Modélisation des pertes de récolte.

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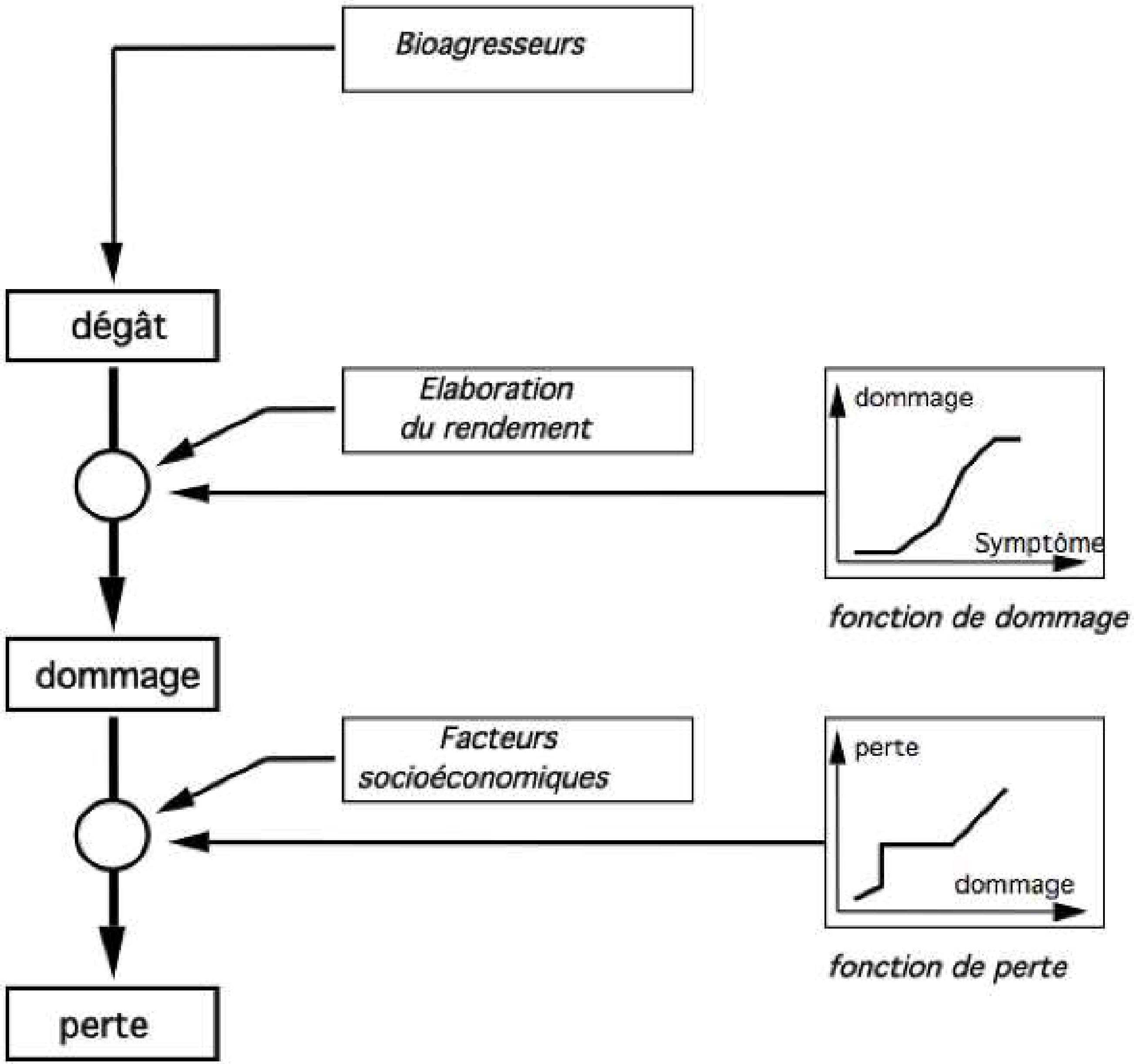
Paris, 01.12.2015

Examples of yield losses caused by pests worldwide (weeds, pathogens, animal pests)

	Rice (%)	Wheat (%)	Potato (%)
Unprotected	77	50	75

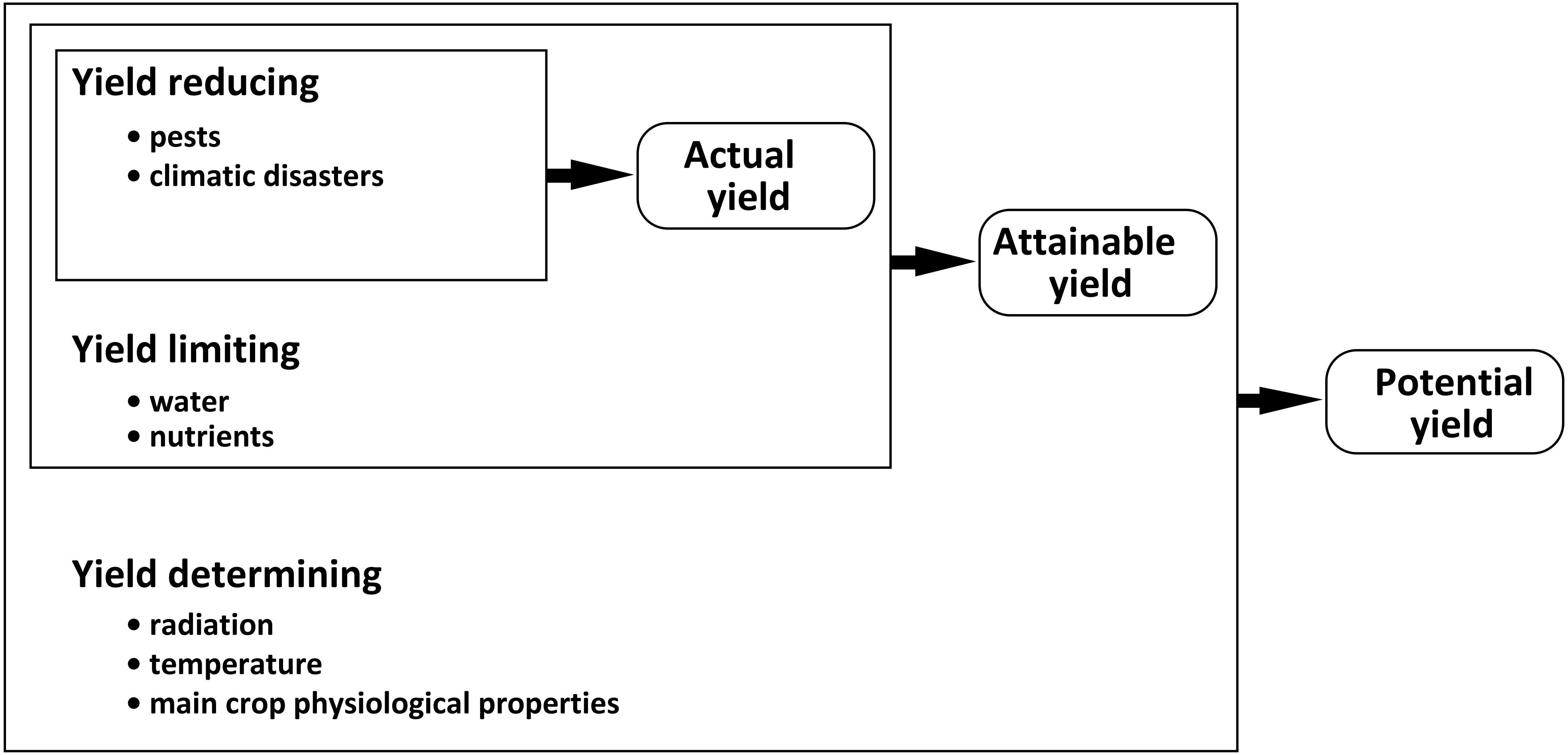
Oerke EC. 2006. Crop losses to pests. Journal of Agricultural Science, 144: 31-43.

Relations entre bioagresseurs, dégâts, dommages, pertes



Savary, 2005

Yield defining factors



Zadoks, J.C., Schein, R.D., 1979. Epidemiology and Plant Disease Management. Oxford University Press, New York.

Rabbinge, R., 1993. The ecological background of food production. In: Chadwick D.J., Marsh, J. (Eds.), Crop Protection and Sustainable Agriculture. John Wiley and Sons, Chichester, UK, pp 2-29.

