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Assessing the performance of different irrigation techniques to enhance the water use efficiency and yield of maize under deficit water supply

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Abstract

Owing to increasing water scarcity, irrigation techniques always play an important role to boost-up agricultural production by enhancing the efficiency of irrigation water use. Field experiments were conducted to evaluate different irrigation techniques for evapotranspiration, water use efficiency and maize yield under deficit irrigation. *Spring and Summer sown maize were the test crops, cultivated during the year 2011. Four irrigation techniques, i.e. furrow irrigated ridge, furrow irrigated raised bed, furrow irrigated raised bed with plastic mulch and sprinkler irrigated flat sowing technique, were used with 100, 80 and 60% field capacity (FC) level. Results indicated that furrow irrigated raised bed treatment in both growing seasons showed maximum harvest index (HI), grain and biological yield in case of 100% FC, while furrow irrigated ridge with 100% FC gave the highest evapotranspiration, LAI (leaf area index) and crop cover, but did not produce the highest grain yield and gave relatively low water use efficiency (WUE) and irrigation water use efficiency WUE_i. Sprinkler irrigated flat treatment produced highest WUE and WUE_i values. Irrigation requirement of corn simulated by the IManSys model showed strong correlation between measured and estimated values, with r^2 values of 0.99 and 0.99 in spring season, 0.95 and 0.99 in summer sown maize, respectively.*

Keywords: wheat deficit, evapotranspiration, water use efficiency, IManSys Model, maize

Introduction

With limited and expensive water supplies in arid zone, enhancing crop production is aimed at reducing the water quantities, while maintaining or increasing the yield production. With a population of more than 150 million, Pakistan cannot meet its need for food, if adequate water is not available for crop production. Per capita water availability has decreased from 5600 m^3 in 1947 to 1000 m^3 in 2014 (Kugelman, 2014). Corn is particularly affected under limited water supply due to higher water requirement (Norwood, 2000). Under such circumstance, deficit irrigation might be an effective technique as it has been successfully applied to different crops in many areas of the world without reducing crop yield (Tyagi, 1987; Trimmer, 1990; Jurriens and Wester, 1994). The success of deficit irrigation is due to three benefits: improved water use efficiency, lesser irrigation cost and more availability of water for other use (English *et al.*, 1990).

The extent of deficit irrigation effect on crop yield depends on level, duration of deficit and crop growth stage. Water stress at any crop stage can reduce corn yield due to distortion in plant physiological processes (Newell and Wilhelm, 1987; Gavloski *et al.*, 1992; NeSmith and Ritchie, 1992; Jama and Ottman, 1993; Traore *et al.*, 2000). With the use of efficient irrigation techniques like raised bed and sprinkler irrigation along with moisture monitoring devices, deficit irrigation technique could be more effective for corn production due to accurate root zone moisture management. Under similar climatic condition, Iqbal *et al*. (2010) reported deficit irrigation with proper irrigation scheduling as an effective way to reduce the irrigation requirement of maize and increase WUE, by slight reduction in crop yield. However, Kiziloglu *et al*. (2009) reported that 100% FC irrigation resulted in maximum WUE and minimum in 20% of FC. Maximum evapotranspiration was noted with full irrigation treatment. Water deficit (20% FC) resulted in a lower cob, leaf, stem and total fresh yields.

Furrow irrigated raised bed-planting, furrow irrigated raised bed with plastic mulch planting and sprinkler have been suggested to be three of the most effective measures to reduce the cost of cultivation, to increase WUE as well as to optimize yield (Sharma, 1984; Haq, 1990). Sayre (2000) observed 29% water saving with bed sowing, and hence is better choice than flat sowing. Hassan *et al*. (2005) also found that bed planting resulted in 34% water saving and 32 and 19% higher yields for maize and wheat crops, respectively. The sprinkler irrigation system has high application efficiency and can attain higher crop yields because of the increased rate of photosynthesis (Clemmens and Dedrick, 1994). Sprinkler irrigation allows more

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frequent irrigation with smaller amount of water and thus helps to lessen crop stress due to frequent availability of water through the soil surface (Jay *et al*., 2005).

Different models had been used as a tool for assessing and developing deficit irrigation. In models, various factors affecting crop yield are integrated to obtain optimum irrigation quantity under different climate (Pereira *et al.*, 2002; Liu *et al.*, 2007). The Irrigation Management System (IMANSYS) is a numerical simulation model which enables the user to predict irrigation requirements (IRR) for crops, soils, irrigation systems, growing seasons, and climate conditions. Most studies have concentrated on investigating the soil water dynamics in field exposed to only one water management practice; only few have made comparisons among a variety of water management practices.

Table 1: Measured soil physical and hydraulic parameters in the four main layers of the experimental site

Depth (cm)	Particle fraction (%) sand	silt	clay*	B.D. (Mg m^{-3})	θ_s	θ_{FC}	θ_{PWP}	θ_{AWC}	K_s cm day^{-1}	SOC (%)
					------------cm^3 cm^{-3}------------					
0-20	40.0	37.40	22.60	1.45	0.44	0.286	0.132	0.154	28.1	0.48
20-40	43.50	34.10	22.40	1.48	0.44	0.273	0.119	0.154	27.2	0.35
40-60	45.21	32.34	22.45	1.55	0.43	0.273	0.120	0.153	19.2	0.27
60-100	46.37	31.19	22.44	1.59	0.42	0.272	0.120	0.152	20.1	0.20

B.D, bulk density; $\theta_{s,}$ saturated water content; θ_{FC}, water content at field capacity level; $\theta_{PWP,}$ water content at permanent wilting point; $\theta_{AWC,}$ available water content,; $K_{s,}$ field saturated hydraulic conductivity; SOC, soil organic carbon; *, loam texture according to USDA triangle

Hence, the objectives of this study were to determine the effects of deficit irrigation on the growth, yield and water use efficiency (WUE) of corn, under different irrigation practices used with different sowing techniques in a semiarid environment and use IMANSYS Model as a tool for assessing and developing deficit irrigation in maize crop, for long term planning.

