Adapting the DSSAT CSM for Saline Soils

Vakhtang Shelia and Gerrit Hoogenboom
Department of Agricultural and Biological Engineering
Global Food Systems Institute
University of Florida, Gainesville, FL, USA

Outline

- Salinity & Plant
- Salinity Modeling & DSSAT
- Case Studies
- Conclusions and Future Steps

Salinity

- Salinity-affected lands:
  - **20%** of the total cultivated land
  - **33%** of irrigated agricultural lands.
  - an estimated **10%** annual increase in salinized agricultural areas worldwide
- Human Activities
  - Irrigation: Using **irrigation water** with high salt content.
  - **Poor drainage**: Prevents salts from being leached away, leading to their accumulation in the root zone.
  - **Over-fertilization**: Excessive use of fertilizers contributes to salt buildup in the soil.
- **Crop models** can play an important role in determining which management systems (crops and agri practices) can mitigate salinization

Chele et al., 2021

Plant and Salinity

- **High salinity** levels can make it difficult for plants to **absorb water and nutrients**, leading to reduced plant growth, lower yields, and even crop failure.
- Plant response to salinity encompasses two phenomena:
  - Water deficits that affect the plant immediately (**osmotic**, due to salts)
  - **Specific ion toxicity** effects are noticeable weeks to months later, after thresholds of specific ions in leaf tissue are surpassed

Munns and Termaat, 1986

Salinity in DSSAT CSM

- The current official version of DSSAT CSM **does not account** for the effects of soil salinity on crop growth.
- This limitation restricts its application in salt-affected soils,
  - Specifically, in **arid and semi-arid** environments, where salinization poses a significant threat to crops.

Salinity for DSSAT CERES & CROPGRO

- Castrignanò et al., 1998
  - A saline stress index for the **CERES-Maize** model, a function of predawn leaf water potential.
  - For each soil type and salinity level combination, a linear piecewise regression model must be fitted to the predawn leaf water potential measurements for further processing.
- Webber et al., 2010
  - An empirical root water uptake (RWU) reduction function within the **CROPGRO-Dry Bean** model to account for soil salinity effects.
  - Soil salinity is considered **constant** within the growing season.

Salinity Model in DSSAT CSM

- Multiple studies have been conducted, but none have been included in the official DSSAT releases.
- To fill this gap, we have been developing a salinity model:
  - That accounts for **transpiration reduction** under saline conditions
  - Considers **salinity dynamics** in the soil profile

Salinity Model - transpiration reduction

- Reduction function:

$$REDF = 1 - \frac{SALRDCT}{100}(SALT(L) - EC_{thr}) \text{ (1)}$$

- *SALRDCT* - **relative rate** of reduction in water use with increasing soil salinity
- *SALT(L)* - **soil salinity**
- EC_{thr} - **crop characteristics**, soil salinity above which plant water use will be suppressed

Webber et al., 2010

Salinity Model - transpiration reduction

- When $TRWU_p > E_{0p}$

$$ET_{red1} = REDF \times E_{op} \quad (2)$$

- When $TRWU_p < E_{0p}$

$$ET_{red2} = REDF \times TRWU_{p,init} \quad (3)$$

Salinity Model - transpiration reduction

- **Iterative routine** that replaces *LL(L)* with a new value $LL_{salt}(L)$ for the calculation of *RWUp(L)*.
- **Second** salinity stress

$$SWFAC_{saline} = SWFAC \times \frac{1}{S_1(SALT_{wa} - EC_{thr}) + S_2} \quad (4)$$

- *SWFAC* - water stress factor for reducing photosynthesis.
- $SALT_{wa}$ – weighted average soil salinity in the root zone
- S_1, S_2 - parameters for adjusting to obtain good model fit with observed data

Salinity Model – salinity dynamics

- **Salt mass balance** equations, using electrical conductivity of the water, EC_{sw}, to represent the salinity as a function of variables from the water balance (water content, irrigation, rain, drain, etc.)
- Saturated paste electrical conductivity:

$$EC_e = EC_{DRN} \frac{SWC}{SWC_s} \quad (5)$$

Kisekka et al., 2022

Salinity Model – inputs

```
! SALINITY.INP file
! ECTH - Crop characteristics for salt tole
!        soil salinity above which plant wat
! S1 - First parameter in reduction factor
!      under saline than non-saline conditio
!      model fit with observed data
! S2 - Second parameter with same meaning
! SRDCT - Relative rate of reduction in wat
! EPS   - Approximation value
! DELTA - Step for increasing approximation

*CULTIVAR
! ECTH     S1    S2  SRDCT
   4.0  0.19  1.08    3.3

*APPROXIMATION
!  EPS  DELTA
  0.02   0.01
```

```
*INITIAL CONDITIONS
@C   PCR ICDAT  ICRT  ICND  ICRN  ICRE  ICWD ICRES ICREN ICREP I
 1    WH 17353   -99   -99     1     1   -99   -99    .3   -99
@C  ICBL  SH2O  SNH4  SNO3  SLNT
 1    20  .186    .7   5.9  1.22
 1    40   .19    .7   5.9  0.90
 1    60   .19    .7   5.9  1.54
```

```
*IRRIGATION AND WATER MANAGEMENT
@I  EFIR  IDEP  ITHR  IEPT  IOFF  IAME  IAMT IRNAME
 1     1    30    50   100 GS000 IR001    10 CONTRL 120%
@I IDATE  IROP IRVAL IRSLN
 1 18046 IR005    70   2.0
 1 18062 IR005    70   2.0
 1 18073 IR005    70   2.0
 1 18083 IR005    70   2.0
```

```
@N GENERAL     NYERS NREPS START SDATE RSEED SNAME.................... SMODEL
 2 GE              1     1     S 17353  2150 SALINITY 4ds/m            CSCER
@N OPTIONS     WATER NITRO SYMBI PHOSP POTAS DISES  CHEM  TILL   CO2 SALIN
 2 OP              Y     Y     N     N     N     N     N     Y     M     Y
```

