Modeling crop losses caused by pests & diseases and management

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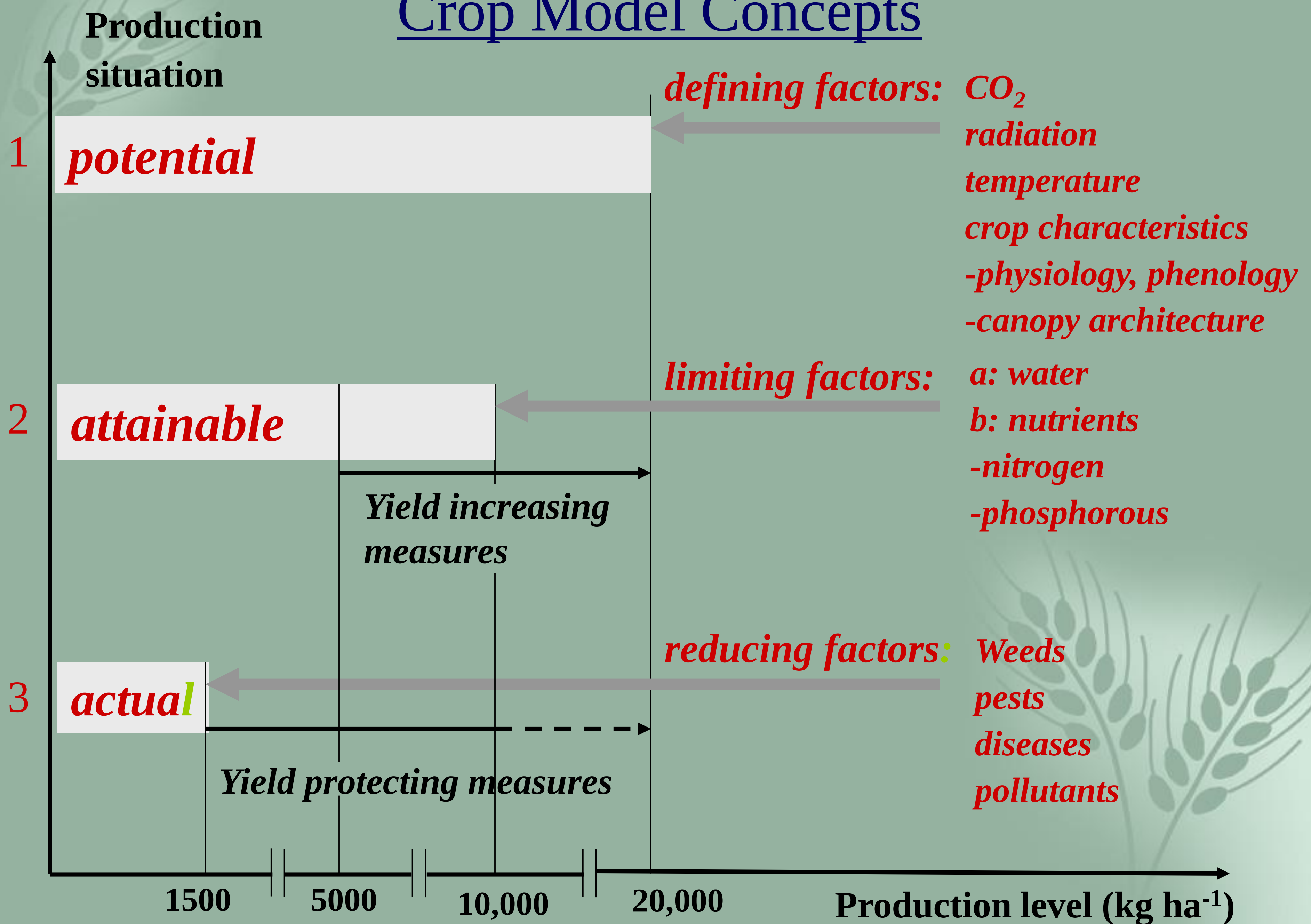
Feb 23-25, 2015

Crop Model Concepts



Coupling Pests in Crop Models

Present Limitations

- Most models predict yield as limited by weather, soil water supply, genetics, & cultural practices.
- Most models do not account for effects of biotic pests. Most do not include chemical application efficacy or crop genetic resistance.
- On-farm trials (or in developing countries) have serious pest limitations (defoliators, nematodes, leaf and soil-borne diseases) that decrease yield below potential yield.

Coupling Pests in Crop Models

How to account for Pests in Crop Models?

- Mechanistic simulation of pest dynamics, with concurrent coupling to the crop model?
- Generic approach – where “scouting data” on pest damage are input into the crop model.
- Goal: To describe how pests affect crop processes of carbon (N) flow, by which C (N) is fixed, moved, and converted to seed yield… whether at the level of input parameter, state variable, or rate process.

Coupling Pests in Crop Models

Pests Couple to Crops at Several Levels

- 1. Reduce Inputs (primarily light, water, and nutrients stolen by weeds)
- 2. Affect State Variables (mass or numbers of organs, leaf, stem, root, shell, seed)
- 3. Affect Process Rates directly (C input from photosynthesis and C losses to respiration, senescence, abscission)

Coupling Pests in Crop Models

Categories of Pest Damage

1. Assimilate sapper
2. Tissue consumer
3. Stand reducer
4. Leaf (assimilation) rate reducer
5. Leaf senescence enhancer
6. Light stealer
7. Water and nutrient stealer
8. Turgor reducer

***Pests can be in multiple categories*

Boote et al. 1983. Coupling pests to crop growth simulators to predict yield reductions. Phytopathology 73:1581-1587.

Coupling Pests in Crop Models
Assimilate Sapper

- **Examples**: Aphids, nematodes, diseases
- **Effect**: Lose soluble assimilate from any tissue
- **Need:** Timing and amount removed
- **Modules:** C & N balance, partitioning

Coupling Pests in Crop Models

Tissue Consumer

- **Examples**: Insects, pathogens
- **Effect**: Consume tissue mass such as leaf or root mass. Decreases these state variables.
- **Need:** When, amount, and distribution of mass removed
- **Modules:** C balance, N balance, light interception.

Coupling Pests in Crop Models
Stand Reducer

- **Examples**: Lesser cornstalk borer
- **Effect**: Lose plant mass (state var.)
- **Need:** Timing, number, and distribution of plants removed
- **Modules:** C & N balance, light interception, branching / tillering

Coupling Pests in Crop Models

Leaf Rate Reducer

- **Examples**: Pathogens, virus
- **Effect**: Decrease electron transport of photosynthesis (rate process)
- **Need:** Quantified pest levels at different canopy layers
- **Modules:** Light interception and photosynthesis

Coupling Pests in Crop Models

Leaf Senescence Enhancer

- **Examples**: Leafspot disease
- **Effect**: Accelerate leaf abscission (rate process)
- **Need:** Leaf senescence rate for canopy layers, as a function of pest infection.
- **Modules:** Light interception and photosynthesis

Coupling Pests in Crop Models
Light (water?) Stealer

- **Examples**: Weeds, pathogens
- **Effect**: Decrease PPFD to crop (input)
- **Need:** Vertical distribution of weed and crop leaf area.
- **Modules:** Light interception and photosynthesis, water balance

Coupling Pests in Crop Models
Turgor Reducer

- **Examples**: Nematodes, root diseases
- **Effect**: Decrease conductivity to water flow (rate process)
- **Need:** Root length density and conductivity
- **Modules:** Water balance, nutrient balance

Coupling Pests in Crop Models

Rootknot nematode – Hypothesizing Damage

1. Competition for plant assimilate
2. Reduction in root length density
3. Reduction in root conductivity to water flow.

Field experiments and model simulations (Stanton) support use of plant assimilate as primary effect for this nematode. Other nematodes may have greater effects on root length density and water flow.

Coupling Pests in Crop Models

Generic Pest Coupling in DSSAT

- INPUT: Scouting data on pest numbers or damage.
- COUPLING SUBROUTINE: Need to know coupling points and relationships of pest damage to crop processes and state variables.
- CROP MODEL: Simulate growth and yield, with or without the pest damage, to evaluate yield loss.

Pest Damage Introduced into DSSAT in 1993:

Batchelor et al. 1993. Extending the use of crop models to study pest damage. Trans. ASAE 36:551-558.

Boote et al. 1993. Pest damage relations at the field level. pp. 277-296. In: Systems Approaches for Agricultural Development. Kluwer Academic Publishers.

Coupling Pests in Crop Models

Pest Damage File (File T) in DSSAT

For Defoliating Pests, need date of damage, plus

1. Percent defoliation, or
2. Leaf mass removed (g/m^2), or
3. Leaf area removed (m^2/m^2), or
4. Numbers of insects (of each instar) per m^2 land area.

