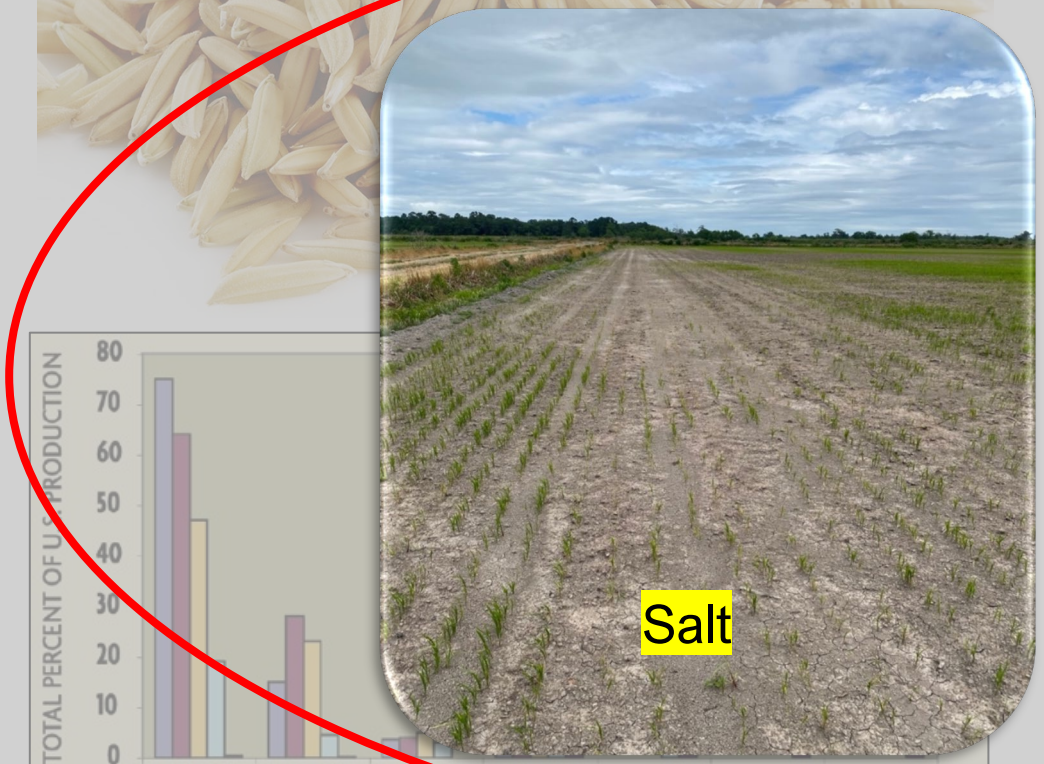
South Carolina Rice Research and Outlook Reports

Gursewak Singh
Ph.D. Candidate

Department of Plant and Environmental Sciences

Rice Production in South Carolina



+

Graph 1. Rice production in United States 1839–1919

Upstream shift of seawater/freshwater boundary

Key Problems in Rice Production in South Carolina

- **Seawater intrusion** threatens SC rice production because current rice cultivars are salt-sensitive.
- The premiere rice cultivar in SC is Carolina Gold, a highly salt-sensitive cultivar.

- **Weeds** are another factor that cause substantial yield losses in organic rice production.
- **Barnyardgrass and Hemp Sesbania** are the two main problematic weeds in SC rice growing areas (Survey 2022).

Limited understanding of salinity impacts on SC rice cultivars and weeds requires detailed research for profitability and effective weed control in organic production.

Problems Identication, Georgetown, SC

1. Presence of salt crust on soil and cracks.

2. Low lying areas look darker in saline soils.

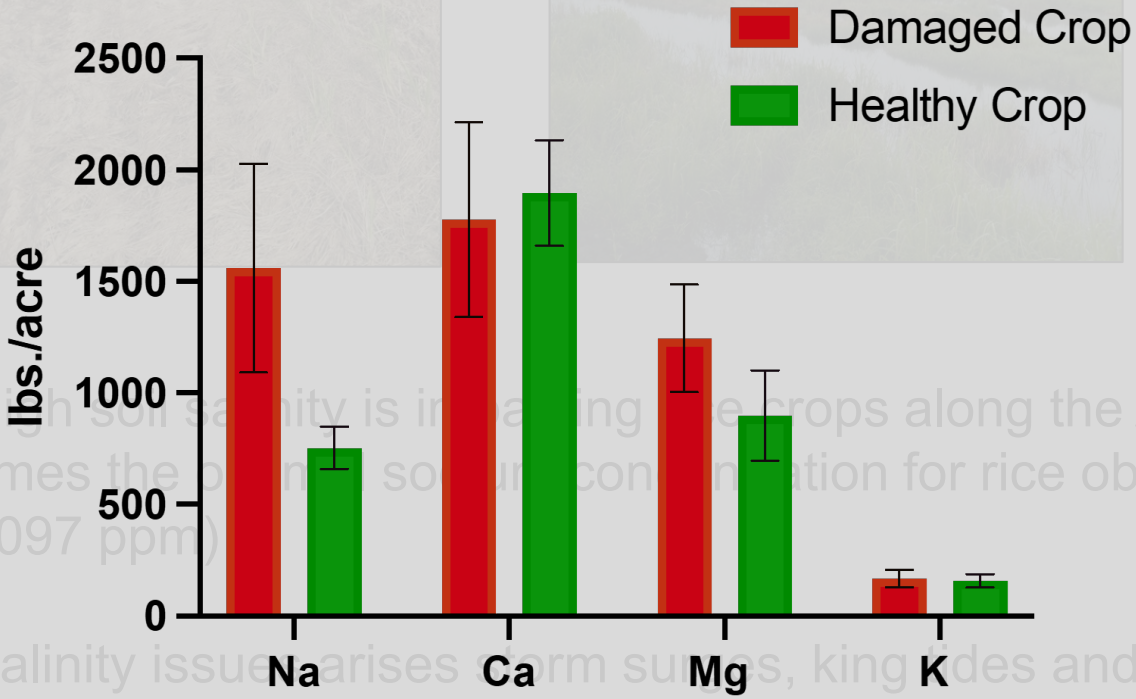
3. Presence of halophytes around ditches

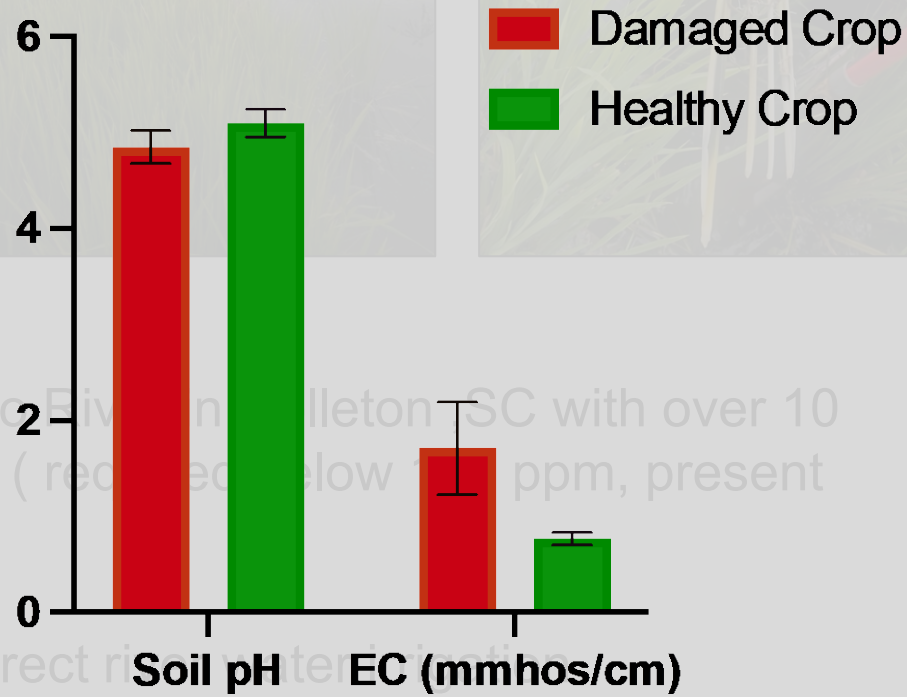
- **Soil Electrical Conductivity (EC): 4.57 mS/cm indicating high salinity**
- **pH Level: Slightly acidic at 5.71**

Need for Tailored Management Strategies:

Strategy: Development of customized soil and water management strategies

Problem Identification, Colleton County, SC





- High soil salinity is impacting rice crops along the Ashepoo River in Colleton, SC with over 10 times the optimal sodium concentration for rice observed. (recommended below 700 ppm, present 1097 ppm)
- Salinity issues arises storm surges, king tides and from direct river water intrusion.
- Saline stress may have been exacerbated by fertilizer use in saline conditions, causing severe plant symptoms like chlorosis, necrosis, and widespread death.

How to Adapt/Manage Salt-Affected Farm Areas?

1. Crop based approach:
   Select or develop varieties which can withstand the salt stress.

2. Environment modifying approach:
By changing environment for the normal growth of plants.

3. Hybrid approach:
Combination of 1 and 2. For eg. local variety with gypsum appl

Benefits:

a. More viable
b. Highly productive
c. Low resource cost

Singh et al. 2021

1. Screening 12 Rice Varieties for Salt Tolerance (2021)

Variety	EC_{50}[a] (g/kg)	Transplant Injury (%)[b]
WC 4644	7.40	80
Bengal	0.51	99
4484	0.12	99
Chin Chin	2.90	75
CM1, Haipong	1.6	85
Doble Carolina	2.52	60
Jupiter	1.43	85
Karang Serang	0.40	99
Katy	0.08	80
M202	1.50	40
Presidio	1.30	99
Sornavari	0.02	80

[a] A five parameter log-logistic model was used to determine the EC_{50} or the effective concentration for 50% of the plantings exhibiting 50% chlorosis, three months after transplanting.

[b] Percent visual injury after transplanting into saltwater three weeks after planting.