Yield loss assessment

$Yield_{loss}=Yield_{attainable}-Yield_{actual}$

$RelativeYield_{loss}=(Yield_{attainable}-Yield_{actual})/Yield_{attainable}$

Yield loss modelling

2 main statistical approaches

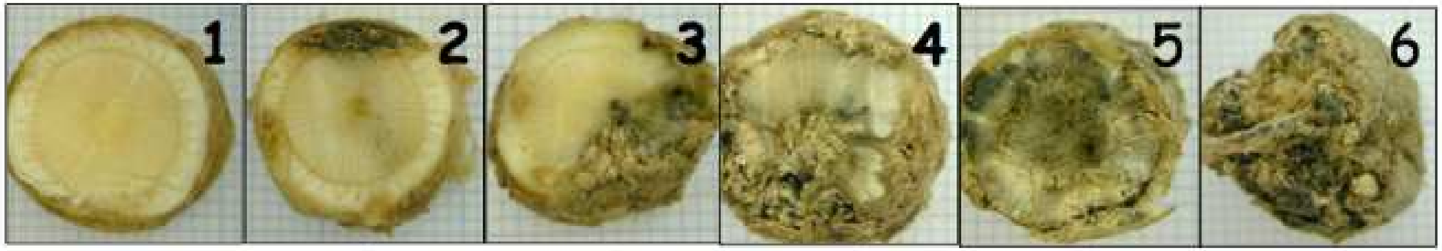
$Yield_{loss}=f(injury)$

$RYield_{loss}=f(injury)$

$Yield_{loss}=f(injury(t))$

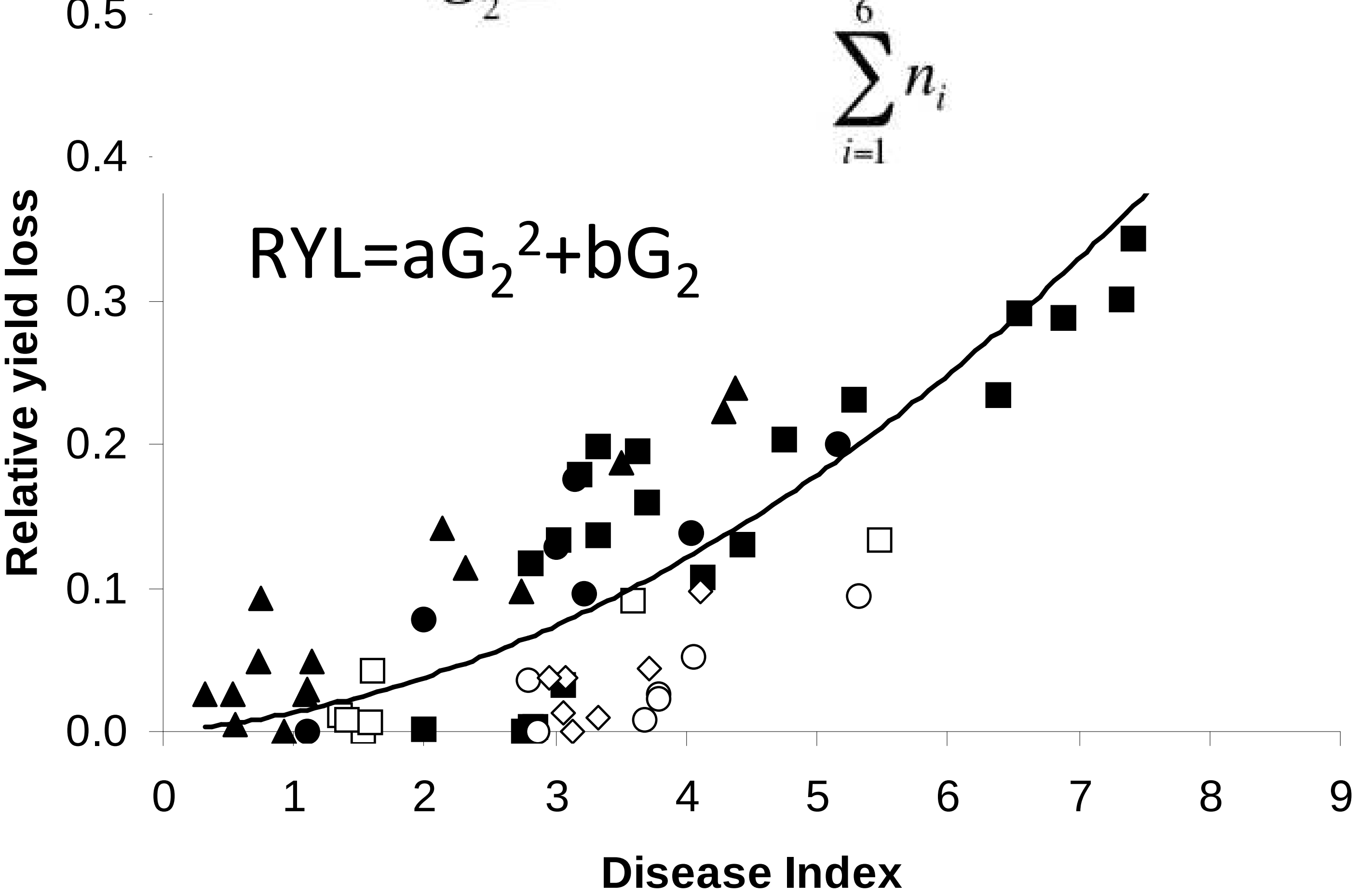
$RYield_{loss}=f(injury(t))$

Dynamic modelling of damage functions associated to a crop model



0 %	0 à 25 %	25 à 50 %	50 à 75 %	75 à 100 %	100 %

$$G_2 = \frac{n_2 + 3n_3 + 5n_4 + 7n_5 + 9n_6}{\sum_{i=1}^{6} n_i}$$



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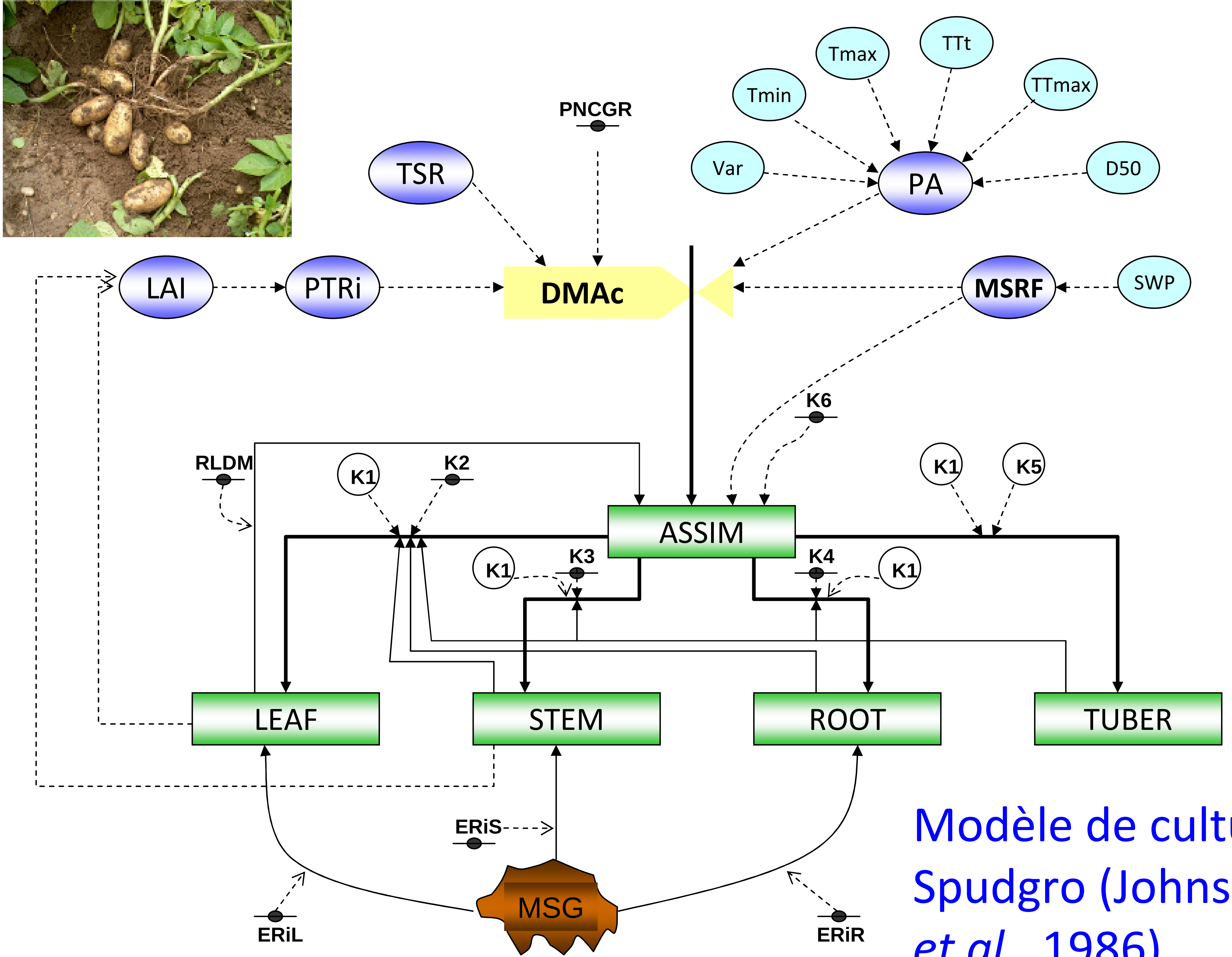


Modèle de culture Spudgro (Johnson *et al.*, 1986)

Calcul de l'âge physiologique dans Spudgro (Francl, 1989)

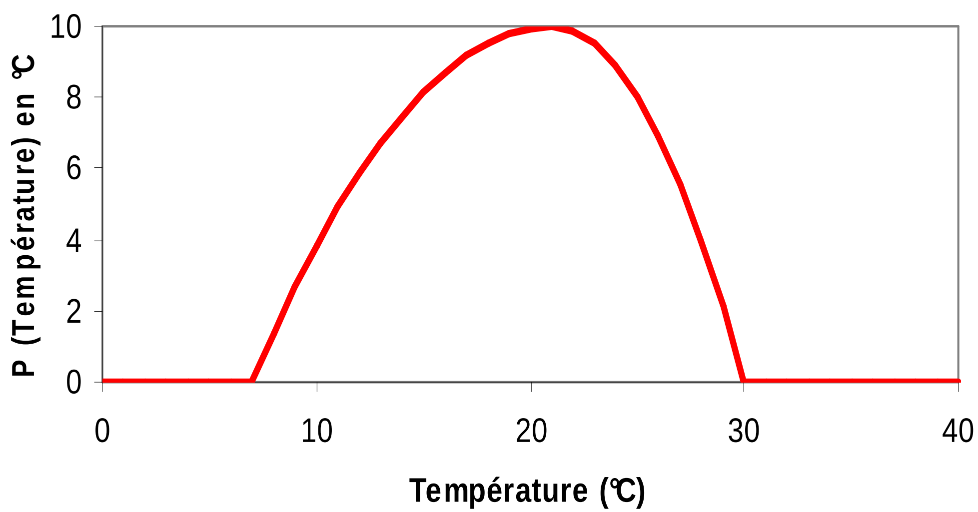
$$Pday = \frac{1}{\Delta t_1}\left[\Delta t_2 P(\theta_{\min}) + \Delta t_3\left[aP(\theta_{\min}) + bP(\theta_{\max})\right] + \Delta t_3\left[aP(\theta_{\max}) + bP(\theta_{\min})\right] + \Delta t_4 P(\theta_{\max})\right]$$

With Δt_1 = 24 h; Δt_2 = 5 h; Δt_3 = 8 h; Δt_4 = 3 h; a = 0.66; b = 0.33

If $\theta < \theta_{Tinf}$ or $\theta > \theta_{Tsup}$, then $P(\theta)$ = 0°C

If $\theta_{Tinf} \leq \theta < \theta_{opt}$, then $P(\theta) = 10\left(1 - \frac{(\theta - \theta_{opt})^2}{(\theta_{opt} - \theta_{T\inf})^2}\right)$

If $\theta_{opt} \leq \theta \leq \theta_{Tsup}$, then $P(\theta) = 10\left(1 - \frac{(\theta - \theta_{opt})^2}{(\theta_{T\sup} - \theta_{opt})^2}\right)$