Case Studies

- Central Jordan Valley, Jordan
  - Agricultural Research Station
- Pakka Anna, Pakistan
  - Bio-saline Research Station

Case Study (1)

- Field experiment
  - the central Jordan Valley, the Agricultural Research Station
- Wheat Cultivar: “Um Qais”, 2018
- 3 irrig levels, 5 appl : R1/R2/R3 - 350/250/200 mm
- 3 water salinity levels : S1/S2/S3 - 2/4/8 dS/m

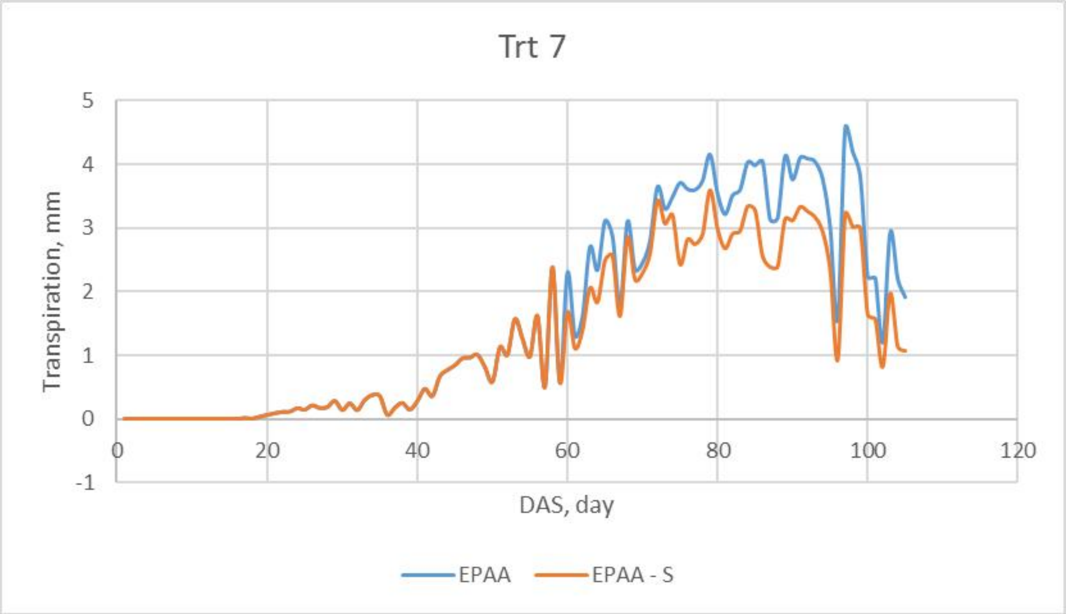
Hamdi et al., 2019

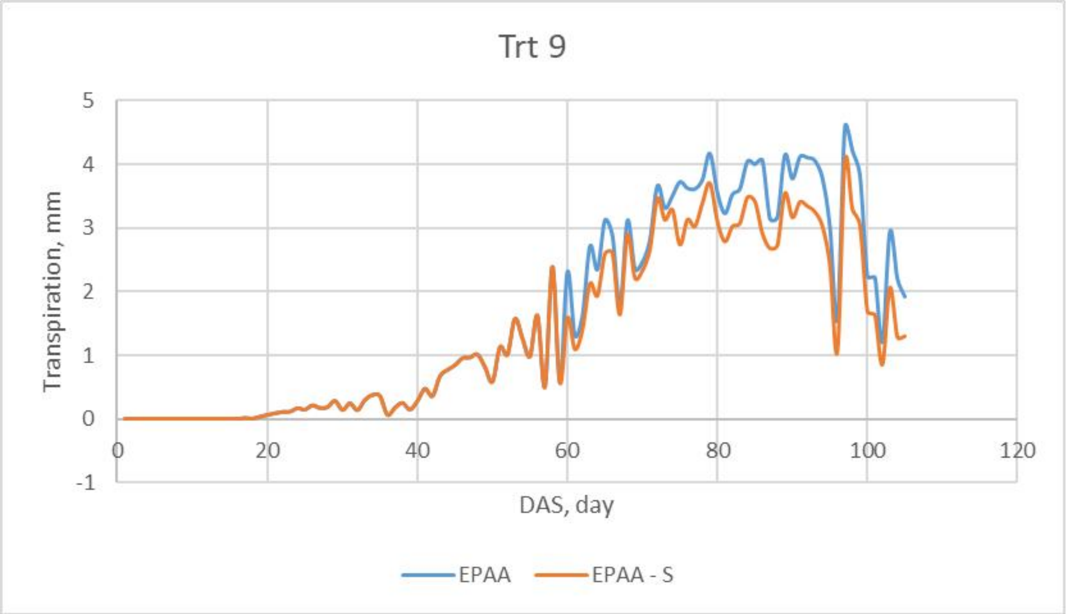
Case Study (1)

- EC_{thr} was estimated - 4 dS/m
- A water use **reduction rate** of 3.3% per dS/m
- Soil type: Entisol with a fine loamy sand texture
  - Clay (%) 16 ± 0.48
  - Sand (%) 73 ± 0.65
  - Silt (%) 11 ± 0.33
- LL – 0.09-1.0, DUL – 0.18-0.2, SAT – 0.38-0.4, KS – 2.59 – cm/h
- Well-drained
- Precipitation – 77 mm

