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VALIDATION OF IRRIGATION SCHEDULING FOR CULTIVATION OF IRRIGATED WHEAT IN SEMI-ARID CLIMATIC CONDITION OF ETHIOPIA

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A B S T R A C T

This study was conducted for three years (2014-2016) to validate irrigation scheduling of irrigated wheat cultivation to determine appropriate irrigation regime. The experiments were irrigation scheduling based on CROPWAT Model 8.0 and validation on field trial. The treatments were arranged in randomized complete block design with three replications. The field trial was involving three irrigation regime treatments were used for comparison. The treatments were Treatment 1 (T1): Optimal irrigation regime as determined by Cowpat for windows that provides irrigation water of D1=50mm at an interval of I1=7 days, Treatment 2(T2): Optimal irrigation regime as determined by Cowpat for windows that provides irrigation water of D2=67mm at an interval of I2=10 days. Treatment 3(T3): Optimal irrigation regime as determined by Cowpat for windows that provides irrigation water of D3=108.3mm at an interval of I3=15 days. Treatment 4(T4): An irrigation regime that provides irrigation water at critical soil moisture depletion and an amount that would refill the soil moisture depletion to field capacity. Result indicated that grain yield was significantly affected by irrigation levels. Irrigation regime of Treatment 4 produced higher grain yield 2400 kg/ha and 20.0q/ha in 2015 and 2016 cropping season. The highest mean yield of wheat (2200 kg/ha) was obtained from critical moisture refill field capacity irrigation application. Whereas, the lowest mean yield (1778 kg/ha) was obtained from T3, 7 days irrigation interval and 50mm irrigation application. This indicates that yield of wheat decrease with decreasing water amount and short interval frequency. Irrigation scheduling based on cowpat model with irrigation regime that provides irrigation water at critical soil moisture depletion and an amount that would refill the soil moisture depletion to field capacity found promising optimum wheat scheduling under Werer and similar areas.

Keywords: Cowpat; irrigation scheduling; Validation; wheat.

INTRODUCTION

Irrigation scheduling is deciding when to irrigate and how much water to apply into the field for crop production (FAO 1997). Irrigation scheduling is becoming more important because of concerns for water quality and possible shortages of water in the future (Zhang & Oweis, 1999). Crop stress and yield loss can result from too little water (Oweis, 1994). Irrigation implies the application of suitable water to crops in right amount at the right time (Sinclair, et al., 1984). Salient features of any improved method of irrigation is the controlled application of the required amount of water at desired time, which leads to minimization of range of variation of the moisture content in the root zone, thus reducing stress on the plants (Desalegn, 1999).

Irrigation has long played a key role in feeding expanding population and will undoubtedly play a still greater role in the future (Musick *et al.,* 1994). Irrigation not only raises the yields of specific crops, but also prolongs the effective crop-growing period in the semi-arid areas where the growing seasons are short, thus permitting multiple cropping where only a single crop could be grown (Wallace & Batchelor, 1997). Irrigation reduces the risk of expensive inputs being wasted by crop failure resulting from moisture stress (Oweis *et al.,* 2000). Irrigation scheduling is commonly defined as determining when to irrigate and how much water to apply (FAO, 1997). Successful irrigation depends upon understanding and utilizing irrigation scheduling principles to develop a management plan (Howell, 2001). Scheduling provides information managers can

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use to develop irrigation strategies for each field on the farm. Irrigation scheduling methods are based on two approaches: a) soil measurements, and b) crop monitoring (Hoffman *et al.,* 1990). Irrigation scheduling based upon crop water status should be more advantageous since crops respond to both the soil and aerial environmental (Yazar *et al.,* 1999).

Irrigation scheduling is the technique to timely and accurately give water to crop. Hence, it is has been described as the primary tool to improve water use efficiency, increase crop yields, greater availability of water resources, and provoke a positive effect on the quality of soil and groundwater (FAO, 1997). According to Oweis *et al.* (2000) field experiments are expensive and time consuming, and are subject to uncontrolled condition such as weather, diseases, etc. Secondly, it is practically difficult to analyze long-term effect and large impact scenarios on the field. One cheap and efficient way to conduct an evaluation of the impacts of irrigation scheduling practice is to use computer-based simulation models (Zhang & Oweis, 1999). This study aimed to find out the responses of wheat optimal irrigation water management (when and how much) options for multifaceted water problems of irrigated agriculture.