Pest parameter file: Defines coupling points or feeding rates

Coupling Pests in Crop Models
Coupling Subroutine in DSSAT

- Interface to crop model, and interpolate from damage files and pest parameter files, to create daily damage to the crop
- Convert damage to appropriate units
- Allows "switch" in model to run with, and without, pest, to predict yield loss

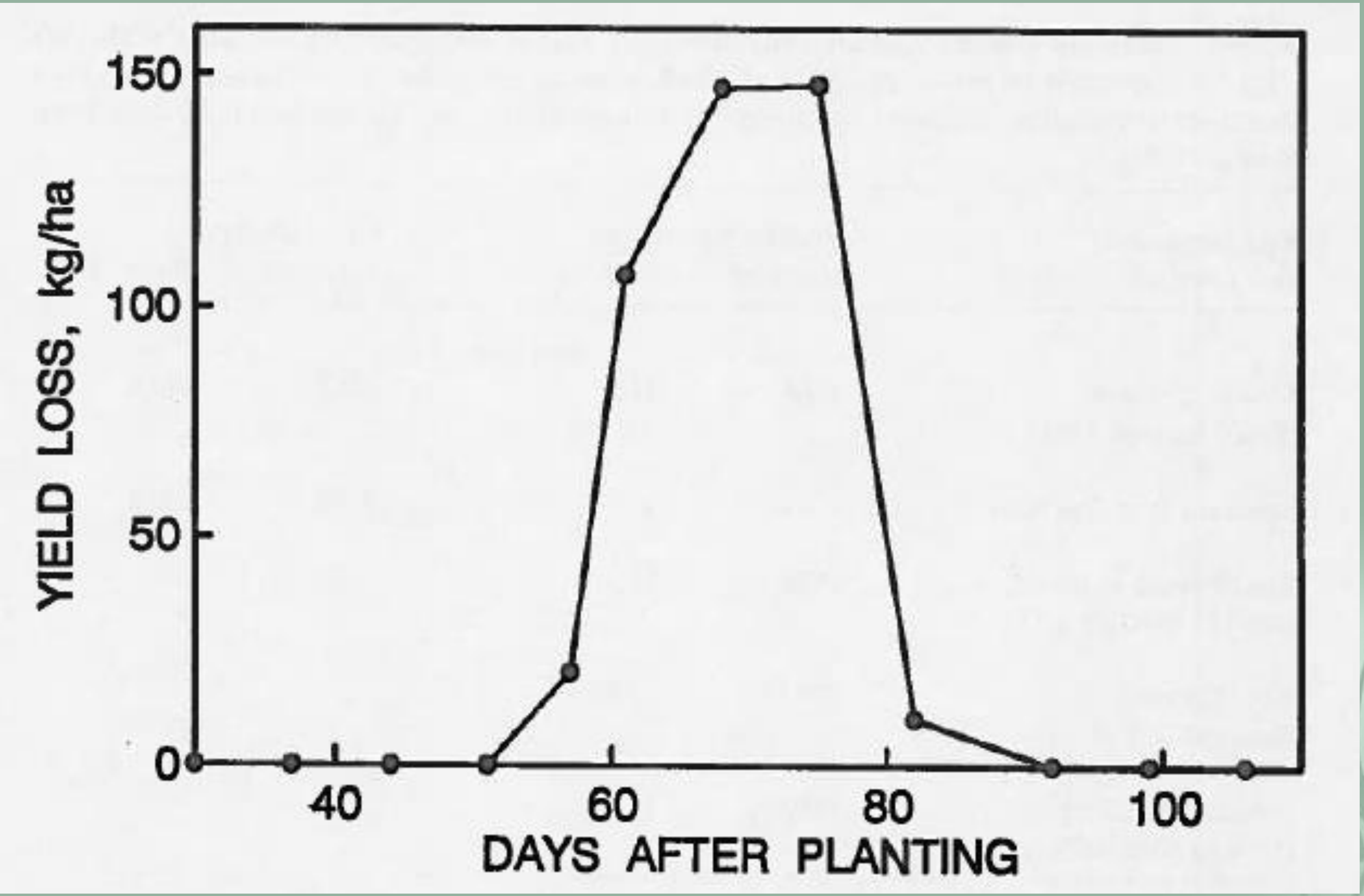
Coupling Pests in Crop Models

Some types of insect pests in DSSAT

• CEW	CEW #/row-m	Corn Earworm
• VBC5	VBC5 #/row-m	5th instar velvetbean caterpillar
• VBC6	VBC6 #/row-m	6th instar velvetbean caterpillar
• SL	SL #/row-m	Soybean looper
• SGSB	SGSB #/row-m	Southern green stinkbug
• FAW	FAW #/row-m	Fall armyworm

- These require values in XXGRO045.PST or MZCER045.PST files to define feeding rate per insect, amount of leaf area per day per instar.

SMARTSOY-simulated yield loss of Bragg soybean in Georgia as affected by introduction of 6.5 corn earworm per m row at different times after planting



Boote et al. 1993. Pest damage relations at the field level.. pp. 277-296. In: Systems Approaches for Agricultural Development. Kluwer Academic Publishers

Coupling Pests in Crop Models

Some types of pest damage in DSSAT

PCLA	% Cum Leaf	Cumulative Percent Leaf Area abscised
PDLA	% Dis. Leaf	Cumulative % Necrosis from Disease
DLA	DIS. LAI cm2/m2	Daily diseased leaf area increase
DLA%	DIS. LAI %/d	Daily % diseased leaf area increase
DLAI	LAI m2/m2/d	Daily leaf area consumed
DLFM	LEAF g/m2/d	Daily leaf mass consumed
DSTM	STEM g/m2/d	Daily stem mass consumed
DSDM	SEED g/m2/d	Daily seed mass consumed

- XXGRO045.PST defines coupling points and conversions. PCLA and PDLA are used for leafspot disease. PDLA has a virtual lesion effect, meaning that it affects 4 times as much leaf area as actual necrosis.

Pest Damage in CROPGRO Models

- Currently defined for all grain legumes:
  - Soybean, peanut, chickpea, drybean, faba bean, etc.
  - Tomato, bell pepper, cabbage
  - Bahia grass, Brachiaria
- Pest levels or damage entered in FileT
- Each crop has a XXGRO045.PST file that contains the definitions of damage or converts from pest level to damage level.
- Grazing animals are handled as pests (DLFM or DSTM = daily leaf or stem mass removed per day).
- For hay harvest, use MOW, to set (enter) residual shoot mass remaining.

Example of Pest Definitions for Peanut

PNGRO040.PST - Notepad

File Edit Format View Help

```
*PEANUT PEST COEFFICIENTS: CRGRO040 MODEL

01 CEW6  Corn Earworm           1 LAD   0.00505000   0.0000   m2/larva/d   Szmedra et al., 1988
02 VBC5  5 Instar Velvetbean    1 LAD   0.00081000   0.0000   m2/larva/d   Reid, 1975
03 VBC6  6 Instar Velvetbean    1 LAD   0.00144000   0.0000   m2/larva/d   Reid, 1975
04 SL4   Soybean Looper         1 LAD   0.00044000   0.0000   m2/larva/d   Reid and Green, 1975
05 SL5   Soybean Looper         1 LAD   0.00071000   0.0000   m2/larva/d   Reid and Green, 1975
06 SL6   Soybean Looper         1 LAD   0.00124000   0.0000   m2/larva/d   Reid and Green, 1975
07 FAW   Fall Armyworm          1 LMD   2.00000000   0.0000   g/larva/d    estimated
08 RTWM  rootworm               1 RLV   1.00000000   0.0000   cm/cm2/lar/d estimated
09 PCLA  Obs.% defoliation      2 LAD   1.00000000   0.0000   %            estimated
10 PSTM  Obs.% Stem damage      2 SMD   1.00000000   0.0000   %            estimated
11 PDLA  % Diseased Leaf Area 3 PDLA  4.00000000   0.0000   %/day        estimated
12 PRP   % Reduction in Photo 3 ASM   1.00000000   0.0000   %/day        estimated
13 PLAI  % daily LAI dest.      3 LAD   1.00000000   0.0000   %/day        estimated
14 PLM   % daily Leaf Mass      3 LMD   1.00000000   0.0000   %/day        estimated
15 PWP   % Whole Plants         3 WPD   1.00000000   0.0000   %/day        estimated
16 PSDN  % All Seed Dest.       3 SDNL  1.00000000   0.0000   %/day        estimated
                                  SDNS  1.00000000   0.0000   %/day        estimated
                                  SDNM  1.00000000   0.0000   %/day        estimated
17 PSHN  % All Shell Dest.      3 SHNL  1.00000000   0.0000   %/day        estimated
                                  SHNS  1.00000000   0.0000   %/day        estimated
                                  SHNM  1.00000000   0.0000   %/day        estimated
18 PPDN  % All Pod Dest.        3 PPDN  1.00000000   0.0000   %/day        estimated
19 PRTM  % Root mass dest.      3 RMD   1.00000000   0.0000   %/day        estimated
23 MOW   Top weight left.       3 TOPWT 1.00000000   0.0000   kg/ha top weight left
```

Example of Pest Damage for Peanut

UFGA7602.PNT - Notepad

File Edit Format View Help

*EXP.DATA (T): UFGA7601PN IRRIGATED, FLORUNNER

! File last edited on day 08/27/2003 at 11:24:45 AM
!