Hamdi et al., 2022

Case Study (1) - Transpiration

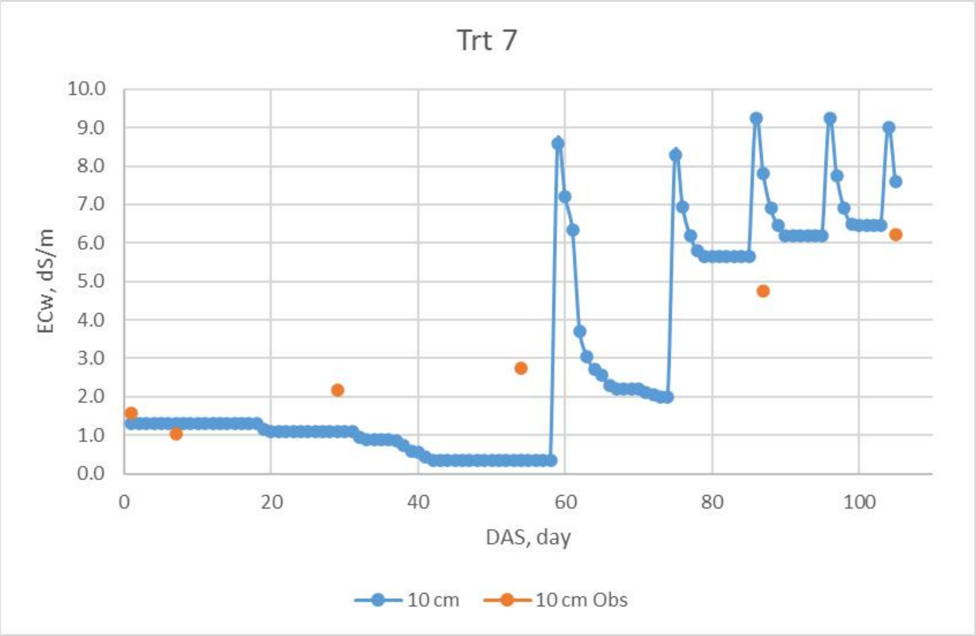


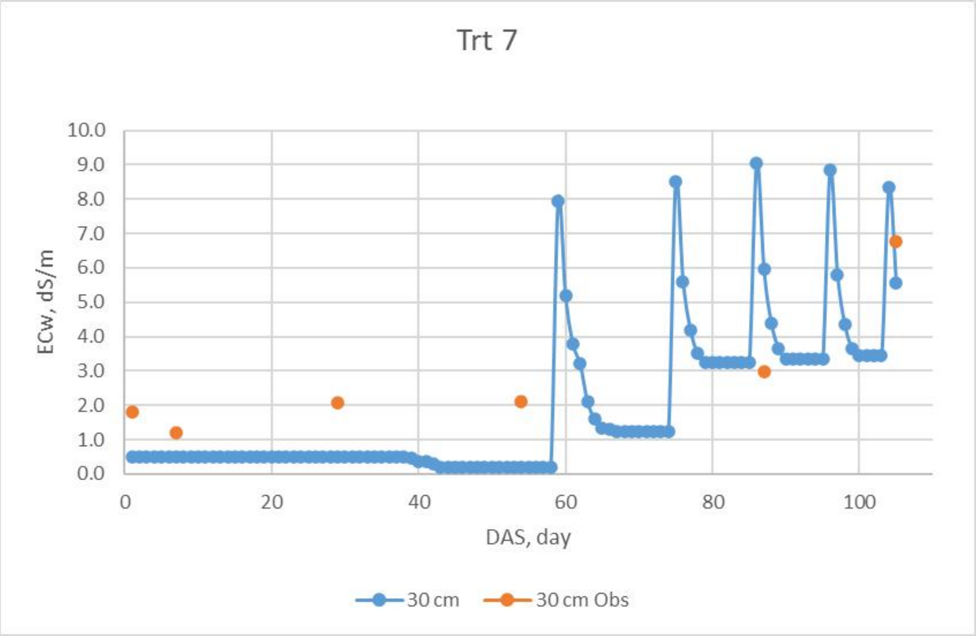


Irrig 350 mm, EC_{irri} – 8 dS/m
Drainage – 185 mm
Total Transpiration:
Salinity on: 129 mm
Salinity off: 166 mm

Irrig 200 mm, EC_{irri} – 8 dS/m
Drainage – 48 mm
Total Transpiration:
Salinity on: 136 mm
Salinity off: 166 mm