MATERIALS AND METHODS

Experiment site: The study was conducted at Werer in Amibara District, Gabiressu zone of Afar National Regional State. Werer, located at 9°12‟8" to 9°27‟46" N latitude and 40°5‟41" to 40°15‟21" E longitude in the Middle Awash Valley at an elevation of about 740 m above sea level along the way Addis Ababa to Djibouti at a distance of 280 km from Addis Ababa to the Northeast direction.

Soil water measurement: Soil water content in the top 90 cm was determined gravimetrically in all experiments. Gravimetric water content was converted into volumetric content using the bulk density of each layer and then accumulated across depths to calculate the water stored within the soil. Cumulative WU (mm) for a given irrigation event was determined by accumulating the water balance between successive soil moisture measurements by equation.

$WU = PE + I + S$ ……………Equation 1

Where PE (mm) is water supplied to soil by effective precipitation, I (mm) is the irrigation, and S (mm) is the change in the stored water within the soil depth and water loss by deep drainage was assumed negligible. Soil moisture content of the first 30 cm was measured by the gravimetric method. The amount of soil moisture in 0.60 m depth was used to initiate irrigation and the values within 0.90 m depth were used to obtain the evapotranspiration of the crop. Evapotranspiration was calculated using the soil water balance method (Heermann, 1985). The equation can be written as;

$ET = R + I - D \pm \Delta W$ …………………………..Equation 2

Where R is the amount of precipitation (mm), I refer to the irrigation water applied (mm), D is the drainage (mm) and ΔW is the variation in water content of the soil profile (mm). Since the amount of irrigation water was only sufficient to bring the water deficit to field capacity, drainage was neglected.

Irrigation scheduling: Irrigation scheduling helps eliminate or reduce instances where too little or too much water is applied to crops. Proper irrigation scheduling involves fine-tuning the time and amount of water applied to crops based on the water content in the crop root zone, the amount of water consumed by the crop since it was last irrigated, and crop development stage. With proper irrigation scheduling, soil reservoir is managed such that optimum amount of water is available when the plants need it. Good irrigation scheduling requires knowledge of Crop water demand at different growth cycles, Moisture content of the soil and soil water capacity and Weather conditions. Direct measurement of soil moisture content is among the most useful methods for irrigation scheduling. The extent to which farmers can utilize advanced irrigation depends on their access to water and labor. The economics, and in particular the critical impact of water availability on the yield play a role on the uptake of advanced irrigation scheduling.

Irrigation schedule, when to irrigate and how much water to apply per irrigation, is one of the most important tools for best management of irrigated agriculture. Optimal irrigation regime results with high irrigation water use efficiency are necessary to conserve limited water resources. In this study, optimal irrigation schedule was worked out using CropWat model 8 windows and validated on station field trial.

CROPWAT Model 8.0 based validation of optimal irrigation scheduling.

Reference evapotranspiration, Eto, Determination: Monthly Eto data series were generated from 40 years' monthly records of metrological parameters by using the CropWat software model, which applies Penman Montheise approach to calculate Eto values from maximum and minimum temperature, relative humidity, wind speed, sunshine hours. ETo data series generated were then be fitted to standard frequency distribution models to identify best fit distribution through Easy fit Professional software model. Best fit frequency distribution models were selected by applying the chi-square test. Then, ETo values at 80% probability of exceedence were estimated from the best fitted frequency distribution, and these Eto values were used to estimate CWR in different months at the study sites.

Crop Water Requirement, CWR, Determination: The CWR was computed by using CropWat computer models. The data input for this model include: Monthly Eto data computed from meteorological data, and Crop data (planting dates, length of each crop development stages, and rooting depth). The model computes CWR by applying the expression:

CWR= ETo*Kc ………………….……………………….Equation 3

Where, Kc, is a fraction representing the empirical ratio of actual crop water use to reference evapotranspiration. In this study, FAO recommended Kc values provided in the CropWat models were used to compute CWR.

Irrigation Requirement, IR, Determination: Long-term monthly rainfall data were used for probability analysis to estimate a dependable rainfall value at 80% probability of occurrence. The values obtained were then used in the computation of IR, which was estimated from the expression:

IR = CWR – Effective rainfall…………..……………Equation 4

Effective rainfall, which is part of rainfall that entered into the soil and made available for crop production in mm, was computed by applying the dependable rain (empirical formula) provided in CropWat model.

Irrigation Scheduling: Optimal irrigation schedule was worked out using CropWat model that permits to select the different irrigation scheduling criteria. The data input for this model include Monthly Eto data; Crop data (planting dates, length of crop development stage, root depth, allowable moisture depletion) and soil properties (Texture, FC, PWP, bulk density, infiltration rate). The Crop Wat for windows provides a number alternative in which optimal irrigation scheduling can be done, and in this particular study the alternative that allows determining optimal scheduling based on fixed interval irrigation application were used.