@TRNO	DATE	LAID	PCLA	PDLA	P#AD	SWAD	GWAD	LWAD	CWAD	PWAD	SHAD	HIPD	SH%D	SLAD
1	76147	0.11	0.0	0.0	0.	44.	0.	50.	93.	0.	0.	0.000	0.0	229.1
1	76154	0.26	0.0	0.0	0.	60.	0.	135.	195.	0.	0.	0.000	0.0	190.0
1	76161	0.52	0.0	0.0	0.	145.	0.	221.	366.	0.	0.	0.000	0.0	234.4
1	76168	0.68	0.0	0.0	0.	235.	0.	335.	570.	0.	0.	0.000	0.0	202.5
1	76175	1.22	0.0	0.0	0.	402.	0.	478.	880.	0.	0.	0.000	0.0	250.8
1	76182	2.91	0.0	0.0	12.	1072.	0.	1186.	2262.	4.	4.	0.002	0.0	246.8
1	76189	4.27	0.0	0.0	111.	1422.	0.	1685.	3160.	53.	53.	0.017	0.0	254.2
1	76196	6.11	0.0	0.0	192.	2616.	91.	2498.	5418.	304.	213.	0.056	21.3	244.6
1	76203	6.28	0.0	0.0	255.	3232.	359.	2600.	6569.	737.	378.	0.112	47.1	241.1
1	76210	6.28	0.0	0.0	487.	3533.	606.	2694.	7579.	1353.	747.	0.178	41.7	233.0
1	76217	6.89	0.0	1.0	359.	3737.	1183.	2644.	8353.	1973.	790.	0.236	59.2	260.1
1	76224	6.20	1.3	2.0	354.	3498.	1759.	2568.	8573.	2506.	747.	0.292	70.1	242.0
1	76231	5.37	14.5	3.0	402.	3874.	2377.	2354.	9507.	3278.	901.	0.345	72.4	228.7
1	76238	5.07	19.3	4.0	603.	3842.	3650.	2309.	10957	4805.	1155.	0.438	76.0	219.2
1	76245	3.42	45.5	5.0	492.	3544.	3539.	1781.	9938.	4614.	1075.	0.464	76.6	192.0
1	76252	2.06	67.2	7.0	475.	3159.	4034.	1187.	9438.	5092.	1058.	0.540	79.1	173.2
1	76259	1.93	69.3	9.0	479.	3127.	4006.	1022.	9267.	5118.	1112.	0.552	78.1	187.4
1	76266	1.12	82.2	10.0	455.	2855.	3815.	644.	8322.	4822.	1007.	0.579	79.2	175.5
1	76273	.	82.2	10.0	574.	3062.	4522.	481.	9102.	5559.	1037.	0.611	81.2	.
1	76280	.	82.2	10.0	577.	3227.	4718.	546.	9580.	5807.	1089.	0.606	81.2	.
2	76147	0.11	0.0	0.0	0.	44.	0.	50.	93.	0.	0.	0.000	0.0	229.1
2	76154	0.26	0.0	0.0	0.	60.	0.	135.	195.	0.	0.	0.000	0.0	190.0
2	76161	0.52	0.0	0.0	0.	145.	0.	221.	366.	0.	0.	0.000	0.0	234.4
2	76168	0.68	0.0	0.0	0.	235.	0.	335.	570.	0.	0.	0.000	0.0	202.5
2	76175	1.22	0.0	0.0	0.	402.	0.	478.	880.	0.	0.	0.000	0.0	250.8
2	76182	2.91	0.0	0.0	12.	1072.	0.	1186.	2262.	4.	4.	0.002	0.0	246.8
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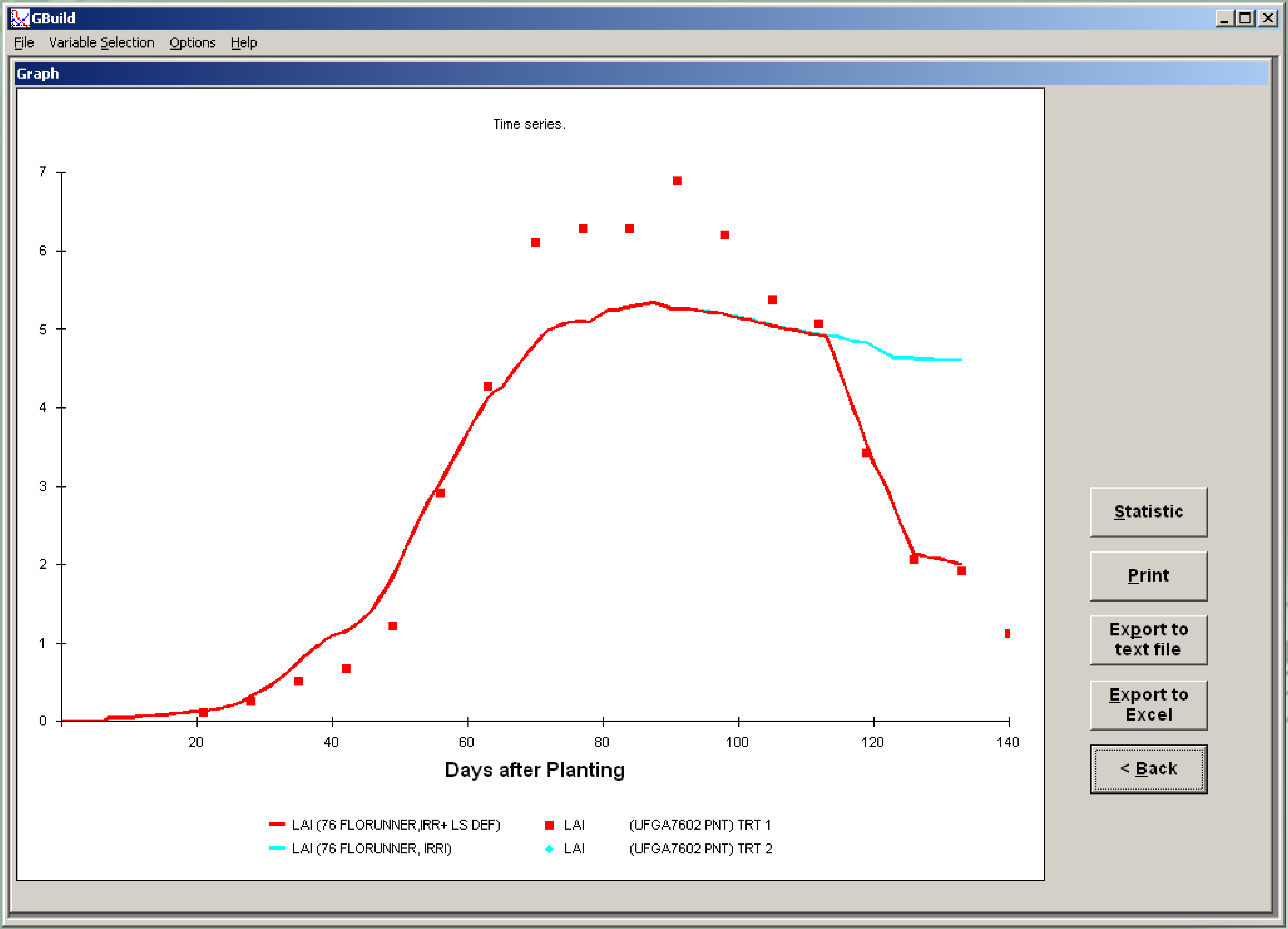
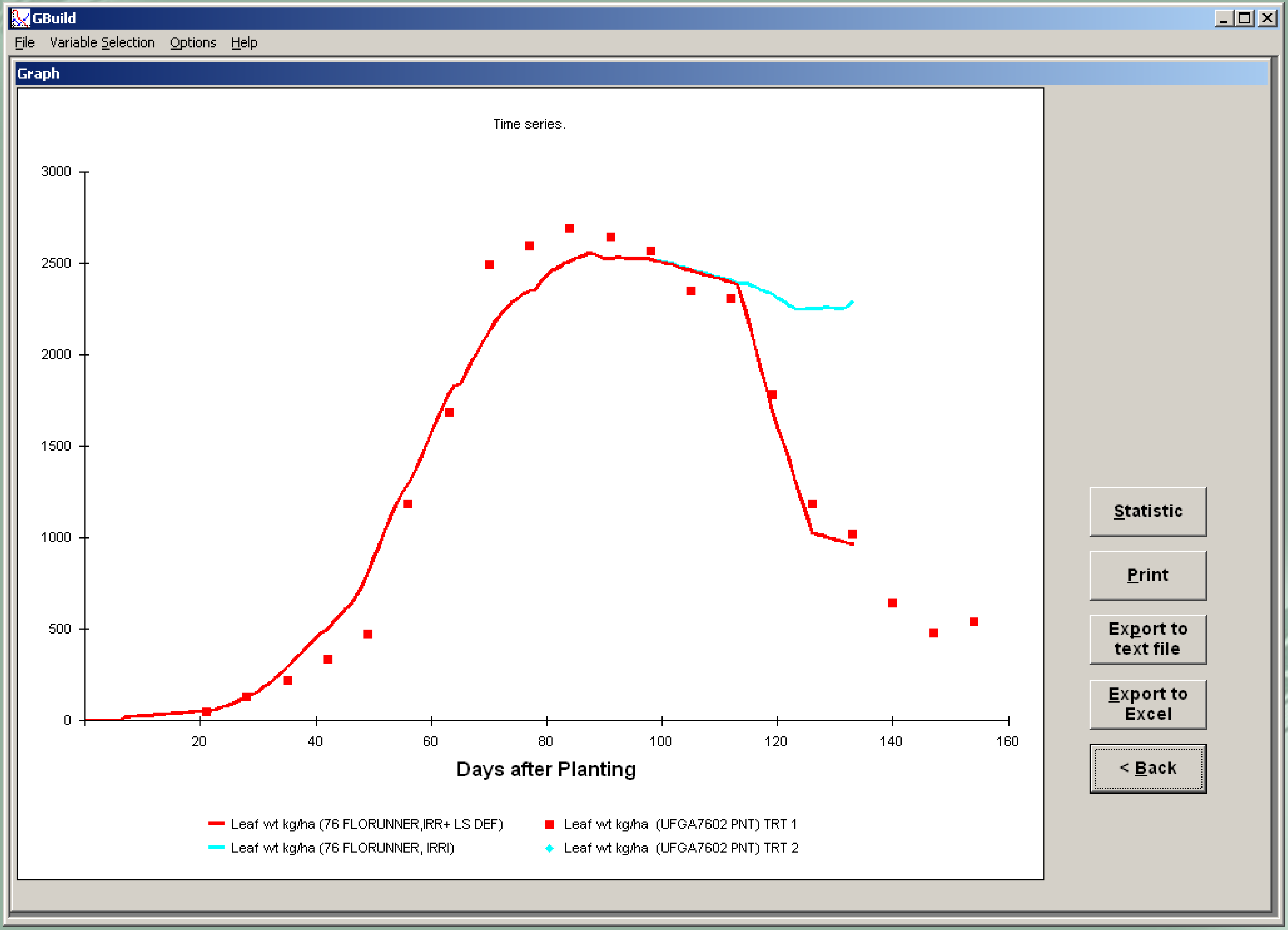
2	76231	5.37	0.0	0.0	402.	3874.	2377.	2354.	9507.	3278.	901.	0.345	72.4	228.7