Case Study (1) - EC_w





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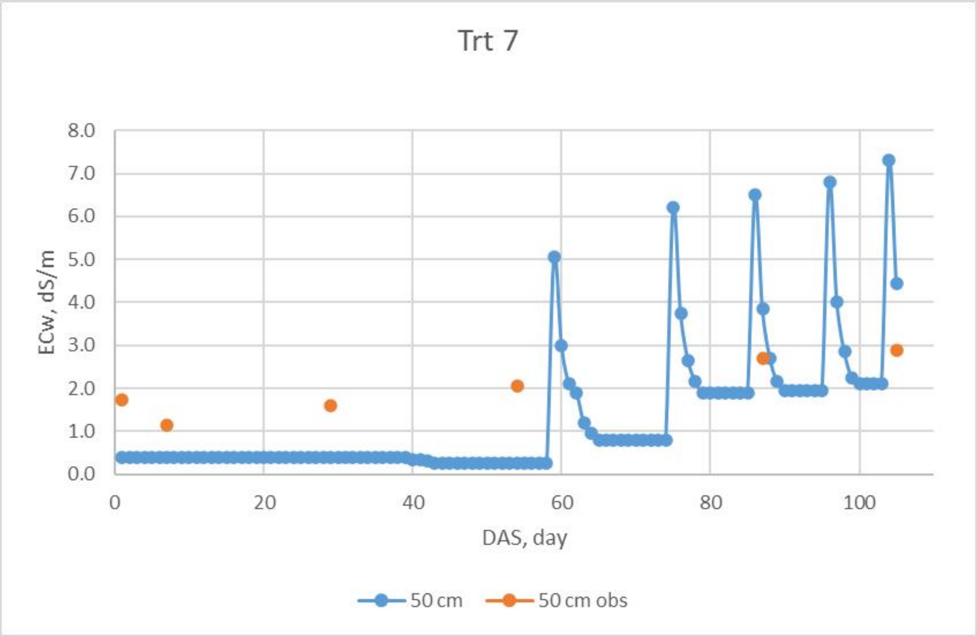
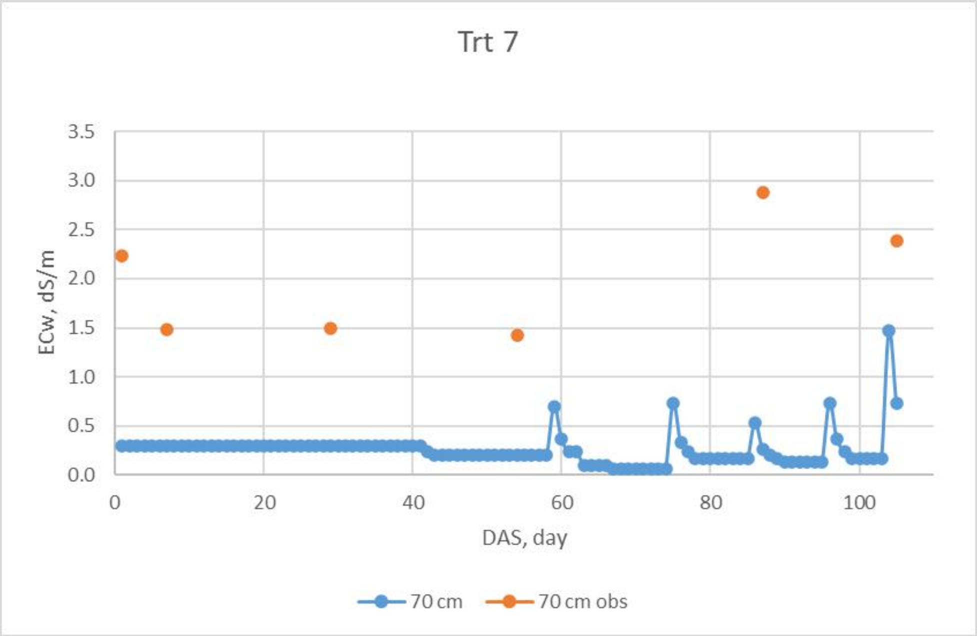
Drainage – 185 mm

Case Study (1) - EC_w





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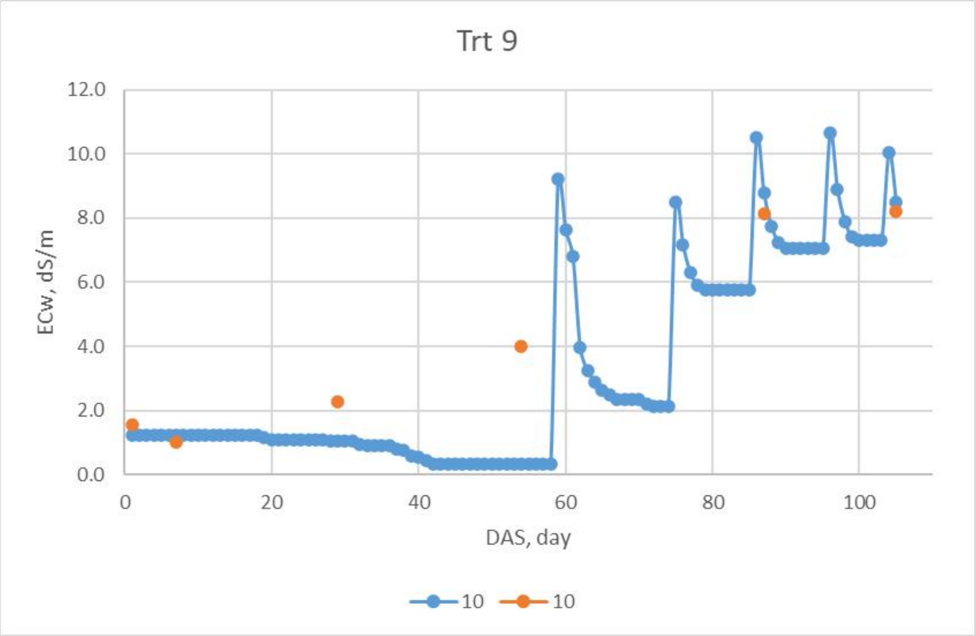
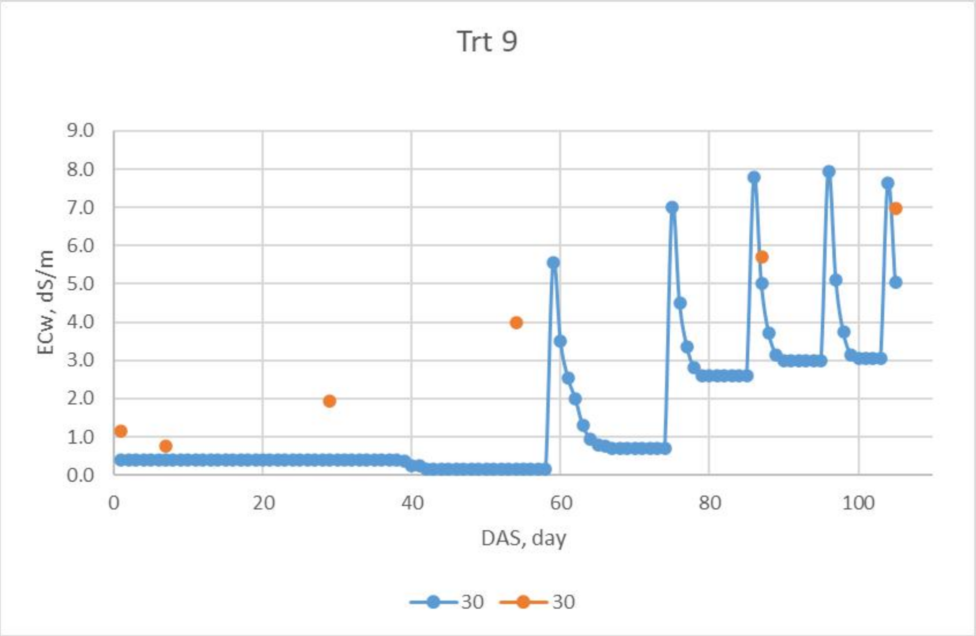
Drainage – 185 mm