Materials and Methods

Experimental site and setup

The field experiments were conducted at the experimental farm of the Institute of Soil and Environmental Sciences, University of Agriculture, Faisalabad, Pakistan (latitude, 31°-26' N and 73°-06' E, 184 m ASL) during the spring and summer growing seasons of 2011. The climate of the study area is semi-arid with more than 70% of the annual rainfall occurring during June to September. Climatic data was collected from already installed automated weather station about 500 m away from the experimental field. Reference evapotranspiration (ET_0) was calculated based on Penman–Monteith equation (Figure 1 and 2). Daily reference evapotranspiration (ET_0) for a hypothetical crop was calculated using the Penman-Monteith FAO-56 Equation (Allen *et al.*, 1998) as follows:

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T_{mean} + 273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \quad \textbf{(1)}$$

where ET_0 is the reference/potential evapotranspiration (mm day^{-1}), R_n the net radiation reaching the crop surface (MJ m^{-2}day^{-1}), G the soil heat flux density (MJ m^{-2}day^{-1}), γ is the psychrometric constant (kPa °C^{-1}), T_{mean} the average daily air temperature measured at 2 m height (°C), u_2 the wind speed at 2 m height (m s^{-1}), e_s-e_a the saturation vapour pressure deficit (kPa), e_a the actual vapour pressure (kPa), e_s the saturation vapour pressure (kPa) and Δ the slope of the vapour pressure curve (kPa °C^{-1}).

The soil type of the experiment site is well-drained Hafizabad loam, mixed, semi-active, isohyperthermic Typic Calciargids (Table 1). The experimental design followed was split plot, with three repeats. Plot size was 4 m^2 and each plot was separated by a 1 m ^{2} buffer strip (crop was not planted on buffer strip). Local high yielding maize hybrid (DK 919) was planted as test crop. The spring maize was sown on February 27, 2011, while summer maize on July 27, 2011. Crop was planted with a 65 cm row spacing and 22.5 cm plant to plant distance. Fields were irrigated uniformly before sowing to ensure optimum germination. Urea was applied at the rate of 250 kg N ha^{-1} in two splits while phosphorous and potassium were applied during sowing at 150 kg ha^{-1} single super phosphate and 105 kg ha^{-1} potassium sulphate, respectively. The spring-sown maize was harvested on May 29, 2011, while summer-sown maize on November 5, 2011. Crop duration was 90 days in both growing seasons.

Experimental treatments

The treatments consisted of four irrigation practices (furrow irrigated ridge, furrow irrigated raised bed, furrow irrigated raised bed with plastic mulch and sprinkler irrigated flat sowing practices). In all these irrigation practices, 3 irrigation levels were applied (100, 80 and 60%

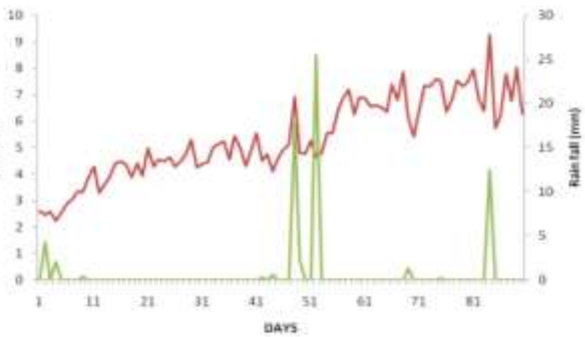

Figure 1: ETP and rainfall during spring session

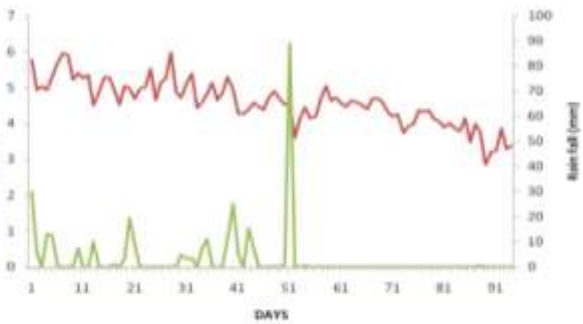

Figure 2: ETP and rainfall during summer session

FC). The experimental design followed was split plot with irrigation practices as the main treatment, and three FC levels (100, 80 and 60% FC) in subplots, with three replications. The amount of irrigation water required to maintain the soil water status at these levels was calculated based on weekly measured water content readings. All irrigations in the field were applied with a pre-measured flow from motor pump. The time required to irrigate the field plot to a required irrigation depth was calculated as follows:

$$t = \frac{Ad}{Q} \qquad \textbf{(2)}$$

where Q is discharge (m^3 min^{-1}) from the pipe of irrigation motor pump, t is time (minutes), A is area of plot (m^2) and d is depth of irrigation (m).

Determinations

Soil bulk density from 0-20, 20-40, 40-60 and 60-100 cm depths were determined by core method as described by Blake and Hartge (1986). Soil saturated hydraulic conductivity (K_{fs}) was measured by Guelph Permeameter (Model 2800 KI), taking three steady-state readings. The K_{fs} was then calculated from the following formula:

$$K_{fs} = (0.0041)(X)(R_2) - (0.0054)(X)(R_1) \qquad \textbf{(3)}$$

Where R_1 and R_2 are the steady-state rates of water fall (cm s^{-1}) in the reservoir at the first (h_1) and second head (h_2) of water (cm), respectively and X (35.5 cm^2) is the reservoir constant which is related to the cross sectional area of the combined reservoir (cm^2). Water retention curve was measured for soil layers of 0-20, 20-40, 40-60 and 60-100 cm depth, by determining water contents at pre-defined matric potential (Dane and Hopmans, 2002) with the help of suction plates at 0.3, 0.6, 1.0, 3.0 and 4.5 bar pressure. A linear regression equation was determined by taking ln (h) versus ln θ/θ_s to get water contents at permanent wilting point (θ_{WP}) and field capacity (θ_{FC}) of different soils (Williams *et al.,* 1983). The following linear regression equation was developed by taking ln θ/θ_s versus ln (h) to get $\theta_{WP,}$ θ_{FC}, θ_{AWC} etc.

$$\ln P = \ln P_e + b\ln(\theta/\theta_s) \qquad \textbf{(4)}$$

P is the matric potential (kPa), "P_e" (intercept) is air entry value/bubbling pressure which is inversely related to "α", and "b" is the slope of $\ln P$ vs $\ln \theta/\theta_s$ water retention curve. Oxidizable soil organic carbon (SOC) was analyzed using the standard procedure given by Ryan *et al.* (2001). Total aboveground biomass and grain yield were determined from the whole plot area, and harvest index was determined as the ratio of grain yield to total biological yield. The leaf area index (LAI) was measured by a digital leaf area meter (YMG-A/YMG-B). However, if the leaf area meter was not available, LAI was estimated following the methods described by Dwyer and Stewart (1986):

$$\text{Leaf area} = L \times W \times A \qquad \textbf{(5)}$$

where L is leaf length (m), W (m) is the greatest leaf width and A is factor having value of 0.75 for maize. Leaf area index was measured 7, 15, 30, 60, 75 days after sowing (DAS) and at harvest.

