Crop growth modeling and OBT

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Based partially on Madrid lectures
(A Melintescu May 2009), unpublished

OBT production in the daytime

- In the simplest approach, we ignore details on respiration and focus on net photosynthesis rate (net of respiration).
- Assume that we know the net assimilation rate of CO_2 as kg CO_2 per unit time and unit surface of crop, Pc.
- One mol of CO_2 and one mol of H_2O gives one mol of photosinthate (the initial organic matter produced), with a generic formula CH_2O.
- The rate of water assimilation in non-exchangeable matter (bound with C) can be obtained using stoichiometric relations (molar mass of CO_2 is 44, molar mass of H_2O is 18) and is 0.41 P_C.
- Consider tritium, as tritiated water → due to higher mass, all reactions rates will be slower.
- Energy of radioactive disintegration (average 5.8 keV) will be used partially for the activation energy of many biochemical reactions.
- Plant varies in their molecular constituent → the balance of slow down and acceleration of biochemical reaction reflects in a variable fractionation (discrimination) ratio, FD (formation of OBT/formation of OBH), with an average of 0.5 and range between 0.45 and 0.55.

- With a known HTO concentration in leaves C_{HTO}, we can assess the formation rate of OBT in light conditions:

  $P_{OBT}=FD*0.41*P_c* C_{HTO}$ (Bq/h/m^2) → we must use the HTO in leaves, because leaves are the site of photosynthesis

- In the same conditions of time and space, the net dry matter production is:

  $P_D= 30/44\ P_c$

- Total organic tritium is higher, because about 22 % is non-exchangeable:

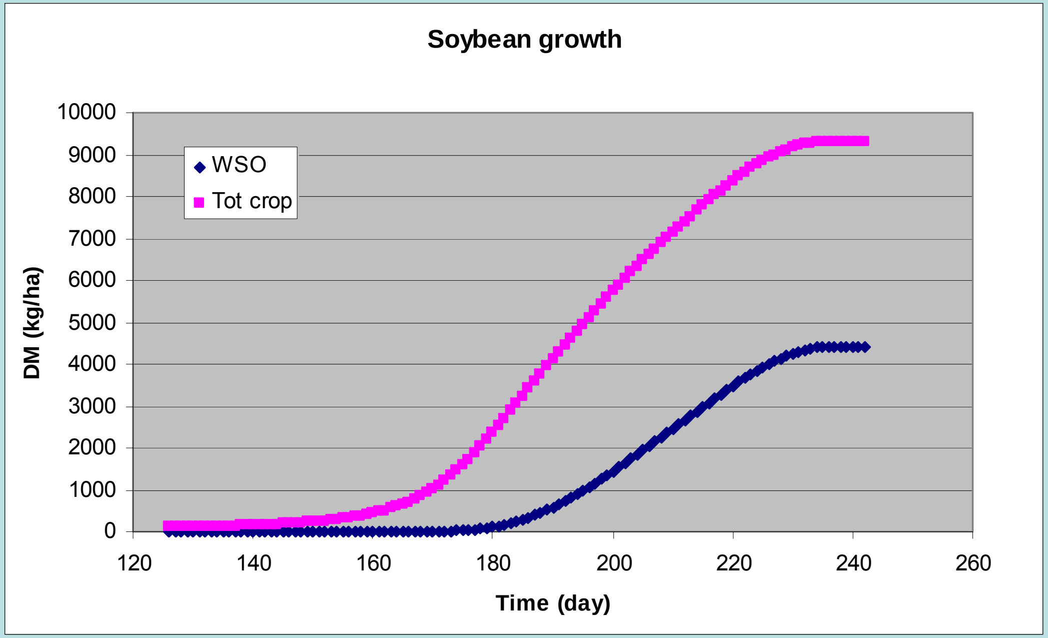
  $P_{OBT}=0.88*P_{OT}$

- In practice, the leaf HTO concentration varies in time → Pc varies, also (with zero in the night time);
- Consider the start of air contamination with HTO, t_0, and a subsequent moment, t, later in time; at start, the net dry matter of the crop is Y_0 and at time t is:

$$Y=Y_0+\int_{t0}^{t} 30/44 P_c(\tau)d\tau$$

(kg dm/m^2)

