Plant-based Monitoring for Yield Prediction of Citrus under Differential Irrigation

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Introduction

- **Water is the major constraint to crop production in many parts of the world.**
- **To sustain crop production in water scarce environments, deficit irrigation (DI) is a suggestable irrigation practice.**
- **DI is an irrigation strategy in which water is applied less than the full water requirement of the crop.**
- **Citrus, the third important fruit crop in India, has low productivity and it varies widely from year to year depending upon climate and water availability in different regions of the country.**
- **In changing climate scenario, it is utmost essential to optimize water management and prediction of yield of the crop.**

Treatment details of sustained deficit irrigation (DI) and Partial root zone drying (PRD) irrigation Scheduling

DI_{50}: Irrigation at 50% ETc

DI_{75}: Irrigation at 75% ETc

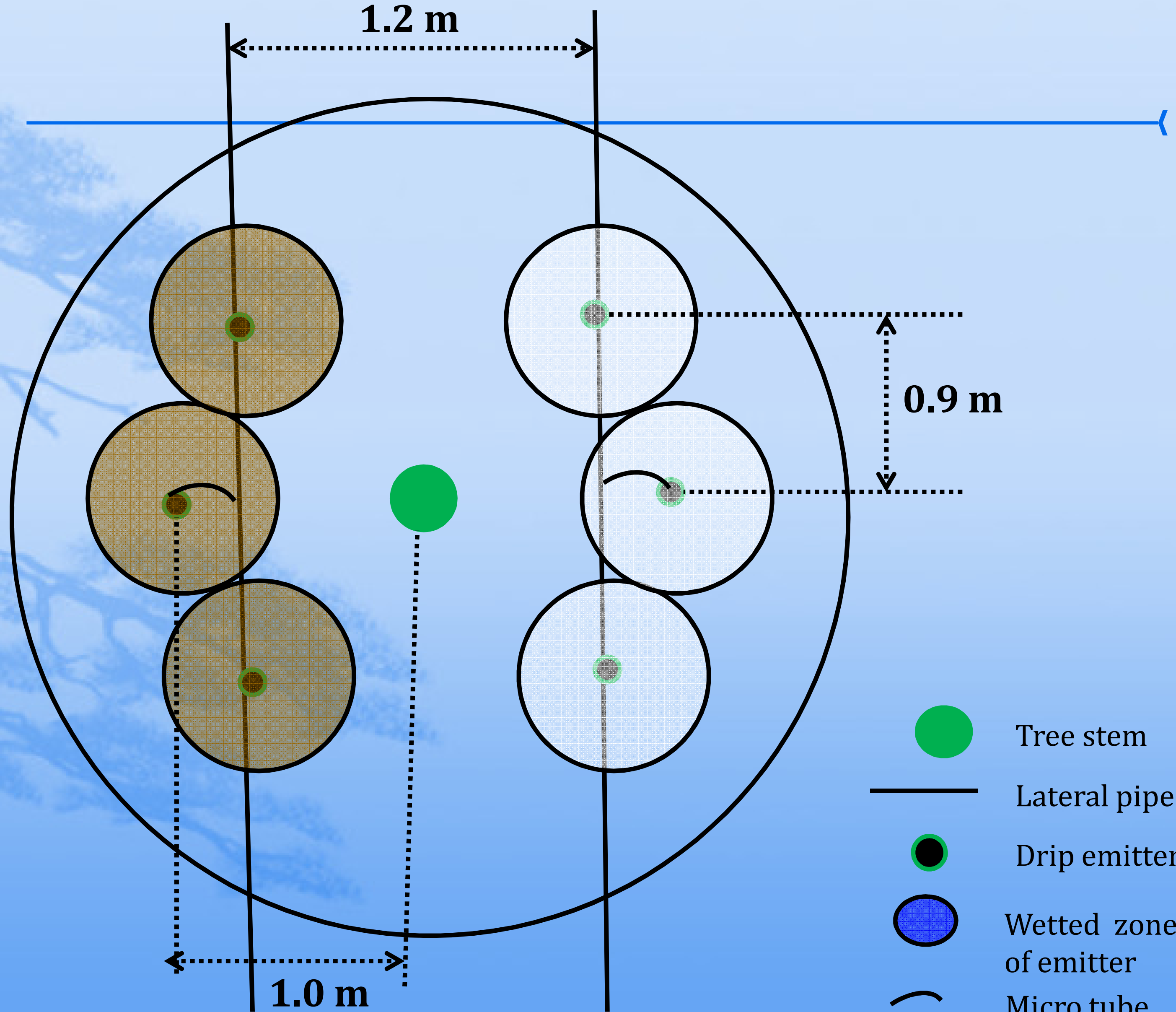
PRD_{50}: Irrigation at 50% ETc through PRD