The crop cover (f_v) was estimated from NDVI (Normalized Difference Vegetative Index) using the formulation of Baret *et al*. (1995):

$$fv = 1 - \left(\frac{NDVI - NDVI\infty}{NDVIs - NDVI\infty}\right)^k \qquad \textbf{(6)}$$

Where NDVI*s* represents the value for bare soil (0.2013), NDVI∞ is the value for a full canopy (0.8986), and k is 0.6175, all of which were experimentally determined. However, NDVI (Normalized Difference Vegetative Index) values were obtained from LAI, using the following relationship (Xavier and Vettorazzi, 2004):

$$NDVI = 0.6868\ (LAI)^{0.1810} \qquad \textbf{(7)}$$

Soil water content and actual evapotranspiration

Soil water content from the upper 100 cm soil layer was measured with Time Domain Reflectometer (Triaxial

Cables Manufacturer) on weekly interval. The soil water content monitoring sensor was calibrated before starting the experiment using gravimetric reference samples from the respective depths as recommended by Fares and Polyakor (2006). Based on soil water measurements, the actual evapotranspiration was calculated using the water balance equation:

IManSys simulation

The Irrigation Management System (IManSys) software was used to calculate available irrigation requirement for maize based on the site specific data for this work (Fares, 2008). IManSys solves the following water balance equation:

Table 2: Measured plant parameters

FC level	Treatment	Spring 2011 Grain yield	Spring 2011 Biological yield	Summer 2011 Grain yield	Summer 2011 Biological yield
		(Mg ha^{-1})			
100%	FIR	5.98 abc¶	14.8 abc	6.02 abc	14.1 abc
	FIRB	6.09 ab	15.1 ab	6.15 abc	15.5 abc
	FIRBM	6.3 a	15.8 a	6.46 a	15.8 a
	SIF	5.73 abcd	14.2 abcd	5.71abc	13.8 abc
80%	FIR	5.94 abc	14.7 abc	5.93 abc	13.3 bcd
	FIRB	5.88 abc	14.6 abc	6.08 abc	13.5 bcd
	FIRBM	6.00 abc	14.9 abc	6.19 ab	15.3 ab
	SIF	5.53 abcd	13.7 abcd	5.65 bc	13.5 bcd
60%	FIR	5.07 cd	12.6 cd	5.47 bcd	11.4 d
	FIRB	5.13 bcd	12.7 bcd	5.35 cd	12.8 cd
	FIRBM	5.37 bcd	13.3 bcd	5.47 bcd	13.2 bcd
	SIF	4.82 d	11.9 cd	4.79 d	12.8 cd
LSD ($p \leq 0.05$)		0.957	2.37	0.78	2.19

FIR, furrow irrigated ridge; FIRB, furrow irrigated raised bed; FIRBM, furrow irrigated raised bed with plastic mulch; SIF, sprinkler irrigated flat; ¶,means sharing the same letter (s) do not differ significantly at *p*< 0.05 according to least significance difference Test

$$ET_a = (I + p) - \Delta S \quad \textbf{(8)}$$

where ET_a is the actual evapotranspiration (mm), I (mm) is irrigation, p (mm) is precipitation, and ΔS (mm) is change in root zone storage. There was no excess water losses below the root zone because irrigation was scheduled based on soil water content regarding in the root zone. The irrigation amount was calculated to replace the water content depleted.

Water use efficiency and irrigation water use efficiency

Water use efficiency (WUE) was measured as described by Hussain *et al.* (1995):

$$WUE = GY/ ET_a \quad \textbf{(9)}$$

Where *WUE* (kg ha^{-1} mm^{-1}) is the water use efficiency for grain yield (kg ha^{-1}), GY is the grain yield (kg) and ET_a (mm). Irrigation water use efficiency (WUE_i) was calculated as follows:

$$WUE_i = GY/I \quad \textbf{(10)}$$

where I (mm) is the irrigation depth applied

STO = RAIN + NIR - DRAIN – RUNOFF - INTERCEPTION – ET **(11)**

Where STO is the change in soil water storage (inches), RAIN is rainfall (inches), NIR is net irrigation requirement (inches), DRAIN is drainage (inches), RUNOFF is surface runoff (inches), INTERCEPTION is interception reduction by the crop (inches), and ET is evapotranspiration (inches).

Equation (11) is rearranged and the gross irrigation requirements are calculated as follows

NIR = (STO – NET RAIN + DRAIN + ET) **(12)**

The model input include climatic data (rainfall, air maximum and minimum temperature, wind speed, and solar radiation), crop data (initial and maximum crop root zone depth, initial, mid and end crop coefficient) and soil water holding capacity for each soil layer. The output data were net irrigation requirement (NIR), effective rainfall, potential evapotranspiration (ET_0), actual evapotranspiration (ET_a) and runoff.

Statistical evaluation

The data collected was statistically analyzed using ANOVA (analysis of variance) techniques according to split plot arrangement for both field trials. The data were homogenous and normally distributed. The means were compared by LSD (least significant difference) test at p≤ 0.05 (Steel *et al.*, 1997). The software packages STATISTICA (Version 8, www.statsoft.com, OK 74104, US), was used for statistical analysis.

Results and Discussion

Yield and yield contributing parameters

The grain yield and biological yield of spring and summer maize (Table 3) was significantly affected due to application of different irrigation techniques with different FC levels. The highest grain yields in spring and summer seasons, i.e. 6.3 and 6.46 Mg ha^{-1}, respectively was observed in case of 100% FC level applied to furrow irrigated raised bed with plastic mulch, and lowest (4.82 and 4.79 Mg ha^{-1}) by maintaining 60% FC level to a flat irrigated sprinkler treatment. The highest biological yield (15.8 Mg ha^{-1}) was produced in furrow irrigated raised bed with plastic mulch using 100% FC irrigation level and was statistically at par with other irrigation treatments, except 60% FC irrigation level with different irrigation practices, development, and plant physiological processes (Rivero *et al.*, 2007; Ali *et al.*, 2011). Similarly, Pandey *et al.* (2000) reported that deficit irrigation during vegetative and reproductive phases of growth resulted in less biological yield. Karam *et al.* (2003) also found 37% yield reduction due to water stress. Likewise, Bozkurt *et al*. (2011) reported maximum yield and yield attributes in case of 100% FC treatment and minimum in 20% FC level. Kiziloglu *et al*. (2009) reported that water deficit resulted in a lower cob, leaf, stem and total fresh yields of maize.

