A Compensated Root Water Uptake Model for Crops under Stress from Water Availability

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Abstract

The agricultural sector is a major consumer of water for irrigation purposes. Precise quantification of irrigation water requirements will help in achieving sustainable water management. Root water uptake (RWU) is driven by transpiration demand exerted by crops and is influenced by factors such as weather and leaf area index (LAI). The root water uptake at a particular depth in the root zone depends on the local moisture content, soil type, and root density. Under certain conditions, lack of availability of soil moisture at a certain depth may be compensated by more water being drawn into the roots from wetter portions of the soil. To incorporate this mechanism, this study presents a compensated root water uptake model (CRWU) with application to maize crops grown in Indian climatic conditions. Irrigation field experiments were conducted at seven field plots with the same soil by adjusting the irrigation supplied to simulate different degrees of water stress. Daily soil moisture data recorded at different depths in the root zone, crop yield and biomass data help in assessing model performance and identifying a critical water stress index that governs the extent of compensation in RWU.

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1. INTRODUCTION

Combined effects of population growth, climate change and decline in soil fertility lead to increased stress on irrigation water for food production.

Selection of irrigation and drainage practices depends on
- ❑ Root water uptake of plants
- ❑ Ability of crops to respond to water stress

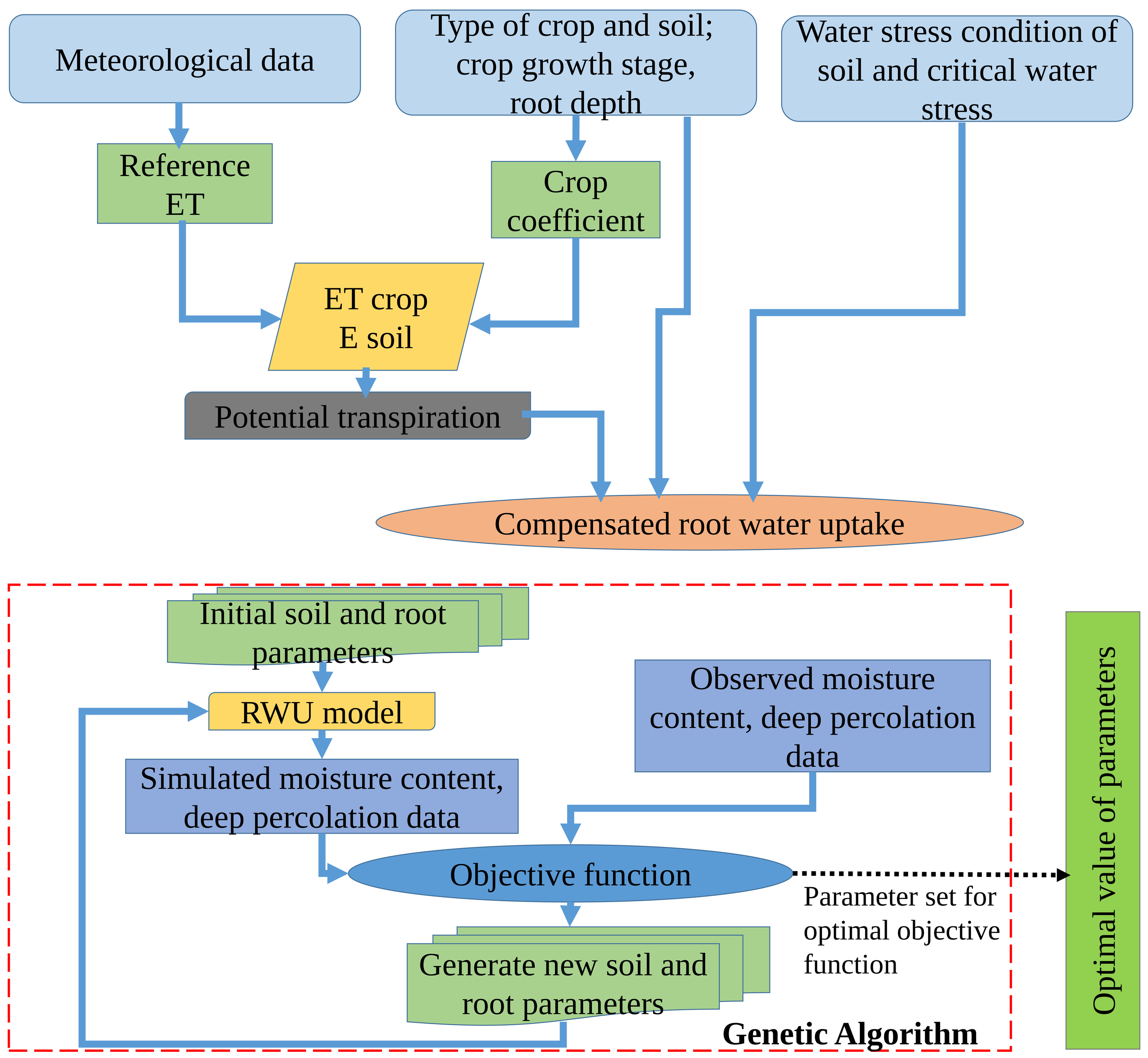
Knowledge of soil moisture patterns allows
- ❑ Efficient planning of irrigation scheduling
- ❑ Better crop yield forecasting

