Screening, Mapping, and Breeding for Flood Tolerance in Soybean

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Acknowledgements

Collaborators

MO – Dr. Nguyen
MO – Drs. Chen & Shannon

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Dr. Wu
Wade Hummer

Flooding Factors

Excessive rain

Rain after irrigation

Zero grade fields

Low tolerance

Climate change

Flooding Damage

Reduced Nutrient Uptake

Reduced Nitrogen Fixation

Stunted Growth

Leaf Defoliation

Plant Death

Screening to identify flood tolerant sources:

- Commercially available varieties
- Advanced Elite Lines
- Plant Introductions (PI)

Mapping QTL/genes for flood tolerance

Developing high-yielding adapted flood tolerant lines

Field Preparations

Plant Counting

Flooding Stages

V5

R1

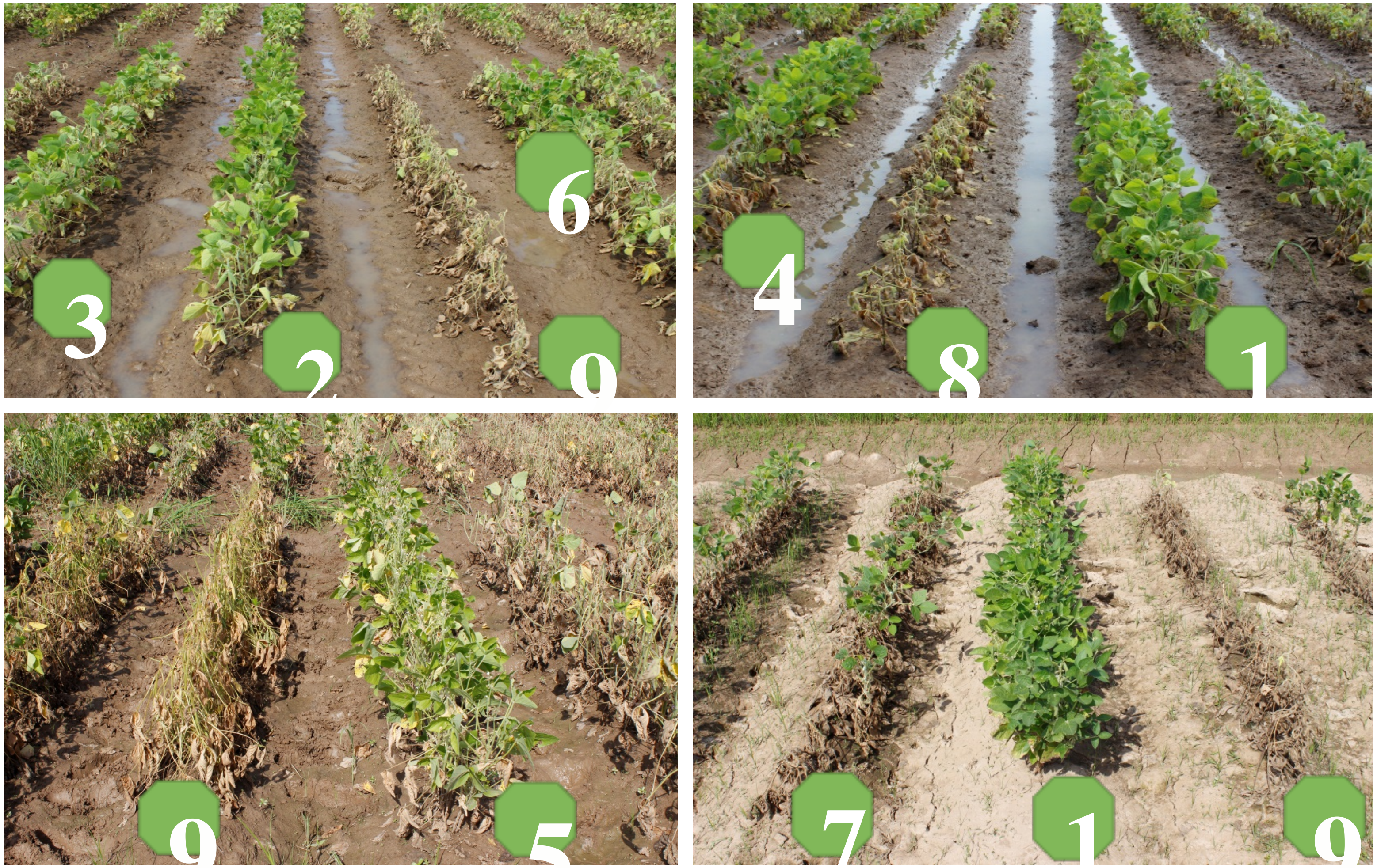
Sensitive plants show foliar symptoms after 4-day flooding