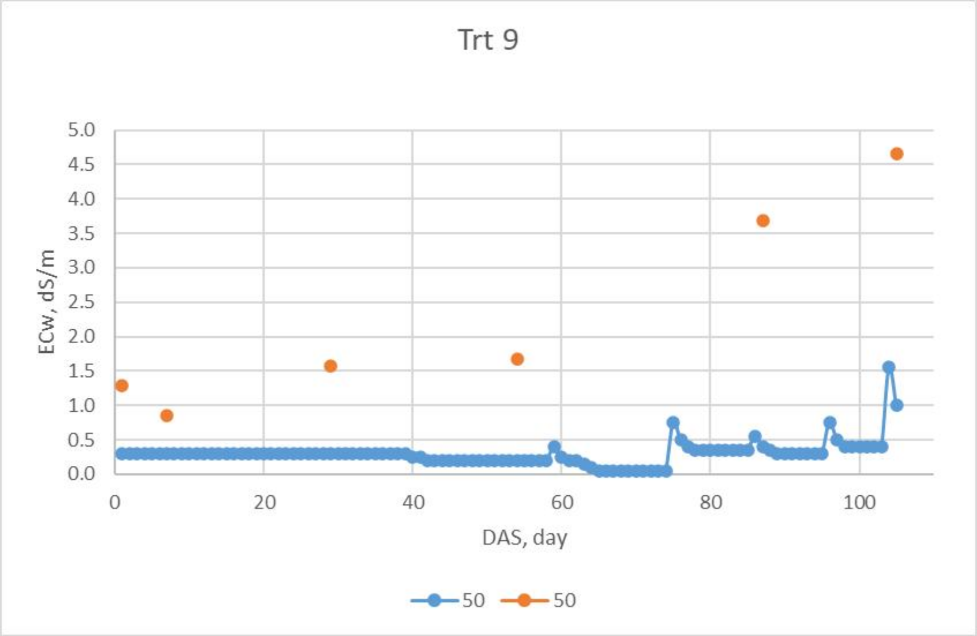
Case Study (1) - EC_w

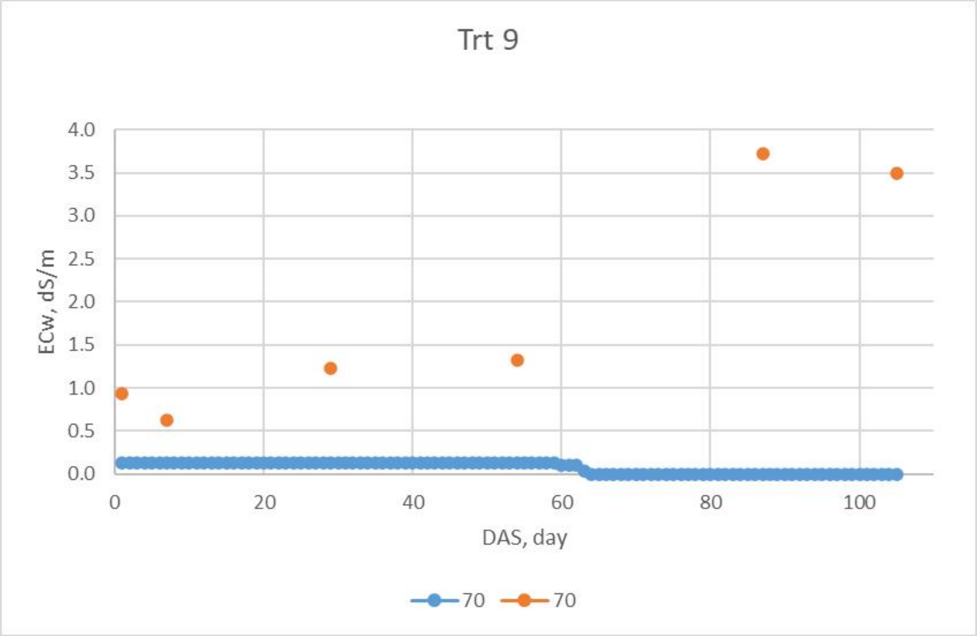




Irrig 200 mm, EC_{irri} – 8 dS/m
Drainage – 48 mm

Case Study (1) - EC_w





Irrig 200 mm, EC_{irri} – 8 dS/m
Drainage – 48 mm

Case Study (2)