PRD_{75}: Irrigation at 75% ETc through PRD

FI : Irrigation at 100% ETc throughout the crop period

Replication: 4; Plants per replication: 2; Design: RBD

Layout of drip emitters in tree basin and their wetted zone under PRD



Irrigation water quantity estimation

The water application for fully-irrigated trees was computed as:

$$ETc = Kp \times Kc \times Ep$$

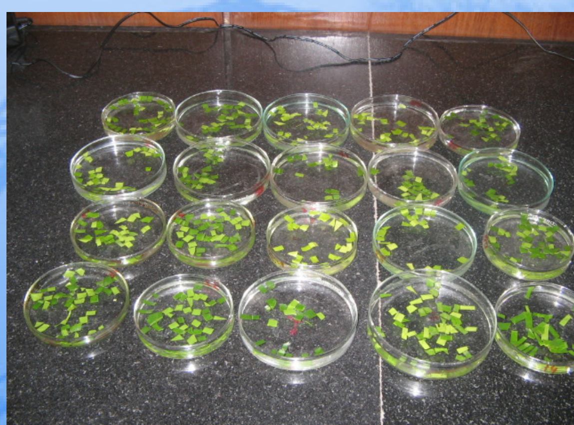
The volume of water applied under 100% ETc was estimated based on the formula (Germanà et al., 1992):

$$V_{id} = \pi \, (D^2 / 4) \times (ET_c - R_e) / E_i$$

Measurements and analysis

Soil water measurement

Leaf and stem water potential measurement



For Relative leaf water content

Leaf physiological parameters

Canopy reflectance

Root sampling and analysis


Mature Kinnow fruits on trees


Harvested Kinnow fruits


Juice of Kinnow


Analysis of Juice

Indices

1. The water stress integral (S_ψ) for each treatment was calculated using the midday leaf and xylem water potential data, according to the equation defined by Myers (1988):

$$S_\psi = \text{Absolute value of } \sum_{i=0}^{i=1} \{(\psi i, i+1) - c\}\ n$$

where S_ψ is water stress integral (MPa day), $\psi_{i,\, i+1}$ is average midday leaf/stem water potential for any interval i and i+1 (MPa), c is maximum leaf/stem water potential measured during the study and n is number of days in the interval.

2. a. Relative leaf water content (RLWC)was determined by the formula (Bowman, 1989):
RLWC (%) = {(FW - DW) / (TW - DW)} x 100

b. Leaf water concentration (LWC) was determined using the formula (Peñuelas et al., 1997):
LWC = {(FW−DW) / (FW)} x 100

3. The spectral reflectance indices related to water deficit conditions are calculated as:

Water band index (WBI) = $(R_{900}) / (R_{970})$ (Penuelas et al., 1995);

Normalized Difference water index (NDWI) = $(R_{857} - R_{1241}) / (R_{857} + R_{1241})$ (Gao, 1995);

Moisture stress index (MSI) = $(R_{1599}) / (R_{819})$ (Hunt et al., 1989);

Normalised difference infrared index (NDII) = $(R_{819}-R_{1649}) / (R_{819}+R_{1649})$ (Jackson et al., 2004),

Simple ratio (proposed) = $(R_{1360}) / (R_{2250})$

where R and the subscript numbers indicate the light reflectance at the specific wavelength (in nm).

