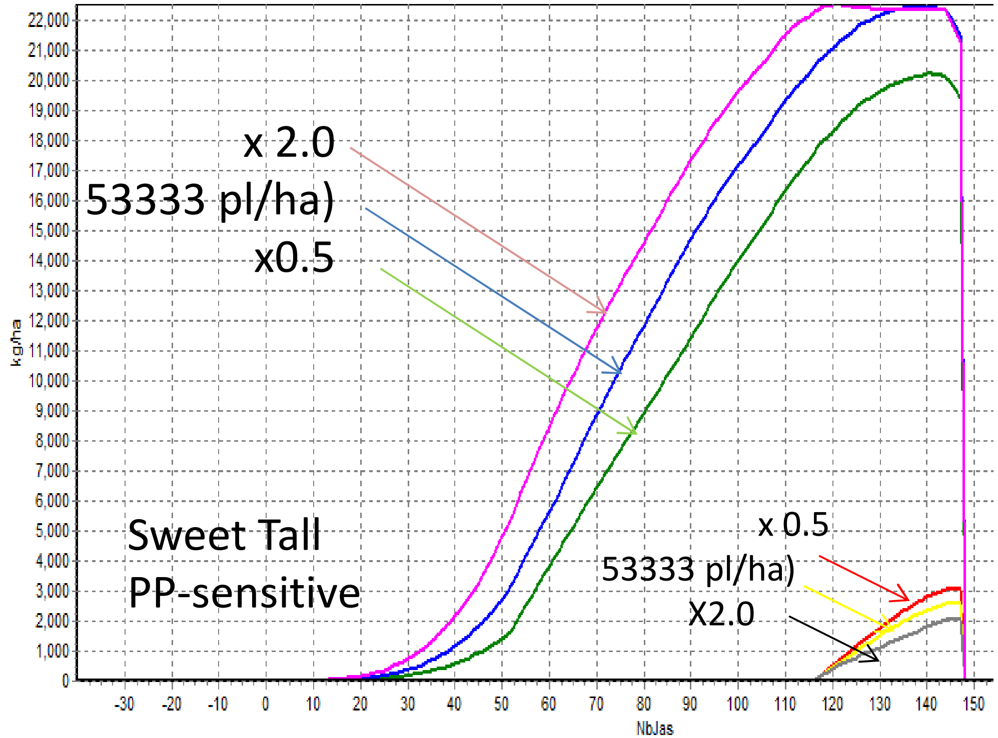


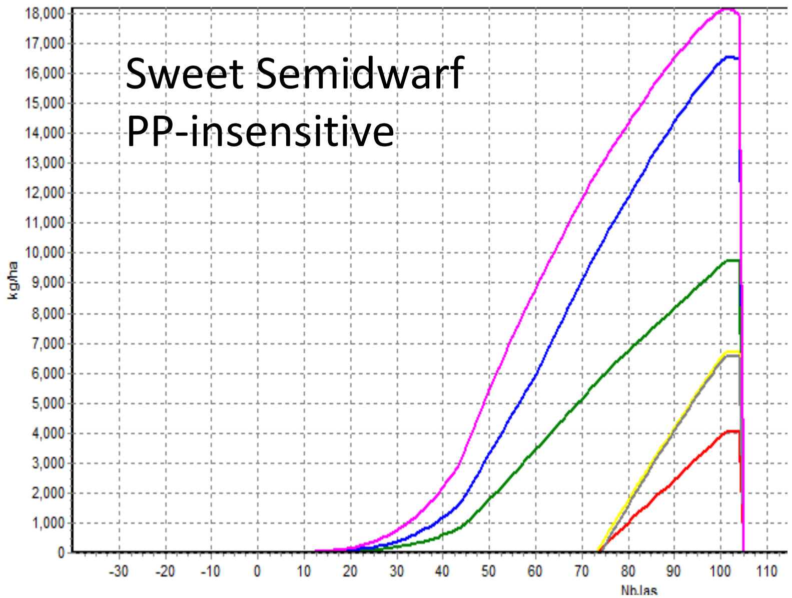
WUE (a.g.BM/H2O lost)

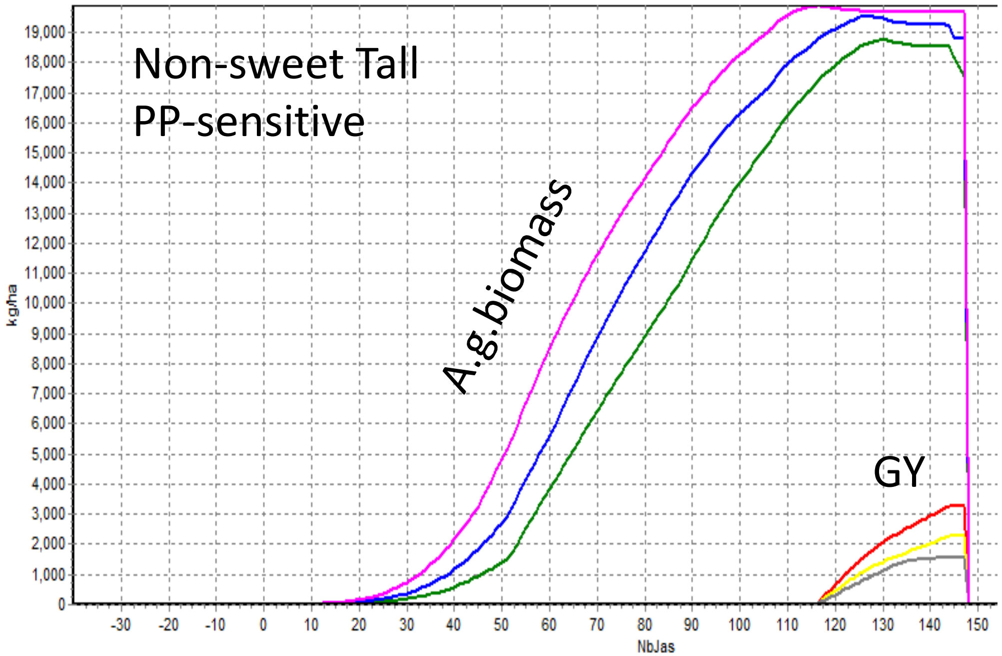


VirtualPopulation Density Vs. Plant Type Experiment

- High pop increases biomass particularly in “modern” type
- High pop increases GY in modern type but decreases GY in traditional types
- Sweetness stabilizes GY across pop densities







DISCUSSION