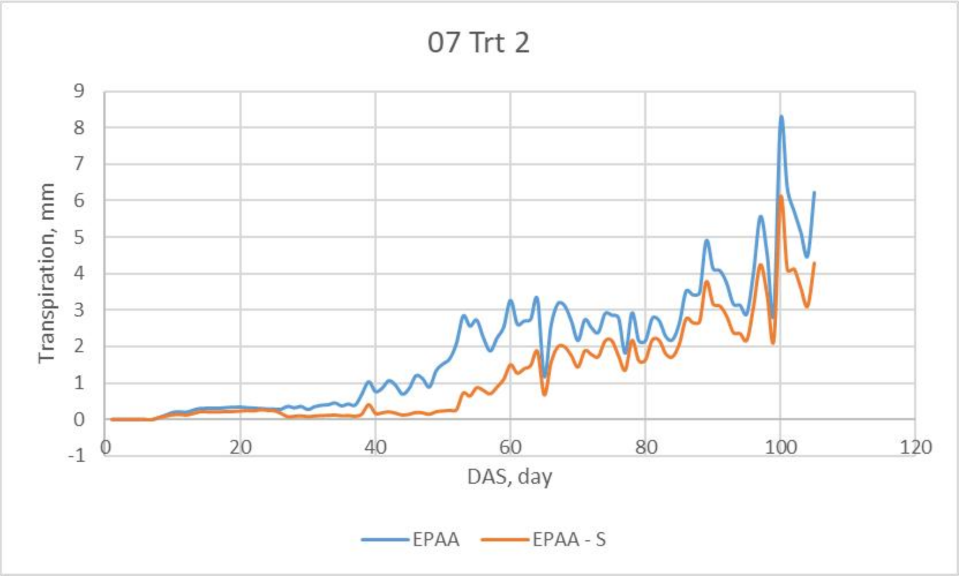
- Pakka Anna, Pakistan
  - Bio-saline Research Station,
- Wheat Cultivar: “Sehar-2006”
- Irrigation: 5 applications, 240 mm, 2007
- Irrigation: 3 applications, 200 mm, 2013
- Salinity IC and at harvest :
  - 6. 8 & 9.3 dS/m (2007)
  - 12.8 & 12.3 dS/m (2013)

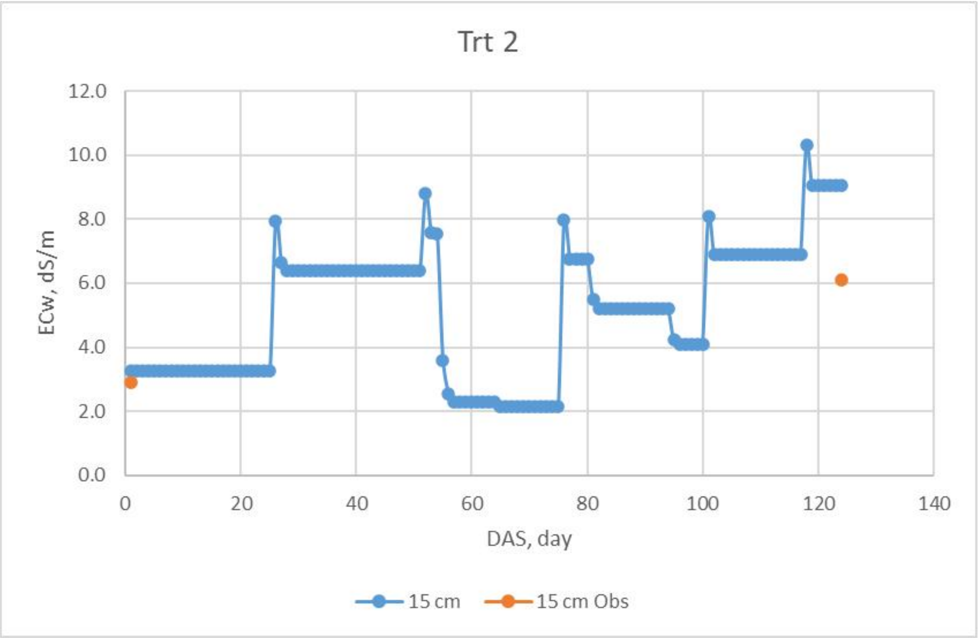
Ishaque et al., 2018

Case Study (2)

- EC_{thr} was estimated - 4 dS/m
- A water use **reduction rate** of 3.3% per dS/m
- Soil type: Entisol with a fine loamy sand texture
  - Clay (%) 5 - 15
  - Sand (%) 64 - 84
  - Silt (%) 11 - 21
- LL – 0.06-0.11, DUL – 0.15-0.22, SAT – 0.34-0.2
- KS – 2.59-6.11 – cm/h
- Excessive
- Precipitation – 67 mm (2007), 124 mm (2013)

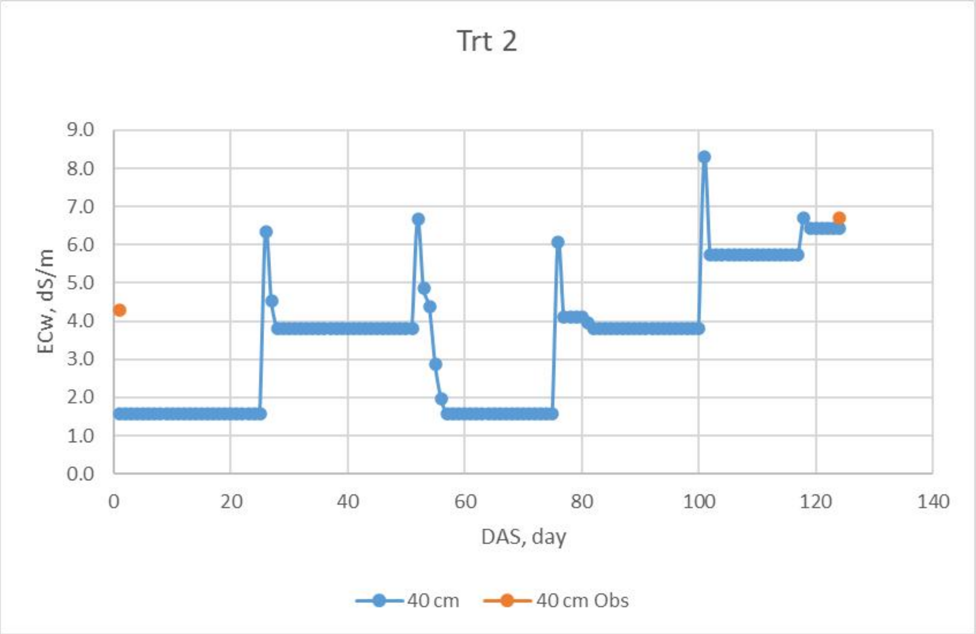
Case Study (2) – Transpiration & EC_w,2007