V5

R1

Leaf Color Change

Visual Rating

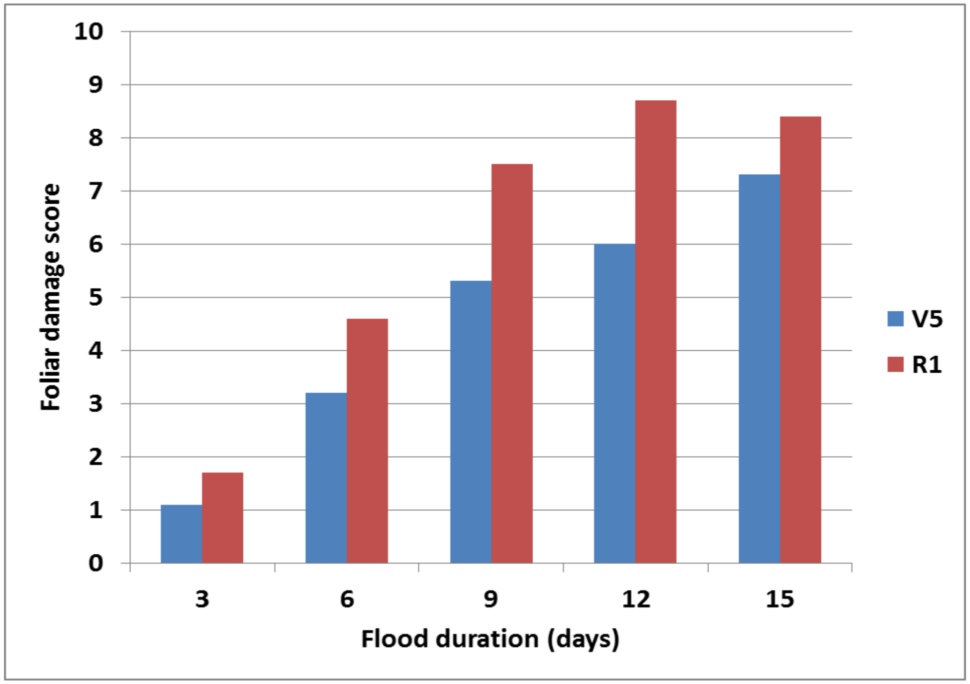


Visual Score & Plant Death over Time

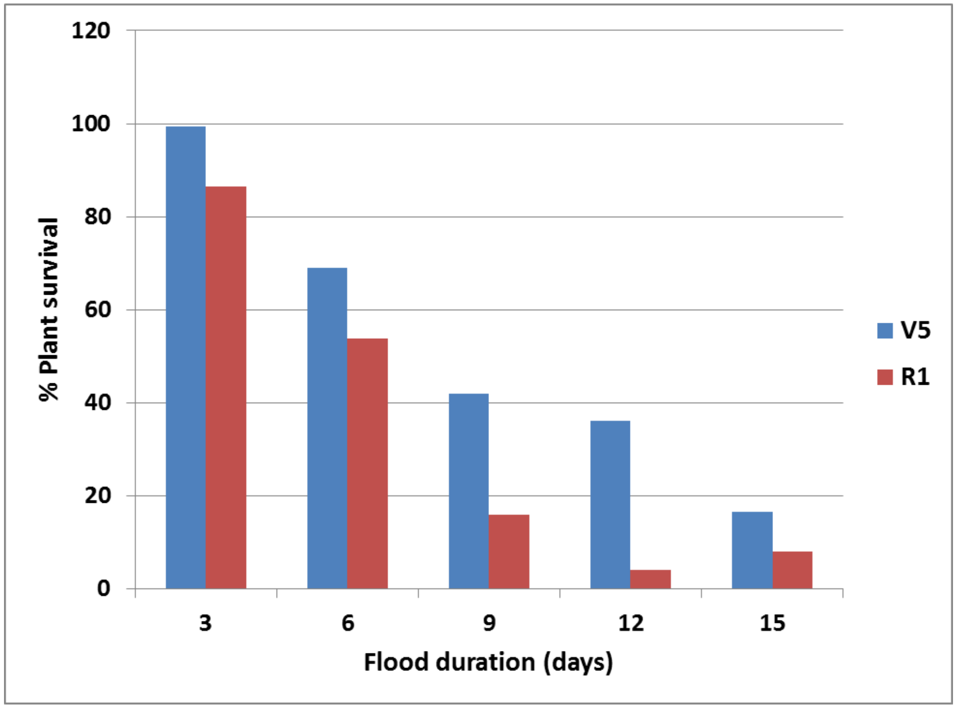
Flood Duration Experiment

- **<u>40 lines:</u> 20 flood-tolerant & 20 sensitive; 3 reps**
- **<u>Flooded:</u> at V5 and R1 stage**
- **<u>Duration:</u> 3, 6, 9, 12, and 15-day flooding**
- **<u>Visual scoring:</u> 4 times (0, 2, 4, 6 day after flood removal)**
  - **Visual score**
  - **Plant survival rate**

Plant Foliar Damage under Flooding for Different Durations



Plant Survival Rate under Flooding for Different Durations



Flood Duration Summary

Test	FDS	PSR (%)	Number of Varieties/Lines		
			Tolerant	Moderately Tolerant	Sensitive
D3V5	**1.1**	**99.4**	**40**	**0**	**0**
D3R1	**1.7**	**86.5**	**40**	**0**	**0**
D6V5	**3.2**	**69.1**	**31**	**8**	**1**
D6R1	**4.6**	**53.9**	**15**	**17**	**8**
D9V5	**5.3**	**42.0**	**11**	**19**	**10**
D9R1	**7.5**	**15.9**	**0**	**1**	**39**
D12V5	**6.0**	**36.1**	**2**	**19**	**19**
D12R1	**8.7**	**4.0**	**0**	**0**	**40**
D15V5	**7.3**	**16.5**	**0**	**6**	**34**
D15R1	**8.4**	**8.0**	**0**	**0**	**40**