2. Salt Tolerance Comparison Study (2022-2023)

Experimental Layout

4 Cultivars (C):

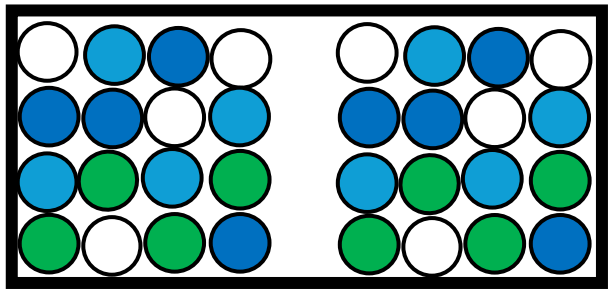
1. Santee Gold
2. Doble Carolina
3. M202
4. Carolina Gold

x

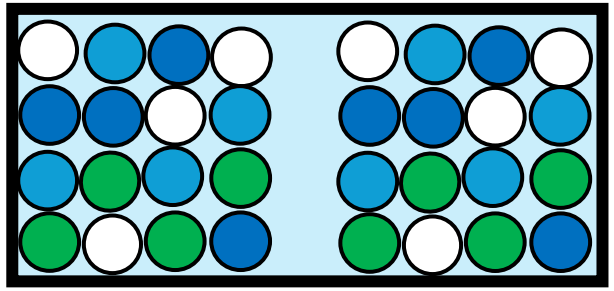
5 Seawater Conc. (%):
0, 0.375, 0.75, 1.5 and 3

x

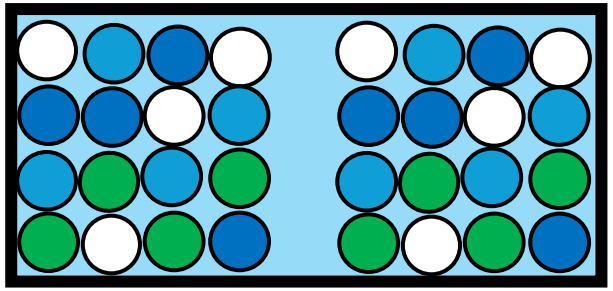
2 Weeding Scenarios:
Hand Weeding
No Weeding



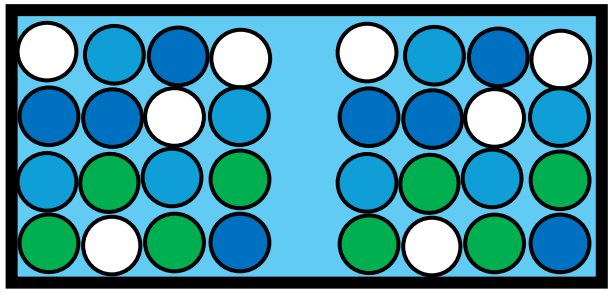
0 % Seawater



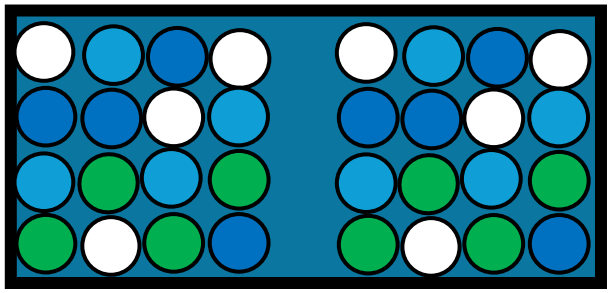
0.375 % Seawater



0.75 % Seawater

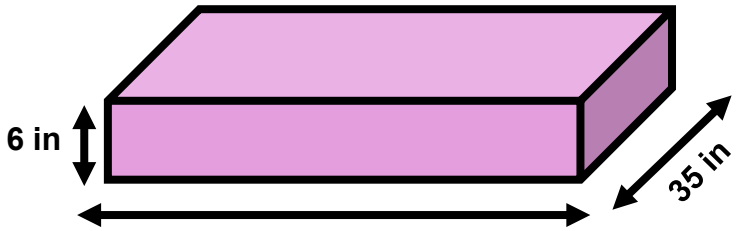


1.5 % Seawater

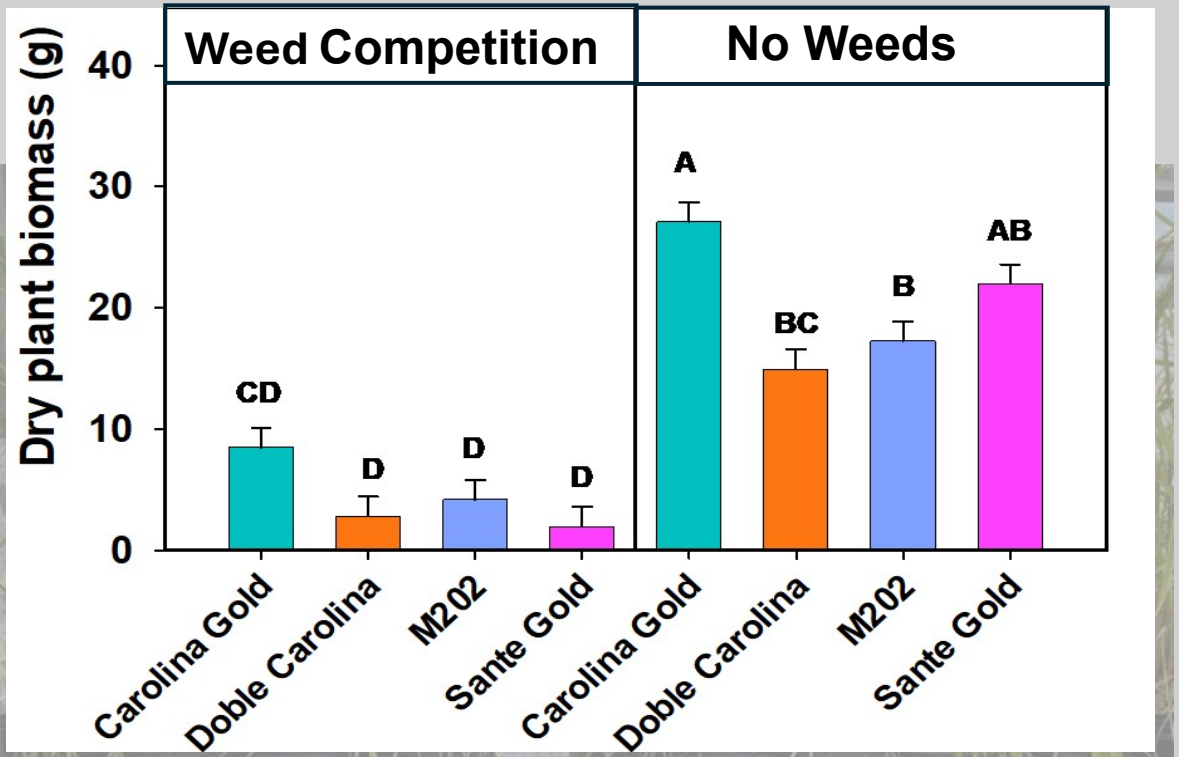


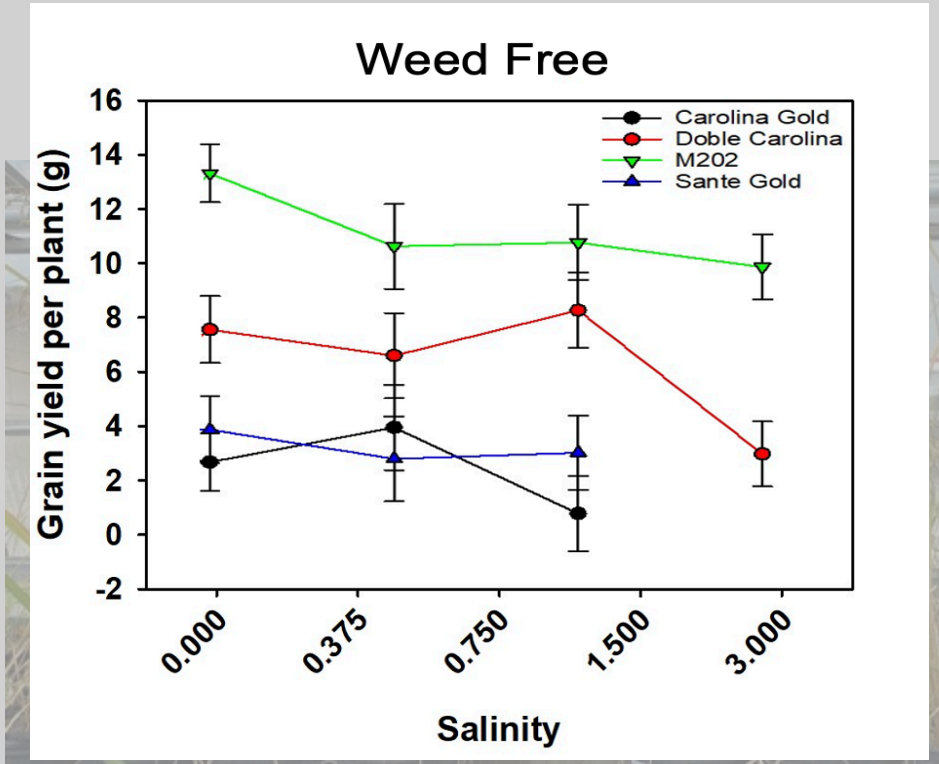
3 % Seawater

3 % ocean water = 0.105 %
or 1050 ppm
or 1.050 ppt
or 2.1 EC



Salt Tolerance Comparison Study Results

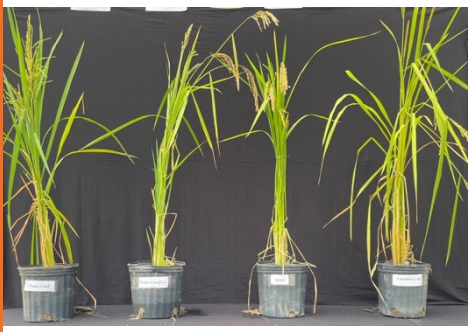
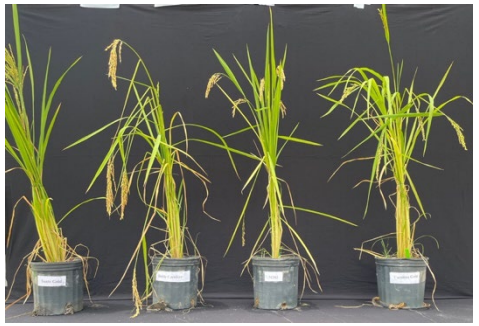
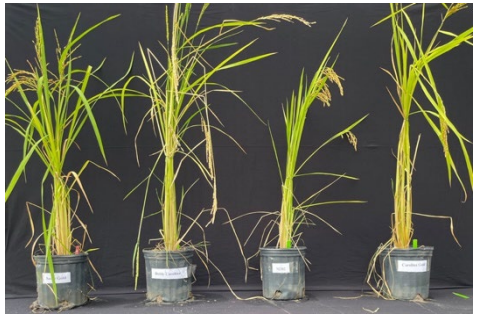
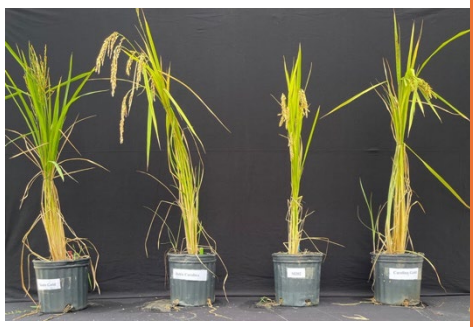




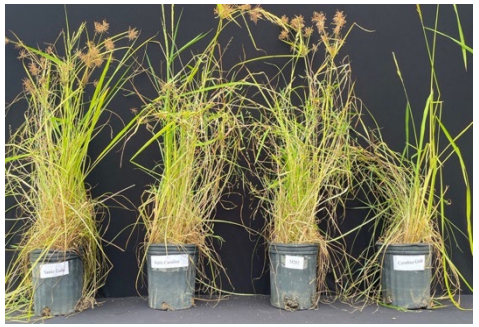
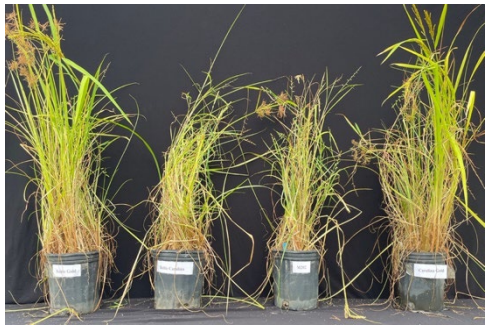
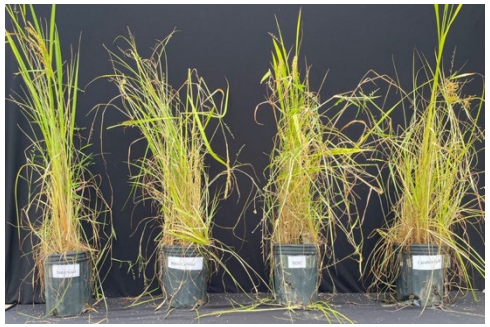
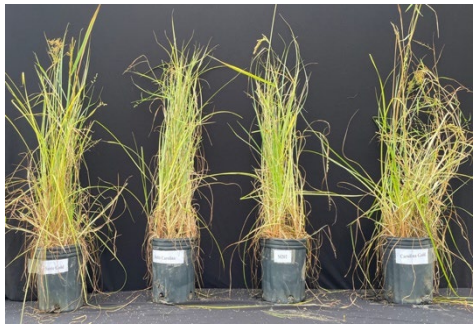
- Weed competition reduced the rice plant biomass by 2-3 times and yield up to 5 times at 3% seawater concentration (EC- 2.10 dS m^{-1}).
- M202 outperformed other cultivars in term of yield at increased salinity.