Leaf Area Index



Leaf weight



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Leaf wt kg/ha (76 FLORUNNER,IRR+ LS DEF)
Leaf wt kg/ha (UFGA7602 PNT) TRT 1
Leaf wt kg/ha (76 FLORUNNER, IRRI)
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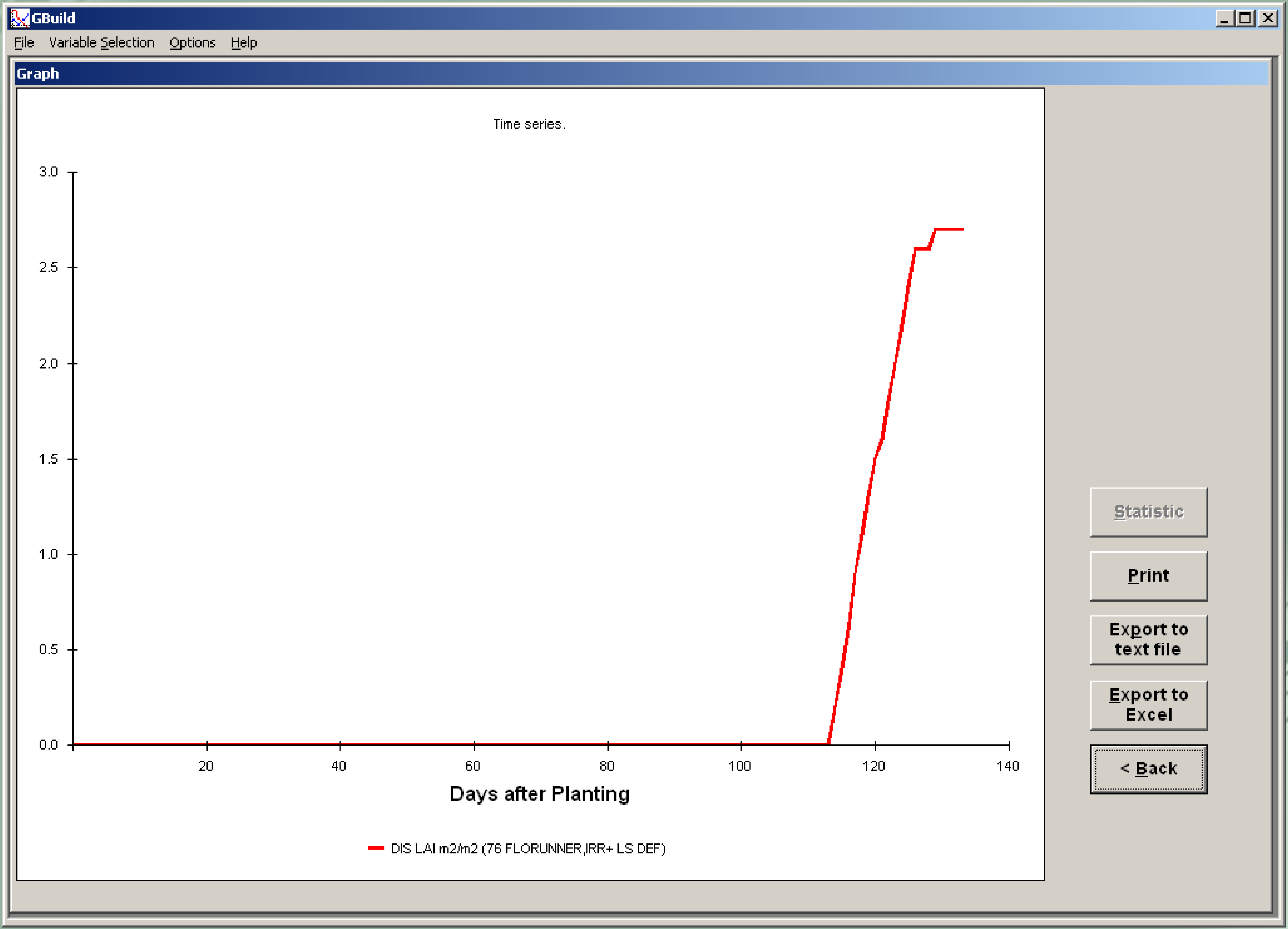
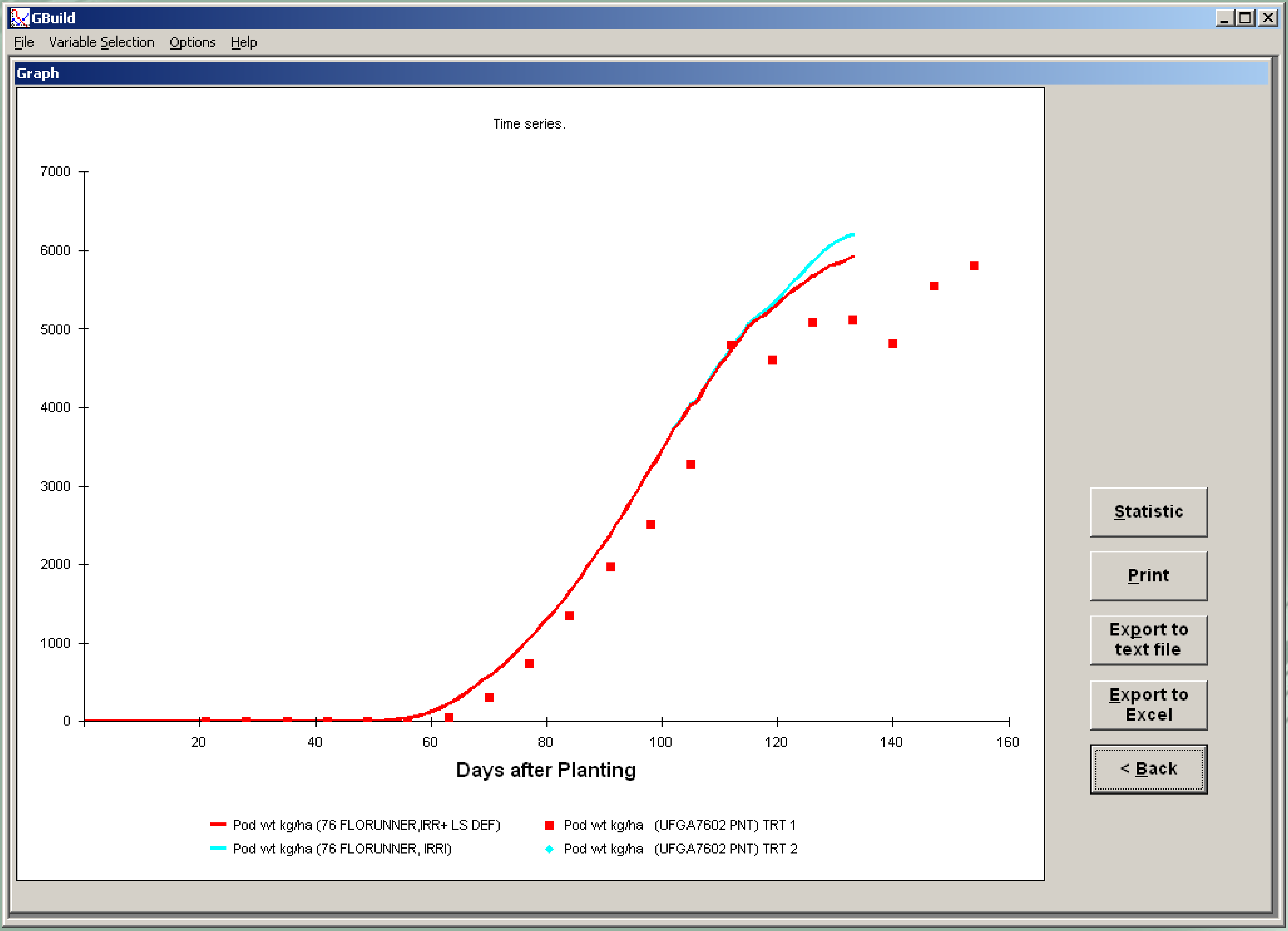
Cumulative Leaf Area Consumed



Pod Weight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Days after Planting
Pod wt kg/ha (76 FLORUNNER,IRR+ LS DEF)
Pod wt kg/ha (76 FLORUNNER, IRRI)
Pod wt kg/ha (UFGA7602 PNT) TRT 1
Pod wt kg/ha (UFGA7602 PNT) TRT 2
Statistic
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Pest Damage in CERES Models

- Currently defined for the following grain cereals:
  - Maize, sorghum and millet.

- Pest levels or damage entered in FileT
- Each crop has a XXCER045.PST file that contains the definitions of damage or converts from pest level to damage level.

Pest Damage in the CERES Models

- Damage types currently available in CERES
  - Leaf weight
  - Leaf area (absolute and percent)
  - Stem weight (absolute and percent)
  - Root weight (absolute and percent)
  - Seed weight (absolute and percent, also reduces seed no.)
  - Whole Plants (absolute and percent)
  - Reduction in daily assimilate produced (percent)

Application of DSSAT Models for Simulating Pest Damage

Examples – Leafspot Disease in Florida & Ghana

Advancing Pest and Disease Modeling
Gainesville, FL (23-25 Feb 2015)