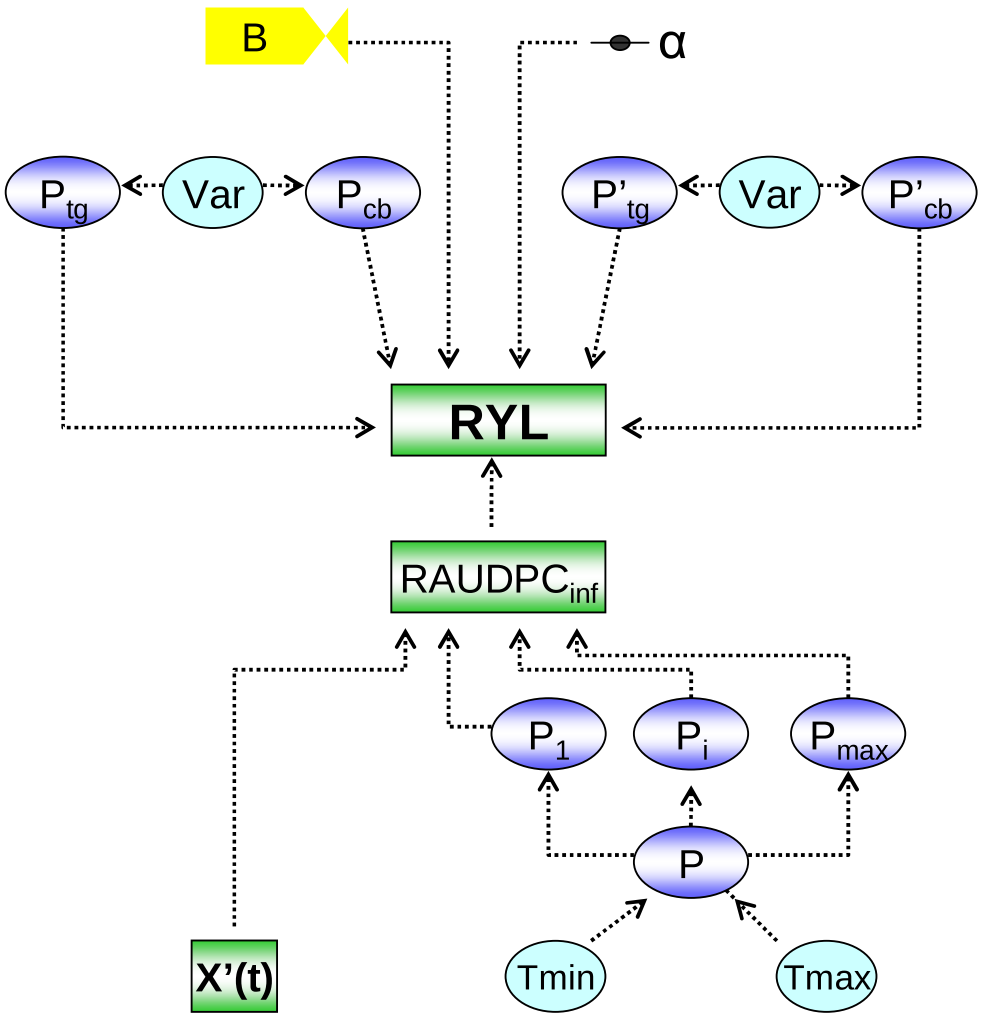
with θ_{Tinf} = 7 °C, θ_{opt} = 21 °C, θ_{Tsup} = 30 °C, and where θ, θ_{min} and θ_{max} refer respectively to the mean, the minimum, and maximum daily temperature respectively.

$$P_x = \sum_{i=1}^{i=x} Pday$$

Rakotonindraina, 2012

Fonction de nuisibilité de *P. infestans* sur Pdt (Shtienberg et al.,1990)

$$RYL = 100\left(1-\left(1-\frac{\alpha\left(RAUDPC_{\inf} - RAUDPC_{ref}\right)}{B}\right)\left(\frac{P'_{cb}-P'_{tg}}{P_{cb}-P_{tg}}\right)\right)$$



$$RAUDPC = \frac{\sum_{i=1}^{i=n}\left(\frac{X_{i+1}+X_i}{2}\right)\left(P_{i+1}-P_i\right)}{P_{max}-P_1}$$

B : taux de tubérisation

A : coefficient de réduction du taux de tubérisation

P : âge physiologique

X' (t) : destruction foliaire en pourcentage

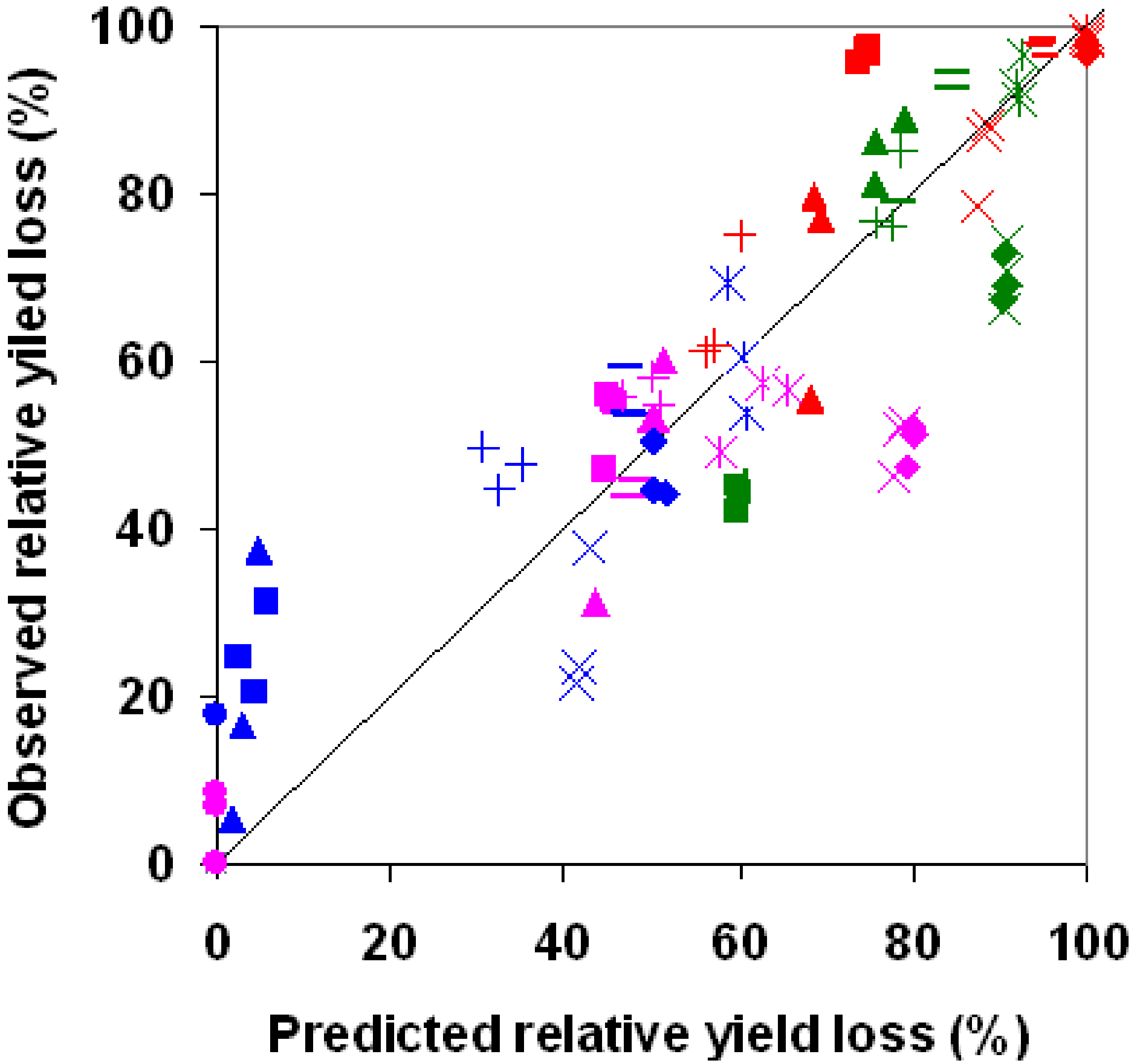
RYL : perte relative de rendement

Evaluation de la qualité prédictive de la relation de nuisibilité de Shtienberg et al. (1990)

Efficiency = 0.80
RMSEP = 13.25 %
Bias = -0.36

□ : Arka
* : Bintje
- : Désirée
Δ : Eden
× : Inra 92T.114.76
¤ : Inra 92T.120.16
+ : Naturella
◊ : Robijn.

- 2006
- 2007
- 2008
- 2009



Rakotonindraina et al, 2012

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$$Yield_{loss} = Yield_{attainable} - Yield_{actual}$$

$$RelativeYield_{loss} = (Yield_{attainable} - Yield_{actual})/Yield_{attainable}$$

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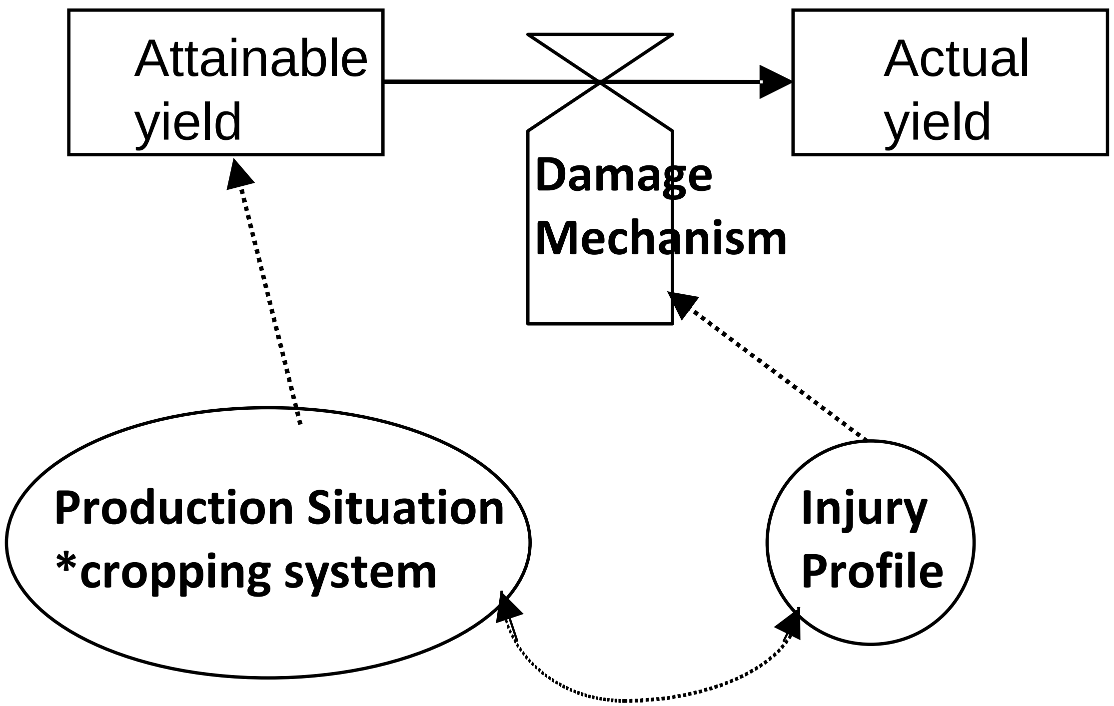
Dynamic modelling of damage functions associated to a crop model

Production Situation*Cropping system and Injury Profile relationship

- Strong link shown for multiple pathosystems of several crops
- Can be used as a framework to assess or model yield losses caused by multiple pests