Weed Free vs Weed Competition

Weed Free

0 % Seawater	0.375 % Seawater	0.75 % Seawater	1.5 % Seawater	3 % Seawater
				
SG DC M202 CG	SG DC M202 CG	SG DC M202 CG	SG DC M202 CG	SG DC M202 CG

Weed Competition

				
SG DC M202 CG	SG DC M202 CG	SG DC M202 CG	SG DC M202 CG	SG DC M202 CG

3. Rice- Weed Competition Study (2022-2023)

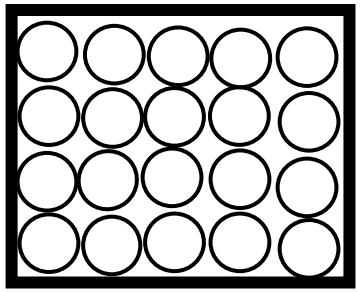
Experimental Layout

5 Rice-weed competition scenarios ✘ **5 Seawater Conc. (%)**

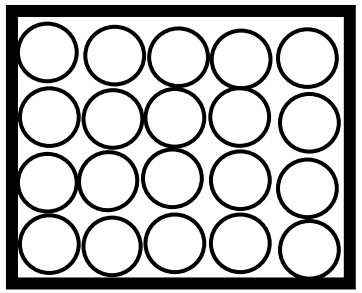
1) Rice (Carolina Gold Cultivar)
2) Barnyardgrass
3) Hemp sesbania
4) Barnyardgrass + Rice
5) Hemp sesbania + Rice

0, 0.375, 0.75, 1.5 and 3

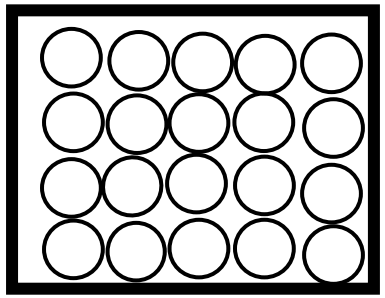
- Rice seeds and weed seeds were seeded directly in the pots at same time.



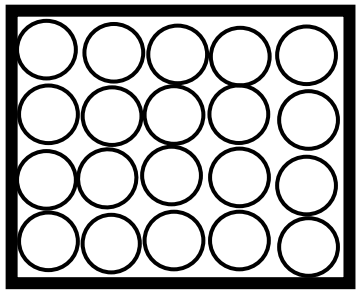
0 % Seawater



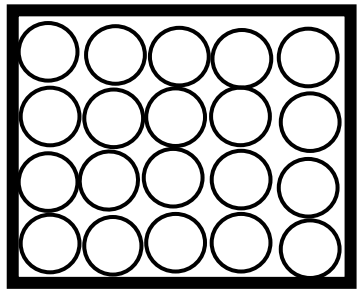
0.375 % Seawater (EC – 0.262 dS m^{-1})



0.75 % Seawater (EC- 0.525 dS m^{-1})

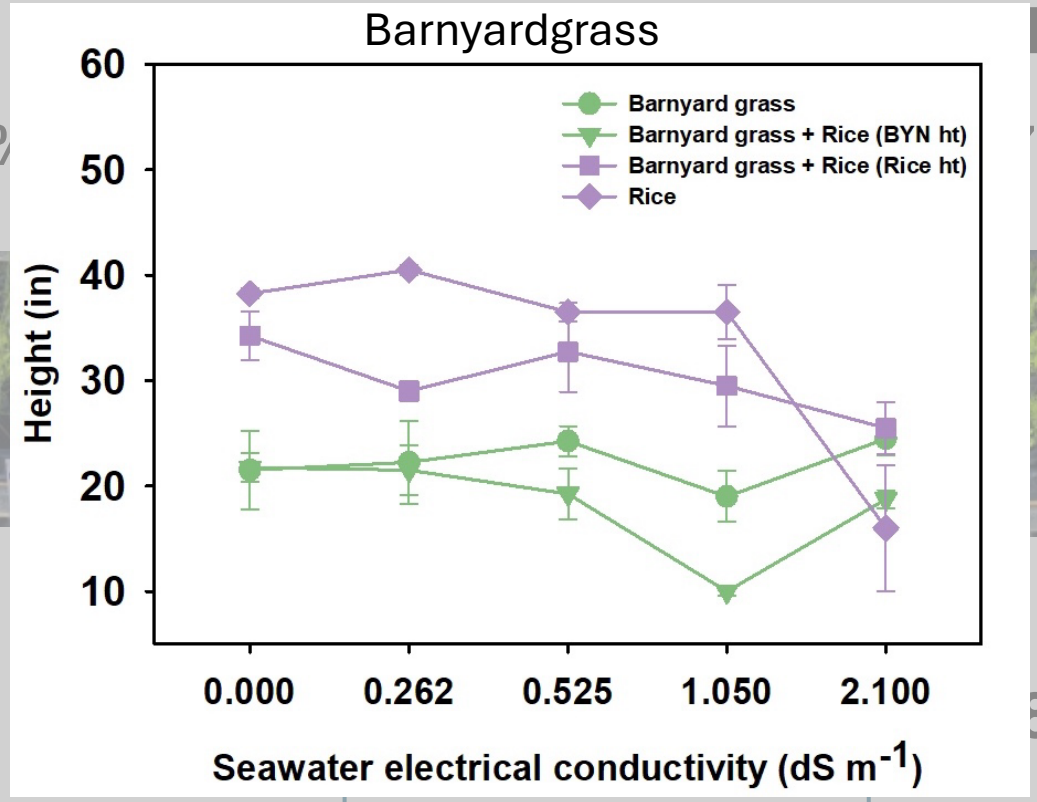


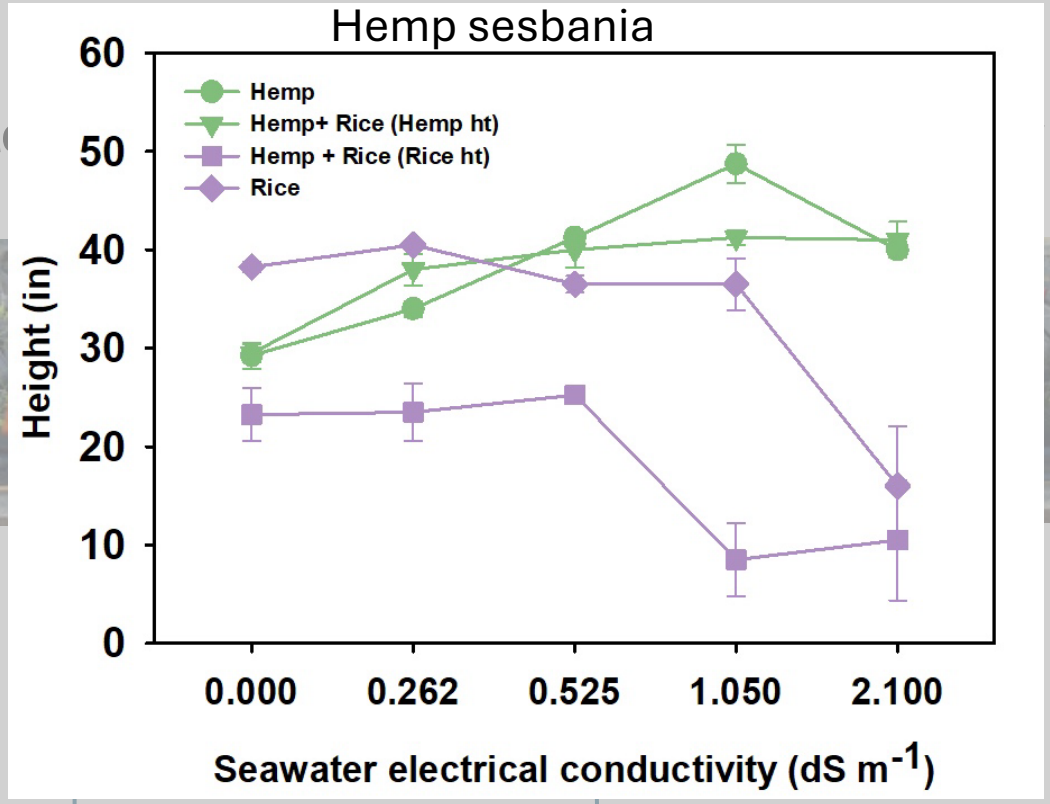
1.5 % Seawater (EC- 1.05 dS m^{-1})



3 % Seawater (EC- 2.1 dS m^{-1})

Rice- Weed Competition Study Results





- At 3% seawater concentration (EC- 2.10 dS m^{-1}), growth of barnyard grass declined, while hemp sesbania showed high salt tolerance.

Impact of Weed Competition on Rice Yield

	P value
Seawater EC	<0.001
Weeds Presence	<0.01
Seawater EC x Weeds Presence	0.036

- Seawater concentration, weed competition and their interaction impacted rice plant growth and yield ($P<0.05$).