P_c-net assimilation rate (net of respiration)



- If we ignore night OBT production we can derive a similar equation of OBT for the whole crop.
- The evolution of OBT concentration C_{OBT} (Bq/kg dm) is of interest in food chain modelling.
- First, we consider the concentration in whole crop (including roots); we have:

$$\frac{dC_{OBT}}{dt} = (\frac{1}{Y}) * P_{OBT} - (\frac{C_{OBT}}{Y}) * P_D$$

where: $A_{OBT} = C_{OBT} * Y$, $dA/dt = Y * dC/dt + C * dY/dt$, $P_{OBT} = Y * dC/dt + C * P_D$

$$\frac{dC_{OBT}}{dt} = (\frac{1}{Y}) * 0.41 * FD * P_c * C_{HTO} - (\frac{C_{OBT}}{Y}) * 0.68 * P_c$$

$$\frac{dC_{OBT}}{dt} = (\frac{1}{Y}) * 0.6 * FD * P_D * C_{HTO} - (\frac{C_{OBT}}{Y}) * P_D$$

- Y and C_{HTO} are function of time
- We demonstrate the close relationship between OBT and C
- P_D/Y is Relative Growth Rate (RGR) - time dependent

$$\frac{dC_{OBT}}{dt} = (\frac{P_D}{Y}) * [0.6 * FD * C_{HTO} - C_{OBT}]$$

$$\frac{dOBT_{plant}(t)}{dt} = -g_r OBT_{plant}(t) + g_r TFWT(t)$$

- C_{HTO} dynamics depends on air concentration AND canopy resistance and this last one depends on P_c

OBT production in night time

- The formation of OBT in the dark is only partly understood because the plant physiological processes implied cannot be quantitatively assessed.
- Possible processes:
  - oxidative respiratory pathways;
  - tricarboxilic acid cycle;
  - isomerisation and hydrolytic splitting reactions
- Various organic molecules are formed in the plant basal metabolism (Thornley, 1990) with addition of water and without the need of light. For example the following organic acids:

  glucose +H_2O+NADPH => <u>citrate</u> + 4 NADH+2 ATP

  glucose +H_2O+NADPH => <u>succinate</u> +2CO_2+6 NADH+2 ATP+GTP

  glucose +H_2O+NADPH => <u>fumarate</u> +2 CO_2 +7 NADH+2 ATP

  0.5 glucose + H_2O => <u>malonate</u> +2 NADH+ATP

  0.6 glucose +0.5 O2 +2H_2O => <u>oxalate</u> +2 CO_2 +4 NADH +ATP

and aminoacids:

  0.5 glucose +NH_3 +H_2O => <u>glycine</u> +CO_2+2 NADDH + NADPH

- Organic acids and glycine add up to 4-8 % of the plant dry mass and we expect that 4-8 % of the new dry matter produced in photosynthesis enters in reactions producing OBT.
- Between anthesis and maturity about 9 g of dry matter is produced per day. Thus about 0.03 g/h is treated by the above mentioned reactions.
- OBT production in night recycles previously day produced photosinthate
- Night OBT production is given by:

$$P_{OBT}=FD*0.41*K*[\text{average prev day } P_c]*\ C_{HTO}$$

where K – coefficient for OBT night production (still unclear → the need for more experimental work and biochemical understanding)