D3V5 = 3-day flooding duration at V5 stage; D3R1 = 3-day flooding duration at R1 stage;

D6V5 = 6-day flooding duration at V5 stage; D6R1 = 6-day flooding duration at R1 stage;

D9V5 = 9-day flooding duration at V5 stage; D9R1 = 9-day flooding duration at R1 stage;

D12V5 = 12-day flooding duration at V5 stage; D12R1 = 12-day flooding duration at R1 stage;

D15V5 = 15-day flooding duration at V5 stage; D15R1 = 15-day flooding duration at R1 stage.

FDS = foliage damage score

Conclusions

- The longer flood duration at either V5 or R1, the more damage.
- Foliar damage scores are negatively correlated with plant survival rate.
- Most soybean plants will not survive after 12 days of flooding in the field.
- The optimum flooding duration for screening in the field is between 9 and 12 for V5 and between 6 and 9 days for R1.

Screening to identify flood tolerant sources:

- Commercially available varieties
- Advanced Elite Lines
- Plant Introductions (PI)

AR Flood Screening

- Commercial varieties (MG-4 and MG-5)
- Arkansas released cultivars and germplasms
- High-yielding lines and potential releases
- Drought-tolerant and flood-tolerant lines
- Mapping populations

Screening of Commercial Varieties in 2016

- 85 MG-4
- 57   MG-5
- RCBD - 2 reps
- Growth stage – R 1

85 MG-4 Commercial Cultivars Screened in 2016

(2 reps, 8-day flooding)

Name	Visual Score	% Plant Survival	Classification
CZ 4590 RY	3.5	67.6	Tolerant
CZ 4044 LL	3.8	62.1	Tolerant
16 Varieties	4.5 – 5.8	38.6 – 60.8	Moderately Tolerant
63 Varieties	6.0 – 7.5	20.6 – 44.0	Sensitive
4 Varieties	8.0 – 8.3	12.8 – 16.5	Highly Sensitive

57 MG-5 Commercial Cultivars Screened in 2016

(2 reps, 8-day flooding)

Name	Visual Score	% Plant Survival	Classification
CZ 5147 LL	3.0	69.7	Tolerant
S11-16653	3.0	72.5	Tolerant
CZ 5242 LL	3.3	71.7	Tolerant
R10-230	3.3	69.1	Tolerant
Dyna-Gro S52LL66	3.8	63.2	Tolerant
UAX 59013C	3.8	61.7	Tolerant
27 Varieties	4.3 – 5.3	39.2 – 57.7	Moderately Tolerant
21 Varieties	6.0 – 7.5	20.4 – 42.8	Sensitive
3 Varieties	8.0 – 8.3	11.1 – 15.6	Highly Sensitive

MO Delta Center Screening of Current Varieties in 2016

10 lines with <2.5 FTS

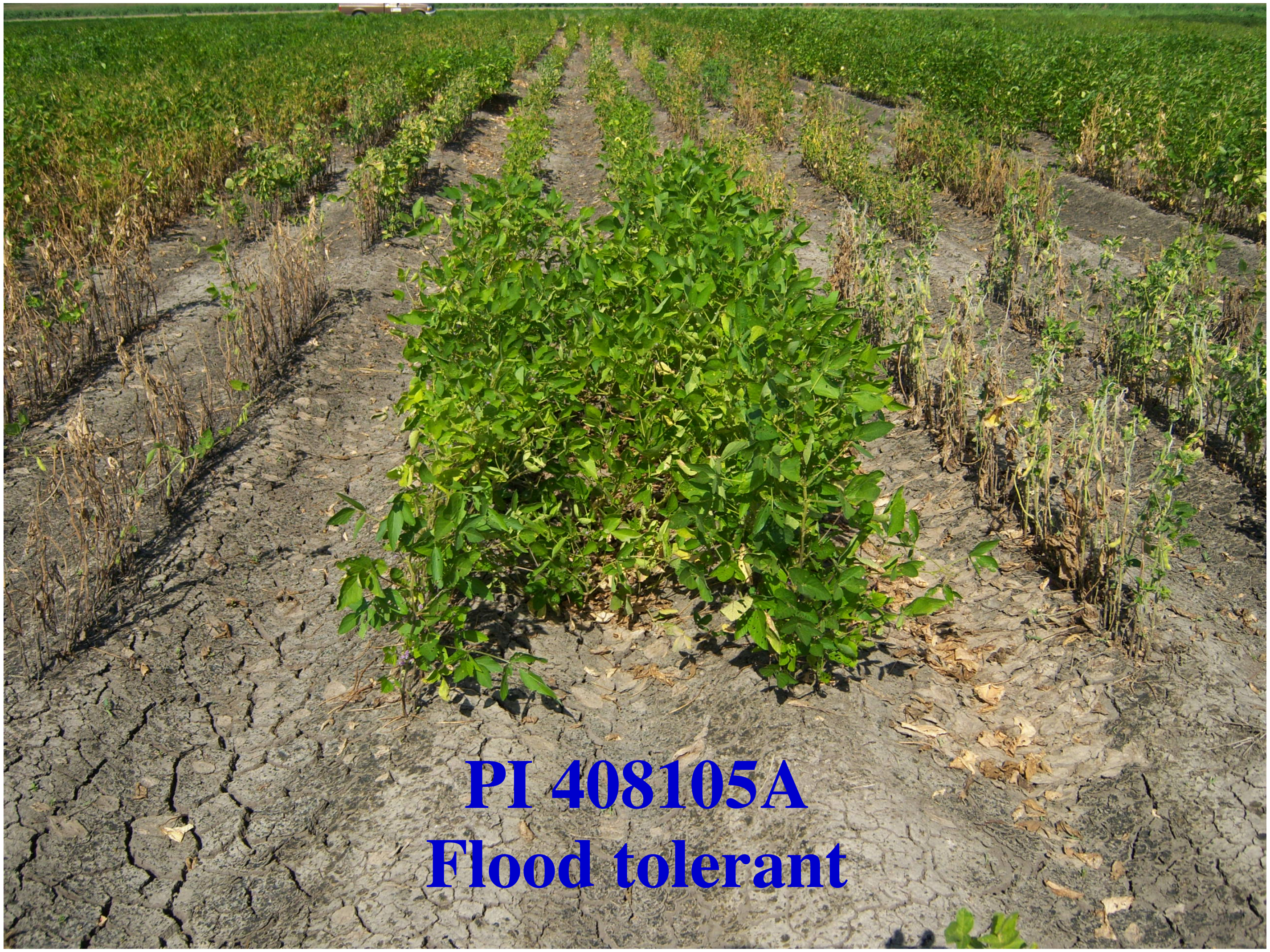
Delta Grow DG4860RR2	Dyna Gro 31RY45
U of MO S12-3791	Progeny 4757
Syngenta 39-T3	Syngenta 45-R7
Armor 48D24	Morsoy LL4524
Bayer CZ5225LL	Dyna Gro S52RY75