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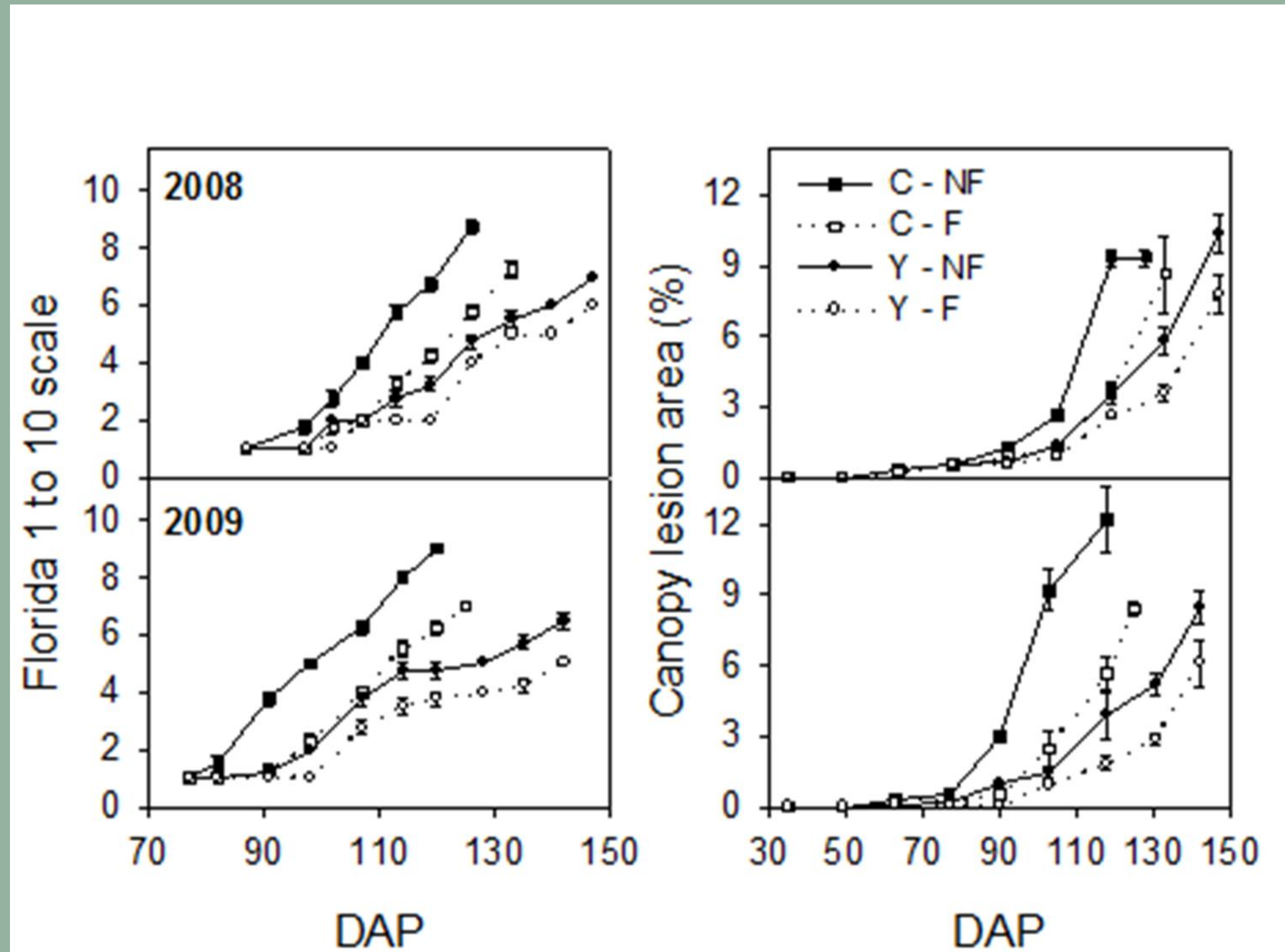
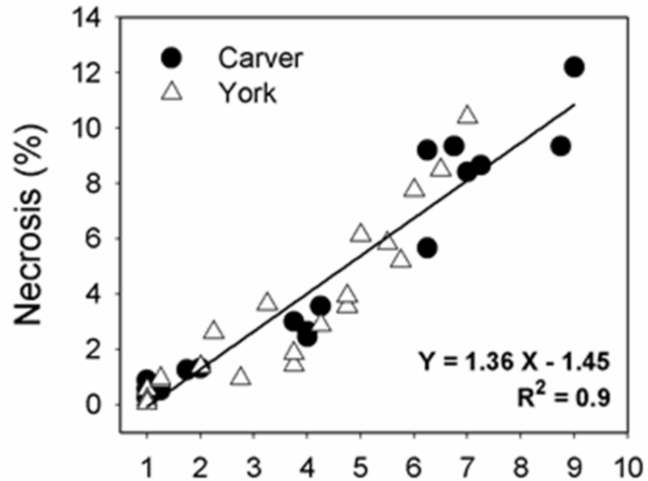
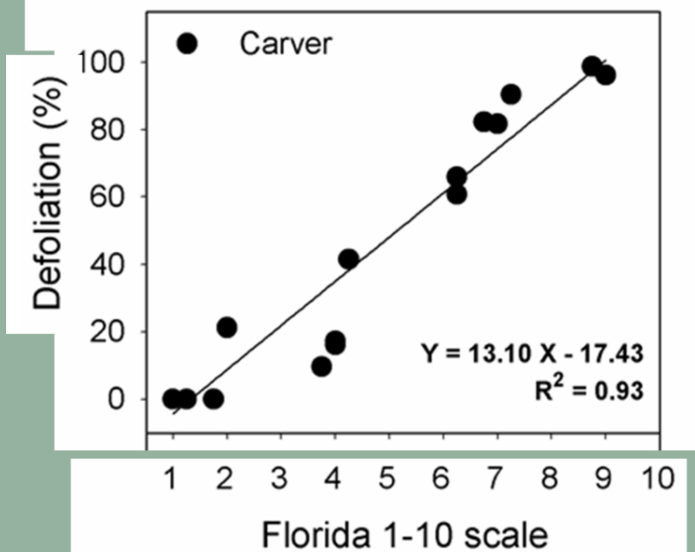
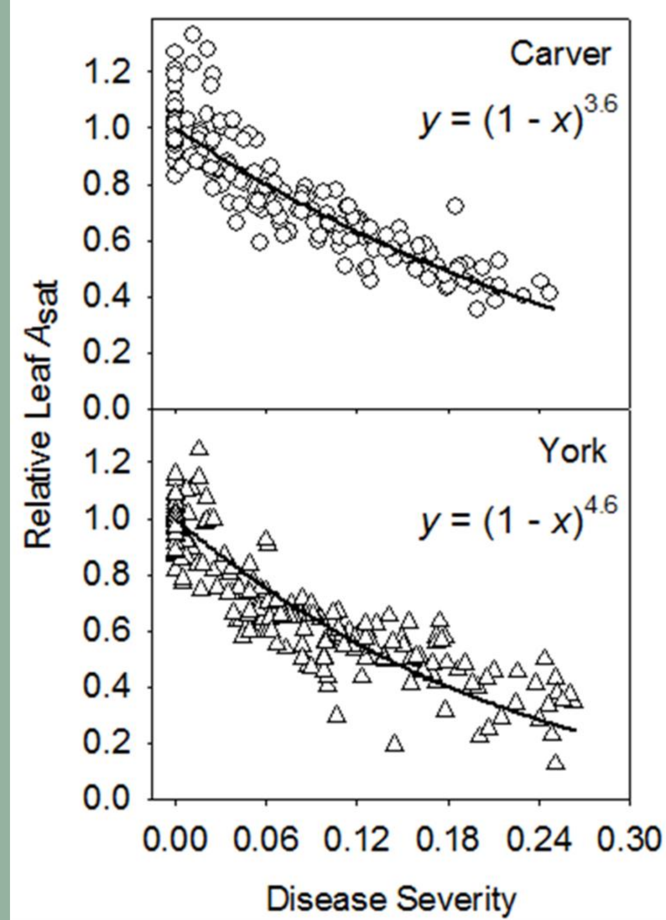
AgMIP The Agricultural Model Intercomparison and Improvement Project



Peanut leaf spot disease rating on 1 to 10 Florida scale and observed percent canopy area necrosis in Florida (Singh et al., 2013).



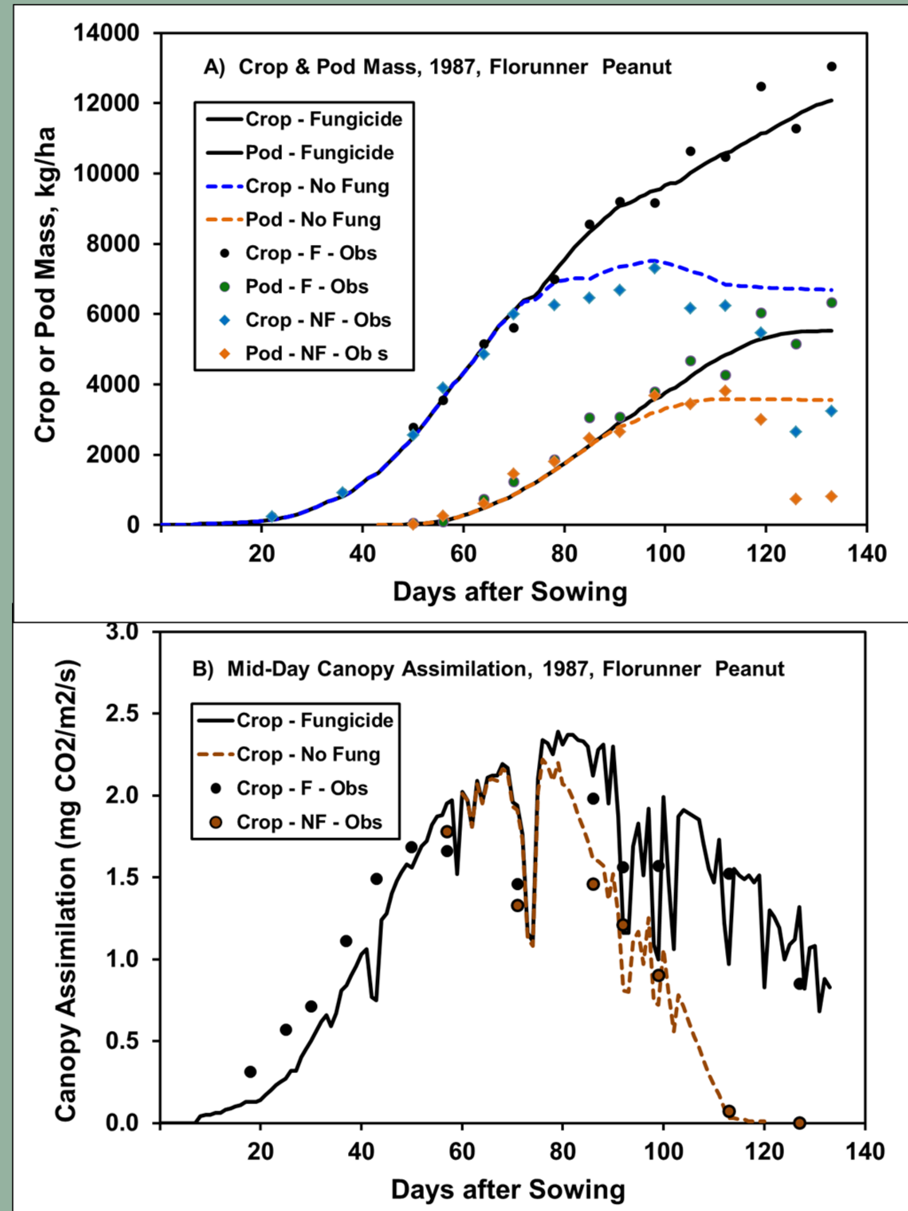




Equations to translate: % defoliation and % necrosis as function of Florida 1-10 leafspot disease scale (Singh et al., 2013). Use as inputs to model.

