Modelo Rinde y Riesgo Cultivos

Understanding the Model

Summary

They want to obtain the accumulated biomass per surface area over a cycle b_T, as a function of variables describing:

- soil
- crop management
- daily climate
- crop
  To this end, they predict (and then add) the daily change in biomass per surface area b_i at day i. Thus, b_i can be interpreted as the biomass generated per surface area at day i.

They say

$$b_T = \int r(t)\, C_E\, \delta_i\, dt$$

where $r(t)$ is the growth rate, C_E is a weather stressor, and δ_i is an "ok-bool" which is 1 if there's **no** flood, and 0 if there's a flood.

Once they have this, they would calculate the yield R as

$$R = b_T \times IC$$

where IC is the Harvest Index: the ratio of plant biomass allocated into harvestable yield. It's basically obtained by dividing the dry weight of harvested yield by the total dry weight of the entire plant. In the document, they first say that IC should be a function of the crop history, but afterwards they say that it's a crop-dependent constant. The latter is corroborated by the fact that in section 1.4 “yield estimation” they give a range for IC for each crop, indicating that they treat it as a *constant*.

In what follows, they'll make the approximation

$$b_T \simeq \sum_i b_i = \sum_i r_i \, C_{E,i} \, \delta_i \, \Delta t$$

with $\Delta t = 1$ day. In this way, they'll estimate b_i for each day of simulation until:

- crop maturity
- environmental stressor acts

1. Simulation of potential yield $r(t)$

> Question
>
> I think they call $r(t)$ the potential yield because C_E must be bounded between 0 and 1. Therefore, under no weather stress, $C_E = 1$ and $\delta_i = 1$ which imply $b_i = r_i$ and $b_T = r_i + b_{T,i-1}$. That would imply that they actually meant to call r_i the potential daily yield.
>
> ANS: yes.

In any case, I think they meant that the total amount of biomass per unit area $b_{T,i} = \sum_{j=1}^{i} b_j$ accumulated at the end of a period i is

$$b_{T,i} = b_i + b_{T,i-1}$$

Now, the daily increment in biomass b_i is computed as

$$b_i = CT \times PAR \times EUR_{ACT}$$

where:

- CT is the canopy cover, also canopy coverage or crown coverage, percentage of area covered by the vertical projection of the tree crowns. This is a crop-dependent parameter, and presents seasonal variations.

- PAR is the incident Photo synthetically Active Radiation, which depends on the location and time of year. Note that this is not just the spectrum Photosynthetically Active Radiation, but the amount of solar radiation (per unit of area I guess) that reaches the surface and is available to plants. It has units of $[MJ\ m^{-2}]$.
- EUR is the Spanish acronym for Radiation Use Efficiency (RUE) is defined as the ratio of dry matter produced to absorbed photo-synthetically active radiation (APAR). It is usually measured in grams of dry matter per mega joule $[g\ MJ^{-1}]$. The subscript ACT refers to "actual", in opposition to POT (potential).

Basically, the amount of mass per unit area generated $[g\ m^{-2}]$ is the radiation per unit area $[MJ\ m^{-2}]$, times the fraction of surface covered $[1]$, times the efficiency at which we convert radiation energy in biomass $[g\ MJ^{-1}]$.

This is supported by this document of a Radiation Use Efficiency Calculator:

> Radiation use efficiency (RUE) is important in understanding and modeling the relationship between plant growth and the physical environment. *Crop growth can be described as* the product of the incident Photo synthetically Active Radiation (PAR); the fraction (f) of PAR intercepted by green leaf (f); and the 'efficiency' with which the PAR is used as Radiation Use Efficiency (RUE). PAR depends on the location and time of year while seasonal fraction (f) is affected by the duration and the area of the canopy. Radiation Use Efficiency (RUE) is defined as the ratio of dry matter produced to absorbed photosynthetically active radiation (APAR). It is usually measured in grams of dry matter per mega joule (g DM MJ-1).

In the above, f is our CT, RUE is EUR, and PAR coincide.

1.1 Crop Phenology

Crop phenology refers to the study of the timing of key biological events in a plant's life cycle, such as germination, flowering, and maturity, and how these are influenced by environmental factors like temperature and day length. Understanding crop phenology is crucial for optimizing agricultural practices and improving yields, which is why it's a common area of study in agronomy and agricultural science. By tracking phenological stages, farmers and researchers can better predict harvest dates, improve pest and disease management, and adapt to climate change.

There's an interesting map in [this page of the FAO]().

This model does not take crop phenology into account yet.

1.2 Capture of Solar Radiation CT

$fPAR = CT \times PAR$?