Root water uptake (RWU) controls plant evapotranspiration and water recharge to groundwater. Deficiency of water in the root zone results in reduced plant growth and affects crop yield. Thus, precise quantification of irrigation water requirements will help in achieving sustainable water management.

2. OBJECTIVE

- ❑ To develop a compensated non-linear RWU model using a sink term in Richards equation as proposed by Ojha and Rai (1996)
- ❑ To evaluate the performance of the compensated RWU model for different available moisture conditions
- ❑ To examine the identifiability of model parameters for different available soil moisture conditions

3. METHODOLOGY



4. COMPENSATED ROOT WATER UPTAKE MODEL

Governing Equation: $$\frac{\partial \theta(h)}{\partial t} = \frac{\partial}{\partial z}\left(K(h)\left(\frac{\partial h}{\partial z}+1\right)\right) - S(z,t)$$

Stress Index, $$\omega(t) = \int_0^{z_r} \alpha(h,z,t) * L(z,t)\, dz$$

Actual transpiration:
$$T_{ac}(t) = \begin{cases} T_{pot}(t) & ; \omega(t) > \omega_c \\ \frac{\omega(t)}{\omega_c} T_{pot}(t) & ; \omega(t) \le \omega_c \end{cases}$$

Model Parameters:
- ❑ ω_c: critical stress indicator for compensation
- ❑ β: non-linear coefficient which depends upon root pattern
- ❑ α_v, n_v: soil water retention parameters
- ❑ K_{sat}: saturated hydraulic conductivity

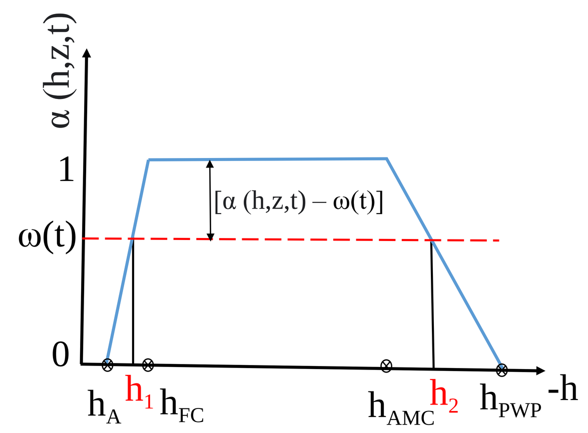


Fig 1: Stress response function variation

Actual compensated uptake:
$$S_{ac}(z,t) = \underbrace{\alpha(h,z,t)L(z,t)T_{pot}(t)}_{\text{uncompensated portion}} + \underbrace{a\left[\alpha(h,z,t)-\omega(t)\right]L(z,t)H\left[\alpha(h,z,t)-\omega(t)\right]}_{\text{compensated portion}}$$

5. FIELD EXPERIMENTS


Fig 2: Different growth stages of maize crop

$$\theta_{RAMC} = \theta_{FC} - DF(\theta_{FC} - \theta_{PWP})$$

Readily available moisture values at 7 different plots were maintained at different moisture contents. This is achieved by changing the depletion factor considered for each field.