Total N, P and K in leaf (%, dry weight basis) of 'Kinnow' mandarin as affected by various irrigation treatments

Treatments	2010			2011		
	N	P	K	N	P	K
DI_{50}	**2.31a**	0.15a	**1.42a**	**2.43a**	0.16a	**1.44a**
DI_{75}	2.46a	0.19a	1.54b	2.46b	0.19a	1.56c
PRD_{50}	2.35a	0.18a	1.48c	2.45b	0.18a	1.49d
PRD_{75}	2.47b	0.21a	1.59a	2.49c	0.19a	1.61b
FI_{100}	**2.69c**	0.22a	**1.64c**	**2.72d**	0.20a	**1.66d**

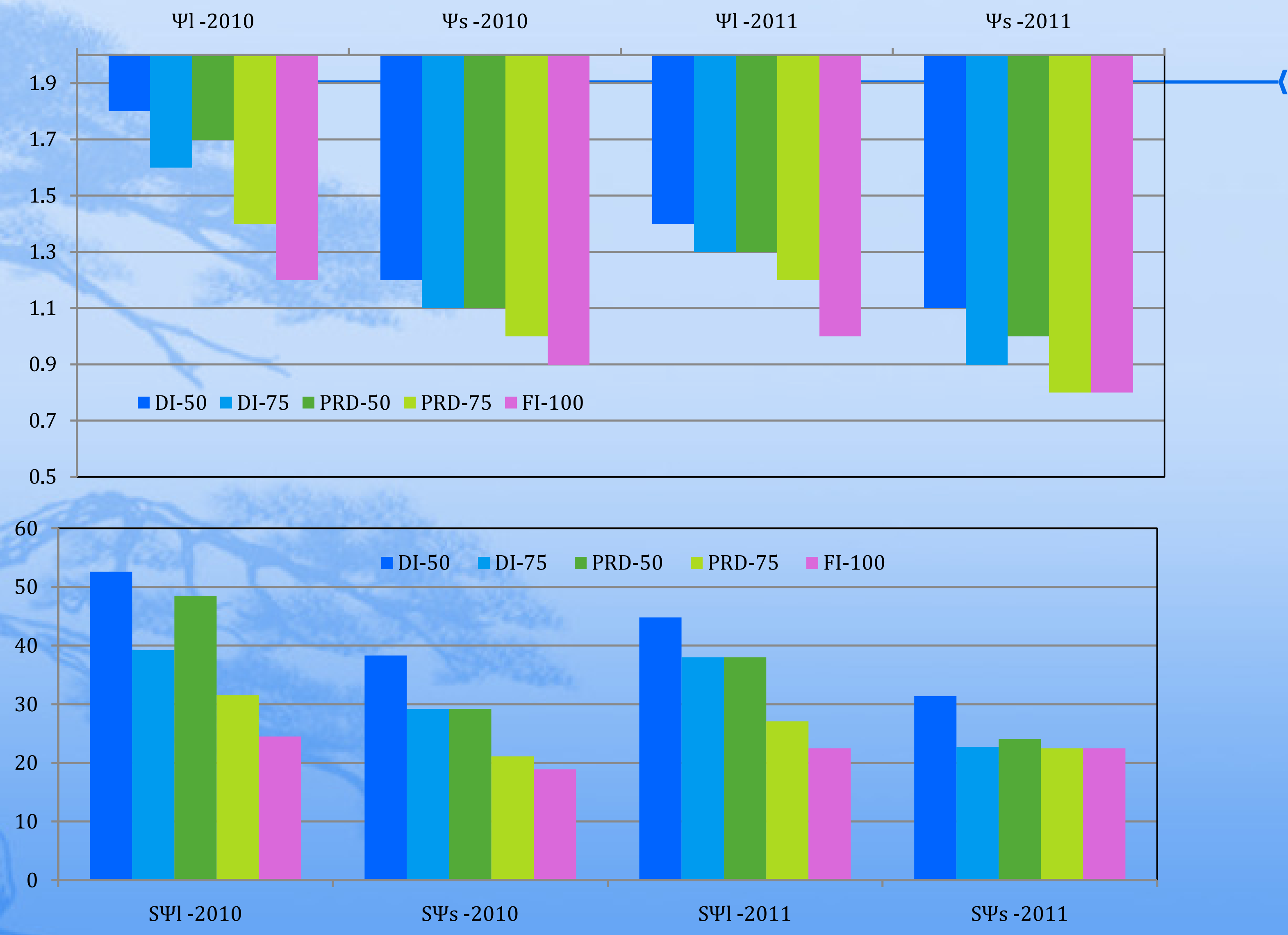
Optimum range of leaf-N (2.28–2.53%), P (0.10–0.13%), and K (1.28–1.63%) for Kinnow (Hundal and Arora, 2001; Srivastava, 2011).