They call $fPAR$ the "interception of solar radiation", but they do not define it. I think it might be the product $fPAR = CT \times PAR$, since in the document mentioned in section 1, the canopy cover is noted as f instead of CT. However, in Figure 2 of section 1, they wrote "$C_T(\%) = fPAR$", so maybe $fPAR$ is just another name for CT.

(The following is what I think would be right.)

We calculate

$$CT(t) = \int_0^t \frac{dCT}{dt}\, dt$$

with initial condition $CT(t=0) = 0$.

We define a non-dimensional time $i = t/\text{days}$ that counts the number of days passed. We think of growth as follows:

1. Initially, after sowing (say, at day $i = 0$), the plant doesn't have any leaves, thus $CT = 0$, and it remains that way for a period of d_{in} days, after which leaves start to grow. *We model the derivative at this stage*

as being $\frac{dCT}{dt} = 0$, and additionally, we have the initial condition $i < d_{in} \implies CT = 0$ and $CT(d_{in}) = C_{in}$.

2. Leaves grow at a rate α under ideal climatic conditions, for a period $i \in (d_{in}, d_{s,max})$. To account for suboptimal conditions, we scale the potential growth rate by a time dependent coefficient $CEH(t)$ (Spanish acronym for "coeficiente de estrés hídrico para expansión foliar") that accounts for the water stress effect on canopy expansion. *We model the derivative at this stage as being $\frac{dCT}{dt} = \alpha \times CEH(t)$.*
3. Once the plant achieves maturity, leaves stop growing. Under ideal conditions, the maximum CT achievable is C_{max}, a value that depends on the crop species and management variables like plant population. This maximum value of CT for the crop is kept for $i \in (d_{s,max}, d_{s,sen})$. *We model the derivative at this stage as being $\frac{dCT}{dt} = 0$.*
4. When the crop enters senescence, leaves start to fall and CT is consequently reduced. This happens at rate $\beta \times CEH(t)$, for the number of days $i \in (d_{s,sen}, d_{s,fin})$. *We model the derivative at this stage as being $\frac{dCT}{dt} = -\beta \times CEH(t)$.*
5. At day $d_{s,fin}$ the canopy cover reaches zero, and stays that way for all future times. *We model the derivative at this stage as being $\frac{dCT}{dt} = 0$, and additionally, we have the final condition $i > d_{fin} \implies CT = 0$.*

Suggested Generalization

I think it'd be a good idea to differentiate between two possibly different times: the time at which the plant has completely underwent its senescence, say d_{fin}, but it's still alive, it still has leaves intercepting solar radiation, so $CT(d_{fin}) = C_{fin} \geq 0$, and it can continue to generate biomass, although at a slower rate; and the time d_{muerte} at which the plant dies, neither generating any biomass nor capturing any radiation (we can think that the plant has lost all of its leaves) having $CT(d_{muerte}) = 0$. In this way, we would have

$$d_{fin} \leq i \leq d_{muerte} \implies CT(i) = CT(d_{fin}) = C_{fin} \geq 0$$

$$i \geq d_{muerte} \implies CT(i) = CT(d_{muerte}) = 0$$

In this way, the present model is just the special case in which $d_{fin} = d_{muerte}$, or in which $C_{fin} = 0$, but we would have a model that generalizes to other possible plants that do not behave in this way. (Clearly the interest in adding this is being able to model situations in which $C_{fin} \neq 0$.)

(I also think we should consistently name in English, e.g., using d_{death} instead of d_{muerte}.)

Following this, we can approximate the integral by a summation and give the following relations for the *sequence* CT_i, with $i \in \mathbb{Z}_0$, at each stage:
0. $i < d_{in} \implies CT_i = 0$

1. $CT(d_{in}) = CT_{d_{in}} = C_{in}$
2. $i \in (d_{in}, d_{s,max}) \implies CT_i = CT_{i-1} + \alpha \times CEH(t)$
3. $CT(d_{s,max}) = CT_{d_{s,max}} \leq C_{max}$
4. $i \in (d_{s,sen}, d_{s,fin}) \implies CT_i = CT_{i-1} - \beta \times CEH(t)$
5. $i \geq d_{s,fin} \implies CT_i = 0$

Which one is fixed: C_{max} or $d_{s,max}$?

The plant grows until reaching C_{max} every time, increasing $d_{s,max}$ under suboptimal conditions? Or at $d_{s,max}$ growth stops, and we are stuck with $CT(d_{s,max}) < C_{max}$? (Modify step 3 according to the answer.)

Ans: At $d_{s,max}$ growth stops.

Does water stress slow down canopy cover reduction under senescence?