Damage mechanisms

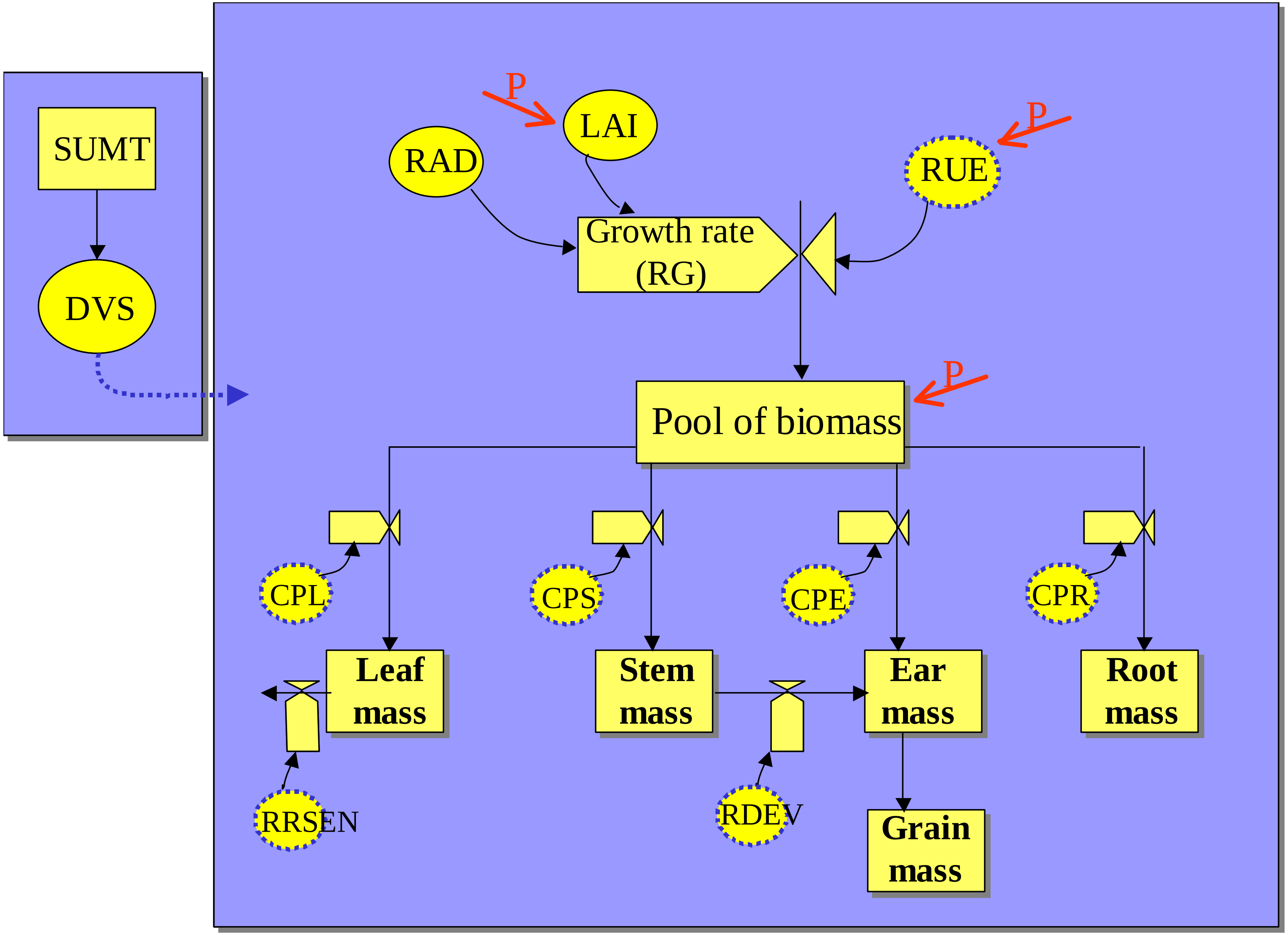
• Damage mechanism: physiological effect of injury on crop growth and yield. Can be incorporated in models to simulate yield losses.

Damage mechanism	**Physiological process/variable affected**	**Examples**
Assimilate sapper	Maintenance/pool of assimilates	Aphids, rusts, septoria blotch
Light stealer	Light interception/green LAI	Rusts, powdery mildew, septoria blotch
Assimilate rate reducer	Photosynthesis/RUE	Eyespot, sharp eyespot, fusarium stem rot, take-all, weeds, BYDV, aphids

Rabbinge, R., Vereijken, P.H., 1980. The effect of diseases or pests upon the host. Z. Pflkrankh. Pflschutz 87, 409-422.

Boote, K.J., Jones, J.W., Mishoe, J.W., Berger, R.D., 1983. Coupling pests to crop growth simulators to predict yield reductions. Phytopathology 73, 1581-1587.

Simplified flow chart of WHEATPEST



Willocquet L, Aubertot JN, Lebard S, Robert C, Lannou C, Savary S. 2008. Simulating multiple pest damage in varying winter wheat production situations. Field Crops Research, 107 (1), p.12-28.

Modelling Actual Yield

Disease	Injury localisation	Data input in the model
Take-all	Roots	Percentage of take-all disease on roots.
Fusarium Stem Rot	Roots, Stems	percentages of tillers with Fusarium stem rot symptoms.
Eyespot	Stems	percentages of tillers with eyespot
Sharp-eyespot	Stems	percentages of tillers with sharp eyespot symptoms
Septoria nodorum blotch	Leaves	Septoria nodorum blotch severity
Septoria tritici blotch	Leaves	Septoria tritici blotch severity
Brown rust	Leaves	Brown rust severity
Yellow rust	Leaves	Yellow rust severity
Powdery Mildew	Leaves	Powdery Mildew severity
Fusarium Head Blight	Ears	percentage of kernels with Fusarium head blight symptoms
Aphids	Affect overall performance	Number of aphids
Weeds	Affect overall performance	Dry biomass of weeds
Barley Yellow Dwarf Viruses	Affect overall performance	Percentages of plants with Barley Yellow dwarf Viruses symptoms

Biomass production

$$RG = RAD * RUE * (1 - e^{-kLAI})$$

RG: Rate of Growth ($[RG]=MT^{-1}L^{-2}$)

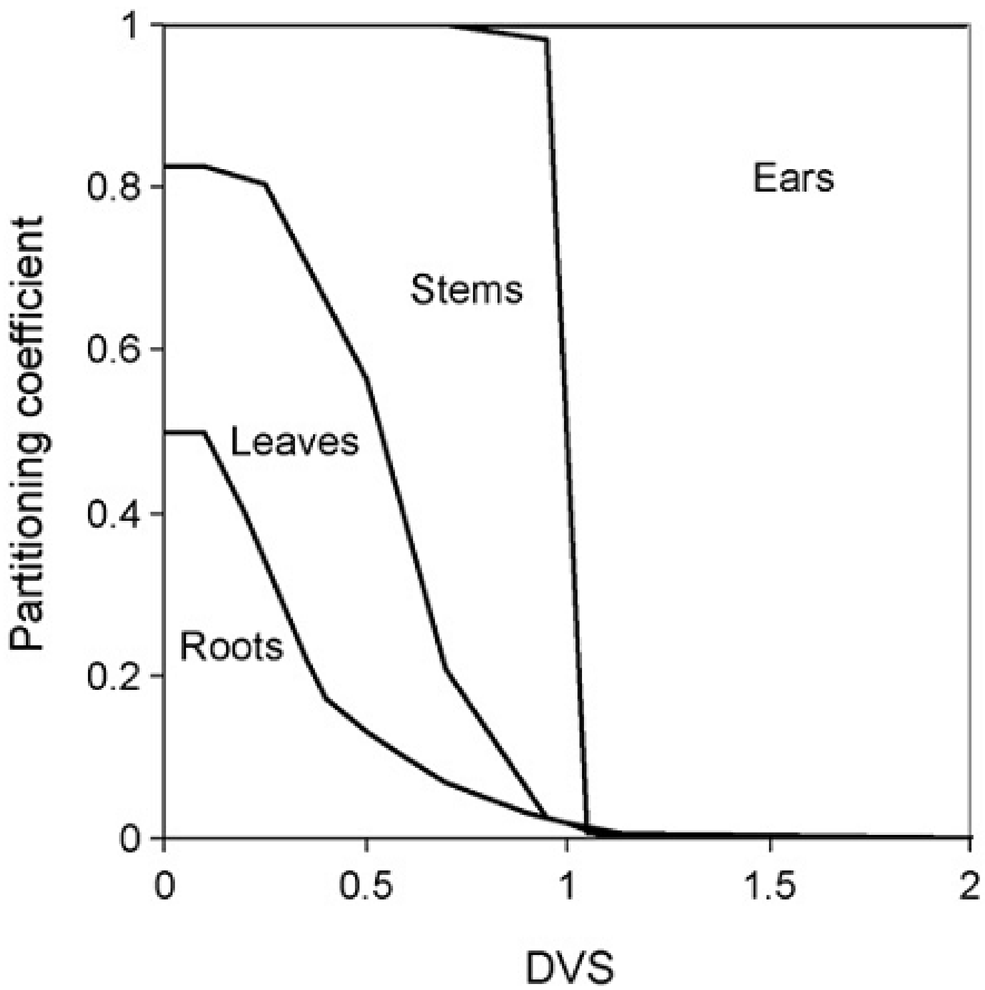
RAD: global RADiation ($[RAD]=MT^{-3}$)

RUE: Radiation Use Efficiency ($[RUE]=T^{2}L^{-2}$)

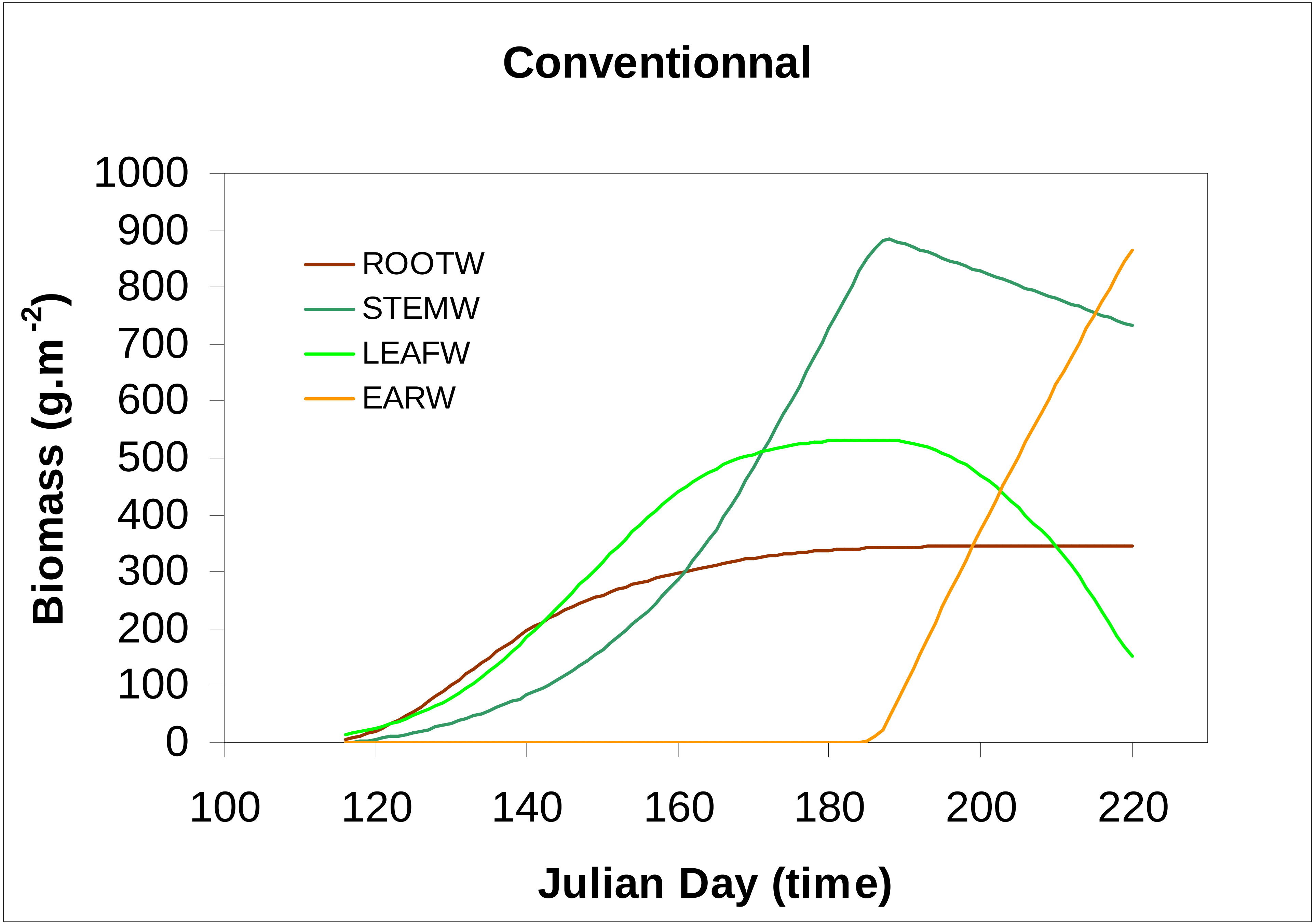
k: coefficient of light extinction ($[k]=1$)