Total Fe, Mn, Cu and Zn in leafs (ppm, dry weight basis of 'Kinnow' mandarin as affected by various irrigation treatments

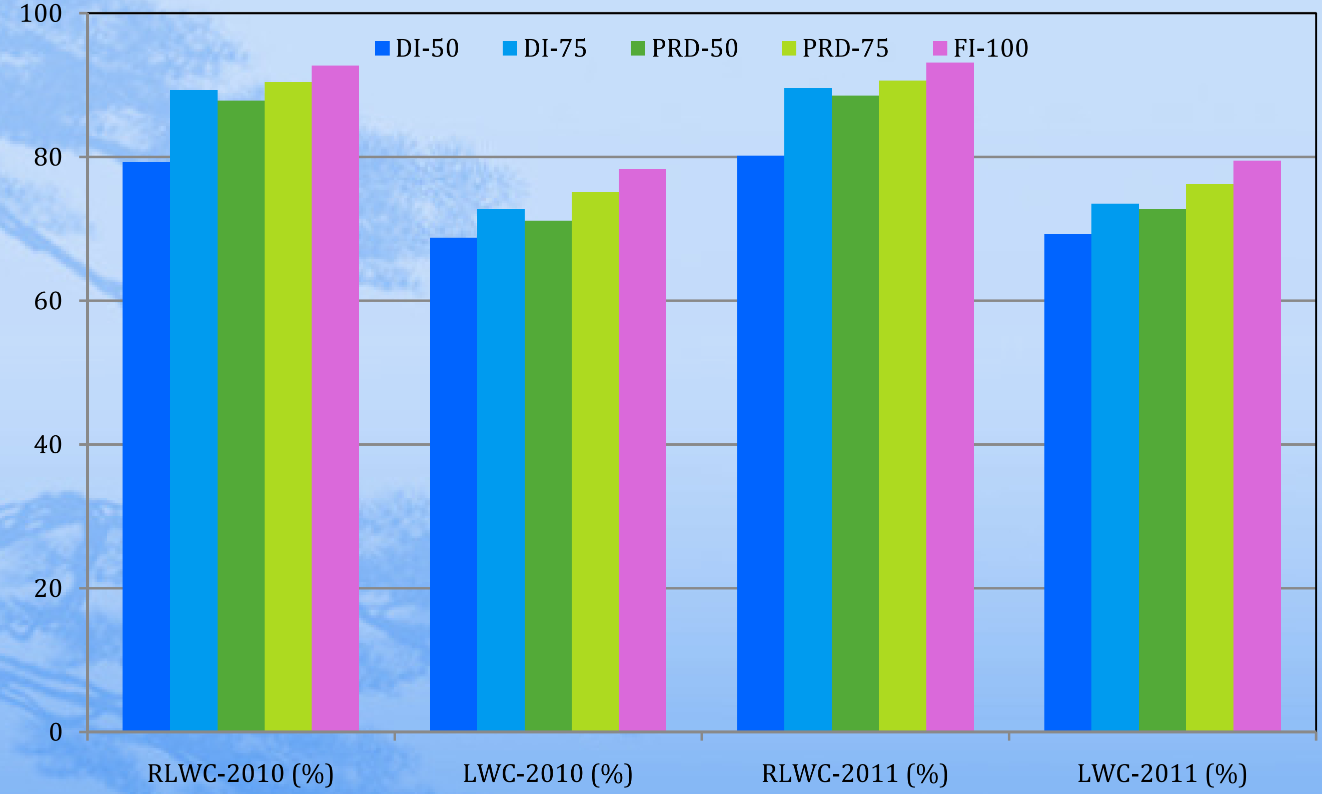
Treatments	2010				2011			
	Fe	Mn	Cu	Zn	Fe	Mn	Cu	Zn
DI_{50}	**54.0a**	**48.6a**	7.3a	**24.7a**	**56.8a**	**50.3a**	7.8a	**24.9a**
DI_{75}	58.4a	57.8a	7.9a	25.6a	58.7a	58.2a	8.2a	24.1a
PRD_{50}	55.6a	51.2a	7.3a	25.2a	56.7a	51.8a	7.9a	25.5a
PRD_{75}	59.9a	58.4a	8.2a	25.8a	61.4a	58.9a	8.4a	26.9a
FI_{100}	**62.6b**	**61.5b**	8.2a	**26.9b**	**62.8b**	**61.6a**	8.9a	**27.2b**

Optimum values (62.3–89.4 ppm Fe, 58.7 – 76.3 ppm Mn, 8.1 – 10.3 ppm Cu and 26.3 – 28.5 ppm Zn) of Kinnow mandarin (Hundal and Arora, 2001; Srivastava, 2011).