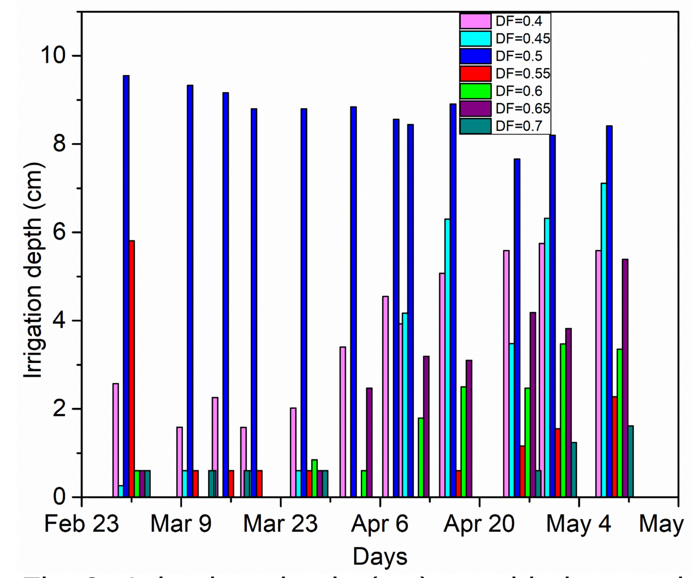


Fig 3: Irrigation depth (cm) provided to maintain different readily available moisture values

Table 1:Percentage particle content in the field soil

Particle on soil	% content
Clay	1.03
Silt	2.38
Very fine sand	6.23
Fine Sand	40.63
Medium Sand	30.5
Coarse Sand	5.25
Very Coarse Sand	3
Gravel	5.25
Soil Type	**Loamy Sand**

Sat. Hydraulic Conductivity= 0.60 cm/min (Guelph Permeameter)