4. Field Evaluation Study (2023-2024)

Objectives

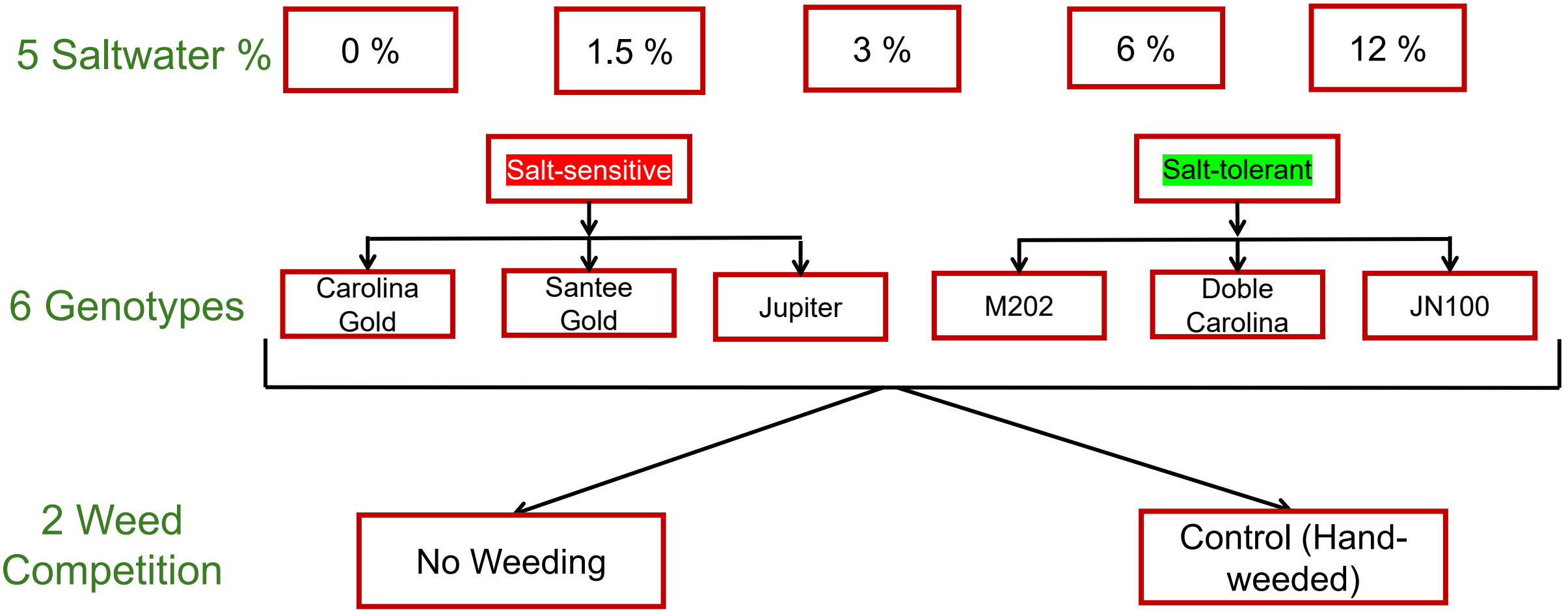
To determine the impact of saltwater and native weed pressure on rice genotypes in organic field conditions and to validate greenhouse observations.

Research Questions:

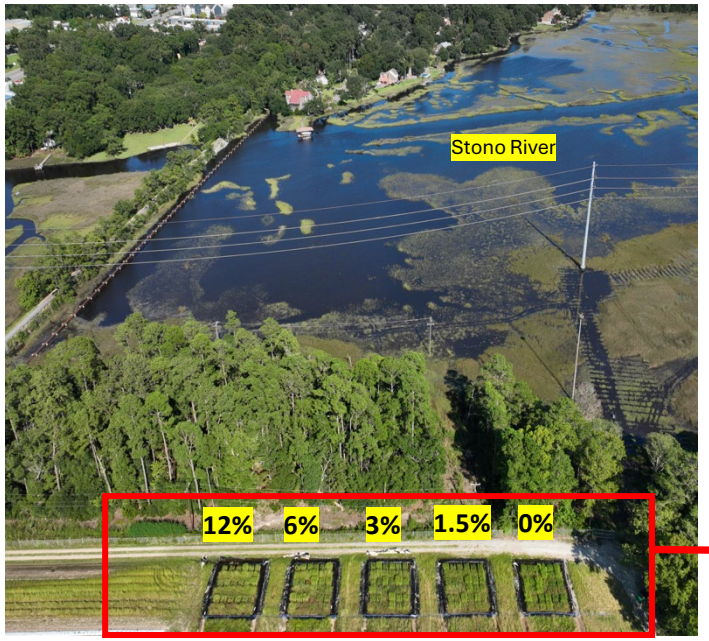
1. Is there a difference in plant response of different rice genotypes at different saltwater concentrations in field conditions?
2. How does weed competition influences organic rice production in partial saltwater agroecosystems?
3. Does saltwater influence native weeds in rice grown under organic settings?

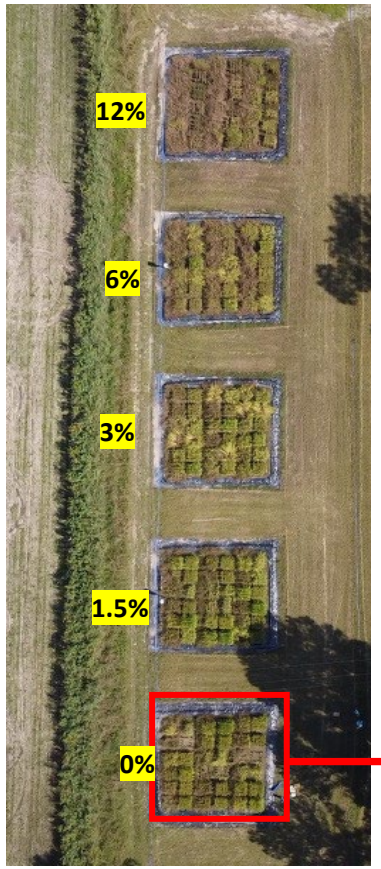
Field Evaluation Study

Experimental Layout



Experiment Layout





No. of Plants = 16
Spacing = 25 cm

100% seawater = 55 dS/m,
or 35 ppt,
or ~35,000 ppm.

Methodology

Transplanting

Hand weeding in weed-free plots

Stone river EC = 40-55 dS/m

Water collected from saltwater river

Saltwater application at late tillering stage

Water Collection: Tidal water was collected from the adjacent marsh using a gasoline pump and stored in a 4000-gallon-capacity reservoir.

Plot Setup: Different treatment plots were designated and marked, including plots for tidal water, freshwater, and mixed treatments, ensuring consistent soil conditions across all plots.

Water Application: Tidal and freshwater volumes were applied to the respective plots while monitoring and adjusting electrical conductivity (EC) to maintain target levels.

Data Management: EC readings and water volumes applied were recorded systematically, and the data was analyzed to assess the impacts of different water treatments on EC and other relevant variables.

100 % ocean water =55 dS m-1 or 35 ppt

Data Collection and Analysis

Photosynthesis Li-COR 6800

EC, TDS, pH and Temp sensors

Other Variables:

1. Plant Height
2. No. of Tillers
3. No. of Panicles
4. Main Panicle Length
5. Sterile Panicles
6. Yield
7. Weed biomass and weeding time
8. Rice plant root and shoot biomass
9. Plant tissues mineral analysis

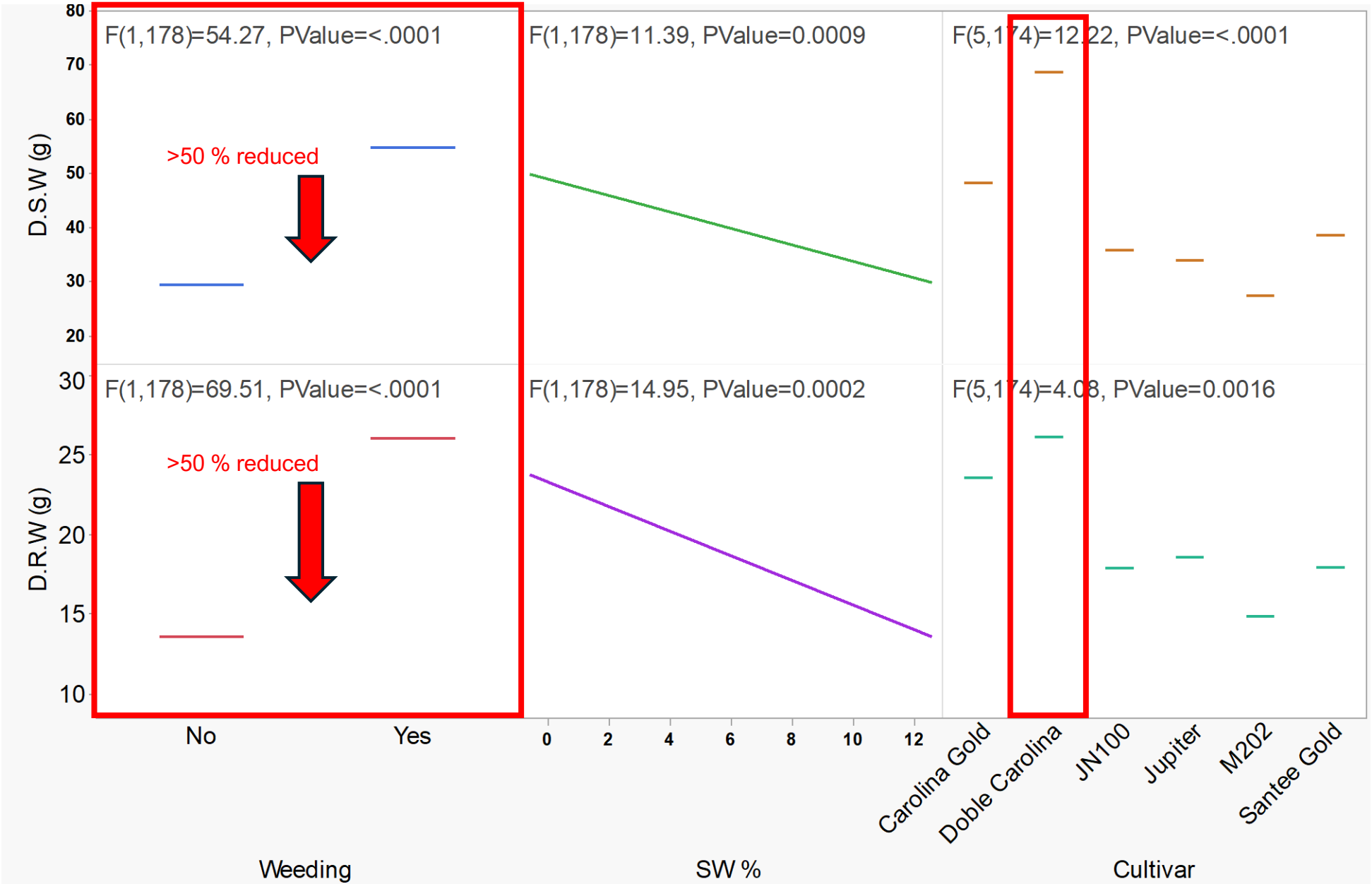
Soil Sampling: 0-30 cm, 30-60 cm, 60-90 cm, and 90-120 cm

Data Analysis: . The data was analyzed using JMP pro 17 and SigmaPlot software to evaluate the impacts of different water treatments on plant parameters, soil properties and other relevant variables.