Flood Tolerance of AR High-yielding Cultivars (2012 - 2016)

Name	Visual score						
	2012	2013	2014	2015	2016	Mean	Classification
UA 5615C	-	2.8	4.0	3.5	4.5	3.7	Tolerant
UA 5612	5.2	4.7	3.8	4.0	4.5	4.4	Moderately Tolerant
UA 5115C	4.6	4.8	5.6	3.8	4.8	4.6	Moderately Tolerant
Osage	5.0	4.2	5.2	4.5	4.8	4.8	Moderately Tolerant
UA 5213C	5.8	4.6	4.4	4.7	5.3	5.1	Moderately Tolerant
UA 5414RR	5.0	6.3	5.1	4.5	6.8	6.0	Sensitive
UA 5715GT	-	5.8	6.4	4.3	6.9	6.2	Sensitive

AR Flood Tolerant Lines
(2012 - 2016)

Name	Visual score						% Plant Survival					
	12	13	14	15	16	Mean	12	13	14	15	16	Mean
R10-4892	3.1	3.3	3.2	3.0	4.3	3.4	83.6	67.6	79.7	82.7	59.4	68.9
R11-6870	-	3.3	4.0	2.7	3.3	3.3	-	65.1	79.6	86.1	67.7	72.3
R10-230	-	2.8	4.0	3.5	4.5	3.7	-	72.4	77.5	84.2	57.1	67.6
R07-6669	3.8	3.1	3.9	3.7	3.8	3.7	82.3	83.7	75.8	69.2	61.6	68.3
R04-342	4.2	3.9	4.0	3.6	4.0	3.9	56.5	62.8	65.7	67.3	63.4	64.0
AG 5606	7.6	7.0	-	-	-	7.3	26.3	24.5	-	-	-	25.4
AG 5335	-	-	-	6.0	6.3	6.2	-	-	-	39.2	29.6	34.4
UA 5014C	8.3	7.7	8.1	8.0	8.0	8.0	6.7	11.5	9.5	9.9	14.9	12.2



PI 408105A
Flood tolerant

Yield comparison of PI 408105A derived lines vs. check under flooding

Line (1st cycle breeding)	BU/A under flood
S11-25108 (S99-2281 x PI 408105A)	23.5
S11-25615 (S99-2281 x PI 408105A)	26.8
Asgrow check AG 483	

Line (2nd cycle breeding)	BU/A under flood
S15-19625 (S11-25108 x S05-11482)	37.1
S15-19719 (S11-25108 x S05-11482)	35.7
Asgrow check AG4835	5.9

Shannon/Chen group

Shannon/Chen group

Comparison of *max* and *soja* PIs for flood Tolerance

Line	Cultivated (max) or wild (soja)	Flood score 1= no damage	Notes
Jake check	Cultivated	4.0	Adapted variety
PI 603910B	Cultivated	2.7	Selected for tolerance
PI 408105A	Cultivated	3.7	Selected for tolerance
UA 5612 check	Cultivated	2.7	Tolerant variety
PI 407729	**Wild**	**1.5**	**Excellent tolerance**
PI 407195	**Wild**	**1.3**	**Excellent tolerance**
PI 424116	**Wild**	**1.0**	**Excellent tolerance**