They say that the recursive rule for getting CT_i for $i \in (d_{s,sen}, d_{s,fin})$ is

$$CT_i = CT_{i-1} - \beta \times CEH(t)$$

If $CEH(t) = 1$ under ideal water conditions (and $CEH(t) = 0$ under the worst possible conditions), this would imply that leaves fall faster under good conditions. Is this the case? I would have thought that the worse the conditions, the faster the reduction in CT, not the other way around.

? Discontinuity in CT?

If $C_{in} > 0$, then we have a discontinuity in CT at day d_{in}. Is that correct?

Ans: Yes.

The parameters α and β are calculated as follows:

$$\alpha = \frac{C_{max} - C_{in}}{d_{s,max} - d_{in}}$$

$$\beta = \frac{C_{max} - C_{in}}{d_{fin} - d_{s,sen}}$$

(Notar que cambié la definición de beta respecto al escrito de ellos, porque les quedaba $\beta < 0$ pero tienen el menos explícito en la fórmula. La pendiente cruda cruda sería $\beta = \frac{C_{in} - C_{max}}{d_{fin} - d_{s,sen}}$ que te sale < 0, pero si querés el menos aparte, tenés que dar vuelta sólo el numerador -- ellos dieron vuelta también el denominador.)

They give a table with values for the crop-dependent parameters $C_{in}, C_{max}, d_{in}, d_{fin}, d_{s,max}, d_{s,sen}$ and even α and β (I should check that they are consistently calculated as they say), for two populations of Maize.

1.3 Radiation Use Efficiency EUR

? Units of EUR

The original document seemed to indicate that EUR has units of $[g \ \ MJ^{-1} m^{-2}]$, but it should have units of $[g \ \ MJ^{-1}]$. (The m^{-2} of b comes from PAR.)

> EURAct expressed in g MJ m2 results from...
> (...)
> ... is called radiation used efficiency (EUR g MJ m2)

Am I right?

Note

They seems to be thinking of $T^\circ EUR$ as a relative EUR (note y axis of Fig. 4). I propose to rename $T^\circ EUR$ to α_T or something like that, and just call α_T the relative efficiency at temperature T under ideal “water conditions” (?), or something like that.

As we said, the efficiency at which absorbed photo-synthetically active radiation is transformed into dry biomass is called radiation use efficiency (EUR), and it's measured in grams of dry matter per mega joule $[g \ \ MJ^{-1}]$. This parameter depends on the crop species and is affected by temperature and water.

The actual efficiency EUR_{Act} might be lower than the potential due to temperature and water effects. We model it as follows:

$$EUR_{Act} = EUR_{Pot} \cdot T^\circ EUR \cdot CEHR$$

where

- EUR_{Pot} is the potential radiation use efficiency, a crop-dependent parameter (a constant) extracted from the bibliography.
- $T^\circ EUR$ is a function of the daily mean temperature. We can interpret it as the relative efficiency for a given temperature, given ideal water conditions.
- $CEHR$ is a function of the amount of water (?), optimal conditions corresponding to a CEHR of 1.

The relative efficiency as a function of the mean daily temperature $T^\circ EUR$ is modeled with linear interpolations between the region of optimal efficiency $T^\circ EUR = 1$, namely $T \in (T^\circ{}_{or1}, T^\circ{}_{or2})$, and the regions of null efficiency $T^\circ EUR = 0$, namely $T < T^\circ{}_{br}$ and $T > T^\circ{}_{cr}$. See Fig. 4. These temperature values are shown for selected crops in Table 2.

1.4 Yield Estimation

As mentioned in the summary, yield R is calculated as

$$R = b_T \times IC$$

In this section, they just report some reference values of the biomass, yield, and IC for Maize, Soybean, and Wheat.

Question to self

I thought IC was just a constant because I saw this table (and because they said at some point that this value came from the bibliography), but maybe this is just a reference value and IC is indeed calculated in some way. I should check this.

2. Simulation of Water Balance

2.1 Available Soil Water

This definition does not match the one in section 2.2

AU_T is actually defined as the maximum **extractible** water per unit area (confirm this) in a given portion of the soil of some depth δ_{soil}. This differs from just the maximum water the soil can hold up due to the existence of a lower bound for soil water concentration.

Soil could be seen as a reservoir of water that can hold up to AU_T, measured in mm of water, when it's saturated. We can calculate the water that is available to the crop AD_T, and express it as a percentaage $\%AU$ of the saturation value AU_T, by balancing the water that enters and exits the soil.

(Note the Spanish acronyms “agua útil” and “agua disponible”.)