Specific Gravity= 2.49
Bulk density= 1.575 g/cc
Dry density= 1.44 g/cc

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6. RESULTS

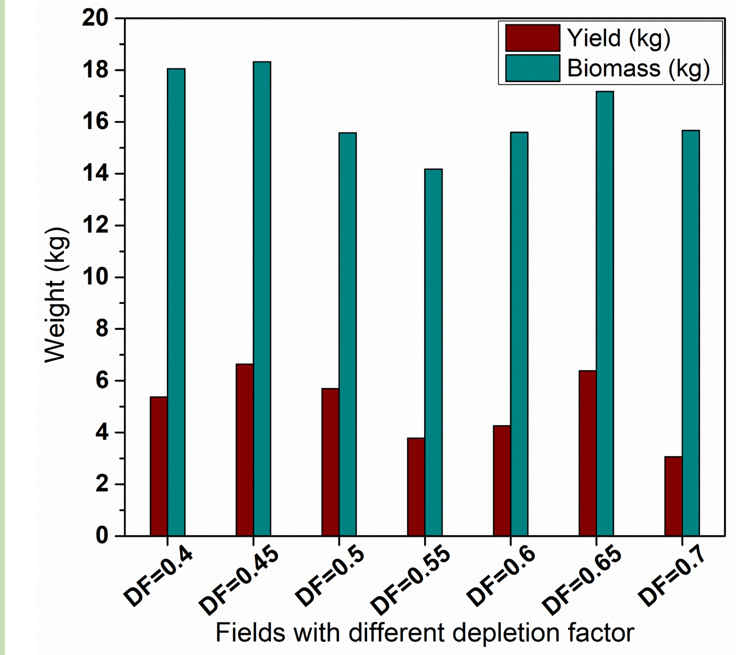

Fig 4: Observed Biomass and yield (in kg) at different fields

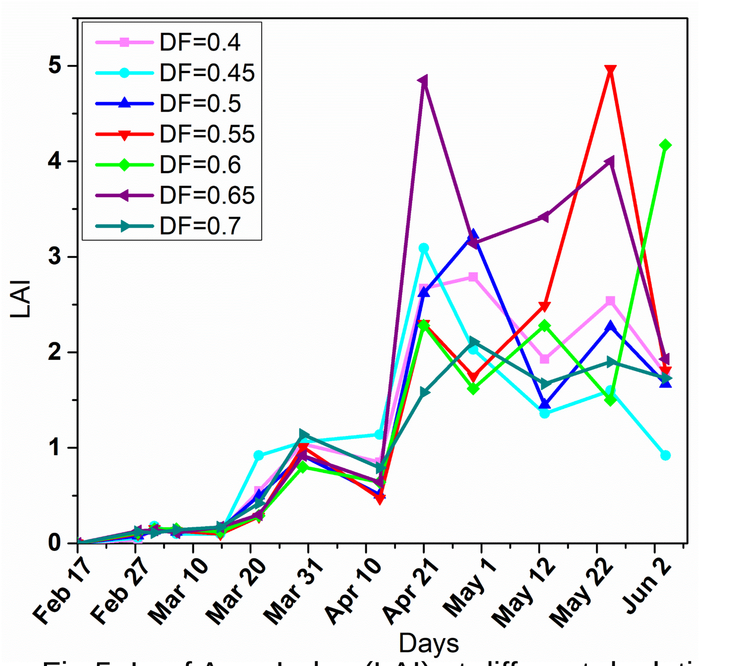

Fig 5: Leaf Area Index (LAI) at different depletion factors

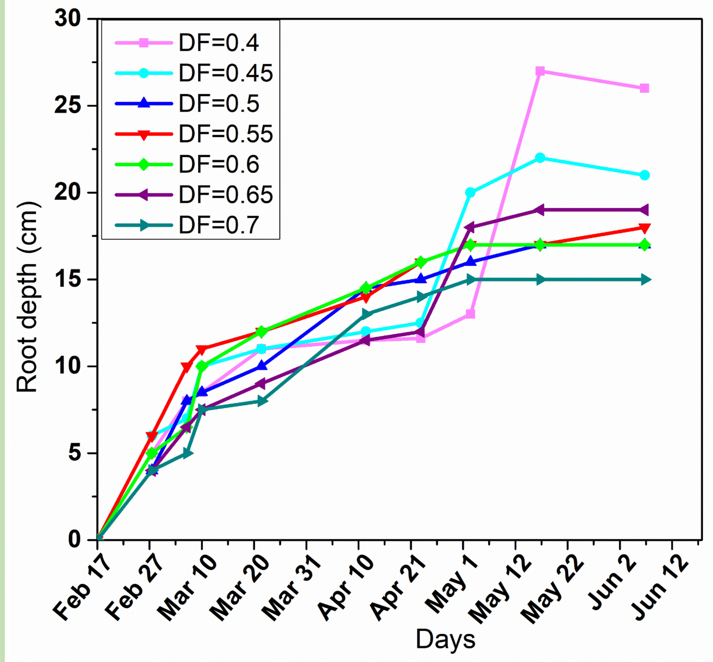

Fig 6: Root depth of maize crop observed at different depletion factors

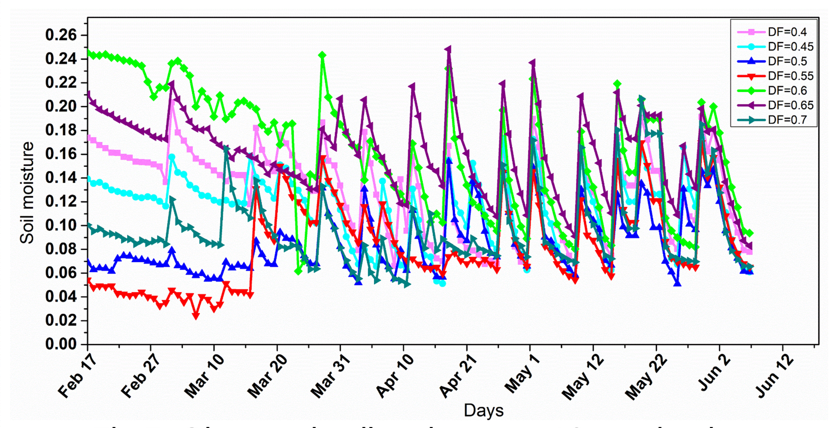

Fig 7: Observed soil moisture at 10 cm depth on different fields for the experiment with maize crop

Table 2: Measured and estimated values (from Genetic algorithm) of soil hydraulic and root water uptake parameters for the experiment with wheat crop on Sandy loam soil

Soil	seed value	True value					Estimated value					No. of generation
		ω_c	β	K_{sat}(cm/day)	α_v(1/m)	n_v	ω_c	β	K_{sat}(cm/day)	α_v(1/m)	n_v	