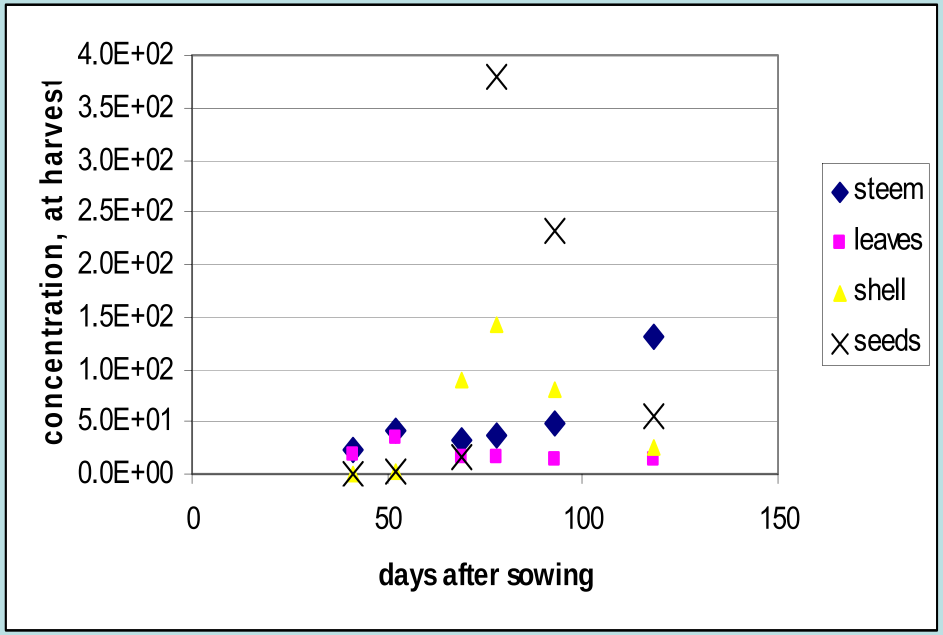
For cereals

$P_{OBT}=FD*0.41*0.012*_{(lai/maxlai)*}C_{HTO}$

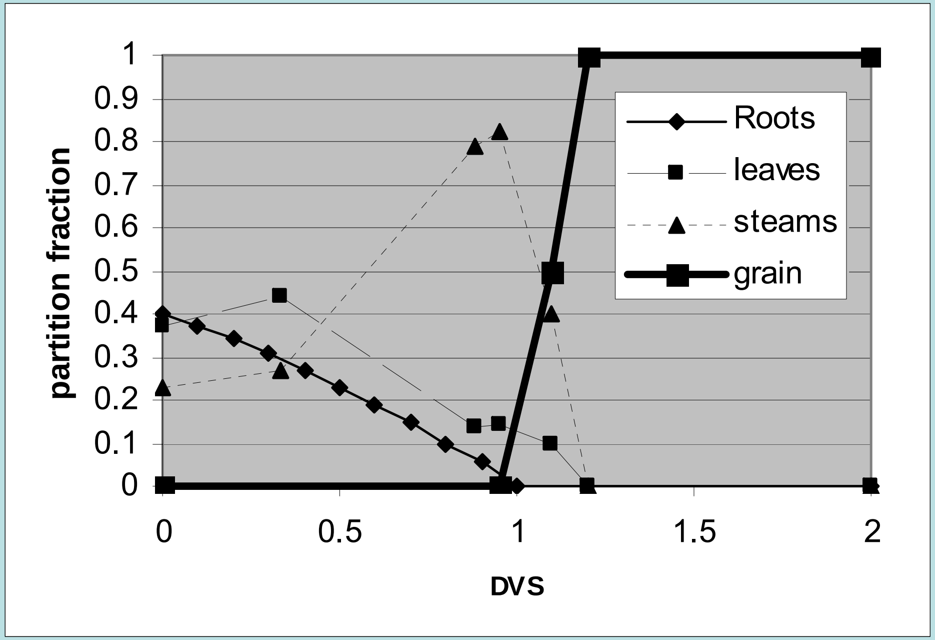
- night production, assumption ;: 2 weeks after anthesis the rate is 5 times less full sun it decreases after as LAI (becoase is linked with basal metabolism) preliminary rate 0.2 * 0.012 kg CO2/m2h
- cdandec2000 decrease 2 times

OBT concentration in edible plant parts (net of respiration)

- At each stage of plant development, the newly formatted net dry matter will be differently distributed to various plant parts → initial uptake and time evolution depends on plant part.
- We must know these partition factors in order to assess OBT in the edible plant part.
- Even for leafy vegetables and pasture, we must know the partition to root.