LAI: Leaf Area Index ($[LAI]=1$)

Partitioning of assimilates to wheat organs as a function of development stage (DVS). Derived from Spitters et al (1989)



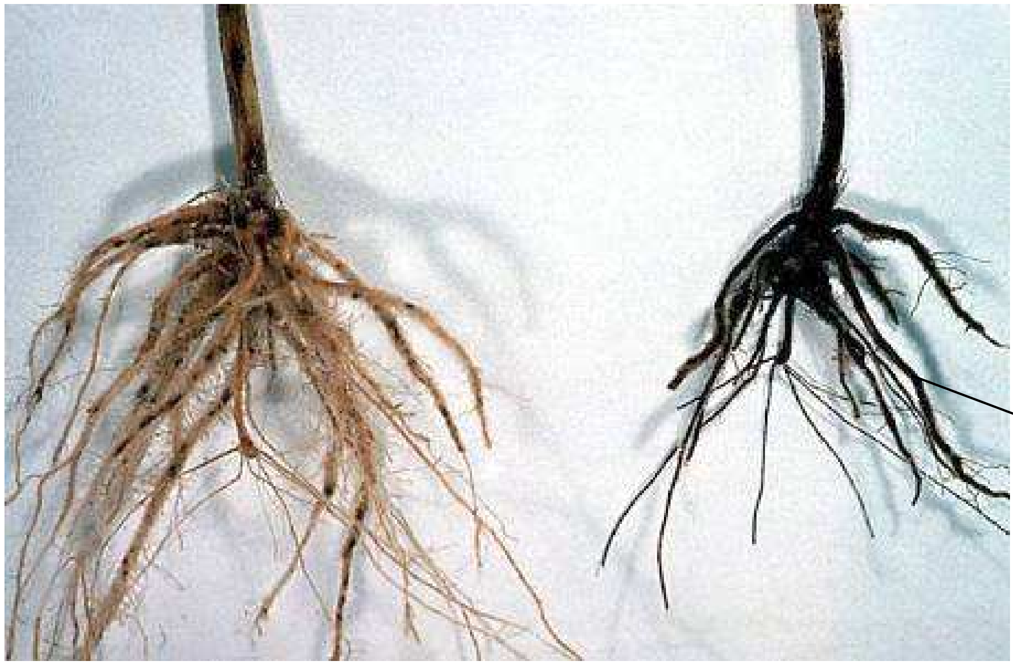
Output examples

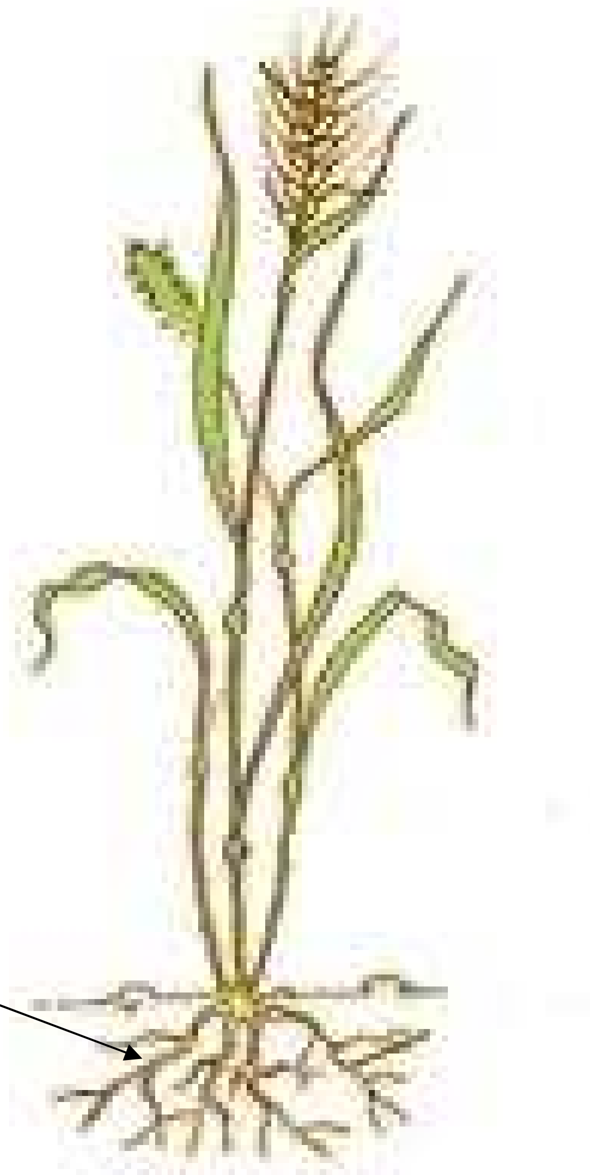


Root diseases

Take-all

• Blackened roots and stem bases on infected plants





Modelling damage mechanisms: take-all (*Gaeumannomyces gramini* var *tritici*)

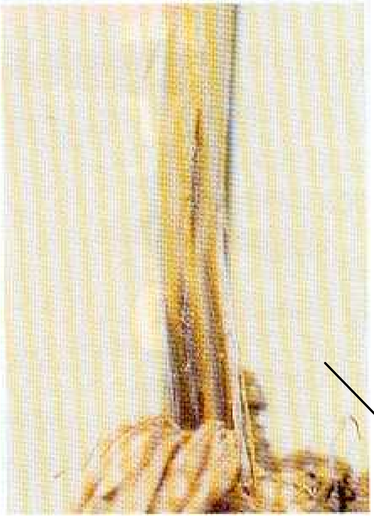
$$RF_{TAK} = 1 - TAK / 100$$

RF_{TAK}: reduction factor of RUE ([RF_{TAK}]=1)

TAK: root disease severity defined as the % of diseased root length ([TAK]=1)

Stem diseases

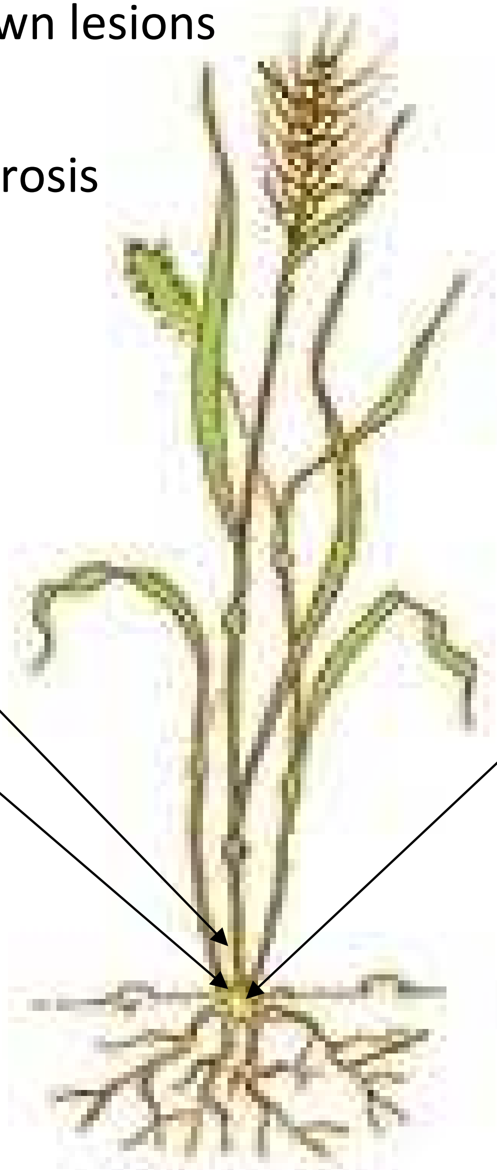
Fusarium Stem Rot



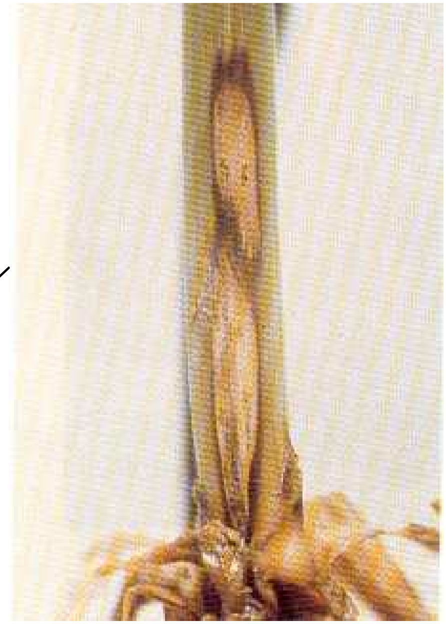
- linear and brown lesions
- no stroma
- superficial necrosis

Eyespot

- necrotic lesion ± limited
- stroma in the center
- severe penetrating lesion can result



Sharp Eyespot



- pale cream oval lesions with a dark brown margin
- superficial necrosis

Modelling damage mechanisms: Fusarium Stem Rot (*Fusarium graminearum, F culmorum, Microdochium nivale*)

$$RF_{FST} = 1 - \left(aFST1/100 + bFST2/100 \right)$$

RF_{FST}: reduction factor of RUE due to FST ([RF_{FST}]=1)

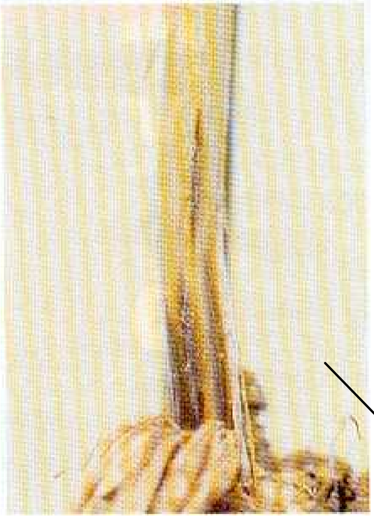
FST1: % of tillers with slight FST symptoms (browning up to second node [FST1]=1)

FST2: % of tillers with severe FST symptoms (browning up to third node or above [FST2]=1)

a and b: parameters derived from Smiley et al. (2005) ([a]=[b]=1)