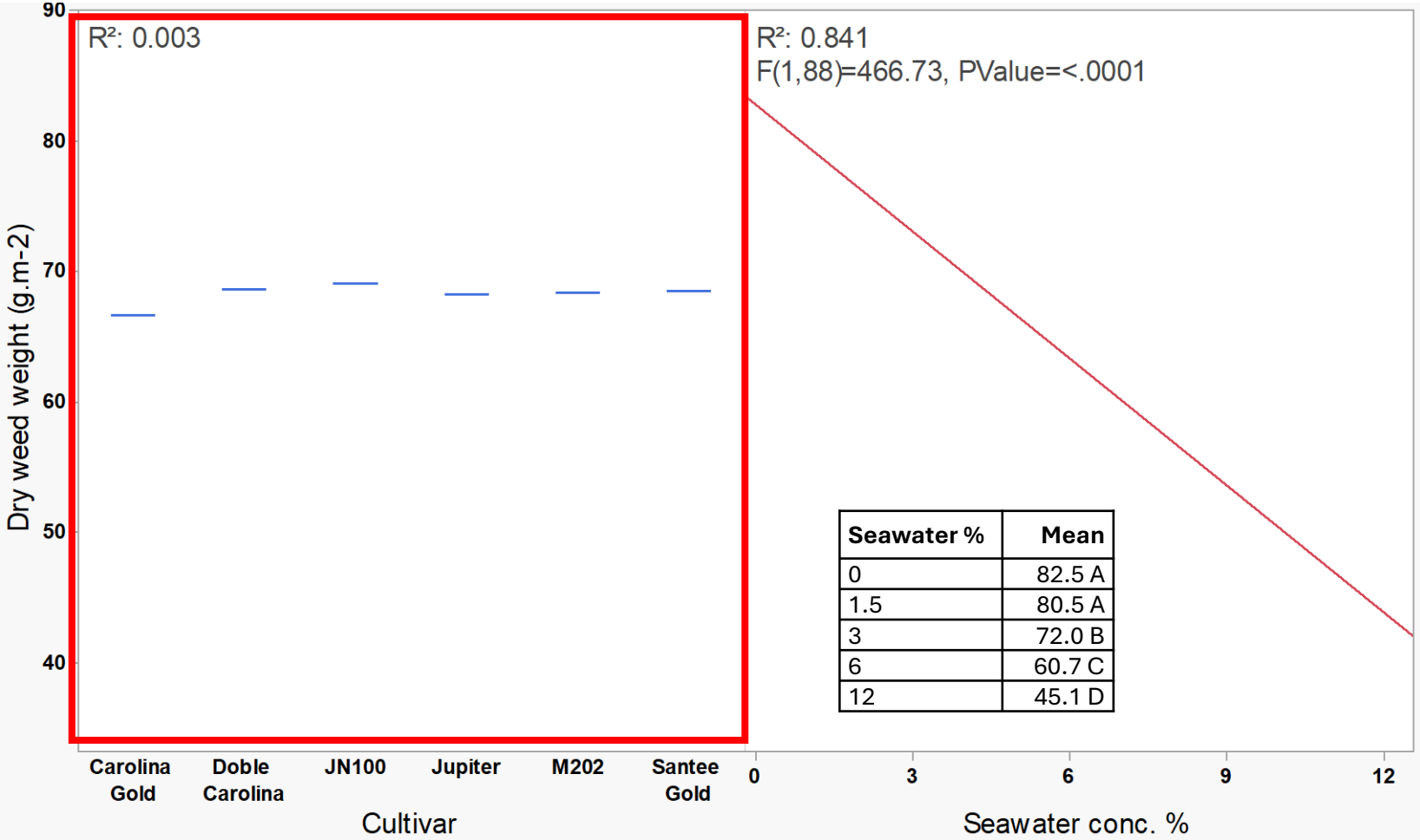
jmp STATISTICAL DISCOVERY

SIGMAPLOT Exact Graphs and Data Analysis

Plant Dry Shoot and Root Weight



Effects of Salinity on Weed Biomass

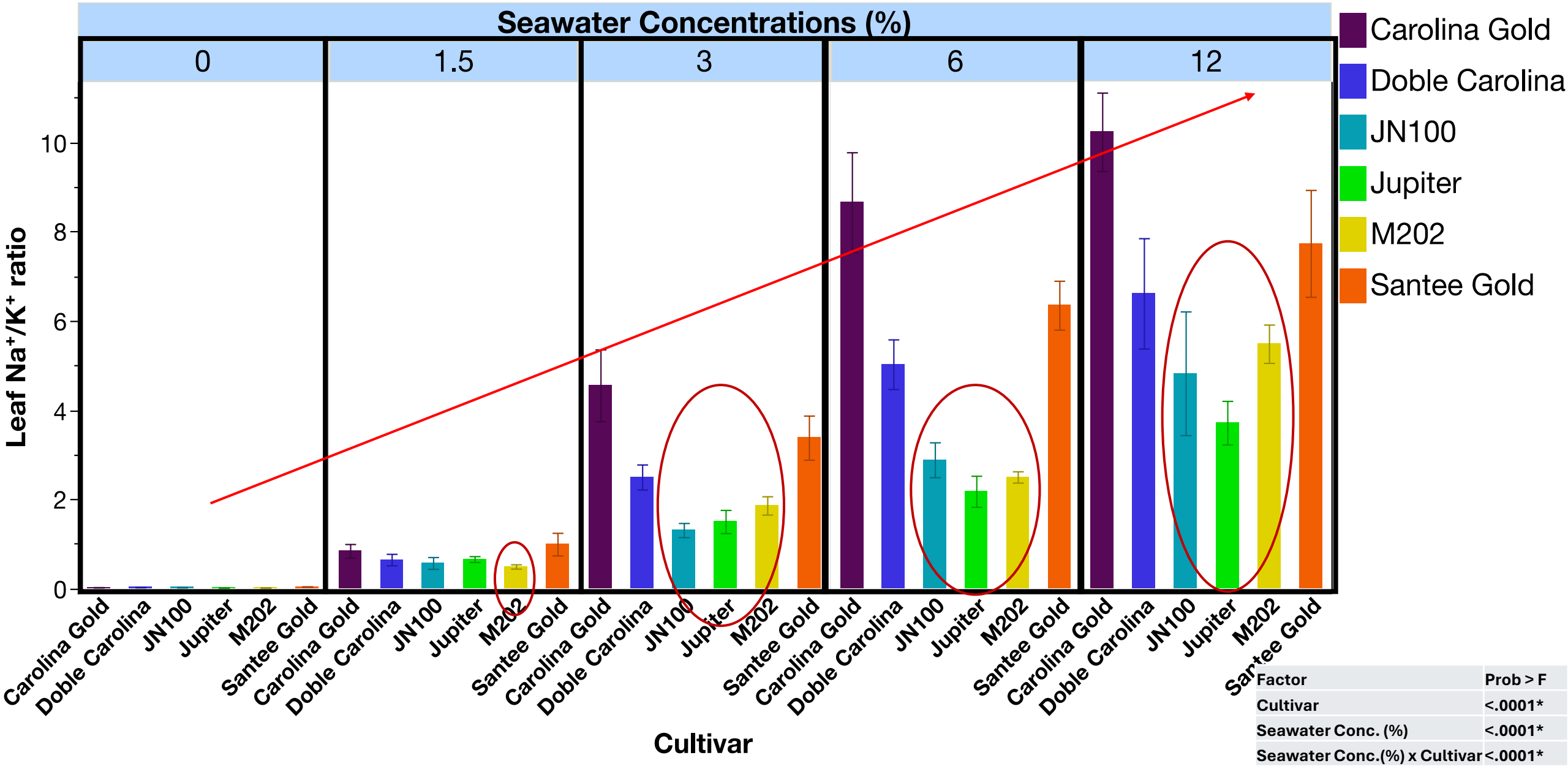


Seawater %	Mean
0	82.5 A
1.5	80.5 A
3	72.0 B
6	60.7 C
12	45.1 D

Weeding time observation:

1. ~3-5 times decrease in weeding time in 6% saltwater treatment (n=16).
2. ~8-10 times decrease in weeding time in 12% saltwater treatment (n=16).

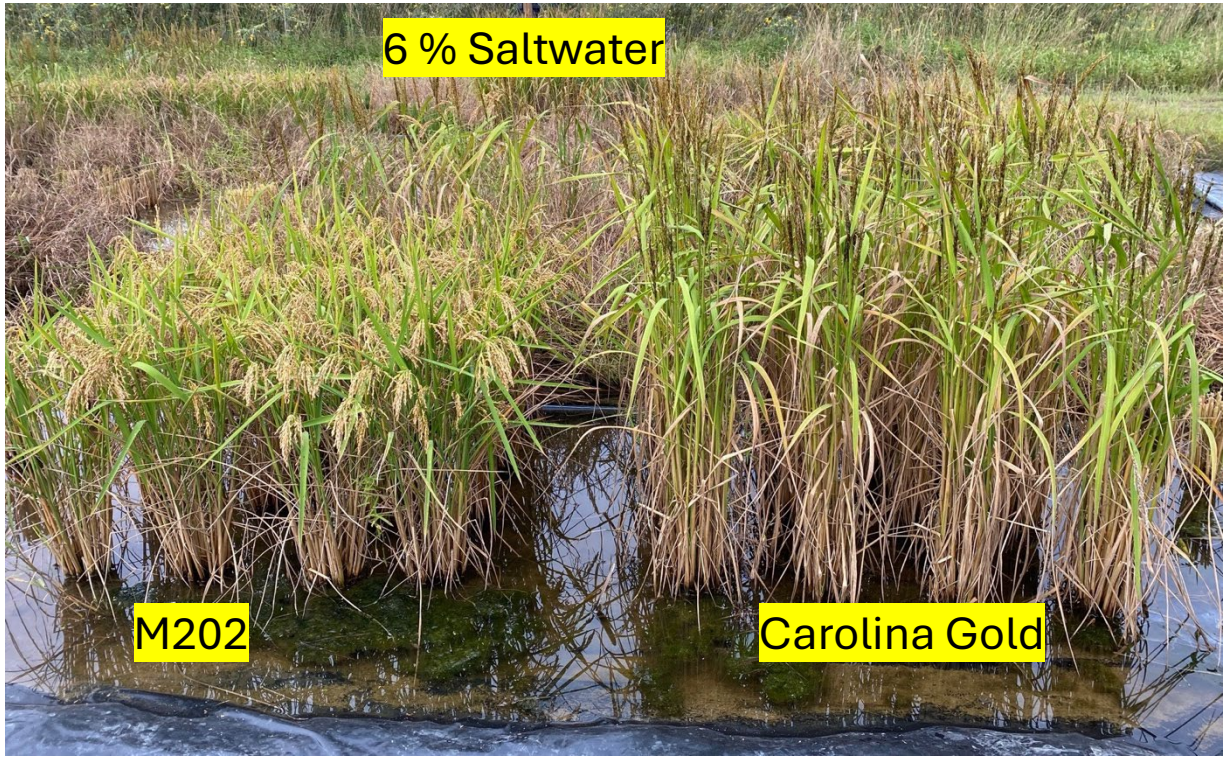
Effects of Salinity on Rice Leaf Na^+/K^+ Ratio