AU_T depends on the soil depth considered

I thought that AU_T was the amount of water measured in mm because we though of it as the amount “per unit area”, and there was actually a m^{-2} multiplying all of it. With that, the actual amount of water per meter squared would be obtained by multiplying AU_T by $1m^2$, and by the density of water at that temperature if you want the result in units of mass instead of volume. Remarkably, in this interpretation there's no mention to the depth of the soil, so we're assuming that this is the total water available in the relevant depth.

However, reading the next section, I interpret that actually CC is some kind of volume density of water in soil (i.e., which percentage of the volume of soil considered is occupied by water). So then, when they say that AU_T can be calculated as CC times the soil depth, the depth considered enters explicitly. If one compares with the previous interpretation, relevant depth is now a variable one should know (which is good, because explicit is better than implicit) *and choose carefully*. I think both interpretations are compatible, and that the second one is the preferable one, but this would imply that AU_T **might be a misleading quantity to define.** We'll see how this continues, but for now, I'm inclined to express dependencies with CC explicitly.

The available water is used to estimate hydric stress.

2.2 Estimation of AU_T

The maximum and minimum amounts of water that the soil can hold correspond to the adimensional variables CC and PMP respectively. We can use these to calculate, for instance, the total amount of water that can be extracted from the soil of a given depth

$$AU_T = (CC - PMP) \times \text{soil depth}$$

(Suggestion: define a variable for the soil depth, e.g., δ_{soil}.)

Change in the definition of AU_T

Note that the definition of AU_T of this section, doesn't match the one of the previous section. See “bug” callout on previous section.

Arbitrary partition of the soil

In what follows, they make explicit the soil depth to consider (good!). They say that as the crop grows, roots grow deeper into the soil, thus accessing more water. However, instead of just using the root depth and CC to calculate the available water at each time step, the desire to use quantity AU_T (told you it was misleading) makes them define an arbitrary partition of the soil into two layers C1 and C2, divided at 600mm depth, and they approximate the water available as the one correponding to C1 when the root depth is less than 600mm, and the total otherwise.
Of course, unless some compelling biological argument is presented, this arbitrary division should be replaced by an integral, later approximated by the corresponding discrete step actualization rule (recursive relation). If $\delta_{\text{root}}(t)$ is the root depth at time t, then the available water per meter squared is

$$AU_T(t) = (CC - PMP) \cdot \delta_{\text{root}}(t)$$

and

$$\delta_{\text{root}}(t) = \int_0^t \frac{d\delta_{\text{root}}(t')}{dt'} dt'$$

where $d\delta_{\text{root}}/dt$ is afterwards modeled as a constant extracted from the literature. (I'm assuming that root growth starts at $t = 0$.)

They report values for the growth rate of roots, in units of $[mm/day]$, for Maize, Soybean, and Wheat.

Question

Fig. 5 in section 2.2 states that the total available water is calculated as

$$AU_T = AU1 + AU2$$

$$AU1 = (CC - PMP) \times 600mm$$

$$AU2 = (CC - PMP) \times \text{root depth}$$

where AU1 is the water corresponding to C1, and AU2, to C2.

However, **I think they meant**

$$AU2 = (CC - PMP) \times (\text{root depth} - 600mm)$$

Nonetheless, I do not think this is very relevant since I would get rid of this arbitrary division anyway.

2.3 Estimation of AD_T

As mentioned in section 2.1, AD_T is estimated daily as a percentage $\%AU$ of AU_T, by balancing the inputs and outputs of water.

They continue to use the division into C1 and C2, and they estimate AD_T separately for the two layers as A.disp1 and A.disp2 respectively (which I'll rename here to $AD1$ and $AD2$). They say that this estimation is done based on the equations that follow and “SMAP images (sm_rootzone)”. I searched for SMAP, and apparently it's a (bit of an old) project of NASA to measure soil moisture. Some resources:

- NASA video on SMAP: [Can data from a NASA satellite help during a food crisis?](#).
- A bit of an old article that might be useful: [NASA Soil Moisture Data Advance Global Crop Forecasts](#).

The equations are:

$$AD1_x = AD1_{x-1} + \text{precipitations} - \text{superficial drainage} - \text{run off} - \text{soil evapor}$$

$$AD2_x = AD2_{x-1} + \text{percolation} - \text{drainage} - \text{crop transpiration} + \text{available wat}$$

This way of modeling could be the reason they divide into C1 and C2 for AU_T, but it's not necessary to use the same discretization for this and that. You can model AD_T like this, with a two part division, but then say that only a layer of root depth is available.