Leaf/stem water potential and leaf /stem water stress integral during 2010 and 2011



RLWC and LWC in 2010 1nd 2011



Leaf physiological parameters under different irrigation treatments in 2010 and 2011

Treatments	2010				2011			
	Pn	gs	Tr	LWUE	Pn	gs	Tr	LWUE
DI_{50}	**2.89a**	**21.07b**	**1.66b**	1.74c	**2.94a**	**20.50b**	**1.53b**	1.92a
DI_{75}	2.92a	24.80d	1.84d	1.58a	3.41b	23.48d	1.60d	2.13b
PRD_{50}	2.90a	20.13a	1.43a	**2.02e**	3.38b	20.04a	1.31a	**2.58d**
PRD_{75}	2.95b	23.13c	1.79c	1.65b	3.45b	22.83c	1.57c	2.17b
FI_{100}	**3.88c**	**37.78e**	**2.08**	1.86d	**4.37c**	**31.07e**	**1.74e**	2.51c

Tree growth under various irrigation treatment

Treatments	2010				2011			
	TH	**SD**	**CD**	**CV**	**TH**	**SD**	**CD**	**CV**
DI_{50}	33.4a	20.4a	25.8a	0.81a	21.7a	19.2a	20.1a	0.64a
DI_{75}	36.2b	22.5b	31.3b	0.83a	26.7b	20.9b	27.5b	0.77a
PRD_{50}	32.5a	19.7a	25.3a	0.79a	21.0a	19.0a	18.8a	0.60a
PRD_{75}	35.9b	22.0b	30.9b	0.80a	26.5b	20.9b	26.9b	0.74a
FI_{100}	**40.7c**	**26.2c**	**48.7c**	**0.86b**	**36.0c**	**25.6c**	**32.3c**	**0.98b**

Mean water band index (WBI), normalised difference water index (NDWI), moisture stress index (MSI) and Normalised difference infrared index (NDII) of Kinnow mandarin under various irrigation treatments.

Treatments	Hyperspectral Indices 2010 WBI	NDWI	MSI	NDII	SR	2011 WBI	NDWI	MSI	NDII	SR
DI_{50}	1.056	0.042	0.561	0.266	3.002	0.992	0.081	0.462	0.219	2.937
DI_{75}	0.966	0.035	0.472	0.243	2.802	0.981	0.064	0.417	0.206	2.811
PRD_{50}	1.006	0.037	0.481	0.251	2.862	0.984	0.076	0.431	0.207	2.828
PRD_{75}	0.932	0.034	0.471	0.241	2.847	0.952	0.057	0.406	0.205	2.796
FI_{100}	**0.917**	**0.033**	**0.469**	**0.239**	**2.711**	**0.815**	**0.031**	**0.384**	**0.203**	**2.629**

Parameters are significantly different from each other

Fruit yield, IWUE, and WUE in 2010

Treatments	2010					
	No. fruits dropped/tree	**No. fruits harvested /tree**	**Average fruit weight (g)**	**Fruit yield (t ha^{-1})**	**IWUE (t ha^{-1} mm^{-1})**	**WUE (t ha^{-1} mm^{-1})**
DI_{50}	**170**d (96*, 52**, 22***)	671a	152.7a	51.23a	0.108c	0.056c
DI_{75}	135c (77, 40, 18)	718b	161.6b	58.01c	0.081b	0.051b
PRD_{50}	148b (80, 48, 20)	703b	160.7b	56.48b **(8.7%)**	**0.119d (83%)**	**0.062c**
PRD_{75}	100a (61, 28, 11)	755c	**163.0b**	58.73c	0.082b	0.053b
FI_{100}	**92**a (64, 15, 13)	**763c**	162.3b	61.91d	0.065a	0.047a