Irrigation techniques along with field capacity levels influenced the leaf area index significantly during spring 2011, starting from 30 DAS till harvest (Table 4). At 45 DAS, significantly highest leaf area index (2.13) was observed in furrow irrigated ridge practices scheduled at 100% FC, compared to rest of the treatments. It was followed by Treatments combinations FIRB (2.10) and FIRBM (2.08), which were at par with each other. Lowest leaf area index was observed in case of sprinkler irrigation scheduled at 60% FC. The similar trend was also observed at 60, 75 DAS and at harvest stages. Leaf area index during summer progressively increased up to 75 DAS and then

Table 3: Effect of irrigation practices along with irrigation levels on leaf area index during spring season

Treatment	Days after sowing (DAS)						
	7 days	15 days	30 days	45 days	60 days	75 days	At harvest
FIR 100% FC	0.08	0.19	0.69	2.13	3.37	4.35	4.05
FIRB 100% FC	0.06	0.19	0.66	2.10	3.31	4.33	4.02
RIRBM 100% FC	0.06	0.19	0.66	2.08	3.26	4.28	4.00
SIF 100% FC	0.06	0.18	0.65	2.06	3.19	4.11	3.86
FIR 80% FC	0.06	0.18	0.65	2.00	2.93	3.81	3.72
FIRB 80% FC	0.06	0.18	0.64	1.98	2.85	3.70	3.67
FIRBM 80% FC	0.06	0.17	0.63	1.81	2.67	3.49	3.40
SIF 80% FC	0.06	0.15	0.62	1.79	2.65	3.43	3.35
FIR 60% FC	0.05	0.14	0.61	1.72	2.56	3.31	3.25
FIRB60 % FC	0.05	0.13	0.58	1.67	2.49	3.24	3.15
FIRBM60 % FC	0.05	0.12	0.56	1.65	2.47	3.17	3.14
SIF 60% FC	0.05	0.12	0.52	1.63	2.44	3.17	3.11
LSD $_{p\leq 0.05}$	ns	0.01	0.08	0.17	0.51	0.42	0.32

FIR, furrow irrigated ridge; FIRB, furrow irrigated raised bed; FIRBM, furrow irrigated raised bed with plastic mulch; SIF, sprinkler irrigated flat and FC, Field capacity

during both seasons. The key contributing factors for furrow irrigated raised bed plastic mulch in increasing grain yield of maize could be improved soil physical properties of raised beds, enhanced soil biological activity under mulch, and high moisture availability to crop at different growth stages due to reduced evaporation. Similar findings were reported by Pandey *et al.* (2000) and Viswanatha *et al.* (2002). Low yield in 60% FC levels could be the consequence of lack of moisture content that produced water stress, thereby affecting the plant growth and started declining (Table 5). At 45, 60 and 75 DAS, furrow irrigated ridge sown crop produced maximum LAI followed by furrow irrigated raised bed sowing compared with the crop sown on flat surface and irrigated by sprinkler; whereas at 7, 15 and 30 DAS, irrigation practices had non-significant effect on LAI. Lesser LAI with deficit irrigation might be due to soil water stress. Regarding crop cover, maximum crop cover values (0.22, 0.30, 0.46, 0.68, 0.82, 0.96, 0.91) were observed after 7, 15, 30, 45, 60, 75 and 90 days of sowing with furrow irrigated ridge (100% FC), while sprinkler irrigated flat (60% FC) resulted in least crop covers with values (0.18, 0.26, 0.42, 0.62, 0.71, 0.80 and 0.80) (Table 5 and 6).

reduced evaporation. Ahmad *et al*. (2002) reported that ridge and raised bed irrigation technique significantly increase crop growth rate, LAI and grain yield. Reduction

Table 4: Effect of irrigation practices along with irrigation levels on leaf area index during summer season

Treatment	**Days after sowing (DAS)**						
	7 days	**15 days**	**30 days**	**45 days**	**60 days**	**75 days**	**At harvest**
FIR 100% FC	0.07	0.18	0.69	2.33	3.85	4.41	3.62
FIRB 100% FC	0.07	0.17	0.66	2.19	3.76	4.31	3.53
RIRBM 100% FC	0.07	0.16	0.63	2.16	3.72	4.21	3.50
SIF 100% FC	0.07	0.16	0.62	2.09	3.66	4.16	3.41
FIR 80% FC	0.07	0.16	0.60	1.98	3.64	4.15	3.24
FIRB 80% FC	0.06	0.15	0.57	1.95	3.57	4.04	3.20
FIRBM 80% FC	0.06	0.15	0.53	1.92	3.49	3.94	3.16
SIF 80% FC	0.07	0.15	0.51	1.85	3.48	3.91	3.16
FIR 60% FC	0.06	0.15	0.49	1.73	3.42	3.83	3.15
FIRB60 % FC	0.06	0.14	0.46	1.66	3.42	3.73	3.03
FIRBM60 % FC	0.07	0.14	0.44	1.62	3.36	3.66	2.94
SIF 60% FC	0.05	0.13	0.41	1.57	3.12	3.53	2.90
$LSD_{p<0.05}$	ns	0.09	0.023	0.053	0.047	0.18	0.28

FIR, furrow irrigated ridge; FIRB, furrow irrigated raised bed; FIRBM, furrow irrigated raised bed with plastic mulch; SIF, sprinkler irrigated flat; and FC, field capacity

Table 5: Effect of irrigation practices along with irrigation levels on crop cover during spring season

Treatment	**Days after sowing (DAS)**						
	7 days	15 days	30 days	45 days	60 days	75 days	At harvest
FIR 100% FC	0.22	0.30	0.46	0.68	0.82	0.96	0.91
FIRB 100% FC	0.20	0.30	0.45	0.67	0.81	0.95	0.90
RIRBM 100% FC	0.20	0.30	0.45	0.67	0.81	0.94	0.90
SIF 100% FC	0.20	0.30	0.45	0.67	0.80	0.93	0.88
FIR 80% FC	0.20	0.30	0.45	0.66	0.77	0.87	0.86
FIRB 80% FC	0.20	0.29	0.45	0.65	0.76	0.86	0.86
FIRBM 80% FC	0.20	0.29	0.46	0.64	0.74	0.83	0.82
SIF 80% FC	0.19	0.29	0.51	0.63	0.74	0.83	0.82
FIR 60% FC	0.19	0.28	0.44	0.63	0.72	0.81	0.81
FIRB60 % FC	0.19	0.27	0.44	0.63	0.72	0.80	0.80
FIRBM60 % FC	0.19	0.26	0.43	0.62	0.72	0.80	0.80
SIF 60% FC	0.18	0.26	0.42	0.62	0.71	0.80	0.80
$LSD_{p<0.05}$	ns	0.02	0.016	0.03	0.047	0.06	0.04

FIR, furrow irrigated ridge; FIRB, furrow irrigated raised bed; FIRBM, furrow irrigated raised bed with plastic mulch; SIF, sprinkler irrigated flat; and FC, field capacity