Sandy Loam	0.3	0.5	2	106	7.5	1.89	0.29	1.21	121	6.1	1.51	119
	0.5	0.5	2	106	7.5	1.89	0.35	2.95	119	5.88	1.45	91
	0.8	0.5	2	106	7.5	1.89	0.27	2.53	131	5.21	2.05	111

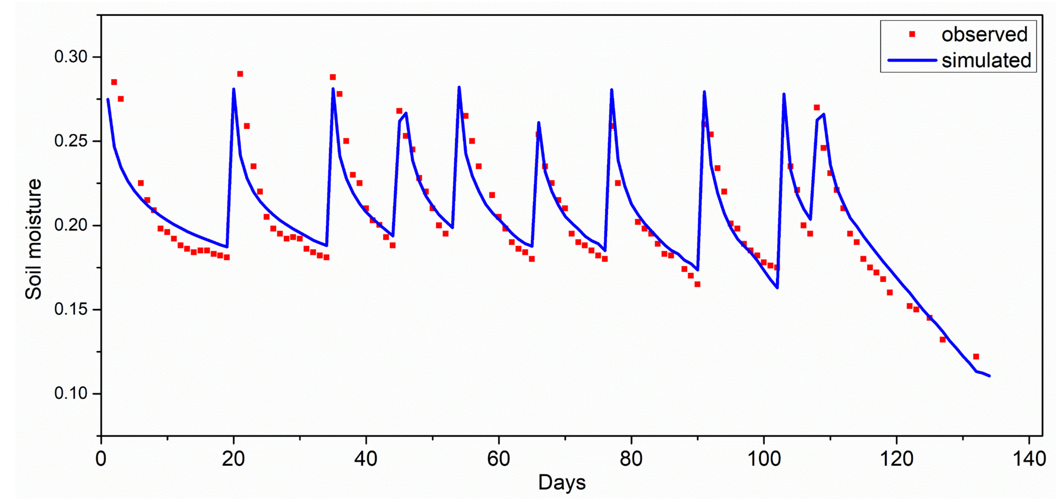

Fig 8:Observed and simulated soil moisture values at 20 cm depth (experiment with wheat crop)

7. CONCLUSION

- ❑ The developed model is able to simulate the actual soil moisture content at different depths
- ❑ The yield and biomass from fields at higher water stress (DF=0.6) is observed to be nearly same as that with lower stress (DF=0.4 or 0.45)
- ❑ Estimated model parameter values, in case of sandy loam soil, were not found to be in good agreement with the true values
- ❑ Simultaneous estimation of both RWU and soil hydraulic parameters in high conductivity soil is ineffective as the vertical flow overshadows the root water uptake