Stem diseases

Fusarium Stem Rot



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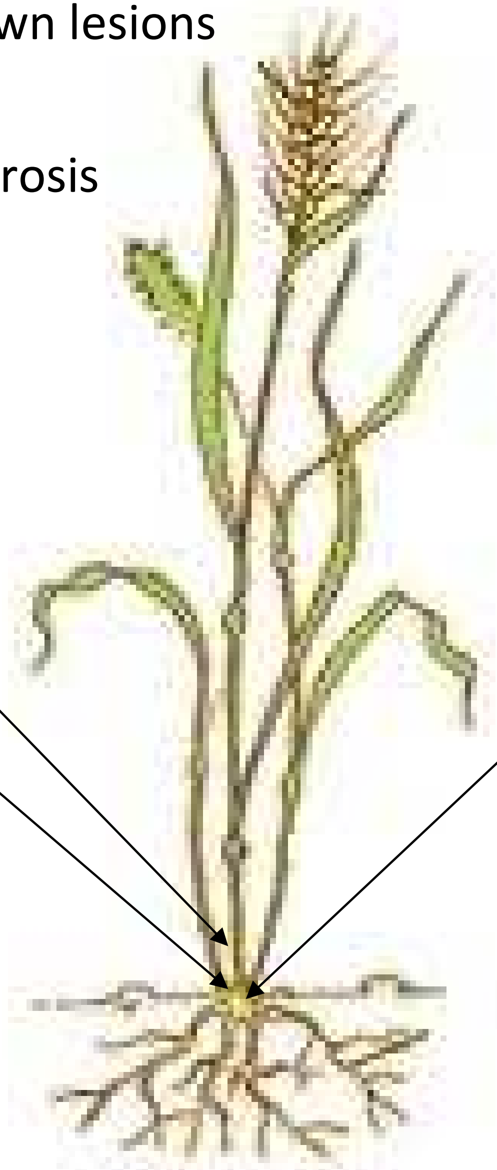


Sharp Eyespot

- pale cream oval lesions with a dark brown margin
- superficial necrosis

Modelling damage mechanisms: eyespot (*Oculimacula yallundae, O acuformis*)

$$RF_{EYS} = 1 - \left(aEYS1/100 + bEYS2/100 + cEYS3/100 \right)$$

RF_{EYS}: reduction factor of RUE due to EYS ([RF_{EYS}]=1)

EYS1: % of tillers with slight EYS symptoms (one or more lesions occupying in total less than half the circomference of the stem; [EYS1]=1)

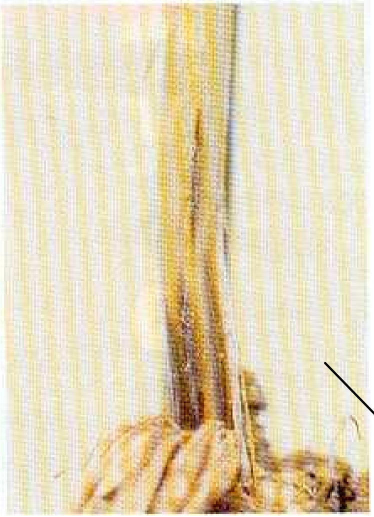
EYS2: % of tillers with moderate EYS symptoms (one or more lesions occupying in total more than half the circomference of the stem;[EYS2]=1)

EYS3: % of tillers with severe EYS symptoms (stem completely girdled by lesions, tissue softened; [EYS3]=1)

a, b, c : parameters derived from Clarkson et al. (1981) ([a]=[b] =[c]=1)

Stem diseases

Fusarium Stem Rot



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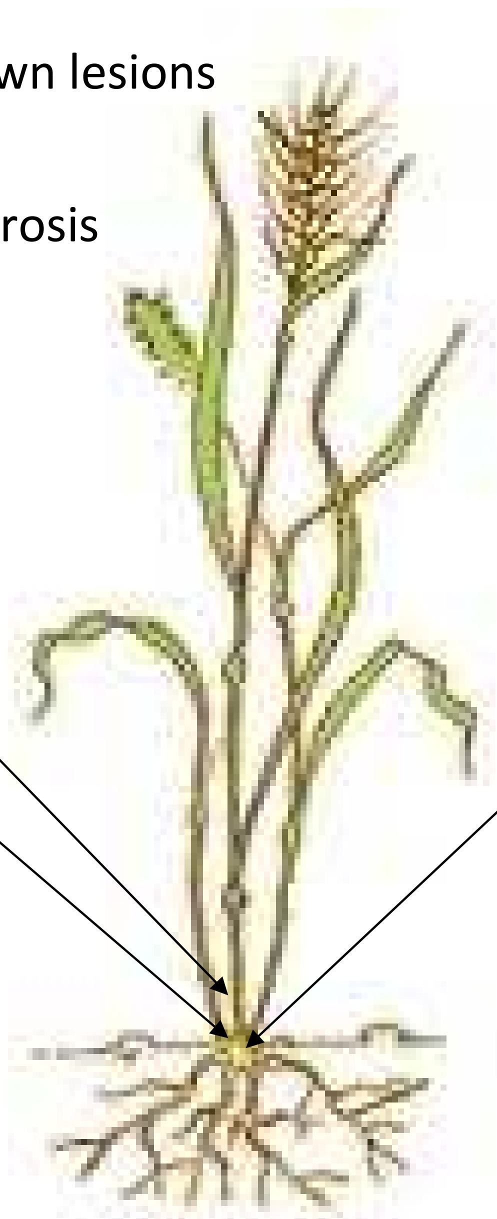
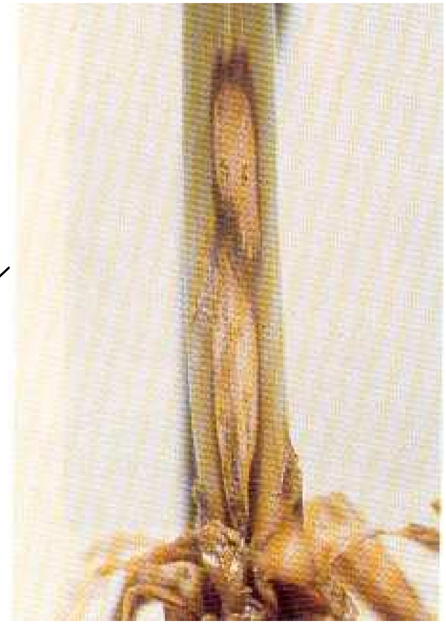


Sharp Eyespot



- pale cream oval lesions with a dark brown margin
- superficial necrosis

Modelling damage mechanisms: sharp eyespot (Rhizoctonia cerealis)

$$RF_{SHY} = 1 - \left(aSHY1/100 + bSHY2/100 + cSHY3/100 \right)$$

RF_{SHY}: reduction factor of RUE due to SHY ($[RF_{SHY}]$=1)

SHY1: % of tillers with slight SHY symptoms ([SHY1]=1)

SHY2: % of tillers with moderate SHY symptoms ([SHY2]=1)

SHY3: % of tillers with severe SHY symptoms ([SHY3]=1)

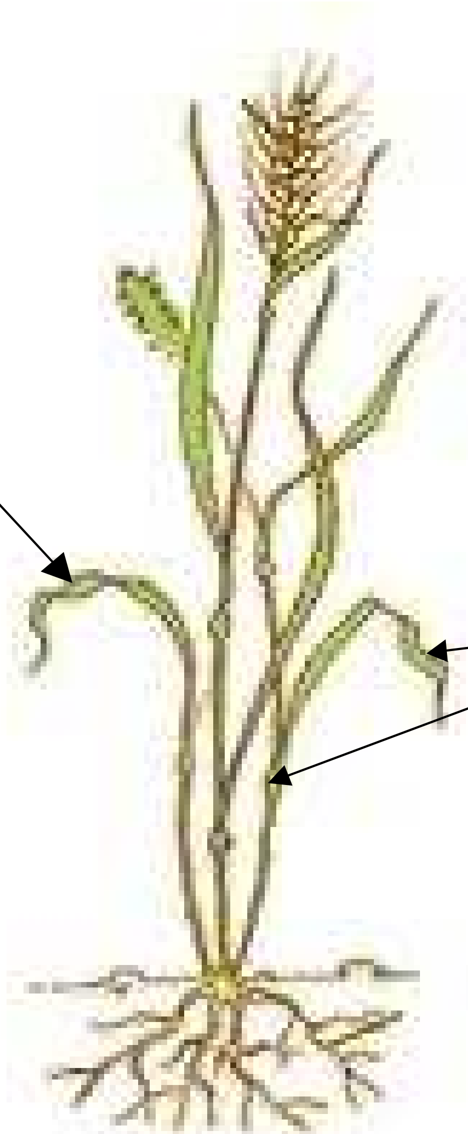
a, b, c : parameters derived from Clarkson and Cook (1983) ([a]=[b] =[c]=1)

Leaf and Stem diseases

Septoria tritici, S nodorum

• elongate ovals lesions, running parallel to leaf veins +chlorotic halo around the lesions.

• black pycnidia (spore cases) in mature lesions.



Powdery mildew

• white fluffy mildew pustule + black spores at the end of vegetation

Modelling damage mechanisms: septoria nodorum blotch (*septoria nodorum*)

$$LAI_{dis} = LAI\left(1 - x/100\right)^{\beta}$$

LAI_{dis}: reduced Leaf Area Index ([LAI_{dis}]=1)

LAI: Leaf Area Index ([LAI]=1)

x: severity of the disease expressed in % ([x]=1)

β: ratio of the virtual lesion area over the actual lesion area ([β]=1)

β=1 (Scharen and Taylor, 1968; Rooney, 1989)

Modelling damage mechanisms: septoria nodorum blotch (*septoria nodorum*)

$$RDIVSN = \alpha.RG.SN / 100$$

RDIVSN: daily rate of assimilate diversion ([RDIVSN]=MT-1L-2)

α: parameter, derived from Scharen and Taylor (1968) ([α]=1)

RG: rate of crop growth ([RG]=MT-1L-2)

SN: severity of septoria nodorum blotch expressed in % ([SN]=1)

Leaf and Stem diseases

Septoria tritici, S nodorum

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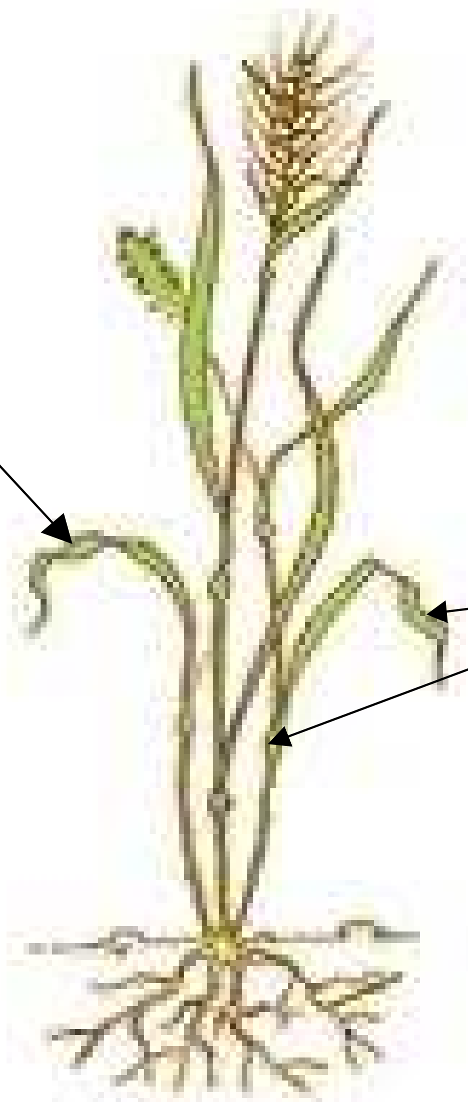