After this, they begin a discussion organized into inputs and outputs

2.3.1 Inputs of water

First layer: the only input is due to precipitations, that we know of from data of the climate.
Second layer: the inputs here are

- percolation of the upper soil layer into this bottom one (which corresponds to the amount of drainage of water of the first layer);
- new available water as a consequence of new soil exploration as roots get deeper.

2.3.2 Outputs of water

2.3.2.1 Superficial Drainage

Drainage occurs (for both layers) when the water available AD_T excedes the maximum amount of extractible water the soil can hold AU_T. They model the drainage D (the letter is a definition of mine) as

$$AD_T \leq AU_T \implies D = 0$$
$$AD_T > AU_T \implies D = c_D \cdot (AD_T - AU_T)$$

where c_D is the drainage coefficient (“Coef. Drenaje”). This could've just been written as

$$D = c_D \cdot \delta_W \cdot \theta(\delta_W)$$

where $\delta_W = (AD_T - AU_T)$ is the water surplus and θ is Heaviside's step function. Notice that this would still work with an arbitrary discretization of soil depth (for which I'd like to define a δ_W in terms of CC and not AU, maybe calling the previous $\tilde{\delta}_W$).

On Fig. 6: it shows a schematic plot of the water content (in mm) of a piece of soil as a function of time, for two different soils that they will say have different drainage coefficients. For the solid black line, they seem to interpret that the water content has first a linear decay until it achieves some constant value (zero, but I think that's because the y axis must the water surplus, not the actual water content as the label seems to say). However, for the dashed line, we see kind of two regimes of linear decay.

To understand how exacly they'll model the decay, we must yet see how they incorporate D into the model. However, if it's just a term in the summation for $AD1_x$ as we saw in section 2.3, it'll give a linear decay followed by a constant, which is compatible with the solid line but not with the dashed line.

Dashed line in Fig. 6 is really a two-regime linear decay?

I don't know if this is just an accident, but this shows a two-regime linear decay instead of a single one as modeled above.

2.3.2.2 Run off

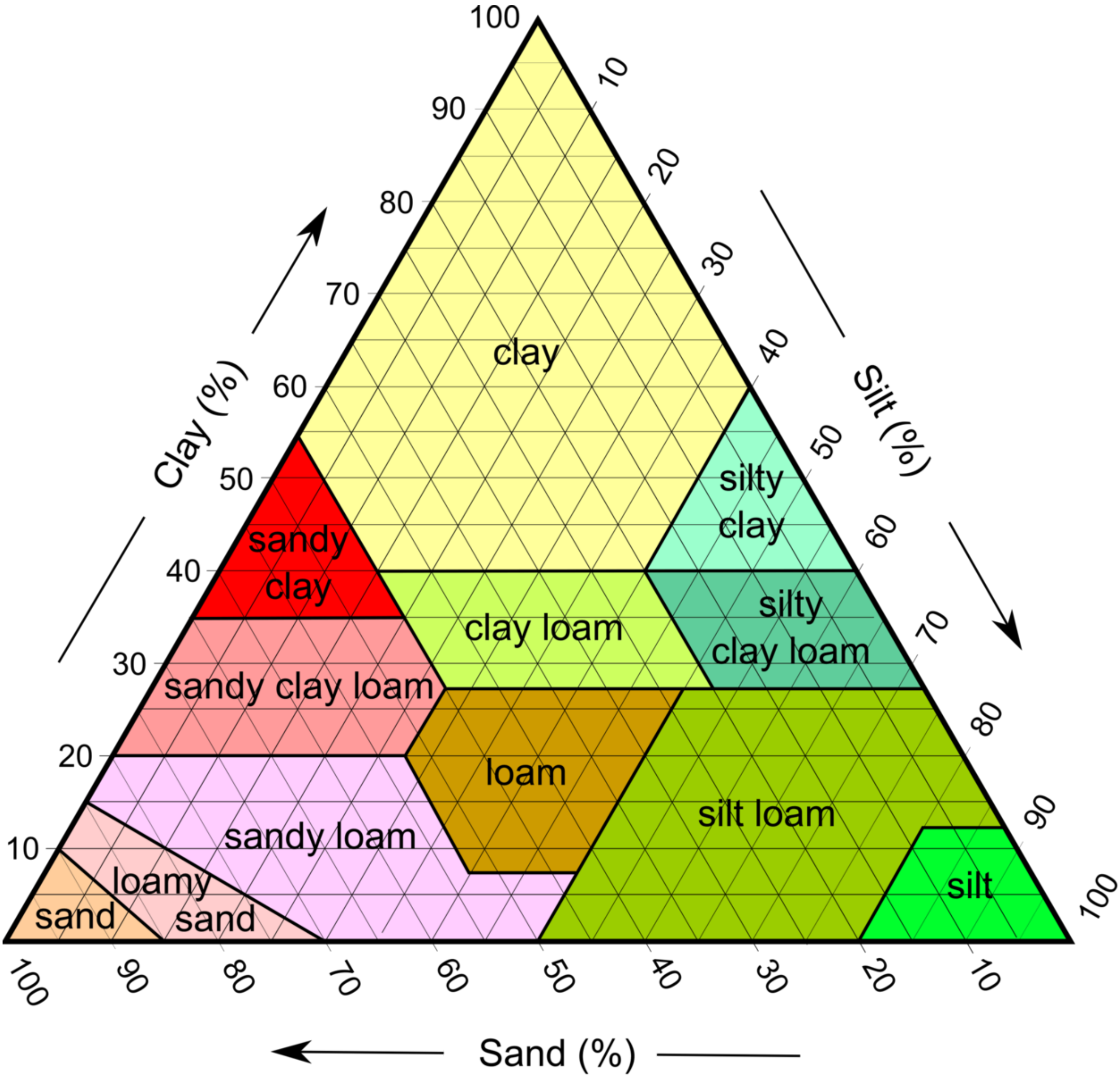
The run off E (“escorrentia”, the use of E is my own) is the amount of water that could not infiltrate into the soil after a rainfall. It increases with the amount of precipitation PP that reaches the soil, information that we get from clima data (see Fig. 7), and it's also modified by the soil texture through a parameter CN called “curve number”:

$$E = \frac{(PP - 0.2 \times S)^2}{PP + S - 0.2 \times S}$$

where S is the “potential maximum storage” for rain water, calculated as

$$S = 254 \times \frac{100}{CN - 1}$$

Then Table 3 (yes, 3 again) shows reference values for c_D, CN, and *soil layer depths* (so maybe the generalization won't be useful...), for several soil textures (soil types by clay, silt and sand composition).



Resources:

- Cool video on Soil types: [Soil and Soil Dynamics](). This is part of a series on Environmental Science ([playlist]()). There's also a very short one on Earth Science ([playlist]()).
- Video on Soil Horizons: [Soil Basics - Soil Profiles](). This is part of a series on Soil Basics ([playlist]()), which also has a video on soil textures I really like: [Purdue Extension - Texture]().
- Homemade demonstration of Soil Type test: [Video - Garden Fundamentals]().

2.3.2.3 Soil Evaporation

For estimating the evaporated water, we first need a potential evaporation $E_{s,pot}$ (“potencial evaporativo”, usually ranging from $4.5mm$ to $10mm$ depending on the soil texture) of the soil when considering it as a wet surface. This is a soil-dependent constant. Right after a rainfall, evaporation is at its maximum (saturation) value, but after some time (two days they say), it starts to decrease. If we measure time in days after the rainfall DDP (“días desde precipitación”), the decay in evaporation starts at $DDP = 2$, and Soil Evaporation E_s (“Evaporación del suelo”) is modeled as