Similar results were recorded during the summer seasons. More crop cover in furrow irrigated plots might be due to ample supply of water due to less evaporation as in furrow water had lesser contact with soil compared to flat. Furrow irrigation also improved soil water status, decreased bulk density and increased shoot to root weight compared to flood irrigation. Increased LAI and crop cover in the furrow irrigation and raised-bed sowing was due to higher moisture contents (Figure 3) and improved soil physical properties. Raised-bed sowing when applied with plastic mulch further increase the moisture status of the soil by

in LAI and canopy cover with decreasing FC levels was due to limited supply of water, thereby affecting the plant growth and development, and plant physiological processes (Rivero *et al.,* 2007; Ali *et al.,* 2011). Similarly, Oktem *et al.* (2003) and Cakir (2004) found that water stress (25, 50 and 75% of FC) reduced crop canopy and leaf area index. Likewise, Pandey *et al.* (2000) found that leaf elongation is most sensitive to water deficit. These results are in line with the finding of Pandy *et al.* (1983) who reported that water stress (50 and 75% FC) resulted in a decreased leaf area development, crop cover and grain yield of maize. Iqbal *et* *al.* (2010) also reported that deficit treatments negatively affected the growth of maize both, via a reduction in assimilation as well as an increase in water losses by soil evaporation.

the profile. Highest soil water depletion was noted at lowest (60%) FC level. At 100 and 80% field capacity, soil moisture content remained above critical limit of readily available water.

Table 6: Effect of irrigation practices along with irrigation levels on crop cover during summer season

Treatment	Days after sowing (DAS)						
	7 days	15 days	30 days	45 days	60 days	75 days	At harvest
FIR 100% FC	0.21	0.29	0.46	0.70	0.85	0.98	0.85
FIRB 100% FC	0.21	0.29	0.46	0.70	0.84	0.96	0.84
RIRBM 100% FC	0.21	0.28	0.45	0.68	0.82	0.94	0.83
SIF 100% FC	0.21	0.28	0.45	0.68	0.80	0.93	0.82
FIR 80% FC	0.20	0.28	0.45	0.68	0.80	0.93	0.86
FIRB 80% FC	0.20	0.28	0.45	0.67	0.78	0.91	0.80
FIRBM 80% FC	0.20	0.27	0.45	0.67	0.78	0.89	0.80
SIF 80% FC	0.19	0.27	0.45	0.67	0.75	0.89	0.80
FIR 60% FC	0.19	0.27	0.44	0.66	0.75	0.88	0.79
FIRB60 % FC	0.19	0.27	0.44	0.66	0.75	0.86	0.78
FIRBM60 % FC	0.19	0.27	0.43	0.66	0.75	0.85	0.77
SIF 60% FC	0.18	0.26	0.43	0.66	0.74	0.84	0.76
$LSD_{p<0.05}$	ns	0.020	0.024	0.031	0.032	0.031	0.036

FIR, furrow irrigated ridge; FIRB, furrow irrigated raised bed; FIRBM, furrow irrigated raised bed with plastic mulch; SIF, sprinkler irrigated flat; and FC, field capacity

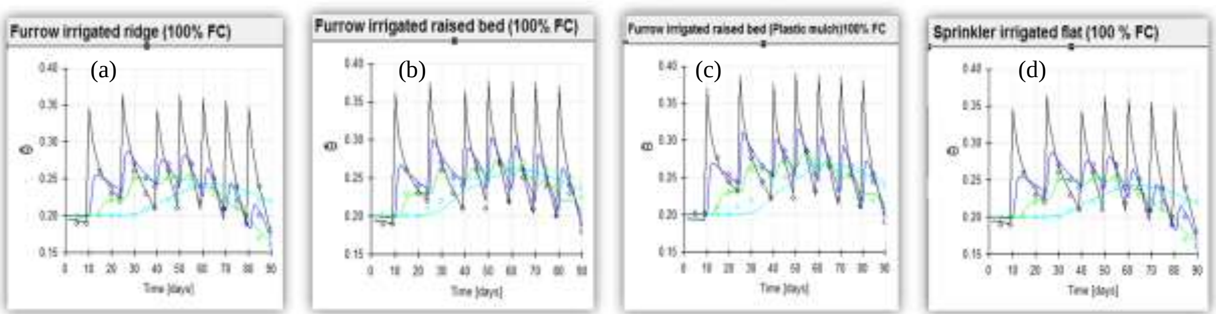

Figure 3 Comparison of measured and simulated soil water contents in the 0-100 cm of soil profile in a maize field with different irrigation practices at 100% FC for Spring season 2011

Seasonal water balance components

Field measured and model simulated soil water content for different irrigation techniques applied to spring maize with 100, 80 and 60% FC levels is shown in Figure 3, 4 and 5 (a, b, c, d). Soil water content in the upper soil profile (0-40 cm) exhibited quite wide seasonal fluctuation among different irrigation techniques with different field capacity levels. Irrigations were applied at 10 days interval for the four irrigation techniques. The degree to which the soil moisture content increased during crop growth was dependent on the duration of the irrigation interval. The results indicated that water content in furrow irrigated raised bed along with plastic mulch treatment was higher than the furrow irrigated ridge at all three field capacity levels (100, 80 and 60%) through-out

The results show that significant differences ($p \leq 0.05$) in soil profile water content of summer maize were also observed due to different irrigation techniques and FC levels (Figure 6, 7 and 8). The soil water content fluctuated between field capacity (0.286) and wilting point (0.132 cm^3 cm^{-3}) which decreased gradually with decreasing FC levels, in all irrigation techniques. Full irrigation treatment (FC 100%) ensured the highest soil water content in all irrigation practices during the study. Soil water depletions in deficit irrigation treatments (60% FC) were higher than the 80% or full irrigation (100% FC), in all irrigation practices. The soil water content in deficit irrigation treatment fell below the readily available level in all irrigation practices. Hence, decreased irrigation amounts applied in deficit irrigation treatment caused excess soil

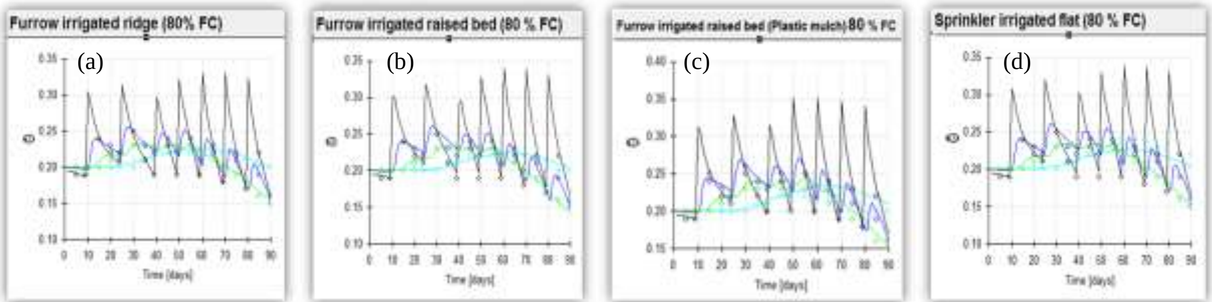

Figure 4: Comparison of measured and simulated soil water contents in the 0-100 cm of soil profile in a maize field with different irrigation practices at 80% FC for Spring season 2011