Powdery mildew

• white fluffy mildew pustule
+ black spores at the end of vegetation

Modelling damage mechanisms: septoria tritici blotch (*Mycosphaerella graminicola*)

$$LAI_{dis} = LAI\left(1 - x/100\right)^{\beta}$$

LAI_{dis}: reduced Leaf Area Index ([LAI_{dis}]=1)

LAI: Leaf Area Index ([LAI]=1)

x: severity of the disease expressed in % ([x]=1)

β: ratio of the virtual lesion area over the actual lesion area ([β]=1)

β=1.25 (Robert et al, 2006)

Modelling damage mechanisms: septoria tritici blotch (*Mycosphaerella graminicola*)

$$RDIVST = \alpha.RG.ST/100$$

RDIVST: daily rate of assimilate diversion ([RDIVST]=MT-1L-2)

α: parameter, derived from Scharen and Taylor (1968) ([α]=1)

RG: rate of crop growth ([RG]=MT-1L-2)

ST: severity of septoria tritici blotch expressed in % ([ST]=1)

Leaf and Stem diseases

Septoria tritici, S nodorum

• elongate ovals lesions, running parallel to leaf veins +chlorotic halo around the lesions.

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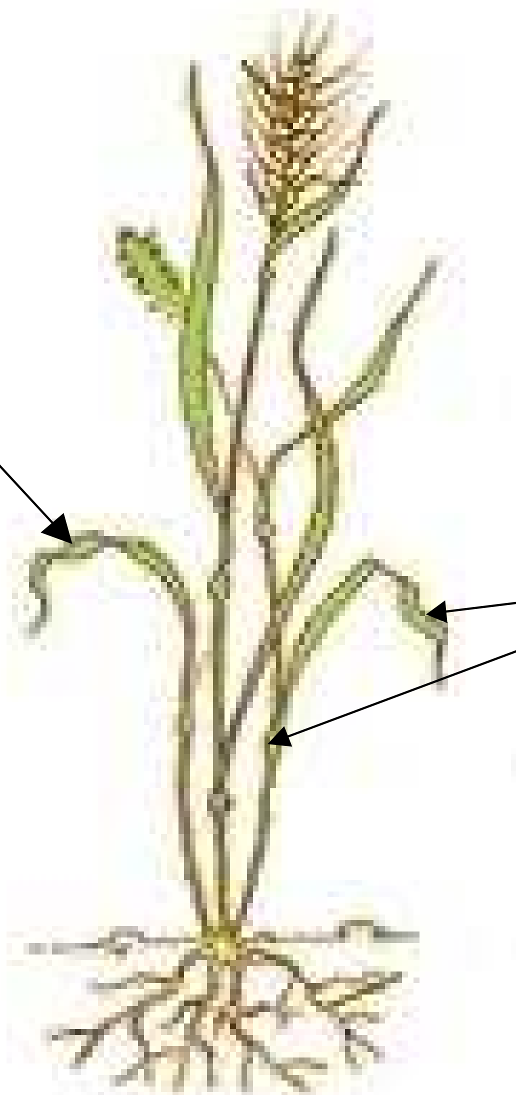


Powdery mildew

• white fluffy mildew pustule
+ black spores at the end of vegetation

Modelling damage mechanisms: powdery umildew (*Blumeria graminis*)

$$LAI_{dis} = LAI\left(1 - x/100\right)^{\beta}$$

LAI_{dis}: reduced Leaf Area Index ($[LAI_{dis}]=1$)

LAI: Leaf Area Index ([LAI]=1)

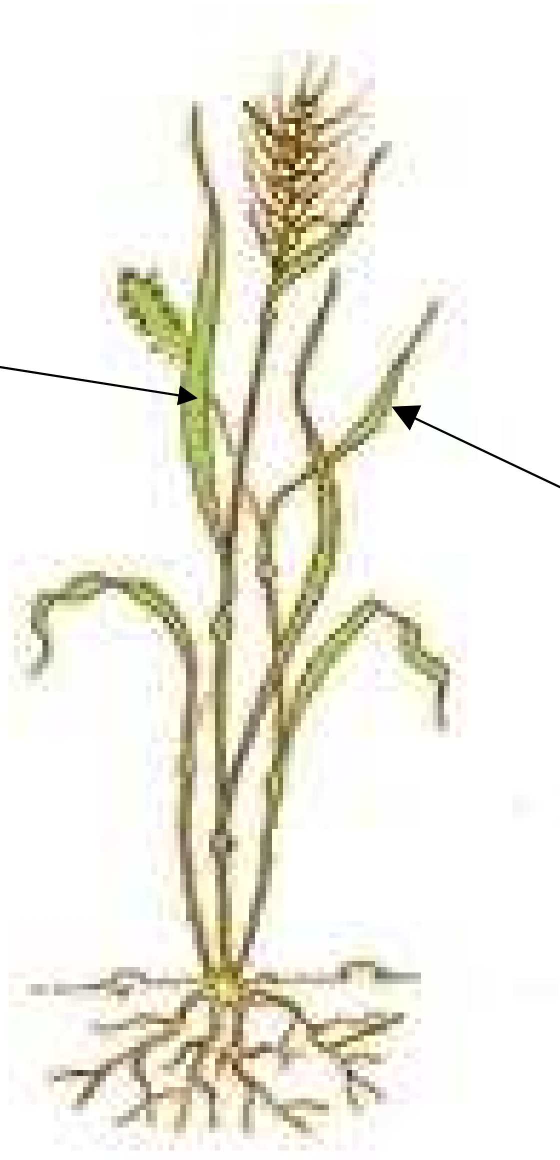
x: severity of the disease expressed in % ([x]=1)

β: ratio of the virtual lesion area over the actual lesion area ($[\beta]=1$)

β=2.5 (Rabbinge et al, 1985)

Leaf and Stem diseases

Yellow rust



Brown rust

• yellow and small pustules between veins in stripes

• big pustules scattered at random

Modelling damage mechanisms: yellow (stripe) rust (*Puccinia striiformis*)

$$LAI_{dis} = LAI\left(1 - x/100\right)^{\beta}$$

LAI_{dis}: reduced Leaf Area Index ($[LAI_{dis}]=1$)

LAI: Leaf Area Index ([LAI]=1)

x: severity of the disease expressed in % ([x]=1)

β: ratio of the virtual lesion area over the actual lesion area ($[\beta]=1$)

β=1.5 (Yang and Zeng, 1988)

Modelling damage mechanisms: yellow (stripe) rust (*Puccinia striiformis*)

$$RDIVYR = \alpha . NPUSYR$$

RDIVYR: daily rate of assimilate diversion ([RDIVYR]=MT-1L-2)

α: parameter, Savary et al (1990) ([α]=1)

NPUSYR: number of pustules of yellow rust per surface unit ([NPUSYR]=L-2)

$$NPUSYR = \left(YR/100\right).\left(LAI / SURFYR\right)$$

YR: severity of yellow rust expressed in % ([YR]=1)

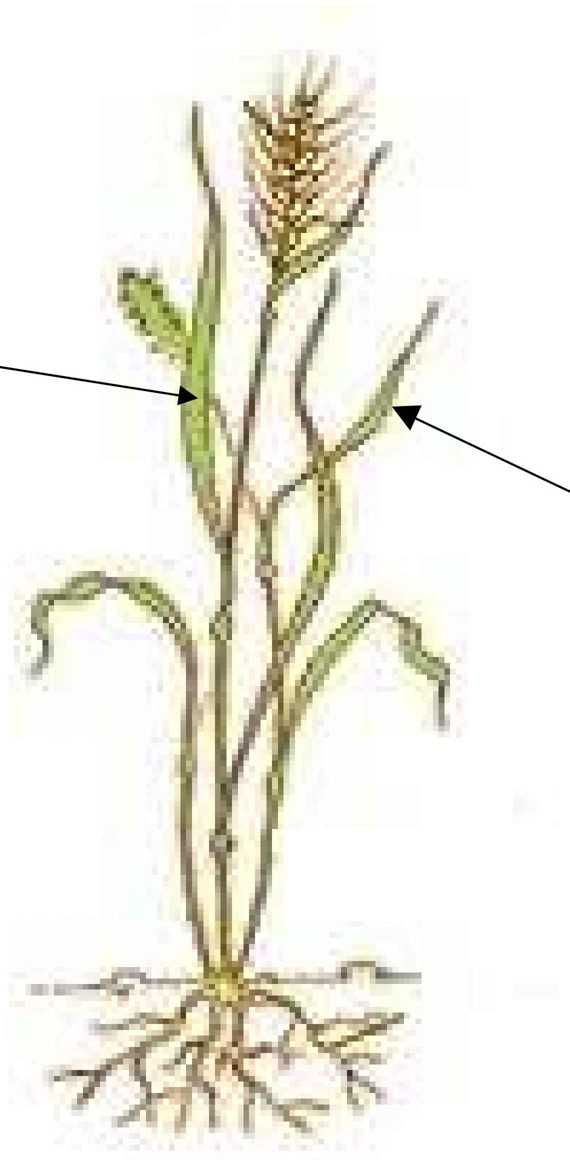
LAI: Leaf Area Index ([LAI]=1]

SURFYR: area of a pustule of a leaf rust ([SURFYR]=L^2)

SURFYR=1.0 10^{-6} m^2

Leaf and Stem diseases

Yellow rust



Brown rust

• yellow and small pustules between veins in stripes

• big pustules scattered at random

Modelling damage mechanisms: brown rust (*Puccinia triticina*)

$$LAI_{dis} = LAI\,(1 - x/100)^{\beta}$$

LAI_{dis}: reduced Leaf Area Index ($[LAI_{dis}]=1$)

LAI: Leaf Area Index ([LAI]=1)

x: severity of the disease expressed in % ([x]=1)

β: ratio of the virtual lesion area over the actual lesion area ($[\beta]=1$)

β=1 (Spitters et al, 1990; Robert et al, 2005)

Modelling damage mechanisms: brown rust (*Puccinia triticina*)

$$RDIVBR = \alpha.NPUSBR$$

RDIVBR: daily rate of assimilate diversion ([RDIVBR]=MT-1L-2)

α: parameter, Savary et al (1990) ([α]=1)

NPUSBR: number of pustules of yellow rust per surface unit ([NPUSBR]=L-2)

$$NPUSBR = \left(BR/100\right).\left(LAI/SURFBR\right)$$

BR: severity of brown rust expressed in % ([BR]=1)

LAI: Leaf Area Index ([LAI]=1)

SURFBR: area of a pustule of a leaf rust ([SURFBR]=L^2)