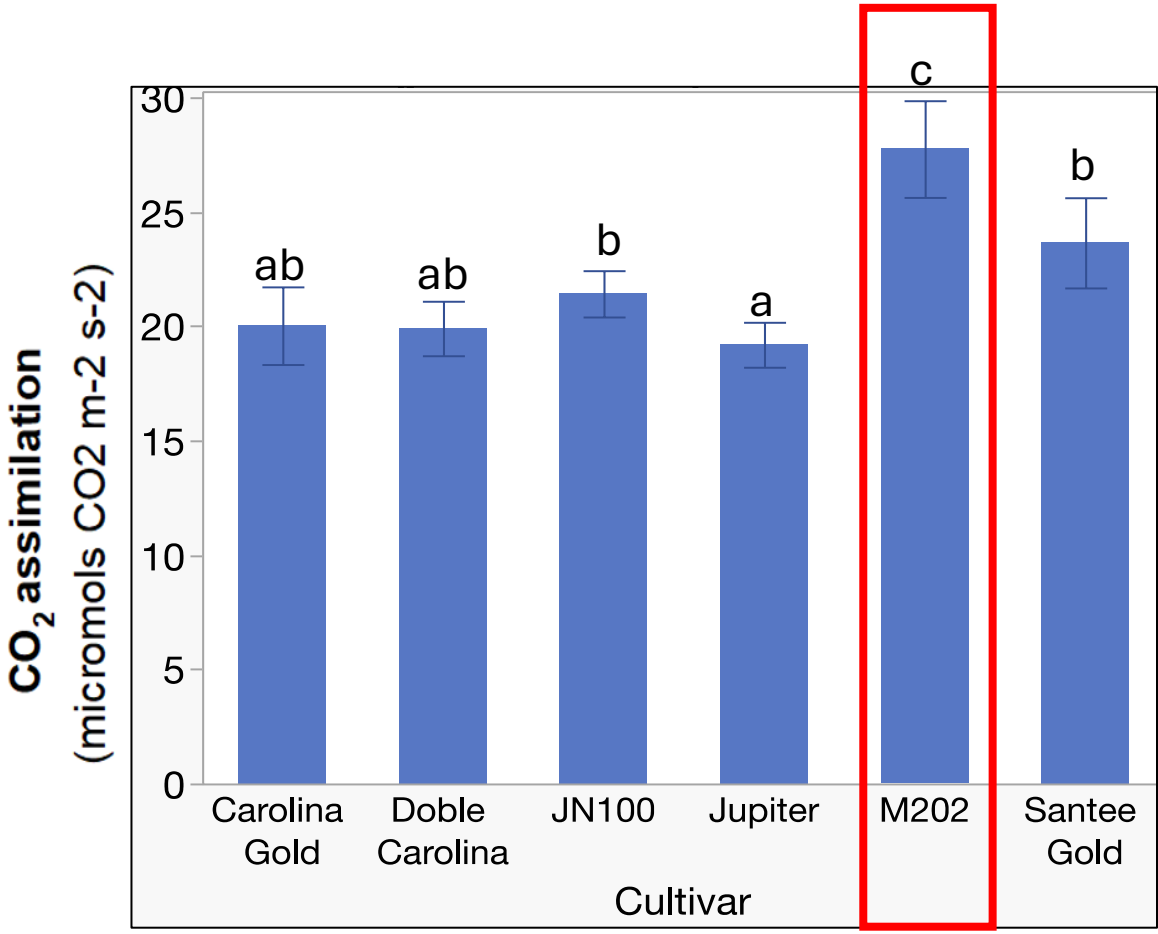


Factor	Prob > F
Cultivar	<.0001*
Seawater Conc. (%)	<.0001*
Seawater Conc.(%) x Cultivar	<.0001*

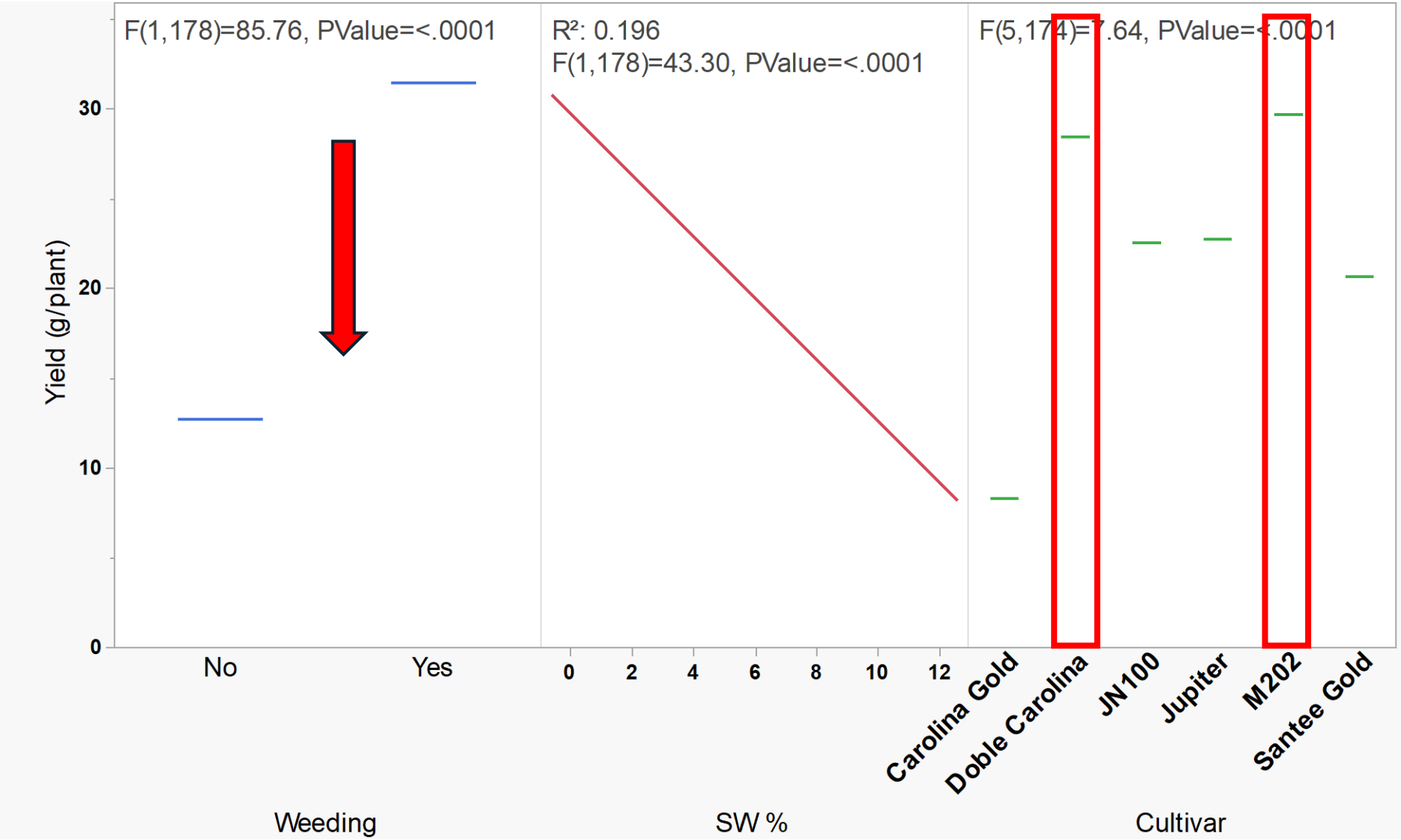
Photosynthesis and Stomatal Conductance

- M202 had significantly higher net CO_2 assimilation under salt stress, indicating improved photosynthetic performance and overall plant resilience.



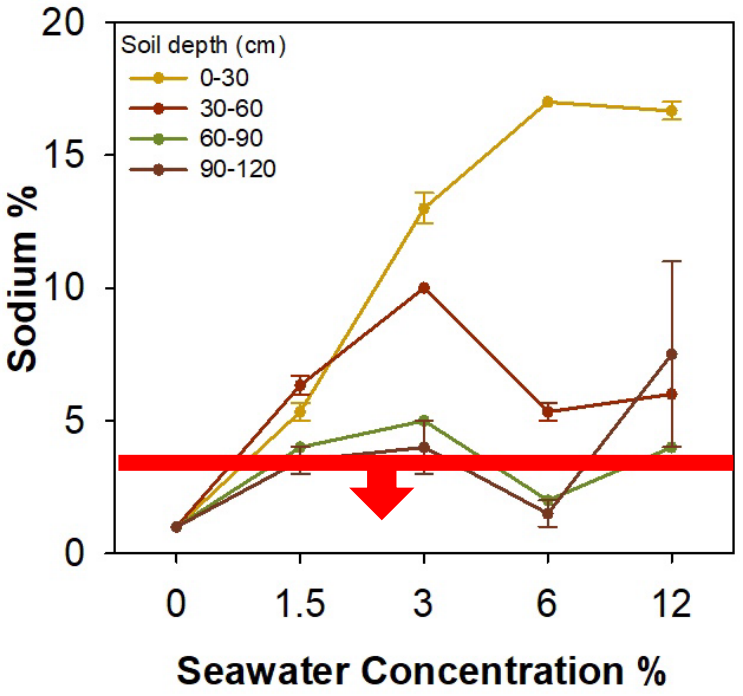


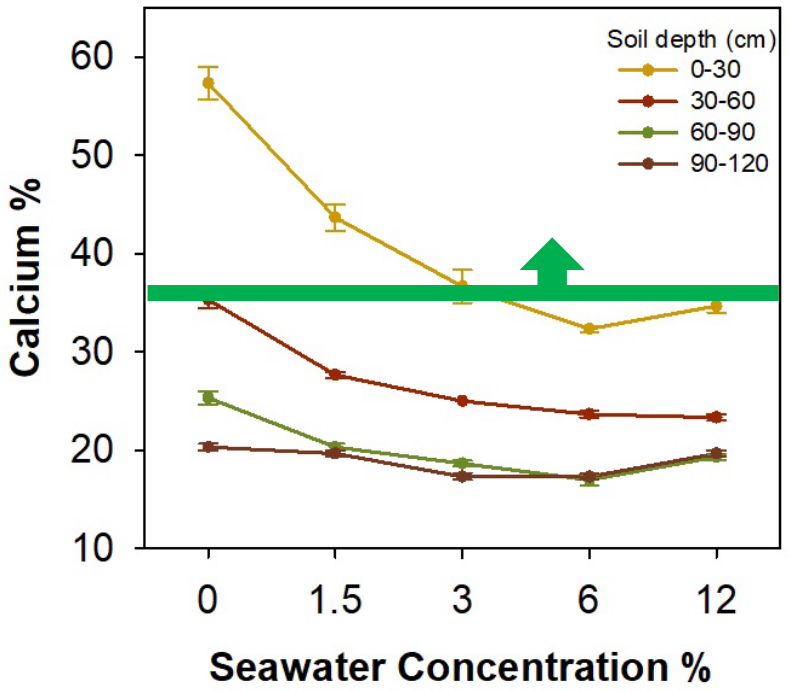
Effects of Salinity on Grain Yield

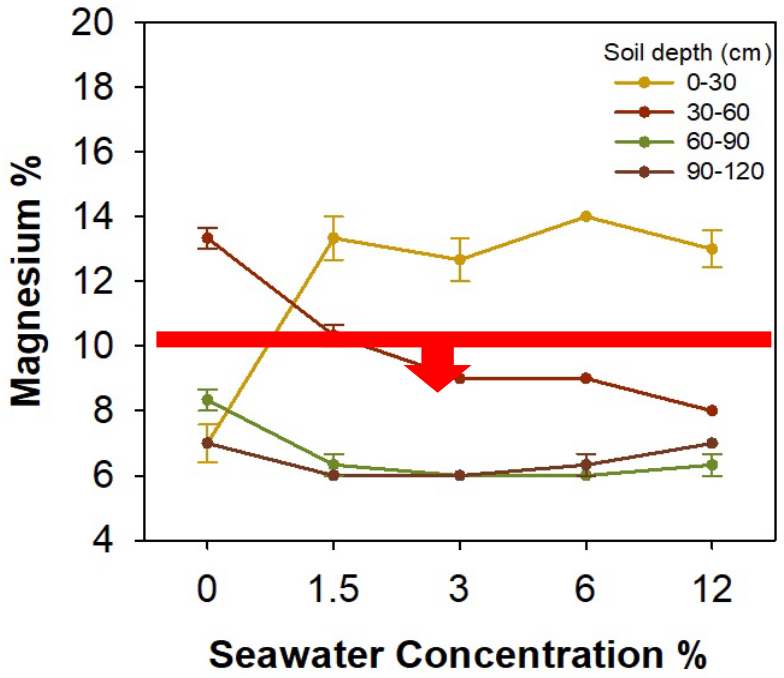


- M202 had higher yield at 6 and 12 % seawater concentration.