Fruit yield, IWUE, and WUE in 2011

Treatments		2011					
		No. fruits dropped/tree	**No. fruits harvested/ tree**	**Average fruit weight (g)**	**Fruit yield (t ha^{-1})**	**IWUE (t ha^{-1} mm^{-1})**	**WUE (t ha^{-1} mm^{-1})**
DI_{50}		**151e** (82*, 50**, 19)	682a	154.7a	52.75a	0.150c	0.071c
DI_{75}		109c (66, 32, 11)	739c	163.1b	60.26c	0.114b	0.067b
PRD_{50}		126d (70, 46, 10)	711b	161.0b	57.23b **(9.4%)**	**0.163d (81%)**	**0.077**d
PRD_{75}		89b (52, 27, 10)	751c	**165.2**b	62.03c	0.118b	0.070c
FI_{100}		**79a** (51, 20, 8)	**776d**	162.8b	**63.20c**	0.090a	0.061a

Fruit quality parameters of Kinnow fruits in 2010

Treatments	2010					
	Juice content (%)	**TSS (^{0}Brix)**	**TA (%)**	**Ascorbic acid (mg/l)**	**Reducing Sugar (mg/l)**	**Total Sugar (mg/l)**
DI_{50}	43.7a	11.4	1.02f	120.4a	50.4c	**73.8c**
DI_{75}	46.7b	10.9c	0.82b	112.1a	42.9b	61.7a
PRD_{50}	45.5b	**11.2b**	0.84b	**119.8a**	**59.3d**	**67.4b**
PRD_{75}	48.2b	10.8b	0.82b	109.0c	47.1c	60.1a
FI_{100}	**49.6c**	10.8c	**0.81b**	116.3b	37.2a	66.4b

Fruit quality parameters of Kinnow fruits in 2011

Treatments		2011					
		Juice content (%)	TSS (^{0}Brix)	TA (%)	Ascorbic acid (mg/l)	Reducible sugar (mg/l)	Total sugar (mg/l)
DI_{50}		43.1a	11.7 a	0.96f	128.7a	54.7c	**75.4c**
DI_{75}		45.9b	11.2c	0.80d	114.7a	45.9b	64.7a
PRD_{50}		44.3b	**11.4b**	0.83e	**123.6a**	**61.7d**	**69.3b**
PRD_{75}		47.9b	11.1b	0.80b	111.9c	49.2b	63.2a
FI_{100}		**49.5c**	10.9c	**0.79b**	119.1b	38.7a	68.7b

Correlation matrix (Pearson's) for plant-based observations during 2010 and 2011 under DI

Parameters	Fruit Yield	SD	CV	Leaf-N	Leaf-K	Leaf-Fe	Leaf - Zn	$S\Psi_l$	$S\Psi_s$	RLWC	LWC	Pn	Tr	gs	LWUE	WBI	NDWI	MSI
SD	0.25*																	
CV	0.33*	0.69*																
Leaf-N	0.57+	NS	0.29*															
Leaf-K	0.61+	NS	0.41*	0.43*														
Leaf- Fe	NS	NS	NS	NS	NS													
Leaf-Zn	0.58*	NS	NS	NS	NS	0.41*												
$S\Psi_l$	**0.59+**	**0.21***	**0.29***	**0.43***	**0.47***	NS	NS											
$S\Psi_s$	**0.62+**	**0.26***	**0.32***	**0.52***	**0.49***	NS	NS	**0.93+**										
RLWC	0.55+	0.20*	0.17*	0.32	0.32*	NS	NS	**0.74+**	**0.79+**									
LWC	0.53+	NS	NS	0.30	0.25*	NS	NS	**0.59+**	**0.69+**	0.74+								
Pn	0.55+	NS	0.23*	0.85+	0.44*	0.78+	0.36	**0.62+**	**0.53+**	0.66+	0.55+							
Tr	0.51+	NS	NS	0.69*	0.51+	0.43*	0.29	**0.78+**	**0.83+**	0.71+	0.69+	0.61+						
gs	0.61+	NS	NS	0.58*	0.55+	0.45*	0.38	**0.79+**	**0.76+**	0.75+	0.66+	0.58+	0.61+					
LWUE	0.60+	NS	NS	0.47*	0.36*	0.42*	0.21	**0.73+**	**0.69+**	0.59+	0.48+	0.39+	0.69+	0.57*				
WBI	0.57+	0.29*	0.29*	0.59+	0.47*	0.44*	NS	**0.65+**	**0.67+**	0.69+	0.52+	0.47*	0.55*	0.51*	0.30+			
NDWI	0.53*	NS	NS	0.53*	NS	NS	NS	**0.38***	**0.48***	0.57*	0.40*	0.33*	0.49*	0.40*	0.21*	0.59+		
MSI	0.79+	0.22*	0.23*	0.51+	0.40*	NS	NS	**0.44***	**0.41+**	0.52+	0.47+	0.42+	0.43+	0.45*	0.17+	0.59*	0.54*	
NDII	0.49*	NS	NS	0.43*	0.36*	0.27*	NS	**0.26***	**0.32***	0.47*	0.49*	0.39*	0.37+	0.39*	0.26*	0.55*	0.48*	0.51*
SR	0.61+	NS	NS	0.54+	0.36*	NS	NS	**0.57+**	**0.62+**	0.63+	0.58+	0.47+	0.50+	0.44*	0.20*	0.84+	0.59*	0.60*