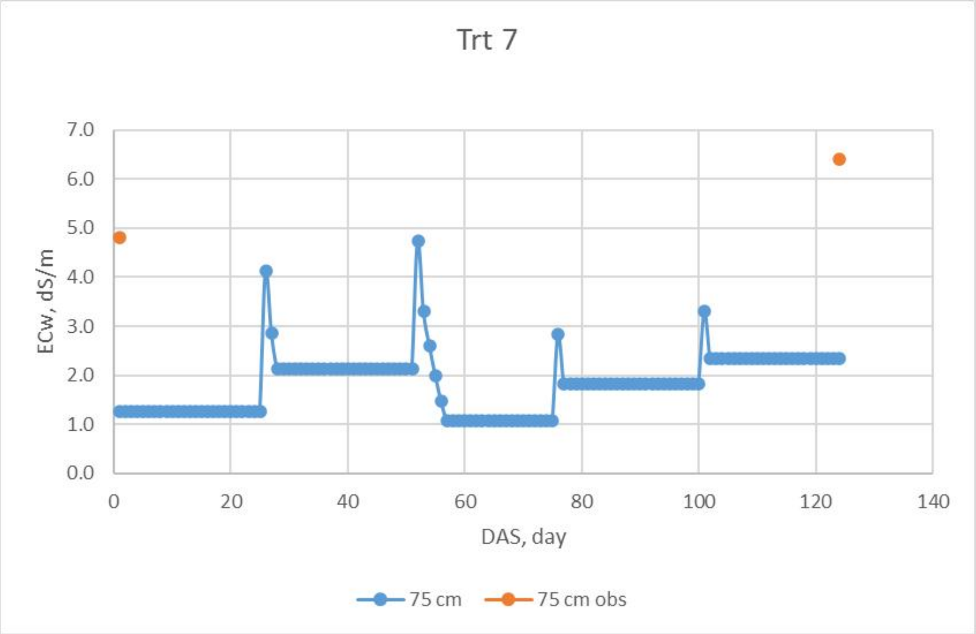




Irrig 240 mm, EC_{irri} – 8 dS/m
Drainage – 67 mm
Total Transpiration:
Salinity on: 188 mm
Salinity off: 286 mm

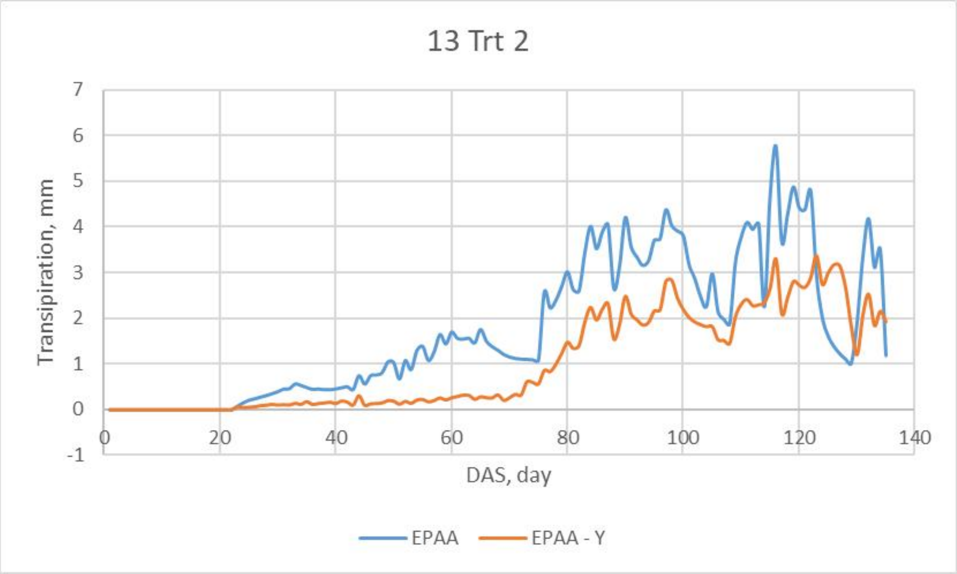
Case Study (2) – Transpiration & EC_w,2007