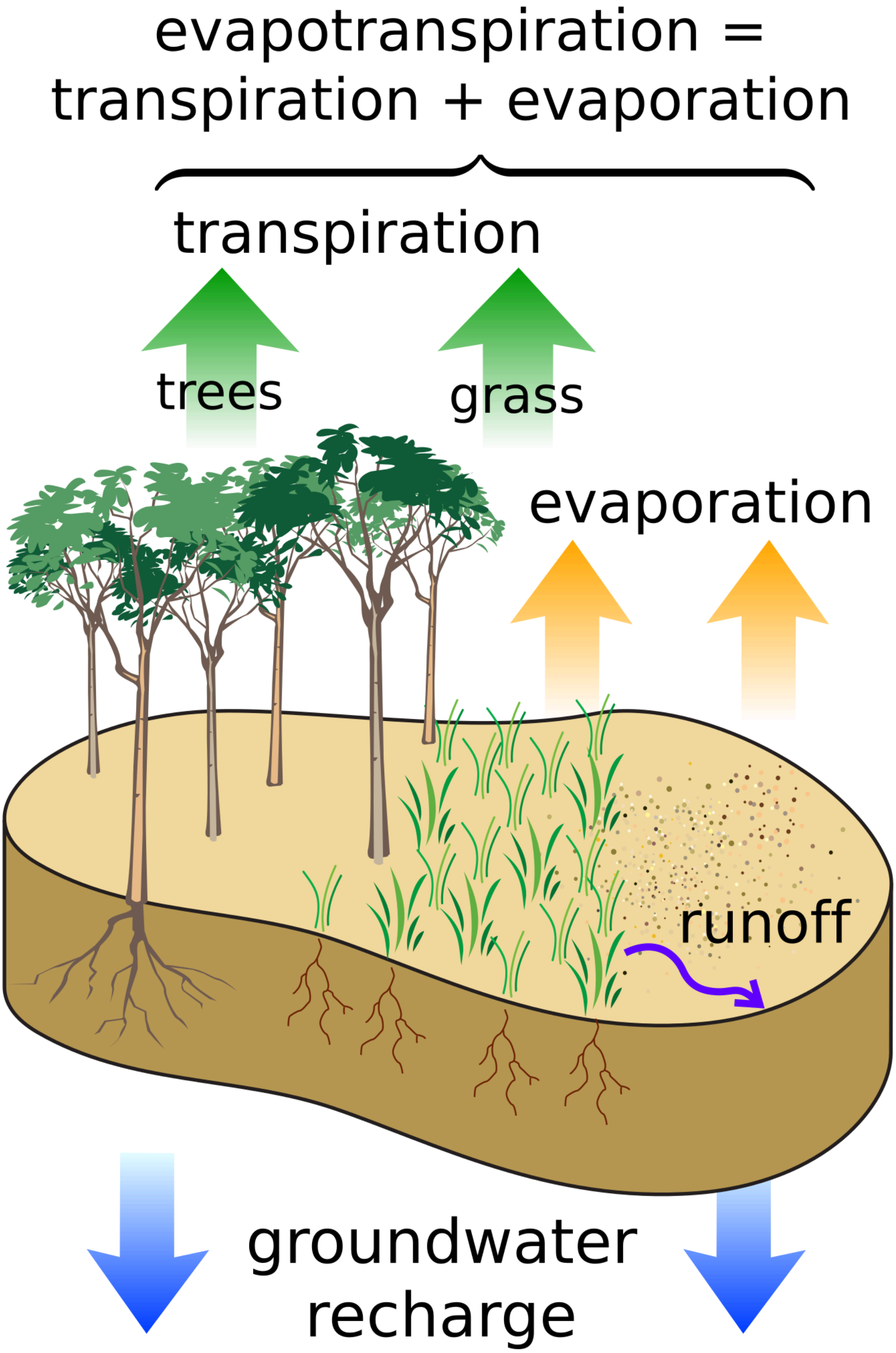
$$DDP \leq 2 \implies E_s = E_{s,pot}$$

$$DDP > 2 \implies E_s = FE_s \cdot \sqrt{DDP}$$

where FE_s (“Factor evaporación suelo”) is the coefficient describing the soil evaporation as the soil dries, and it is a soil-dependent constant.

Evaporation or Evapotranspiration?

In this section, they never mention transpiration, which is treated in the following section. However, they wrote “evapotranspiration” whenever I wrote evaporation in the text above.



2.3.2.4 Crop Transpiration

Crop transpiration and growth are linked because both processes depend on air diffusion through stomata (plural of stoma). Concretely, there are two variables that'll help us link them:

- DPV: the vapor-pressure deficit (should be VPD in English) is the difference between actual vapor pressure and saturated vapor pressure (i.e., pressure of saturation) at a given temperature. We can think of it as the difference between the amount of moisture in the air and how much moisture the air can hold when it is saturated. It quantifies the "drying power" of the atmosphere. It is measured in Pascals ($[DPV] = Pa$). In the model, this comes from climate data.
- TE: crop Transpiration Efficiency ("Ef. Transpiratoria") is the rate of crop mass (biomass) production per unit of water transpired by the crop (see auxiliary resources below), i.e.

  $$TE = \frac{b_i}{W_i}$$

  where W_i is the water transpirated by the crop at day i per unit area (**CHECK THIS**). Note that we're keeping our notation from section 1, referring to b_i as the biomass produced at time day i, and to $b_{T,i}$ as the total accumulated by that time. This is taken as a crop-dependent parameter ("input cultivo"). Regarding units, *if our definition is correct*, and considering that b_i is the biomass produced at day i per unit area, we have that

  $$[TE] = \frac{[b_i]}{[W_i]} = \frac{[\text{mass}]/[\text{area}]}{[\text{mass}]/[\text{area}]} = 1$$

  which makes perfect sense since any efficiency should be adimensional. **However,** reported efficiencies in Table 4 are said to have units of Pa (pressure).

Are the definition of TE and its units correct?

Figure 9 shows an equation relating the three components:

$$\text{Transpiración del cultivo} = \frac{b_i \times DPV}{TE}$$

Now, if we interpret "Transpiración del cultivo" as being our previously defined W_i, this doesn't make any sense.

How do we interpret the above formula?