Effects of Salinity on Soil Chemistry: Na, Ca and Mg %



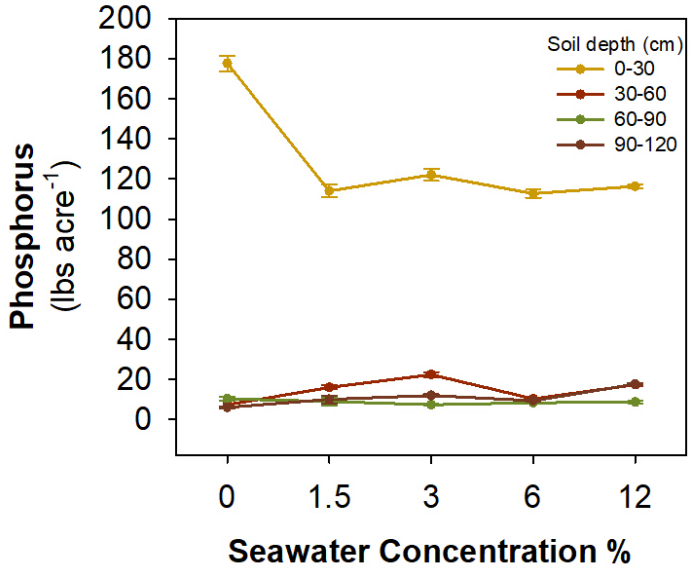


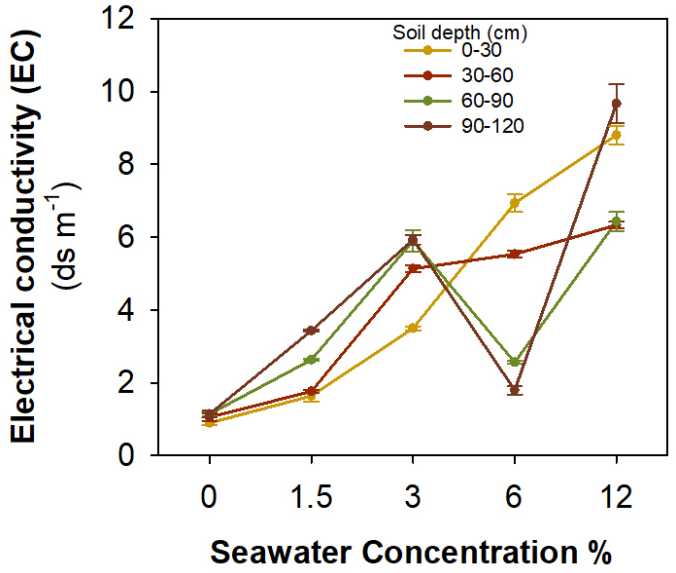


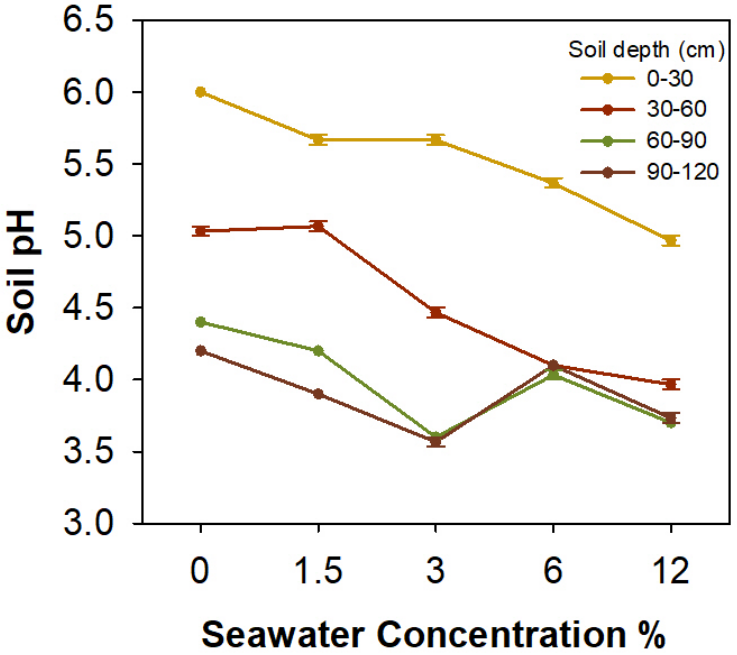
*1 % Na/Ca/Mg = 10000 ppm

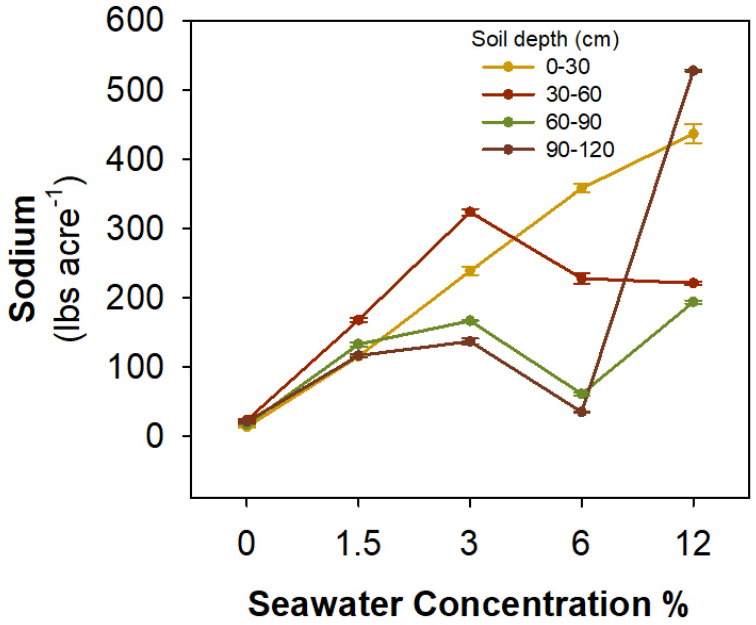
Practical Insights:

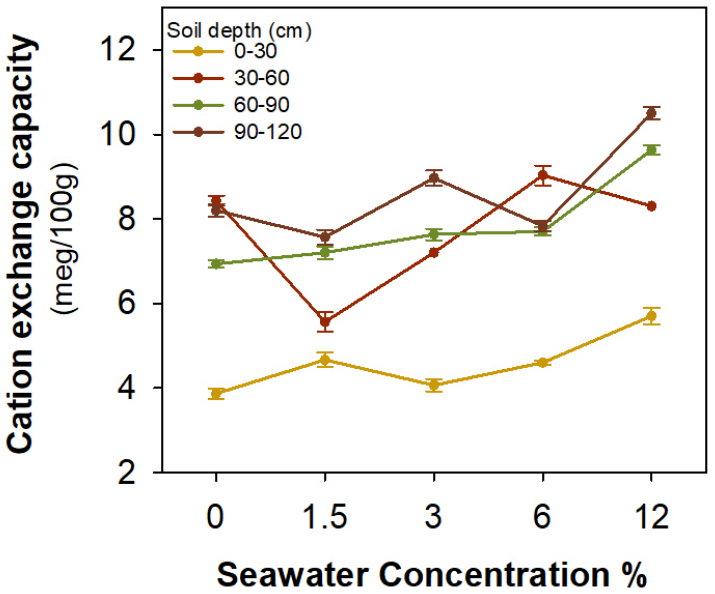
- **Sodium** (Na): Should be kept below **~30,000 ppm (3%)** to avoid severe salinity issues.
- **Calcium** (Ca): Levels above **350,000 ppm (35%)** are ideal for maintaining good soil health and structure.
- **Magnesium** (Mg): A balance with calcium is critical. Mg concentrations exceeding **100,000 ppm (10%)** can reduce calcium uptake.


Phosphorus
(lbs acre-1)
Soil depth (cm)
0-30
30-60
60-90
90-120
Seawater Concentration %


Electrical conductivity (EC)
(ds m-1)
Soil depth (cm)
0-30
30-60
60-90
90-120
Seawater Concentration %


Soil pH
Soil depth (cm)
0-30
30-60
60-90
90-120
Seawater Concentration %


Sodium
(lbs acre-1)
Soil depth (cm)
0-30
30-60
60-90
90-120
Seawater Concentration %


Cation exchange capacity
(meg/100g)
Soil depth (cm)
0-30
30-60
60-90
90-120
Seawater Concentration %

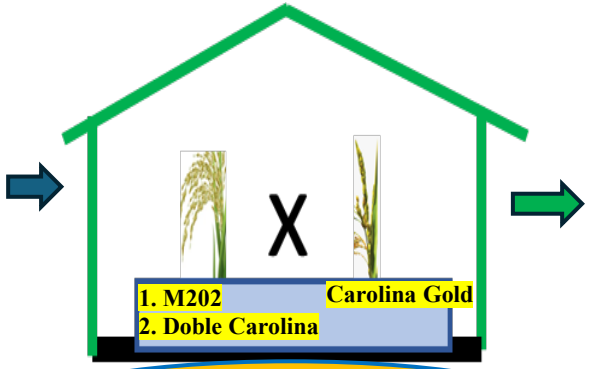
Conclusions

- **M202 cultivar** exhibited the highest salt tolerance, demonstrated significantly higher CO_2 assimilation rates, higher yields, and required less time to mature.
- **Caroline Gold** is highly salt-sensitive cultivar.
- **Weed biomass, weeding time and regrowth of weeds** declined significantly above 3 % seawater concentration when compared to control.
- Weeding time decreased by **3-5 times decrease in 6% seawater treatments and by ~8-10 times in 12% seawater treatments,** as compared to the 0% seawater.