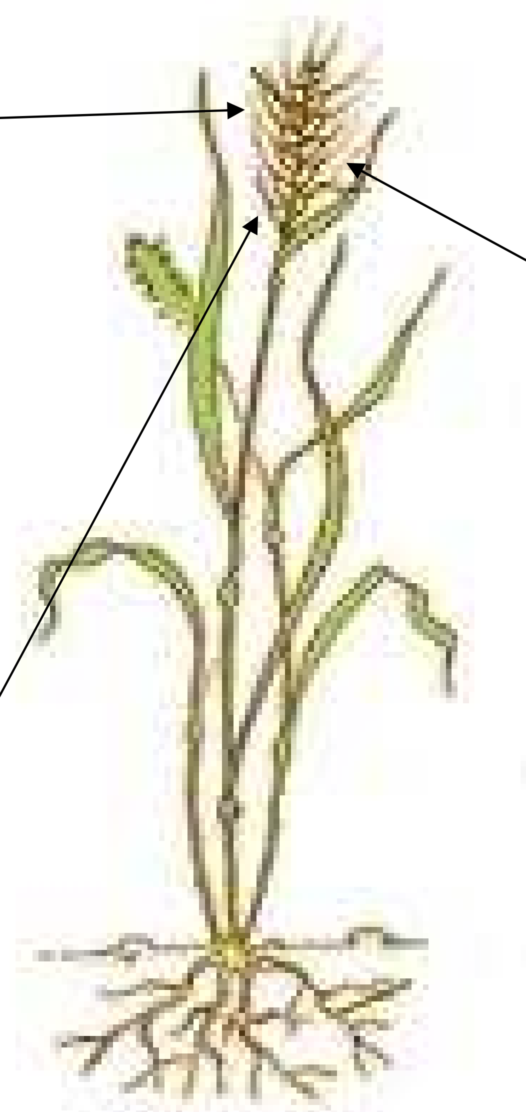
SURFBR=1.0 10^{-6} m^2

Ear diseases

Fusarium head blight

- brownish spot + discoloration
- premature death or bleaching of cereal spikelets

Septoria nodorum



- purple-brown lesions

Powdery mildew

- white mould mainly on surface of glumes

Modelling damage mechanisms: Fusarium head blight (*Fusarium graminearum, F culmorum, F avenaceum, F poae, Microdochium nivale*)

$$RF_{FHB} = 1 - \left(aFHB / 100 \right)$$

RF_{FHB}: reduction factor of grain biomass due to FHB ($[RF_{HB}]=1$)

FHB: percentage of disease kernels ([FHB]=1)

a=1.1 : parameter derived from Mesterhazy et al. (2003, 2005) ([a]=1)

…
aphids
weeds
viruses
…

Modelling damage mechanism: aphids (*Sitobion avenae*)

$$RSAP = RRSAP * APHBM * APH$$

RSAP: daily rate of assimilate sapping by aphids ([RSAP]=$MT^{-1}L^{-2}$)

RRSAP: relative feeding rate ([RRSAP]=T^{-1})

APHBM: fresh biomass of an individual aphid ([APHBM]=M)

APH: number of aphids per surface unit ([APH]=L^{-2})

Modelling damage mechanism: aphid example (*Sitobion avenae*)

$$RF_{APH} = MAX(1 - HONEY * 0.015; 0.8)$$

RF_{APH}: reduction of RUE caused by honeydew deposition ($[RF_{APH}]=1$)

HONEY: mass of accumulated honeydew per surface unit ($[HONEY]=ML^{-2}$)

$$RHONEY = 0.35 * RSAP$$

RHONEY: daily rate of honeydew accumulation ($[RHONEY]=MT^{-1}L^{-2}$)

Parameters from Mantel et al. (1982) and Rossing (1991)

...
aphids
weeds
viruses
...

Modelling damage mechanism: weeds

$$RF_{WD} = e^{-\alpha WD}$$

RF_{WD}: reduction factor of RUE due to weeds ($[RF_{WD}]=1$)

WD: dry biomass of weeds per surface unit ($[WD]=ML^{-2}$)

α=0.003: parameter (Willocquet et al, 2000) ($[\alpha]=L^2M^{-1}$)

…
aphids
weeds
viruses
…

Modelling damage mechanism: Barley Yellow Dwarf Viruses

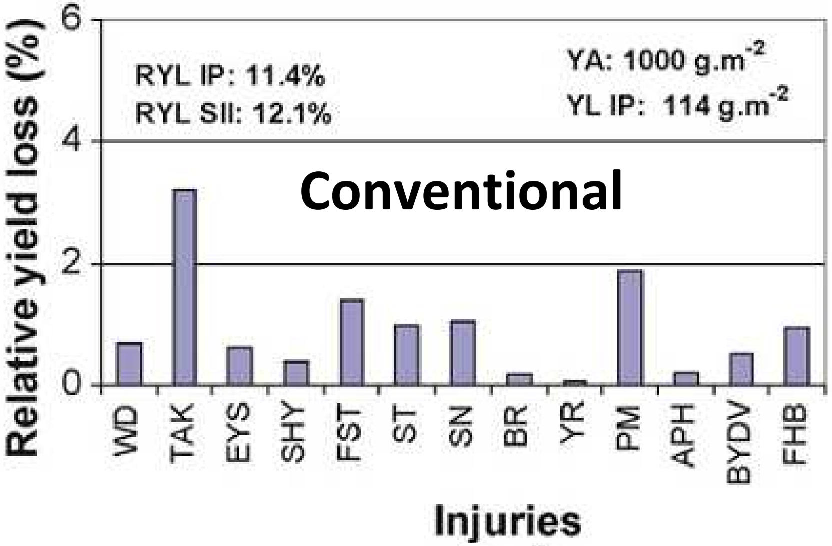
$$RF_{BYDV} = 1 - aBYDV / 100$$

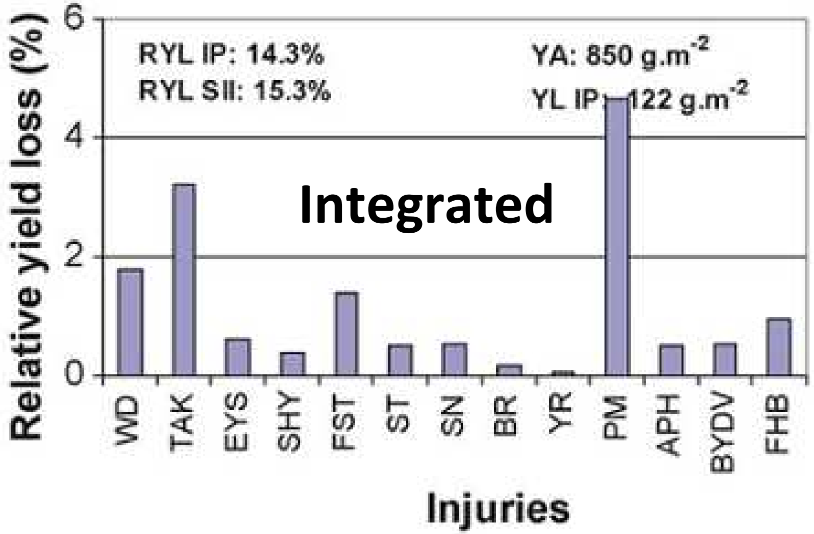
RF_{BYDV}: reduction factor of RUE due to BYDV ($[RF_{BYDV}]=1$)

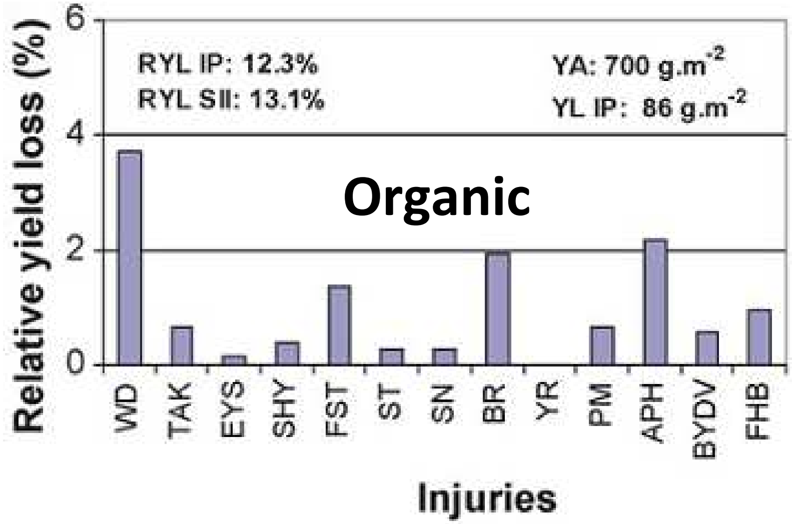
BYDV: % of diseased plants ([BYDV]=1)

a=0.35: parameter (Perry et al., 2000; McKirdy et al, 2002) ([a]=1)

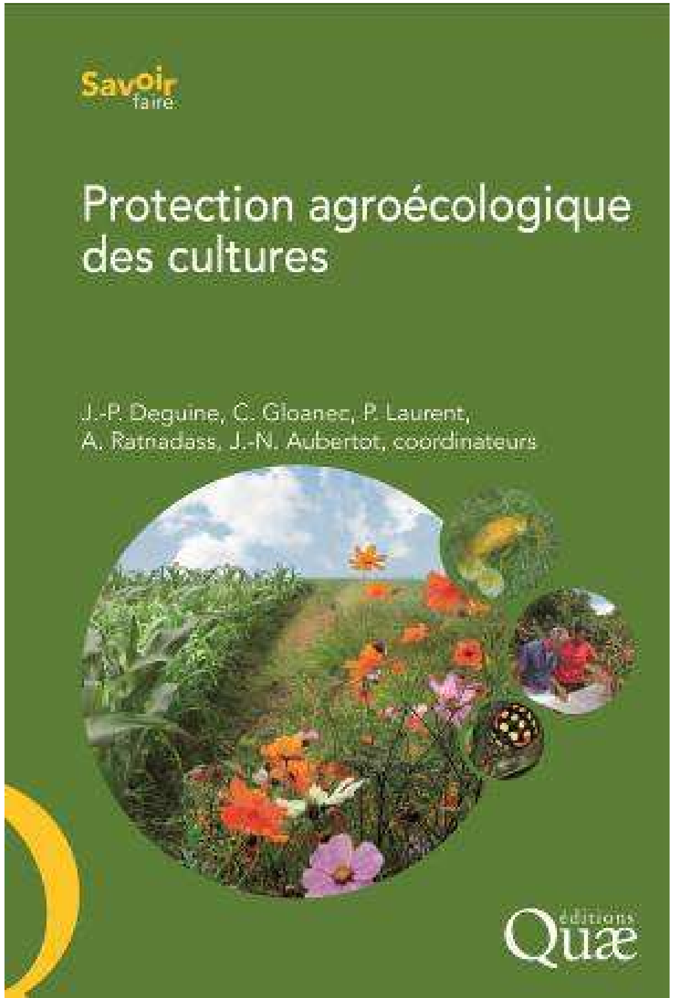
Output examples







Conclusion/perspectives



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