Shannon/Chen group

Conclusions

There are flood tolerant commercial varieties, advanced elite lines, and PIs

MO PI-derived lines show yield improvement under flooding conditions compared to check cultivar

Wild soybean (*soja*) can be used as a new flood tolerance source

Effect of Flood on Germination

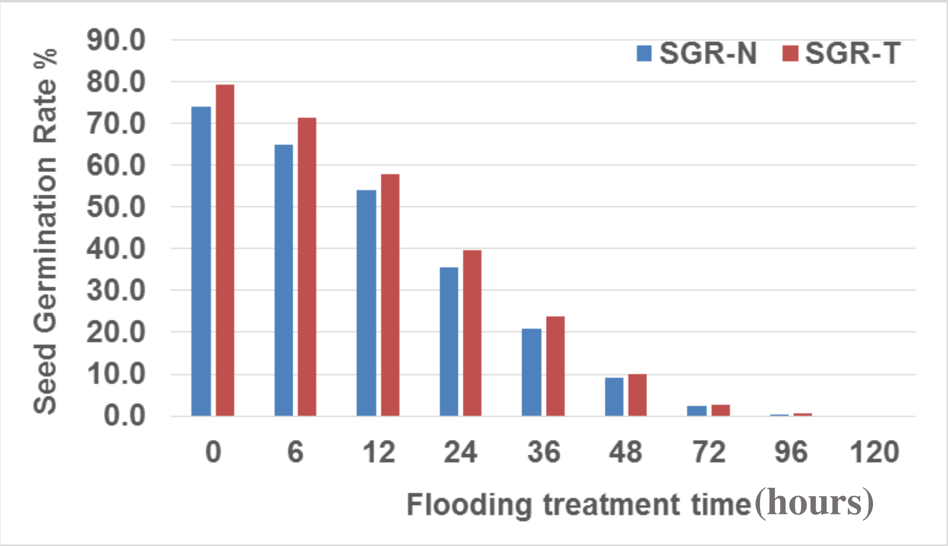
<u>20 Genotypes:</u>
7 Tolerant
6 Mod. Tolerant
7 Susceptible

Untreated

Treated
(Apron Maxx RTA)

0 (Control) 6 12 24 36 48 72 96 120
Hours under flood

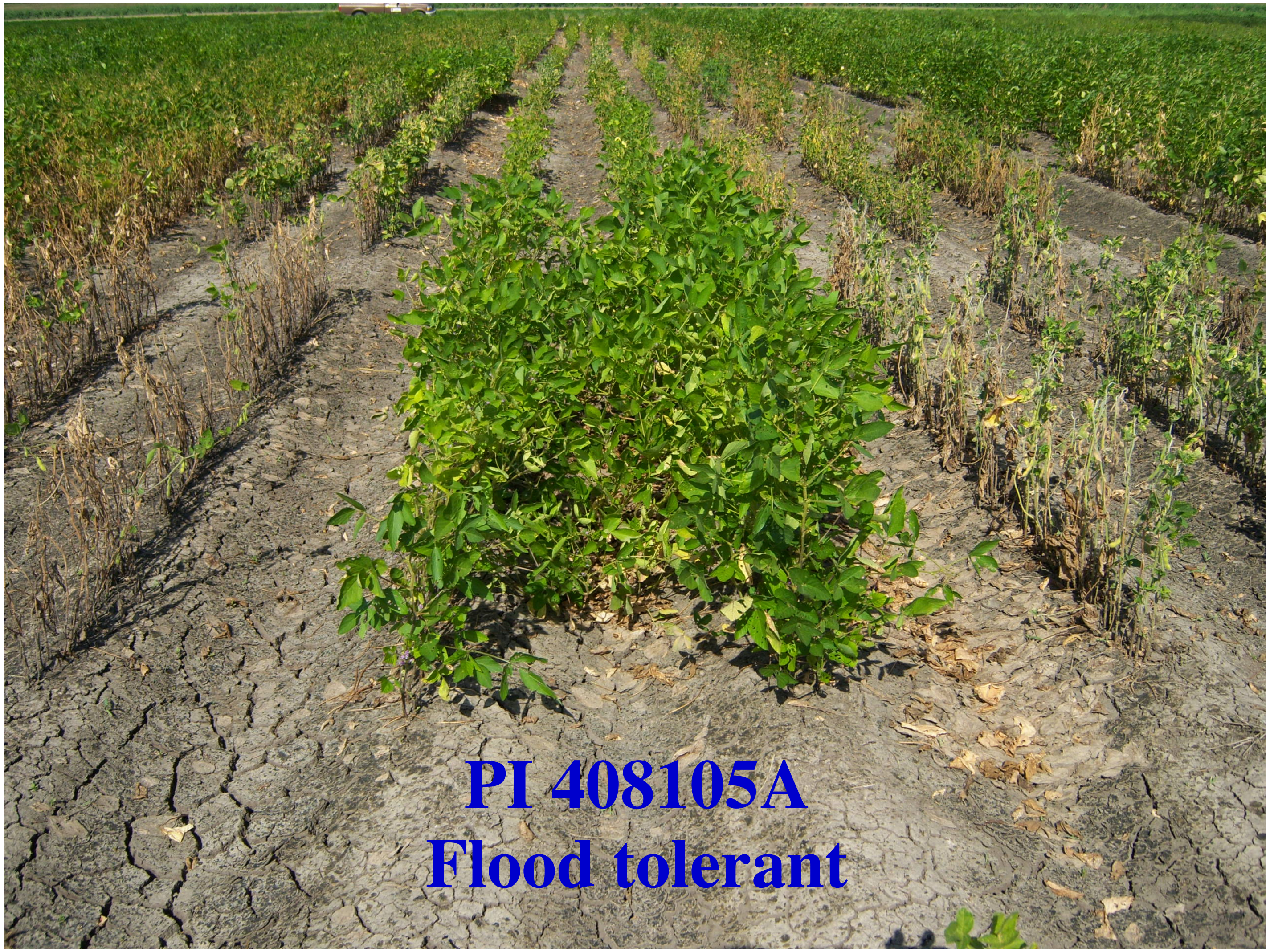
Germination Rate under Flooding Durations