Correlation matrix (Pearson's) for plant-based observations during 2010 and 2011 under PRD

Parameters	Fruit Yield	SD	CV	Leaf-N	Leaf-K	Leaf-Fe	Leaf-Zn	$S\Psi_l$	$S\Psi_s$	RLWC	LWC	Pn	Tr	gs	LWUE	WBI	NDWI	MSI
SD	0.19*																	
CV	0.27*	0.59*																
Leaf-N	0.59+	NS	0.23*															
Leaf-K	0.62+	NS	0.30*	0.21*														
Leaf- Fe	NS	NS	NS	NS	NS													
Leaf-Zn	0.58*	NS	NS	NS	NS	0.33*												
$S\Psi_l$	**0.63+**	**0.27***	**0.19***	**0.38***	**0.40***	NS	NS											
$S\Psi_s$	**0.69+**	**0.29***	**0.22***	**0.42***	**0.49***	NS	NS	**0.91+**										
RLWC	0.55+	0.20*	0.16*	0.22	0.33*	NS	NS	**0.70+**	**0.87+**									
LWC	0.51+	NS	NS	0.29	0.24*	NS	NS	**0.63+**	**0.65+**	0.87+								
Pn	0.59+	NS	0.20*	0.84+	0.40*	0.74+	0.31	**0.54+**	**0.55+**	0.60+	0.50+							
Tr	0.57+	NS	NS	0.61*	0.48+	0.38*	0.27	**0.80+**	**0.80+**	0.77+	0.66+	0.59+						
gs	0.44+	NS	NS	0.52*	0.50+	0.40*	0.33	**0.82+**	**0.82+**	0.68+	0.60+	0.75+	0.75+					
LWUE	0.60+	NS	NS	0.38*	0.33*	0.40*	0.28	**0.74+**	**0.67+**	0.50+	0.49+	0.37+	0.64+	0.59*				
WBI	0.50#	0.21*	0.27*	0.58+	0.42*	0.42*	NS	**0.69+**	**0.65+**	0.66+	0.52+	0.44*	0.55*	0.50*	0.32+			
NDWI	0.49*	NS	NS	0.50*	NS	NS	NS	**0.37***	**0.44***	0.59*	0.40*	0.34*	0.44*	0.43*	0.17*	0.55+		
MSI	0.59+	0.15*	0.11*	0.51+	0.41*	NS	NS	**0.46***	**0.35+**	0.38+	0.47+	0.42+	0.42+	0.47*	0.19+	0.73*	0.50*	
NDII	0.40*	NS	NS	0.43*	0.39*	0.21*	NS	**0.28***	**0.33***	0.42*	0.46*	0.30*	0.32+	0.30*	0.29*	0.57*	0.61*	0.49*
SR	0.64+	NS	NS	0.54+	0.37*	NS	NS	**0.59+**	**0.59+**	0.64+	0.59+	0.44+	0.51+	0.40*	0.22*	0.81+	0.74*	0.63*

Principal components with Eigen values and variances

PC	DI				PRD			
	Variables	**Eigen value**	**% variance**	**Cumulative % of variance**	**Variables**	**Eigen value**	**% variance**	**Cumulative % of variance**
1	**$S\Psi_s$, Leaf-N, Leaf-K, $S\Psi_l$, RLWC**	6.964	40.20	40.20	$S\Psi_s$, Leaf-N, Leaf-K, $S\Psi_l$, RLWC	5.744	38.46	38.46
2	**gs, Pn**	3.716	33.54	73.74	gs, Pn	2.899	32.11	70.57
3	**WBI, SR**	2.449	15.28	89.02	WBI, SR	2.219	13.77	84.34