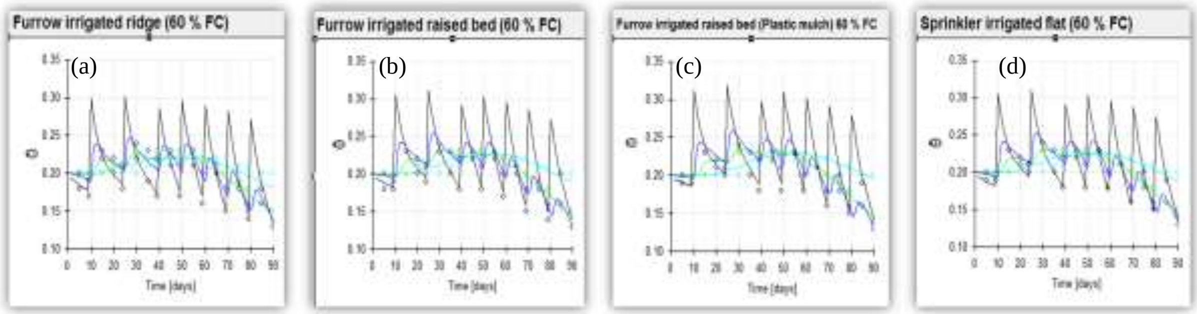

Figure 5: Comparison of measured and simulated soil water contents in the 0-100 cm of soil profile in a maize field with different irrigation practices at 60% FC for Spring season 2011

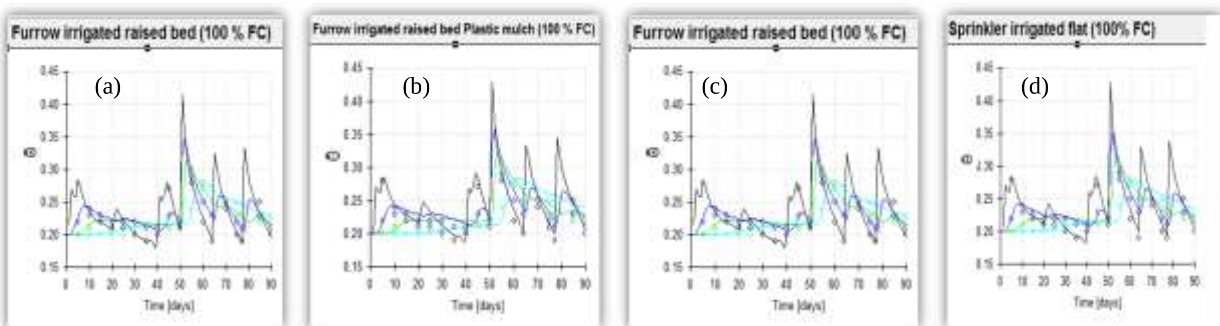

Figure 6: Comparison of measured and simulated soil water contents in 0-100 cm of soil profile in a maize field with different irrigation practices at 100% FC for the Summer season 2011

water depletion, consequently, relatively higher yield reduction. Among different irrigation techniques, flat-bed maize with plastic much depicted highest soil moisture contents and proved the best treatment. These results are in lines with Li *et al*. (2013) who showed that plastic mulch resulted in more soil water conservation compared to straw mulching. Zhou *et al*. (2011) also found maximum soil water storage and less evaporation with plastic mulch in furrow irrigation practice.

A summary related to seasonal amount of irrigation water applied (I), crop water use (ET_a), soil storage and WUE and the WUE_i of corn for the 100, 80 and 60% FC levels with different irrigation techniques in both spring and summer seasons. In spring season, seasonal total water applied (irrigation water plus rainfall) varied from 366.8 mm in flat irrigated sprinkler irrigation treatment to 516.6 mm in furrow irrigated ridge plots (Table 7). Seasonal total irrigation water applied in our study are higher than the other reported values such as Iqbal *et al*. (2010) described that total water requirement of summer and spring maize in semiarid condition of Pakistan is 272 mm and 407 mm, respectively.

However, similar to our results, Cavero *et al.* (2000) reported the 505-568 mm irrigation requirement for the semiarid region of Spain. Likewise, a similar value, i.e. 581 mm was observed by Yazar *et al.* (2002) for southeast Turkey. The seasonal crop ET_a varied from 453.7 to 525.7 mm among the different irrigation techniques with different FC levels. During the summer seasons, seasonal total water applied (irrigation water plus rainfall) varied from 330 mm in flat irrigated sprinkler irrigation treatment to 435 mm in furrow irrigated ridge plots.

increased with increasing FC levels. Seasonal crop ET_a was higher at higher irrigation levels than the deficit irrigation treatments. Similarly, Istanbulluoglu *et al.* (2002) found that evapotranspiration values of maize crop ranged from 586 mm to 353 mm for full and non irrigated treatments in semiarid condition of Turkey. Payero *et al.* (2006) noted that evapotranspiration of corn range from 625 to 366 mm under different irrigation practices ranging

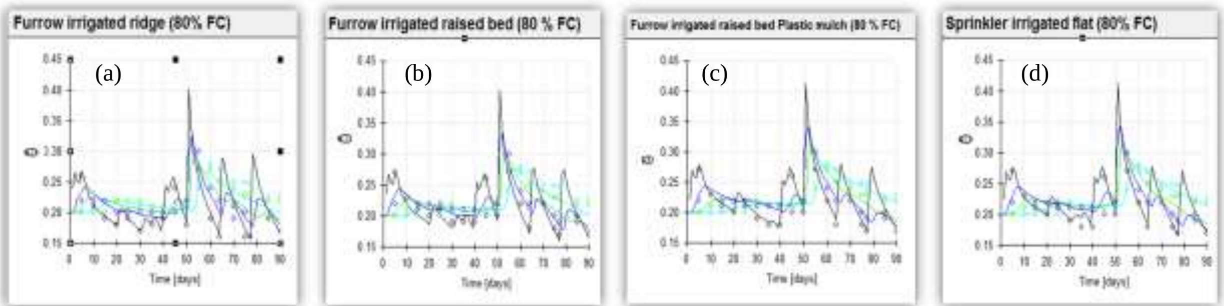

Figure 7: Comparison of measured and simulated soil water contents in 0-100 cm of soil profile in a maize field with different irrigation practices at 80 % FC for the Summer season 2011