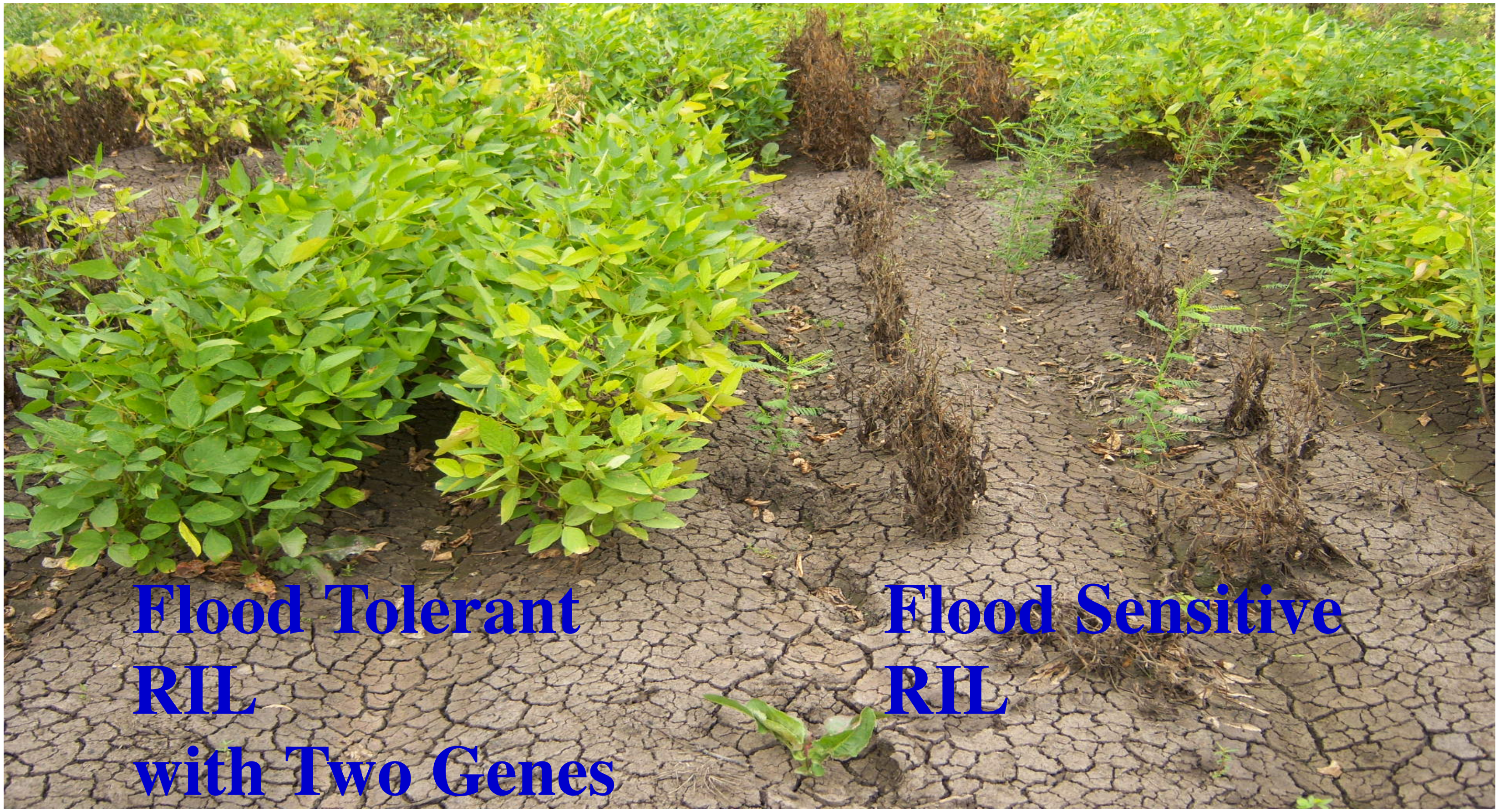
Conclusions

- Fungicide (Apron Maxx RTA) treatment increases soybean seed germination about 5% regardless of flooding duration.
- Longer flood durations cause lower germination rate.
- One day flooding causes 50% less germination rate compared to non-flooding .
- We did not find significant difference on seed germination rate between tolerant and susceptible groups.