Define cultivar sensitivity (Beta) of leaf assimilation (Asat) vs. percent necrosis (Singh et al., 2011).

Simulated and observed: (A) crop and pod mass & (B) mid-day canopy assimilation of Florunner peanut with, and without fungicide application using disease function (Bourgeois et al., 1991, 1992).



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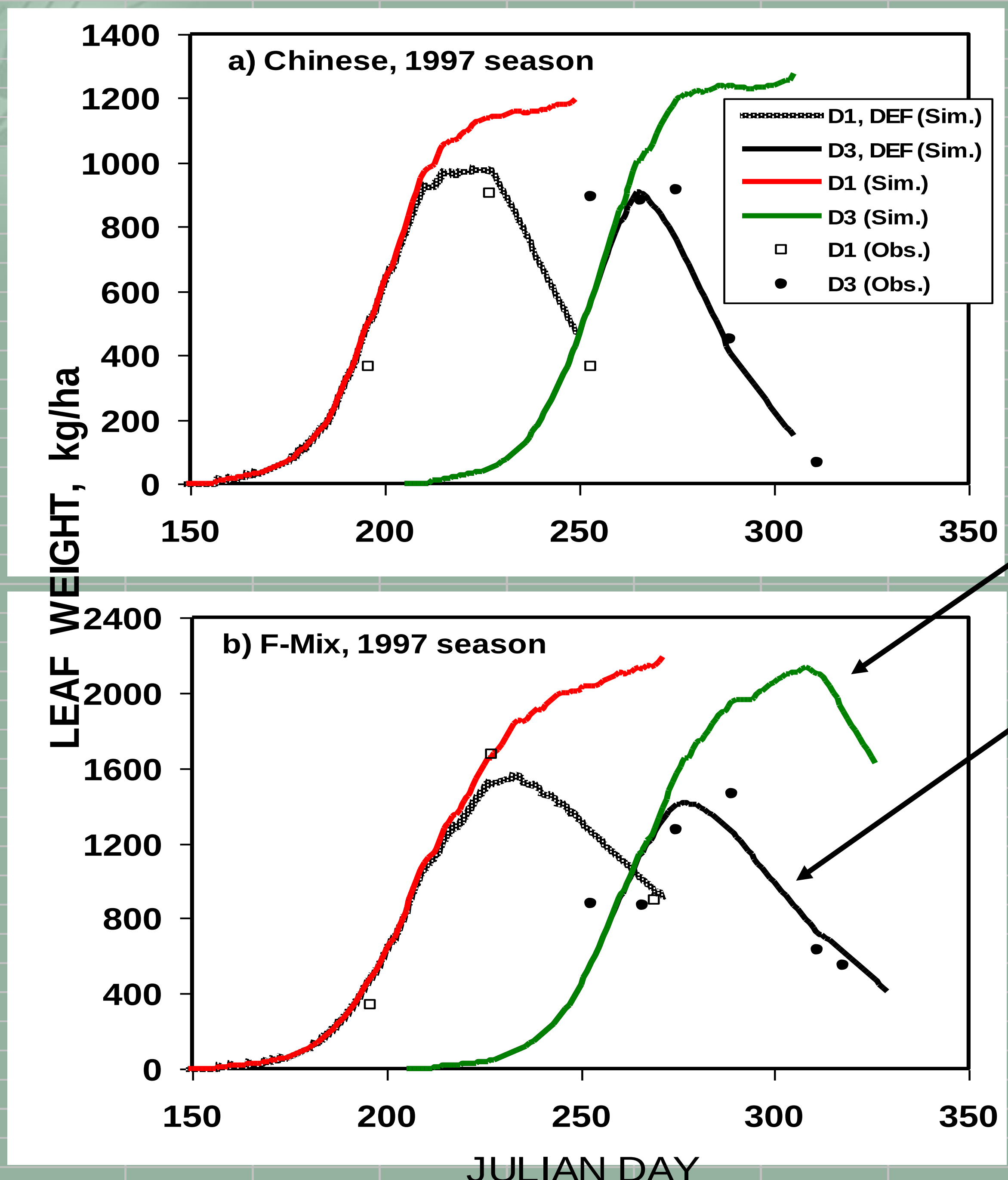


Peanut CRSP

J. Naab – Ghana

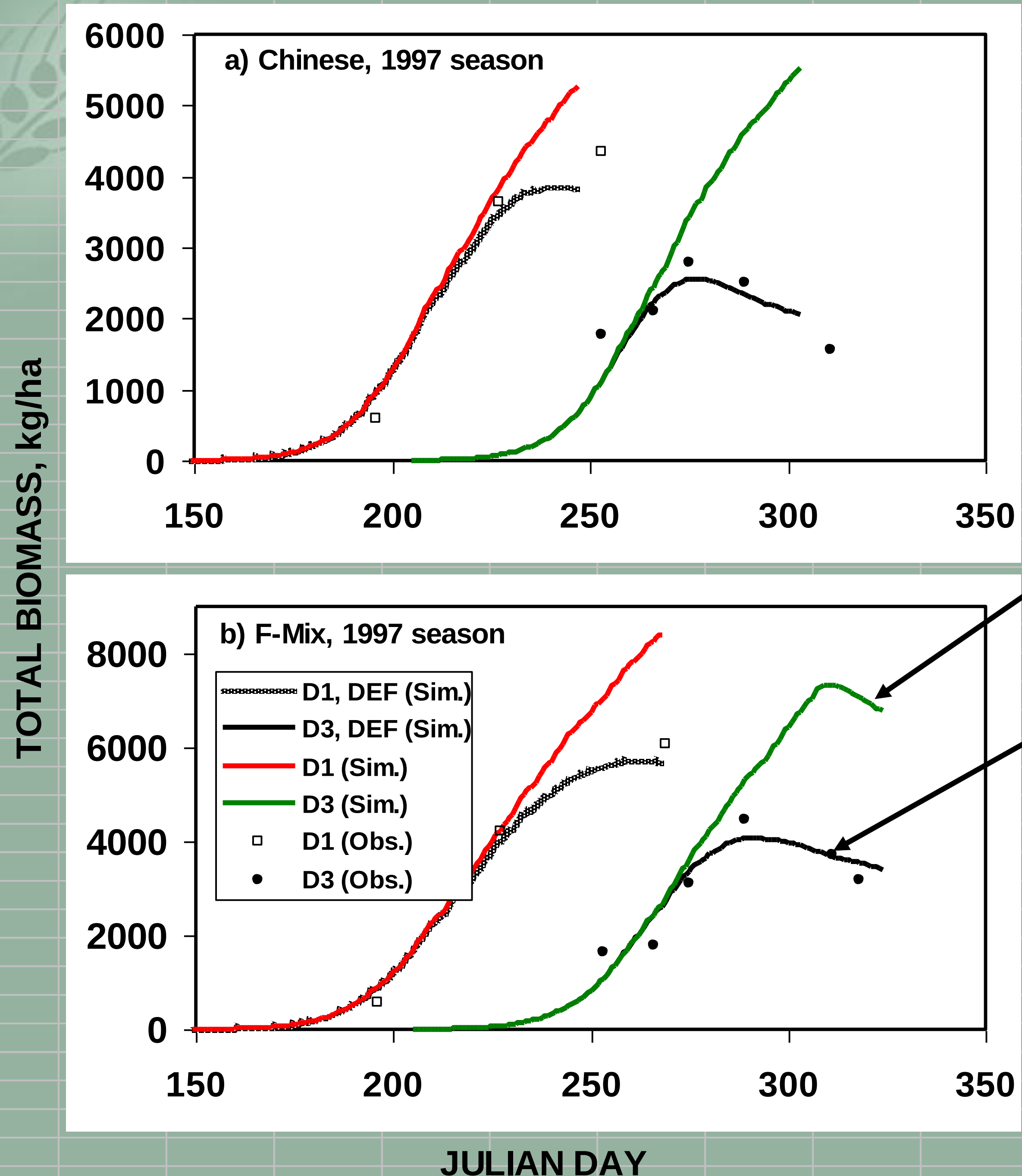
Naab et al. 2004. Agron. J. 96:1231-1242.

Simulated with no disease effect

Simulated with input defoliation to match observed.