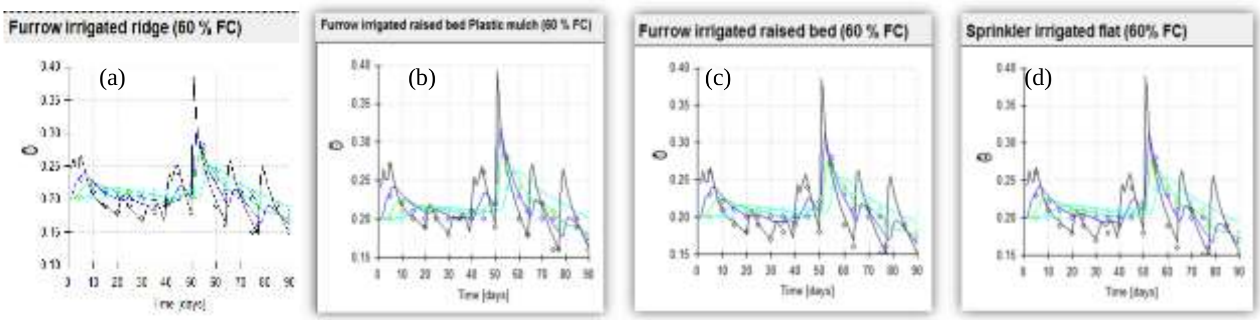

Figure 8: Comparison of measured and simulated soil water contents in 0-100 cm of soil profile in a maize field with different irrigation practices at 60% FC for Summer season 2011

The seasonal crop ET_a varied from 318 to 420.4 mm among the different irrigation treatments with different irrigation levels. Variation in ET_a of two different season crop was attributed to the differences in climatic situation (temperature, humidity and wind speed) and length of growing seasons. In case of 80% FC irrigation level, the amounts of water applied in spring season varied from 376.8 to 471.8 mm among different irrigation techniques. In case of summer season, amount of water applied varied from 323 to 417.5 mm in different irrigation techniques. The highest values of ET_a (504.6 and 415.3 mm) were observed in furrow irrigated ridge sowing irrigation technique, and the lowest values of ET_a were measured in flat irrigated sprinkler treatment, i.e. 440.6 and 315.5 mm, in spring and summer seasons, respectively. Seasonal ET_a from maximum to deficit irrigation. Cavero *et al.* (2000) also found that amount of irrigation for corn varied from 357-587 mm and 505-568 mm in semiarid region of Spain during two years of experiment under full to limited irrigation.

The effect of different irrigation techniques along with different FC levels on WUE_i is presented in Table 7. The WUE_i values in this study varied from 15.63 to 11.57 kg ha^{-1} mm^{-1} in spring season and 17.5 to 13.8 kg ha^{-1} mm^{-1} in summer sown maize. The highest WUE_i (13.2 kg ha^{-1} mm^{-1}) was found in 100% FC with furrow irrigated raised bed with plastic mulch treatment, and the lowest (10.42 kg ha^{-1} mm^{-1}) was found in 60% FC with furrow irrigated ridge irrigation practice. Similarly, in case of summer sown maize, maximum (17.5 kg ha^{-1} mm^{-1}) WUE_i was noted in

Table 7: Measured and estimated NIR, ET_a, ΔS, WUE and WUE_i in case of 100, 80 and 60% FC

Irrigation Techniques	FC level	Measured (mm)			Estimated (mm)			WUE	WUE_i
		NIR	ET_a	ΔS	NIR	ET_a	ΔS	kg ha^{-1} mm^{-1}	
		Spring 2011							
FIR	100	516.6	525.7 a	-8.9	523.4	531	-7.6	11.3 e	11.57 g
FIRB		451.8	499.7 b	-47.9	456	505	-49	12.1 c	13.47 e
FIRBM		416.8	481.7 cd	-64.9	421.3	486.1	-64.8	13.2 a	15.31 b
SIF		366.8	453.7 f	-82.9	371	458	-87	12.6 b	15.63 a
FIR	80	471.8	504.6 b	-32.8	479.2	509	-29.8	11.78 d	12.60 f
FIRB		441.8	490.6 c	-48.8	446.3	494.5	-48.2	11.99 d	13.31 e
FIRBM		411.8	476.6 de	-64.8	416	479.8	-63.8	12.59 b	14.57 c
SIF		376.8	440.6 g	-63.8	381.1	446.4	-65.3	12.55 b	14.68 c
FIR	60	436.6	486.6 c	-49.8	442	493.5	-51.5	10.42 g	11.62 g
FIRB		406.8	471.6 e	-64.8	412.4	476.5	-64.1	10.89 f	12.62 f
FIRBM		381.8	453.6 f	-71.8	384	458.8	-74.8	11.84 d	14.07 d
SIF		341.8	422.6 h	-80.8	345	427.8	-82.8	11.40 e	14.10 d
		Summer 2011							
FIR	100	435	420.4 a	14.6	442	422.2	19.8	14.3	13.8 b
FIRB		400	395 b	5	404.4	396.2	8.2	15.5	15.3 ab
FIRBM		392.5	375.2 cd	17.3	401	377.4	23.6	17.2	16.4 ab
SIF		330	318 f	12	335.3	324.1	11.2	17.9	17.3 ab
FIR		417.5	415.3 b	2.2	425.3	416.1	9.2	14.2	14.2 ab
FIRB	80	392.5	387.2 c	5.3	397.9	389.1	8.8	15.7	14.2 ab
FIRBM		382.5	365.2 de	17.3	384.2	371.1	13.1	16.9	16.1 ab
SIF		323	315.5 g	7.5	330.4	316.6	13.8	17.9	17.5 a
FIR	60	337.5	360.3 c	-22	345.2	368.6	-23	15.1	16.2 ab
FIRB		327.5	334.4 e	-6.9	335.6	338.9	-3.3	16.6	16.4 ab
FIRBM		300.2	325.2 f	-25	306.2	328.5	-22	17.0	16.0 ab
SIF		292.5	315 h	-22	294.0	317.0	-23	15.2	16.1 ab

NIR, net amount of water to be applied; ET_a, actual evapotranspiration; ΔS, change in soil water storage; WUE, water use efficiency; WUE_i, Irrigation water use efficiency

case of 80% FC with sprinkler irrigation technique and minimum (13.8 kg ha^{-1} mm^{-1}) with 100% FC along with furrow irrigated ridge sowing technique. As far as WUE is concerned, higher value (17.9 kg ha^{-1} mm^{-1}) was noted in case of 100 and 80% FC with sprinkler irrigation practice, while least value (14.3 kg ha^{-1} mm^{-1}) in case of 100% FC with furrow irrigated ridge sowing. Similarly, Oktem *et al.* (2003) and Wan and Kang (2006) reported that the low irrigation amount (75% FC) resulted in higher values of WUE, copmpared to high irrigation amount. Similar results were reported by Cetin (1996). Likewise, WUE values for maize crop under different irrigation practices ranging from 11.0 to 18.0 kg ha^{-1} mm^{-1}, 9.3 to 13.8 kg ha^{-1} mm^{-1} and 11.4 to 14.4 kg ha^{-1} mm^{-1} have been reported by Tijani *et al*. (2008), El-Tantawy *et al. (*2007) and Meena *et al. (*2009), respectively. Fahong *et al*. (2004) also found that raised bed planting with furrow irrigation enhanced WUE by 21-30% combined with 17% savings in applied irrigation water, compared to flat irrigation.