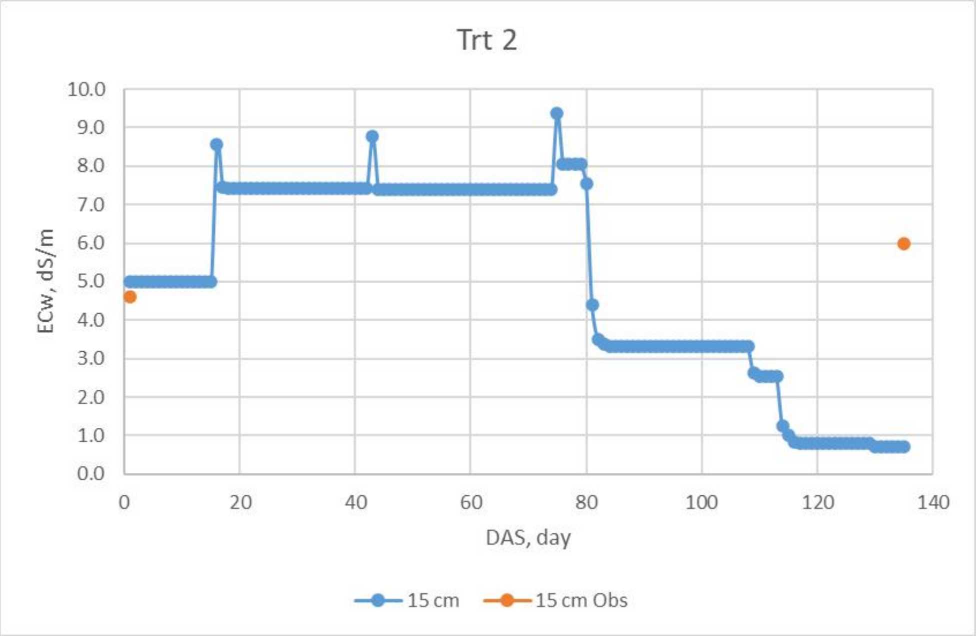




Irrig 240 mm, EC_{irri} – 8 dS/m
Drainage – 67 mm

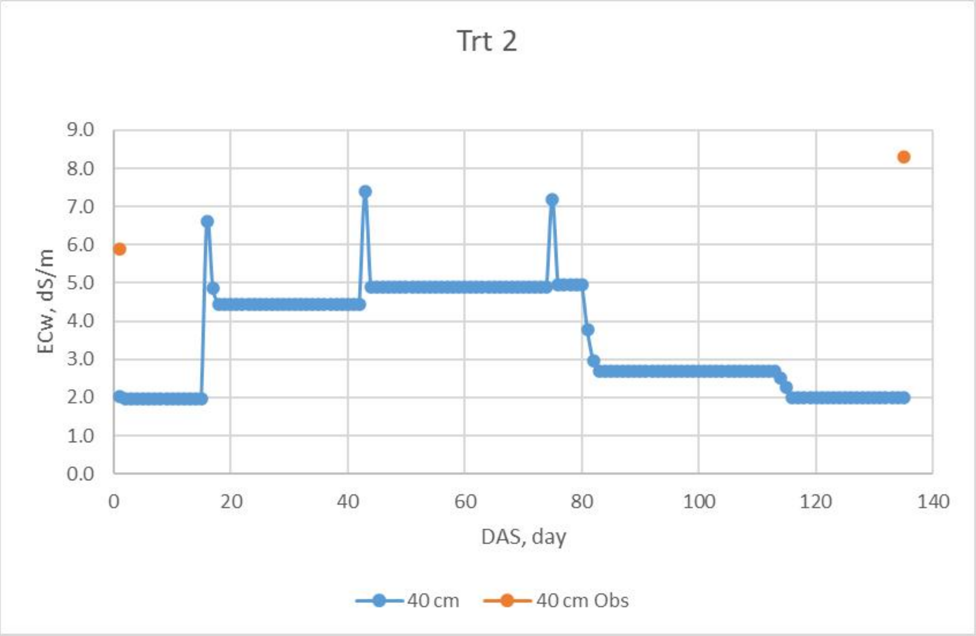
Case Study (2) - Transpiration EC_w 2013

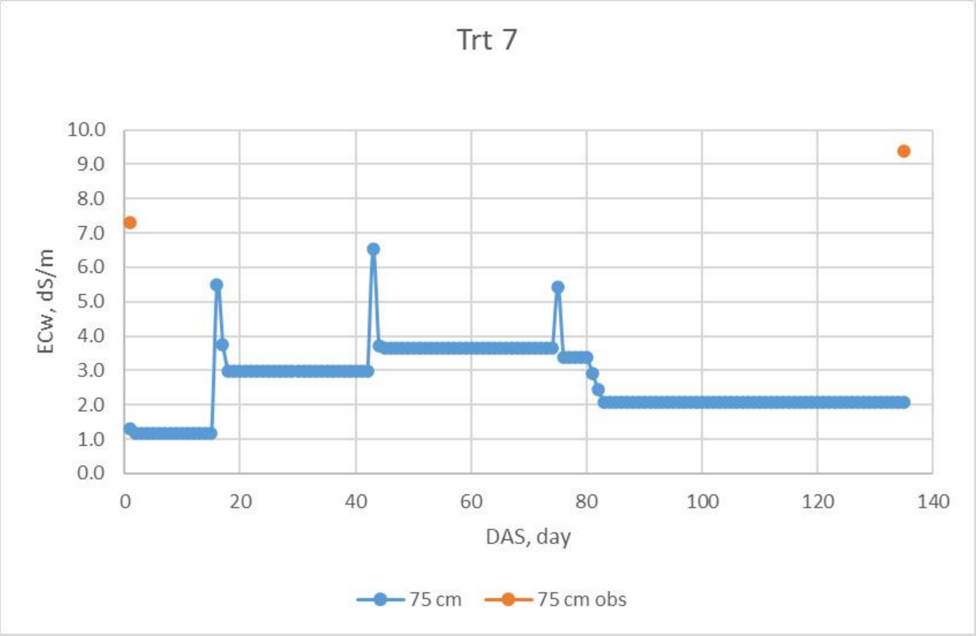




Irrig 200 mm, EC_{irri} – 8 dS/m
Drainage – 346 mm
Total Transpiration:
    Salinity on: 139 mm
    Salinity off: 236 mm

Case Study (2) - Transpiration EC_w 2013





Irrig 200 mm, EC_{irri} – 8 dS/m
Drainage – 346 mm

Conclusions and Future Steps

- The model that included salinity effectively captured the salinity-induced reduction in transpiration.
- The model performed substantially better at the top layers (up to 50 cm) than for deeper soil layers.
- The model testing using the robust datasets of the field data which include water balance components for further model improvements.

References

- Chele KH, Tinte MM, Piater LA, Dubery IA, Tugizimana F (2021) Soil salinity, a serious environmental issue and plant responses:A metabolomics perspective. Metabolites 11. https://doi.org/10.3390/metabo11110724
- Munns R, Termaat A (1986) Whole-plant responses to salinity. Aust J Plant Physiol 13:143–160
- Castrignanò, A. Katerji, N. Karam, F. Mastrorilli, M. Hamdy, A., 1998. A modified version of CERES-Maize model for predicting crop response to salinity stress. Ecological Modeling, 111, 107–120.
- Webber, H.A., Madramootoo, C.A., Bourgault, M., Horst, M.G., Stulina, G., Smith, D.L., 2010. Adapting the CROPGRO Model for Saline Soils: The Case for a Common Bean Crop. Irrigation Science, 28 (4), 317–329.

Thank You