OBT concentration for soybean at harvest for 1 hour air contamination at various plant development stages



Partition fraction of newly produced dry matter to roots, leaves, stems and edible grains as function of development stage (0=emergency; 1= flowering; 2= full maturity) for maize cultivar F320 (South Romania)

- PARTITION FACTORS DEPEND ON CULTIVAR (GENOTYPE), not only on PLANT
- P_c depends on:
  - crop type;
  - development stage (DVS);
  - leaf area index (LAI);
  - temperature;
  - light;
  - water stress (air vapour deficit and soil water)
- We must understand the plant growth
- Development stages:

  0 -1 - emergence to anthesis (flowering) → generative stage
  1 -2 - anthesis to maturity → reproductive stage
  } both can be finer divided
- Evolution of plant development depends on Thermal time = sum of air temperature over a basis
- At least, we must know crop specific accumulated thermal time until anthesis and maturity → we can define the increasing of development stage each day → partition factors → increase in leaf mass → green leaves → LAI
- Knowing the ambient data on temperature, light, vapour pressure and soil water, we can determine P_c, P_D, P_{OBT}

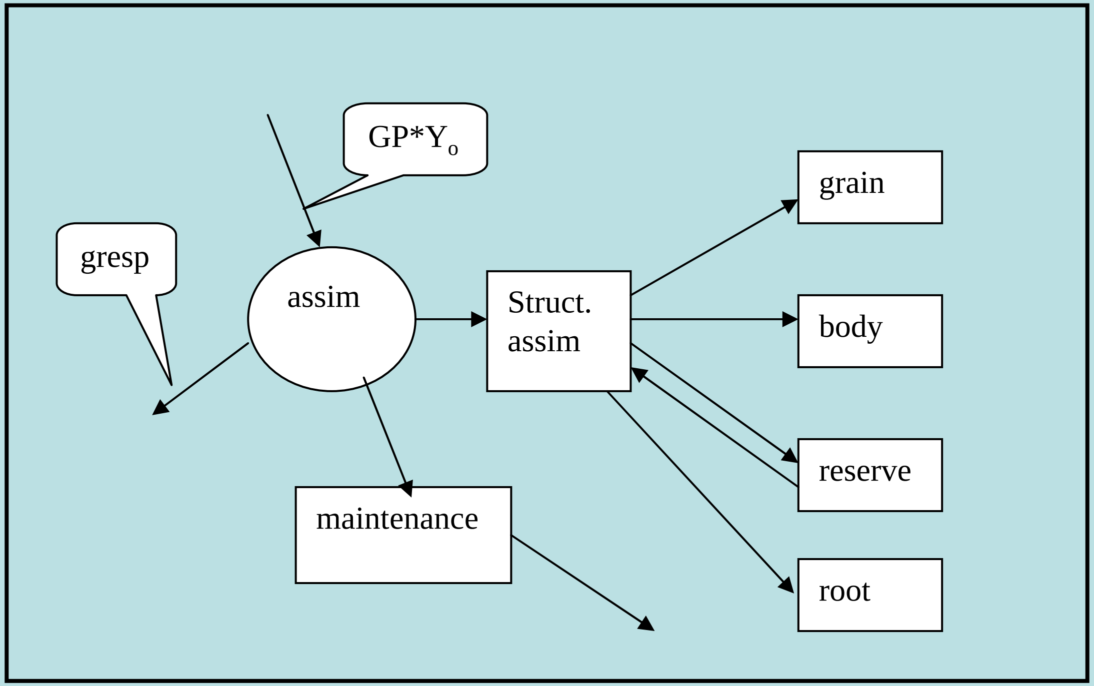
<u>OBT concentration in plant part i</u>

- Partition fraction PF_i (DVS) → $PF_i(t)$

  $P_{D,i}=P_D*PF_i$

  $P_{OBT,i}= P_{OBT}* PF_i$

$$\frac{dC_{OBT,i}}{dt} = (\frac{1}{Y_i}) * P_{OBT,i} - (\frac{C_{OBT,i}}{Y_i}) * P_{D,i}$$


GP*Yo
gresp
assim
Struct.
assim
grain
body
reserve
root
maintenance