Performance of IManSys Model

After calibration of model, it was used to reproduce the NIR for both growing seasons at all FC levels. Figure 09 shows that the simulated NIR by IManSys model were in good agreement with the values measured in field during both the seasons (Figure 9), with a correlation coefficient value ranging from 0.97 to 0.99. Crop estimated NIR values under different irrigation techniques with 100% FC during the spring season produced a relationship, which indicates that model overestimated the net irrigation requirement. Similarly model also overestimated the NIR values under different irrigation techniques with 80% FC during the summer season. Model fitted best at the 80 and 60% FC levels during spring maize, and at 100% FC level during summer maize.

Many scientists successfully used IManSys model for predicting irrigation scheduling of different crop (Fares, 2009). Fares *et al*. (2013) studied irrigation requirement of corn by IManSys model. The simulation results of IManSys

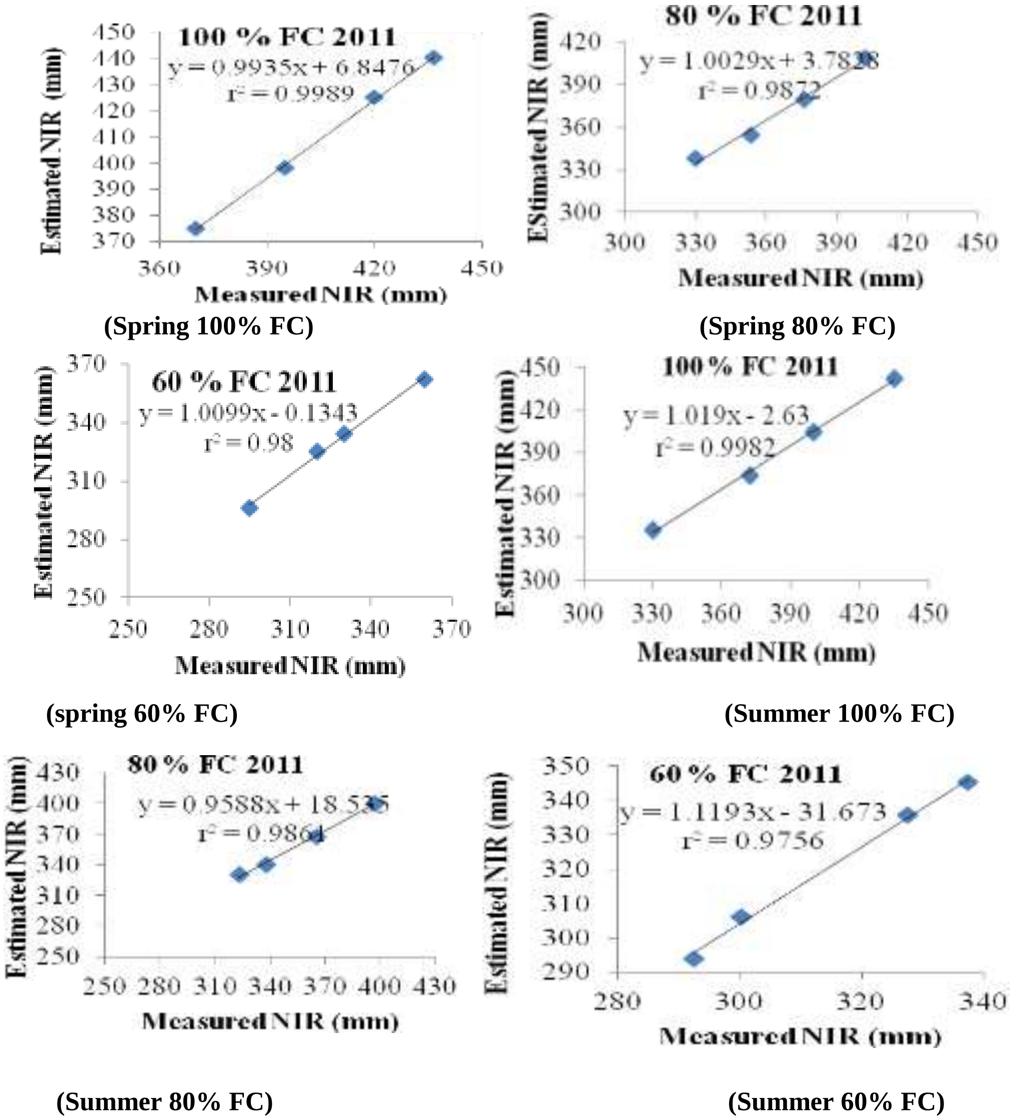

Figure 9: Correlation between measured and estimated net irrigation requirement (NIR) in spring and summer season in case of 100, 80 and 60% Fc

also showed that evapotranspiration and crop irrigation requirement is directly affected by different irrigation techniques and irrigation levels.

Conclusion

Irrigation techniques play an important role to reduce the irrigation water quantities, while maintaining or even increasing the yield production. We evaluated different irrigation technique, i.e. furrow irrigated ridge, furrow irrigated raised bed, furrow irrigated raised bed with plastic mulch and sprinkler irrigated flat sowing technique for suitable management strategy to enhance yield, WUE and WUE_i in arid to semiarid region which are facing water shortage problem. We evaluated these irrigation techniques at three different FC levels. Furrow irrigated raised bed with plastic mulch proved best irrigation technique with maximum harvest index (HI), grain and biological yield in case of 100% FC, however, highest evapotranspiration, LAI (leaf area index) and crop cover with furrow irrigated ridge with 100% FC level. Sprinkler irrigated flat treatment produced highest WUE and WUE_i values. A simplified process-based simulation model, known as Irrigation Management System Model (IManSys), simulated the soil water balance components reasonably well, during both growing seasons. This model can be useful tool to study the irrigation scheduling on crop yield under different FC levels and sowing techniques.

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