Crop had no fungicide applied

Late sowing ~more disease



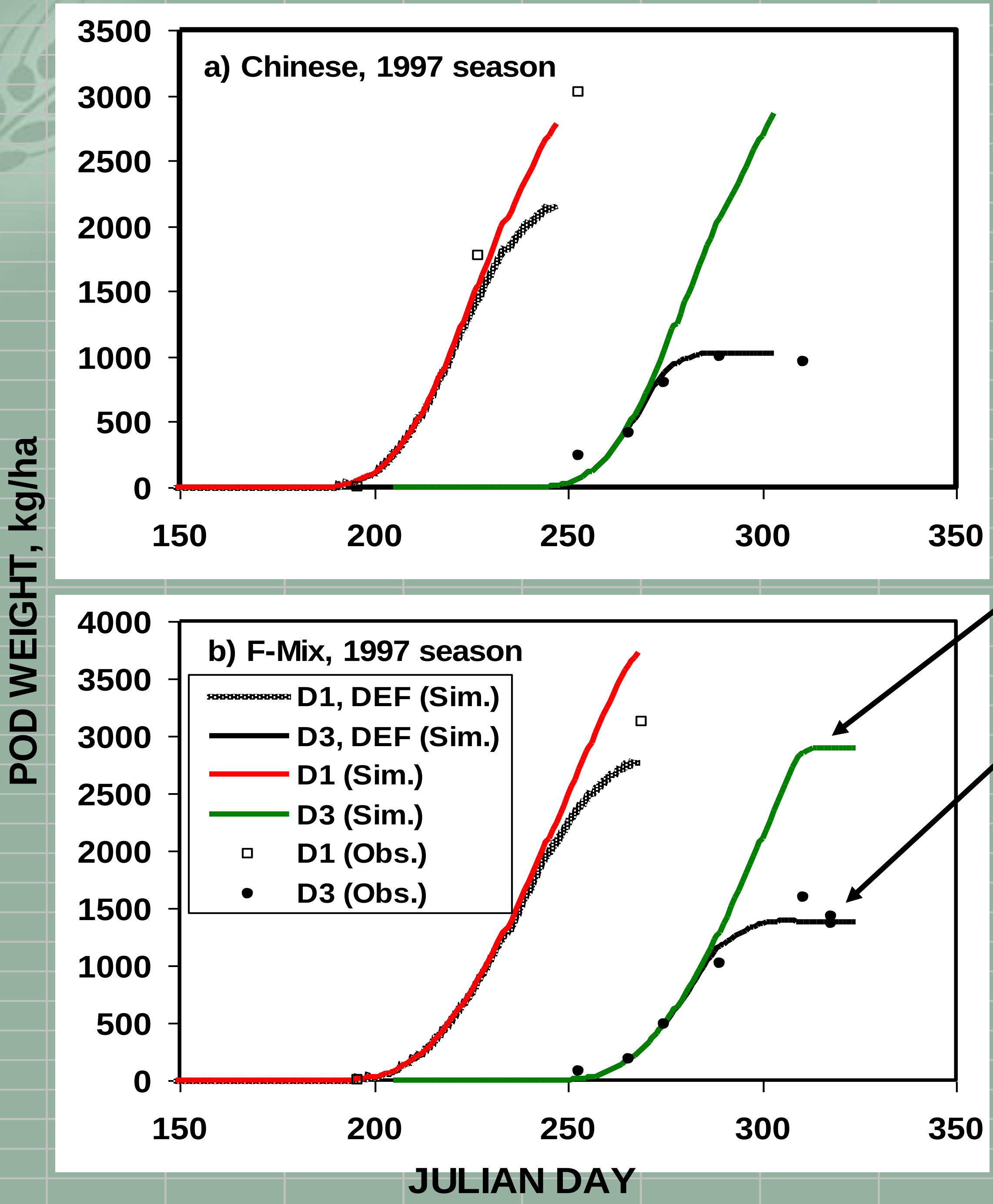
J. Naab – Ghana,

Two peanut cult.

Simulated with no disease effect

Simulated with input defoliation and leafspot injury

Crop had no fungicide applied



J. Naab – Ghana,

Two peanut cult.

Simulated with no disease effect

Simulated with input defoliation and leafspot injury

Crop had no fungicide applied

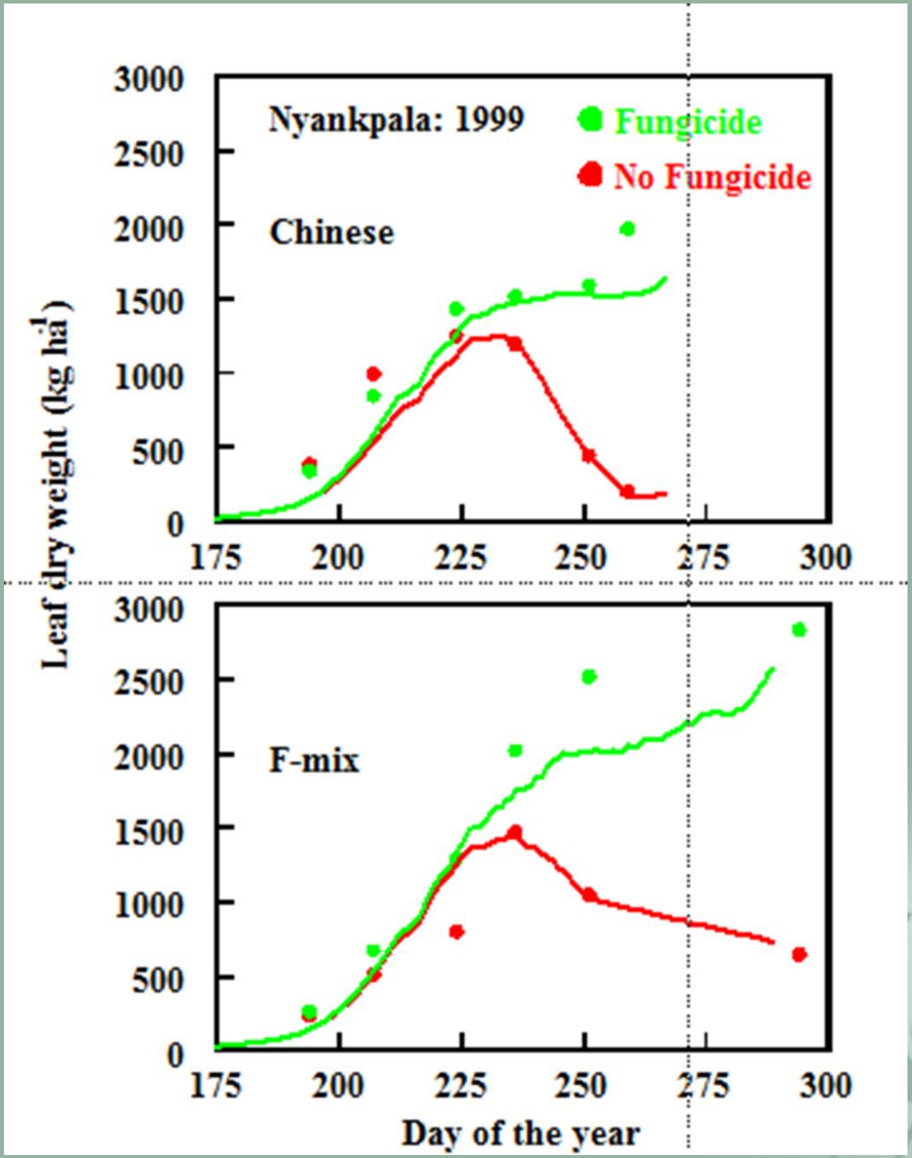
Simulating Yield Loss from Leafspot in Ghana Peanut CRSP project

- Simulation analyses (1997 & 1998) suggested yield losses of 50 to 70% from leafspot disease in Ghana (based on input of defol. & necrosis).
- This suggested a need for experiments to verify yield increase possible with fungicide.
- J. B. Naab & F. K Tsigbey conducted split-plot fungicide trials (1999, 2000, 2001). Fungicide treatment reduced defoliation & disease, and increased pod yield 75% in on-station trials.
- On-farm trials (4 seasons) confirm this response.

Simulated and observed leaf mass for Chinese and F-mix peanut, with and without fungicide.

With fungicide, leaf does not abscise.

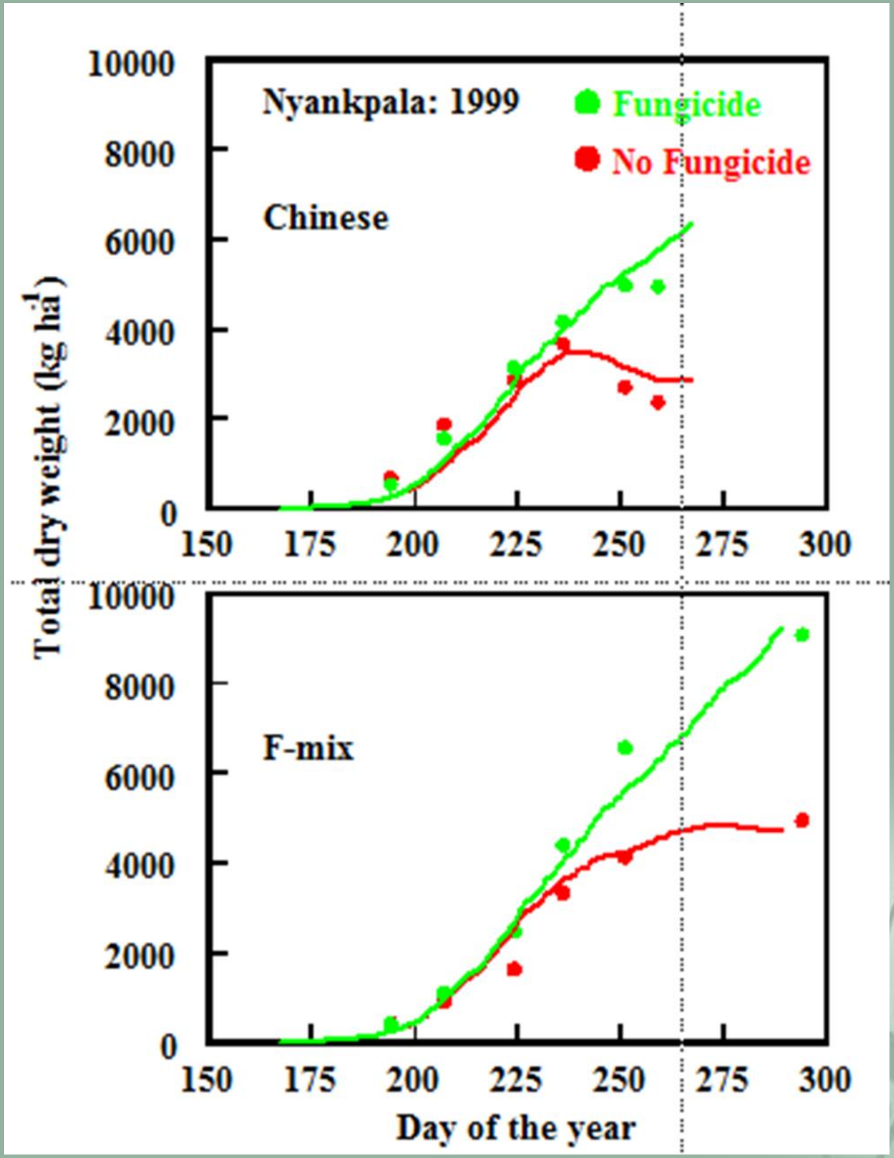
Naab, unpublished



Simulated and observed crop mass for Chinese and F-mix peanut, with and without fungicide.