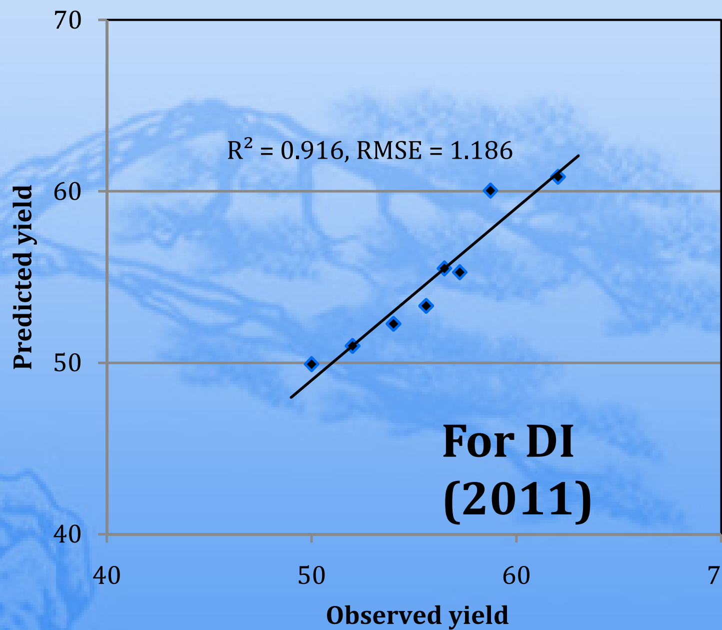
Yield prediction under DI and PRD

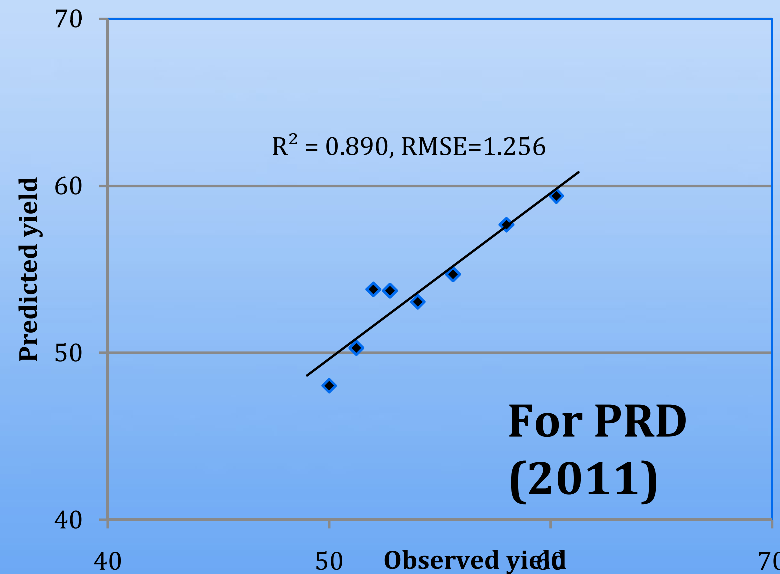
(i) For DI:

Fruit yield = -0.957 (Leaf-N) + 42.441 (Leaf-K) – 0.275 ($S\Psi_s$) + 0.138 (gs) + 17.510 (WBI) – 17.630 ($P < 0.05$; $R^2 = 0.98$; RMSE = 0.30%) (for 2010)

(ii) For PRD:

Fruit yield = 3.042 (Leaf-N) + 33.478 (Leaf-K) – 0.162 ($S\Psi_s$) - 0.089 (gs) + 13.409 (WBI) – 7.713 ($P < 0.05$; $R^2 = 0.94$; RMSE = 1.31%) (for 2010)





Conclusions

- **PRD at 50% FI produced 9% less fruit yield, with marginally lower vegetative growth of the plants in comparison to that under FI. However, 50% water saving under PRD_{50} boosted the irrigation water use efficiency up to 83% higher than that under FI.**

- **Yield prediction using PC-regression with leaf-N, leaf-K, stem water potential stress index, stomatal conductance and water band index gives satisfactory result. Therefore, this technique can be used for yield forecasting of citrus orchards under differential water stress condition and such methodology may be tried for other crops also.**

THANK YOU