Mapping QTL/genes for flood tolerance

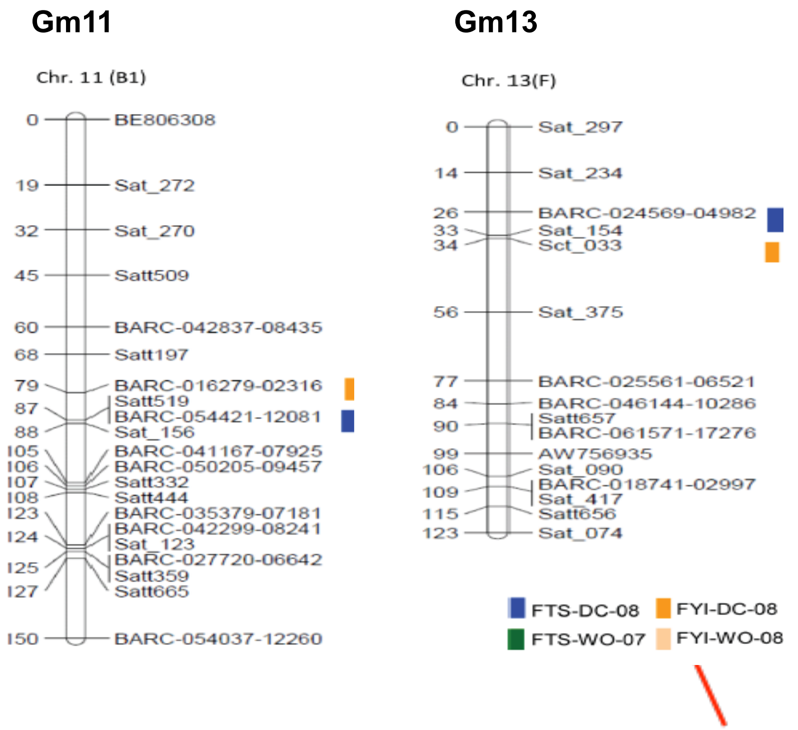


PI 408105A
Flood tolerant



RIL segregating for flood tolerance (S99-2281 x PI 408105 A)

QTL Identification
S99-2281 x PI 408105A (exotic)



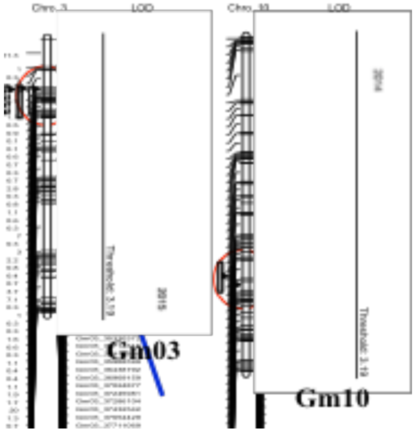
Major QTL with donor from exotic PI

- ***qFT_Gm11*** **with donor from the elite line.**
- ***qFT_Gm13*** **is the major one with donor from exotic PI.**
- **Near isogenic lines have been developed for *qFT_Gm13* and QTL validation is ongoing.**
- **DNA markers flanking the QTL have been developed for MAS.**

Nguyen et al. 2012. Crop Sci.

New QTL Identification
S99-2281 x PI 561271 (exotic)

QTL	Year	Nearest marker	*a*	*R2* (%)	Donor
qFT_Gm03	2013	Gm03_3087237	-0.27	18.1	PI 561271
	2014	Gm03_3087237	-0.39	33.1	PI 561271
	2015	Gm03_3225968	-0.28	16.8	PI 561271
qFT_Gm10	2013	Gm10_43840376	0.26	15.4	S99-2281
	2014	Gm10_43107961	0.20	8.5	S99-2281

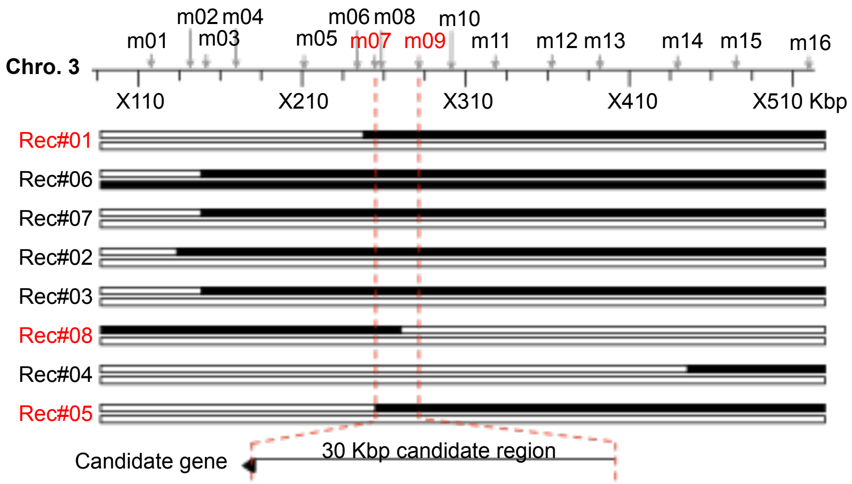


Mapped across all 3 years in DC; donor from PI.