Auxiliary resources:

- Review paper - Vadez et al. Transpiration efficiency: new insights into an old story, Journal of Experimental Botany. In the introduction, it says:

  > At a plant level, the transpiration efficiency (TE), an important component of WUE (water-use efficiency), is defined as TE = biomass/water transpired.

- Paper - Thomas R. Sinclair. Effective Water Use Required for Improving Crop Growth Rather Than Transpiration Efficiency, Frontiers in Plant Science. In the introduction, it says:

  > Crop transpiration efficiency (TE) is often defined as crop mass production per unit of crop transpiration.

3. Water Stress Coefficients C_E

As mentioned before, crops respond to the lack of water in the soil by limiting growth. As a consequence, $\%AU$ could be used for estimating crop stress. These hydric stresses will be characterized by the already mentioned hydric stress coeficients:

- CEH for the effect on the canopy cover CT;
- $CEHR$ for the effect on radiation use efficiency RUE (case in which we can interpret it as a relative efficiency given ideal temperature conditions).

(I would put section 3.2 first, and then 3.1 to match the order of sections 1.2 and 1.3, and because of the naming convention where 3.1 uses the parameters in 3.2 just adding an “r” to them as a subscript.)

3.1 Water Stress Effects on EUR_{Pot}

The actual radiation use efficiency EUR_{Act} results from the potential one EUR_{Pot} by multiplying this last one by the relative efficiency that depends on the temperature $T^{\circ}EUR$ (see section 1.3), and the one that depends on the water content of soil $CEHR$. This last one is 1 if the water content of the soil $\%AU$ is above a saturation threshold UD_r. On the other hand, below the value Unc_r, CEH is 0. In the middle, i.e. in the interval (Unc_r, UD_r), $CEHR$ is modeled as an increasing function of the $\%AU$ as follows

$$CEHR = 1 - \frac{e^{Rrs\times\mathrm{cof.formaR}} - 1}{e^{\mathrm{cof.formaR}} - 1}$$

where the relative stress Rrs is defined as

$$Rrs = \frac{\%AU - Unc_r}{(UD_r - Unc_r)/100}$$

and where UD_r, Unc_r, and $\mathrm{cof.formaR}$ are culture dependent parameters extracted from the bibliography. Fig. 10 shows an example curve for $CEHR(\%AU)$, and Table 5 shows some reference values for the parameters of Maize, Soybean, and Wheat.

3.2 Water Stress Effect on Canopy Expansion

In this section, they seem to be thinking mainly about the growth period, where

$$i \in (d_{in}, d_{s,max}) \implies CT_i = CT_{i-1} + \alpha \times CEH(t)$$

but remarkably, not on the senescence period (on which the functional form of the dependency needs fixing). Here, α is the growth rate under no hydric stress, and the actual growth rate is obtained by multiplying by this hydric stress coefficient CEH, which is modeled to be

$$CEH = 1 - \frac{e^{Hrs\times\mathrm{cof.formaH}} - 1}{e^{\mathrm{cof.formaH}} - 1}$$

where the relative stress Hrs is defined as

$$Hrs = \frac{\%AU - Unc}{(UD - Unc)/100}$$

and where UD, Unc, and $\mathrm{cof.formaH}$ are culture dependent parameters extracted from the bibliography. for which some reference values are given in Table 5. Fig 11 shows an example plot for $CEH(\%AU)$.

4. Catastrophic Events Coefficients δ_i

4.1 Floods

(?)

4.2 Frost

In section 1.3 on the effect of temperature on Radiation Use Efficiency, there is a lower temperature threshold $T^\circ{}_{br}$ under which the thermic relative efficiency becomes zero, i.e. $T < T^\circ{}_{br} \implies T^\circ EUR = 0$ (see Figure 4 in section 1.3). They say that this is the way in which the model takes into account low temperatures.

4.3 Hail

After hailing, the land is reseeded to a percentage that depends on the percentage of damage, which in turn is identified via climatic data. The reseeding percentage as a function of the damage percentage is modeled as follows:

- $\%\mathrm{Damage} < 20\% \implies \%\mathrm{Reseeding} = 0$
- $20\% < \%\mathrm{Damage} < 60\% \implies \%\mathrm{Reseeding} = 20\% \sim 95\%$
- $60\% < \%\mathrm{Damage} \implies \%\mathrm{Reseeding} = 95\%$

The reseeding percentage in the intermediate case lacks further specification. Figure 12 plots an example of this dependency, taking this intermediate percentage to be 20%.

⚠ No definition of δ_i

The model seems to be incomplete in this regard.

5. Appendix

This section has a list of variables that we should remake after the questions have been answered.