Breeding Program Updates

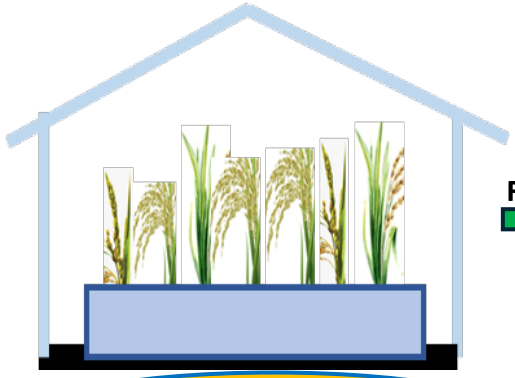
Greenhouse (2022-2023)

Field (2023-2024)



Crosses made between salt-tolerant and Carolina gold cultivar

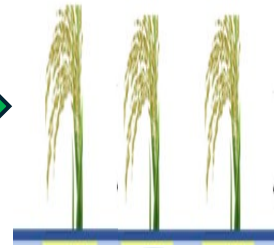
Crosses made (2022-2023)



F2 'Carolina Gold' type rice lines in greenhouse under tidal water

F2 screening (2024)

F6-F7



Salt-tolerant/weed competitive cultivar

Continue

Rice Lines Provided by Dr. Jai

Cross Name	Name	Cross #	F2 seeds#	Seeds germinated#	Germ. %
Carolina Gold × M202	F1	168-1	400	397	99.25
Carolina Gold × M202	F1	168-5	400	397	99.25
Carolina Gold × M202	CG Female Parent-1	168-15	100	100	100.00
Carolina Gold × M202	CG Female Parent-2	168-16	100	100	100.00
Carolina Gold × M202	CG Female Parent-3	168-17	100	100	100.00
Carolina Gold × M202	M202 Male Parent-1	168-18	100	97	97.00
Carolina Gold × M202	M202 Male Parent-2	168-19	100	98	98.00
Carolina Gold × M202	M202 Male Parent-3	168-20	100	100	100.00
M202 × Carolina Gold	F1	172-1	500	489	97.80
M202 × Carolina Gold	F1	172-11	400	389	97.25
M202 × Carolina Gold	M202 Female Parent-1	172-15	100	100	100.00
M202 × Carolina Gold	M202 Female Parent-2	172-16	100	97	97.00
M202 × Carolina Gold	M202 Female Parent-3	172-17	100	100	100.00
M202 × Carolina Gold	CG Male Parent-1	172-18	30	29	96.67
M202 × Carolina Gold	CG Male Parent-2	172-19	100	99	99.00
M202 × Carolina Gold	CG Male Parent-3	172-20	60	60	100.00
Doble Carolina × Carolina Gold	F1	175-6	40	38	95.00
Doble Carolina × Carolina Gold	F1	175-7	37	37	100.00
Doble Carolina × Carolina Gold	F1	175-9	25	24	96.00
Doble Carolina × Carolina Gold	F1	175-12	41	40	97.56
Doble Carolina × Carolina Gold	F1	175-13	38	37	97.37
Doble Carolina × Carolina Gold	DC Female Parent-1	175-15	100	98	98.00
Doble Carolina × Carolina Gold	DC Female Parent-2	175-16	100	100	100.00
Doble Carolina × Carolina Gold	DC Female Parent-3	175-17	100	99	99.00
Doble Carolina × Carolina Gold	CG Male Parent-1	175-18	100	99	99.00
Doble Carolina × Carolina Gold	CG Male Parent-2	175-19	50	50	100.00
Doble Carolina × Carolina Gold	CG Male Parent-3	175-20	100	60	60.00
Carolina Gold × Doble Carolina	F1	177-1	65	63	96.92
Carolina Gold × Doble Carolina	F1	177-2	72	67	93.06
Carolina Gold × Doble Carolina	F1	177-6	56	56	100.00
Carolina Gold × Doble Carolina	F1	177-8	70	70	100.00
Carolina Gold × Doble Carolina	F1	177-12	56	53	94.64
Carolina Gold × Doble Carolina	CG Female Parent-1	177-15	100	99	99.00
Carolina Gold × Doble Carolina	CG Female Parent-2	177-16	100	99	99.00
Carolina Gold × Doble Carolina	CG Female Parent-3	177-17	100	100	100.00
Carolina Gold × Doble Carolina	DC Male Parent-1	177-18	100	98	98.00
Carolina Gold × Doble Carolina	DC Male Parent-2	177-19	100	98	98.00
Carolina Gold × Doble Carolina	DC Male Parent-3	177-20	100	99	99.00
		Total Seds	4440		

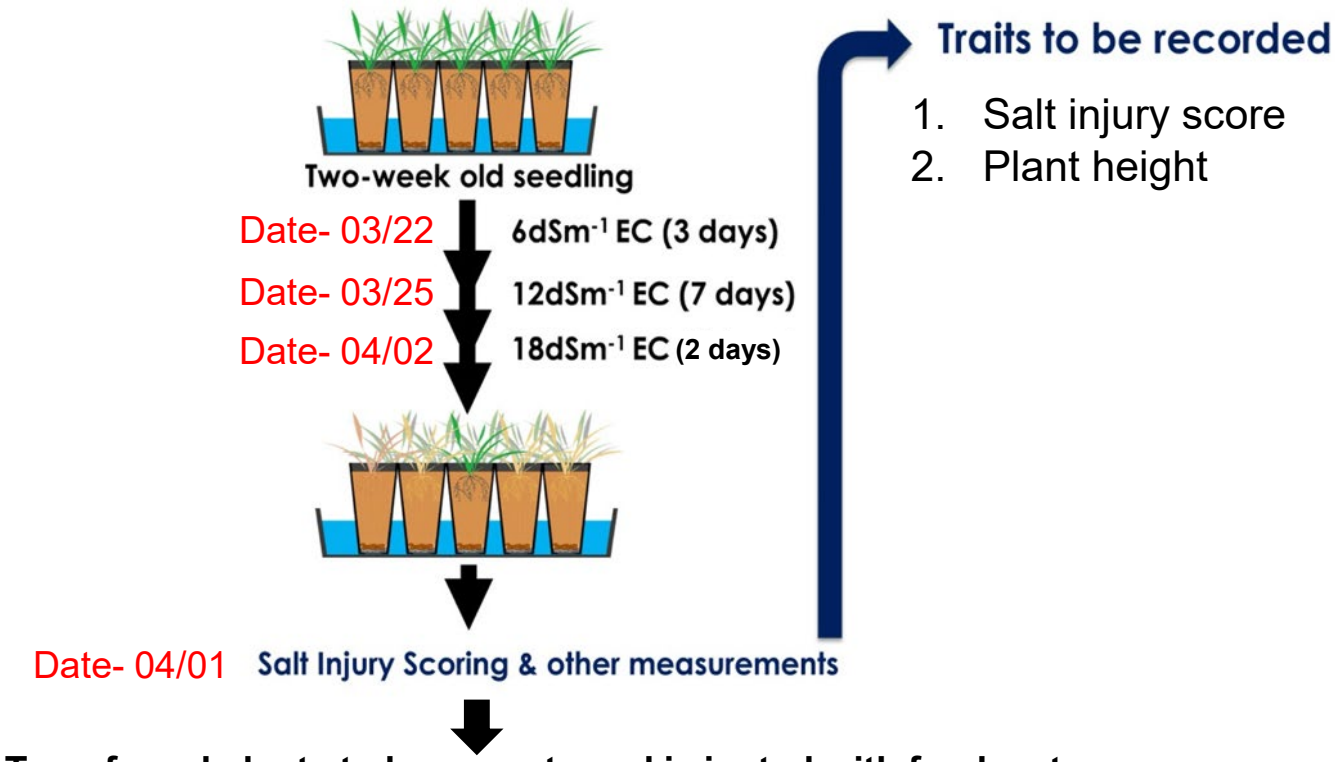
F1 vs. Female/Male Parent Lines: Key Differences

Aspect	F1 Generation	Female/Male Parent Lines
Definition	Hybrid offspring from two parent plants	Individual parental plants used in the cross
Role	Represents the **offspring** of a cross	**Female**: Seed-bearer, **Male**: Pollen-donor
Naming	Labeled as "F1" (e.g., 168-1)	Labeled as “Female/Male Parent” (e.g., CG Female Parent-1)
Trait Inheritance	Contains a mix of traits from both parents	Represents individual parent’s genetic contribution
Purpose	Evaluate hybrid performance (germination, vigor)	Assess parent quality and viability for future breeding

Carolina Gold × M202 (CG Female Parent-1): A seed-bearing plant (Carolina Gold) in a specific breeding cross with M202.

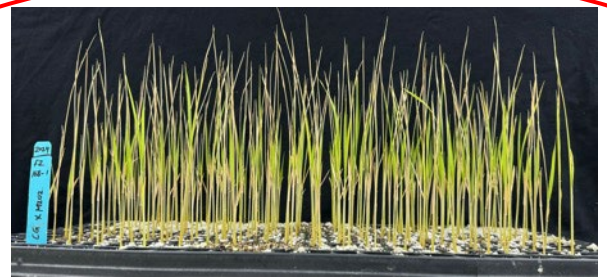
M202 × Carolina Gold (CG Male Parent-1): Here, Carolina Gold provided pollen (male role), while M202 bore the seeds (female role).

Steps In Phenotypic Evaluation Stage



- Plants were initially exposed to EC 6 dS m^{-1} for 3 days, followed by EC 12 dS m^{-1} for 7 days, and finally, EC 18 dS m^{-1} for 2 days (Chapagain et al., 2022).
- The SIS score range from 1.0 (highly tolerant) to 9.0 (highly susceptible), and scores of 3.0, 5.0, and 7.0 were given to tolerant, moderately tolerant, and susceptible seedlings, respectively.

Selection of F2 Plants: Observations



M202 x Carolina Gold (SIS ranges - 1-3)

Doble Carolina x Carolina Gold (SIS ranges - 7-9)

Cross Name	Cross #	SIS Score (range)
Carolina Gold × M202	168-1	1-7
Carolina Gold × M202	168-5	3-5
M202 × Carolina Gold	172-1	1-3
M202 × Carolina Gold	172-11	1-3
Doble Carolina × Carolina Gold	175-6	5-9
Doble Carolina × Carolina Gold	175-7	5-9
Doble Carolina × Carolina Gold	175-9	1-9
Doble Carolina × Carolina Gold	175-12	5-9
Doble Carolina × Carolina Gold	175-13	5-9
Carolina Gold × Doble Carolina	177-1	7-9
Carolina Gold × Doble Carolina	177-2	7-9
Carolina Gold × Doble Carolina	177-6	7-9
Carolina Gold × Doble Carolina	177-8	5-9
Carolina Gold × Doble Carolina	177-12	5-9

Table 1. Modified standard evaluation score (SES) of visual salt injury at seedling stage.

Score	Observation	Tolerance
1	Normal growth, no leaf symptoms	Highly tolerant (HT)
3	Nearly normal growth, but leaf tips of few leaves whitish and rolled	Tolerant (T)
5	Growth severely retarded, most leaves rolled; only a few are elongating	Moderately tolerant (MT)
7	Complete cessation of growth; most leaves dry; some plants dying	Susceptible (S)
9	Almost all plants dead or dying	Highly susceptible (HS)

Source: Gregorio *et al.*, (1997)

Selection of F2 Plants: Observations

- SIS scores 1-9 reflect salt tolerance variance among genetic crosses.
- M202 crosses showing better salt tolerance at seedling stage observations.
- Salt Tolerant lines' seeds will progress to the next generation.

Acknowledgements

Advisors: Dr. Matthew Cutulle and Dr. Brain Ward

Co- Advisors and Collaborators: Dr. R. Karthikeyan, Dr. Sarah White, Dr. Mike Marshall, Dr. Jai Rohilla and Dr. Prasanta K. Subudhi

CREC Staff: Sam White, Matt Horry, Tyler Campbell, Tom, Paco, Shoaib, Simardeep and all other summer interns.

GSOR (Genetic Stocks Oryza) – DBNRRC.

Funding: NIFA-ORG-Grant #2021-51106-35494.

Dr. Matthew Cutulle
Associate Professor/Weed Scientist

Dr. Brian Ward
Assistant Professor/Organic Specialist/Rice Specialist

CLEMSON UNIVERSITY

USA Rice

USDA NIFA

United States Department of Agriculture
National Institute of Food and Agriculture

Thank You and Questions?