- **2 QTL were mapped: *qFT_Gm03* and *qFT_Gm10*.**
- **The effect of *qFT_Gm10* is relatively minor; mapped in 2013 and 2014.**
- ***qFT_Gm03* is the major QTL and with the donor source from exotic PI.**
- **DNA markers flanking the QTL regions have been developed for MAS.**
- **Effects of the major QTL have validated at the near-isogenic background at both early vegetative and reproductive stages.**

Nguyen lab. Unpublished data

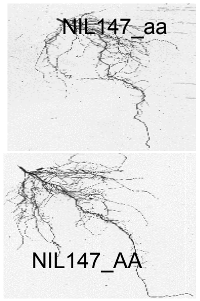
Map-based Cloning of the Major Gene



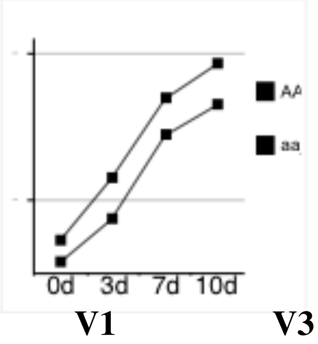
- Identified NILs from HIFs (F8) that still is segregating the *qFT_Gm03*
- Screen recombinants
- Developed high-resolution map
- Progeny tests of the recombinants
- Key recombinants Rec#01, 05, 08
- Gene was delimited between markers m07 and m09

Gene's Function at NIL Background

Root phenotypes

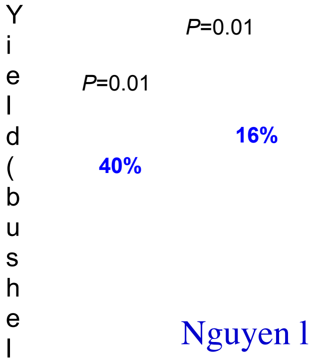


Total root length



NILs in the field

Yield (Non-stress)



Nguyen lab. Unpublished data

Developing high-yielding adapted flood tolerant lines

2016 AR Flood Project Overview

Advanced Test	35 lines
Preliminary Test	43 lines
Progeny Rows	341 rows (15 populations)
	→ 27 selected
F4	10 populations
F3	13 populations
F2	22 populations
F1	25 populations
New Crosses	18 combinations

Twenty populations from crosses to improve soybeans for flooding tolerance MO Delta Center

Cross	Generation	Current status
S10-11227 x PI479740	F6	Advance in CR - gene mapping
S10-11227 x PI603155	F6	Advance in CR - gene mapping
S10-11227 x PI603910B	F6	Advance in CR - gene mapping
S13-15826 x S13-13342	F4	Advance in CR - variety dev
S12-25615 x S13-13342	F4	Advance in CR - variety dev
S13-15826 x S12-1362	F4	Advance in CR - variety dev
S13-15826 x S12-25615	F4	Advance in CR - variety dev
S12-25615 x S12-1362	F4	Advance in CR - variety dev
S12-25108 x Summit	F6	Advance in CR - variety dev
S12-25108 x Lorian	F6	Advance in CR - variety dev
S12-25108 x M09-W105	F6	Advance in CR - variety dev
S12-25108 x M11-HO31	F6	Advance in CR - variety dev
S12-3782 x S12-25615	F1	Advance in CR - variety dev
S13-10590 x S12-25615	F1	Advance in CR - variety dev
S13-11061 x S12-25615	F1	Advance in CR - variety dev
[illegible]	F1	Advance in CR - gene mapping

Current USB Flooding Tolerance Project (2017-2019)

Collaborators

- MO – Dr. Nguyen
- MO – Drs. Chen & Shannon
- NC – Dr. Carter
- MS – Dr. Orlowskii
- LA – Dr. Buckley

Current USB Flooding Tolerance Project (2017-19)

Obj 1. Characterize germplasm and identify genes for flooding tolerance.

- **Screen germplasm (~500 exotic and wild) to identify additional promising lines in field (reproductive stage) and greenhouse (vegetative stage).**
- **Characterize environmental factors affecting stability of flooding tolerance.**
  - Test 70 selected lines in multiple states for G × E study: MO, AR, NC, MS. LA.
  - Soil profiling: pH, nutrients and *Phytophthora*.
- **Identify flooding tolerant genes in RIL populations.**
  - Perform QTL mapping in 4 new mapping populations.
  - Fine-map and clone significant QTLs for allele mining and gene-based markers.
  - Develop new populations (**elite × wild**) and **NILs** for tolerance mechanisms.
- **Conduct GWAS in diverse lines using high density SNP markers.**
  - Flooding tolerance at vegetative stage in greenhouse (~500 lines).
  - Flooding tolerance at early reproductive stage in field (~500 lines MGs III-V).

Current USB Flooding Tolerance Project (2017-19)

Obj 2. Improve germplasm for flooding tolerance.

- Develop functional markers associated with flooding tolerance QTLs and genes.
- Improve germplasm by pyramiding and stacking flooding tolerance QTLs into elite lines (MGs III to V) utilizing MAS (4 mapped QTL).
- Conduct field evaluation of yield and flooding tolerance in the new germplasm.

Obj 3. Develop high yielding and flooding tolerant varieties.

- Develop breeding populations using new germplasm and select new varieties based on field performance and marker-assisted selection.
- Release varieties with improved flooding tolerance and high yield.

Thank you!