With fungicide, crop mass continues to increase to maturity

Naab, unpublished

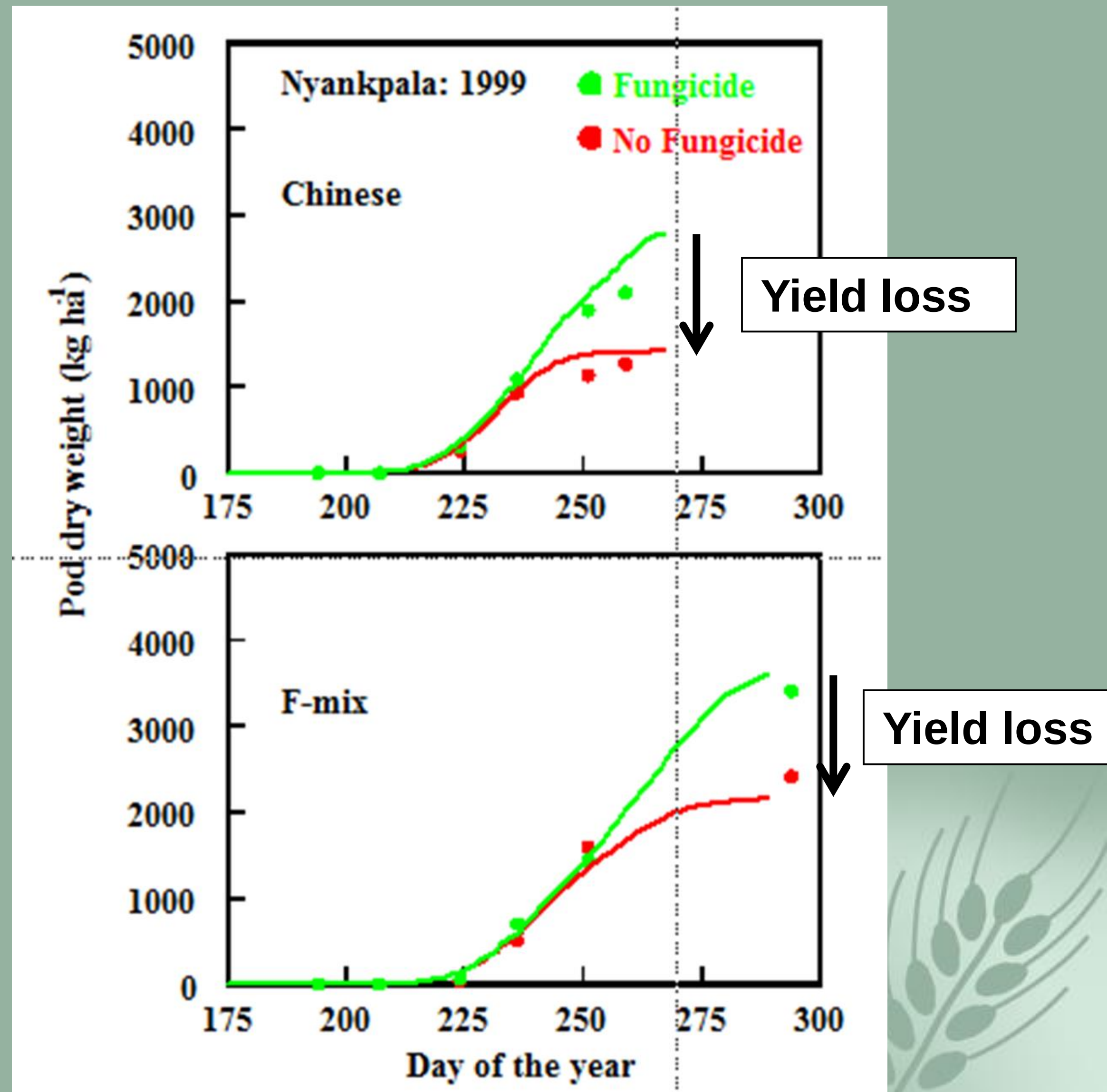


Simulated and observed pod mass for Chinese and F-mix peanut, with and without fungicide.

With fungicide, pod yield is higher.

Difference is yield loss

Naab, unpublished



What Disease, Weather, and Crop Data to Record?

- Disease rating (Peanut example):
  - ICRISAT scale (1-10) – Need to "translate"
  - Percent defoliation
  - Percent necrosis of remaining tissue
  - Disease records taken are useful as scouting inputs in current method, AND useful as data to test future mechanistic simulators of disease.
- Crop information: Prior crops for past 2-3 years, residue incorporation, fungicide type, amounts & timing, insect vector control.
- Weather data (max & min temperature, rainfall, solar radiation, relative humidity, dew duration, irrigation record.

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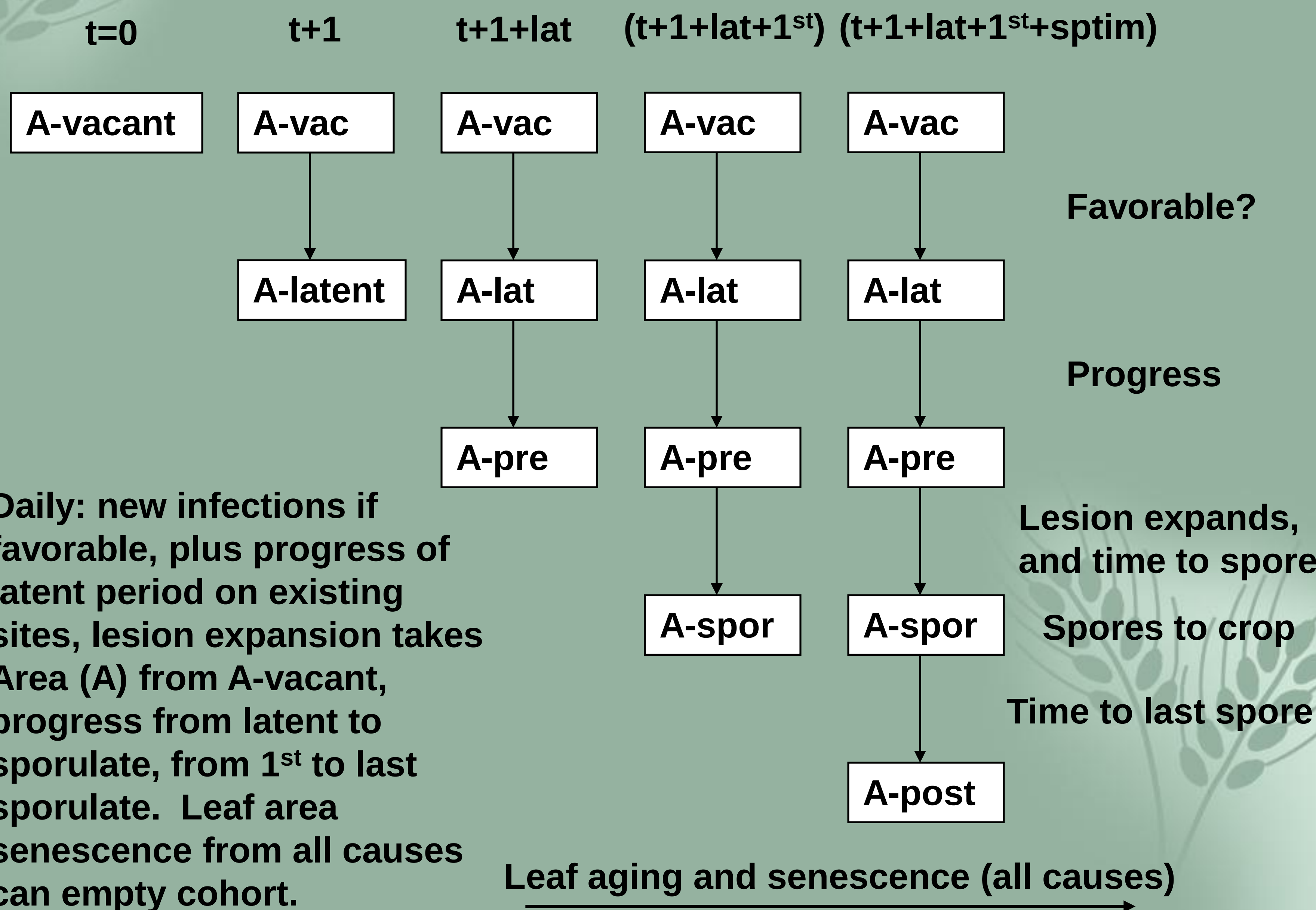
AgMIP The Agricultural Model Intercomparison and Improvement Project

Summary: Past, Present, & Future

- **Past:** Leafspot disease simulator of Bourgeois was linked to PNUTGRO, pre-DSSAT V3.5. Code predicted infection, latent period, lesion expansion, and sporulation (polycyclic epidemic) on leaf cohorts. No longer functioning.
- **Present**: Entry of pest damage (as scouting data) in DSSAT allows after-the-fact evaluation of yield losses to pests in research experiments.
- **Future:** Create simple simulators of disease damage as a function of temperature, humidity, rainfall, crop stage, genetics, and fungicide efficacy. Couple with the crop model to predict disease effects on the crop without need for input of disease damage.

Leaf spot Disease on a Single Leaf Cohort



Daily: new infections if favorable, plus progress of latent period on existing sites, lesion expansion takes Area (A) from A-vacant, progress from latent to sporulate, from 1st to last sporulate. Leaf area senescence from all causes can empty cohort.