Field trial validation of optimal irrigation scheduling for irrigated wheat: The field trial involved 3 irrigation regime treatments were used for comparison. The treatments were;

Treatment 1 (T1): Optimal irrigation regime as determined by CropWat for windows that provides irrigation water of D1=50mm at an interval of I1=7 days.

Treatment 2(T2): Optimal irrigation regime as determined by CropWat for windows that provides irrigation water of D2=67mm at interval of I2-10 days.

Treatment 3(T3): Optimal irrigation regime as determined by CropWat for windows that provides irrigation water D3=108.3mm at interval of I3-15 days.

Treatment 4(T4): an irrigation regime that provides irrigation water at critical soil moisture depletion and an amount that would refill the soil moisture depletion to field capacity. The trail was laid out in a RCBD in three replications; and 12 experimental plots with dimensions 5m by 10 m were used. All plots were provided with common cultural practices throughout the crop growth period. The amount of irrigation water applied was controlled, and a measured amount was applied to each plot using 2'' Parshall flume.

Table 1. Irrigation regime treatment.

Treatments	Interval	Net Depth	Gr. Depth	Seas. Net Ir	Losses	Eff.
T-1	7 days	30mm	50mm	540mm	54.7mm	89.9
T-2	10 days	40mm	67mm	520mm	39.1mm	92.5
T-3	15 days	65mm	108.3mm	520mm	55.3mm	89.4
T-4	critical SMDL	Refill to FC				

SMDL: Soil Moisture Depilation Level FC: Field Capacity Eff: Efficiency.

Statistical Analysis: Collected data were analyzed using analysis of variance (ANOVA) through Statistical Analysis System (SAS 9.0 for Windows) appropriate for a randomized complete block design.

Means were compared by the Student Test at the 5% level of significance. The mean values of each treatment are designated by letters *a, b.* These letters represent the significance degree of the difference between the means.

RESULT AND DISCUSSION

Scheduling using CROPWAT 8.0 model: Two types of criteria were used to determine optimal irrigation schedule for irrigated wheat in this study:

Criteria 1: Applying irrigation water when soil moisture reaches critical level (FAO ASMDL) with a depth of water just enough to refill moisture to FC.

Criteria 2: Irrigating at fixed interval with user adjusted depth of water that would maximize WUE with no yield losses. Three irrigation intervals were used to determine optimum schedule- 7 days, 10 days, & 15 days.

As it is shown in Table 2, design reference evapotranspiration, Eto values, for middle awash region (Werer) during the growing period of irrigated wheat which ranges from late November to mid-March vary from 4.6 mm/day to 5.8 mm/day with a general increasing trend from December to March. According to the Crop Wat based out puts of the study, the seasonal CWR and IR of irrigated wheat growing in Middle Awash valley region planted in the last decade of November and growing for 120 days were found to be 443.8 mm and 439.7 mm, respectively as illustrated in Table 4.

Table 2. Reference Evapotranspiration, Eto values of Werer (1970-2014).

Monthly Eto values at 80% probability of Exceedence				
Month	Best fit distribution	Chi-square	P-value	Eto (@80% PEc) (mm/day)
January	Gen. Extreme Value	0.11432	0.99843	4.7
February	Inv. Gaussian	0.46644	0.9933	5.4
March	Frechet	0.6761	0.95424	5.8
April	Gen.Gamma	1.08	0.95586	6.0
May	Rayleigh	0.03871	0.84402	8.5
June	Burr	0.09263	0.99896	7.2
July	Burr	1.5781	0.81272	6.4
August	Weibull	0.26875	0.99174	5.9
September	Johnson SB	0.86912	0.92895	5.9
October	Dagum	0.77311	0.85589	5.5
November	Lognormal	0.33103	0.98772	5.1
December	Nakagami	1.5128	0.82437	4.6

Table 3. Crop Water Requirement (CWR) and Irrigation Requirement (IR) of Irrigated Wheat.

Crop Water Requirement, CWR, of Irrigated Wheat at Werer					
Eto Station: Werer			Crop: Spring Wheat	Planting Date: 21/11	
Month	Decade	Stage	Kc	Et crop(mm/day)	Et crop (mm/dec.)
November	3	Initial	0.30	1.47	14.7
December	1	Initial	0.30	1.42	14.2
December	2	Initial	0.30	1.36	13.6
December	3	Development	0.46	2.09	23.0
January	1	Development	0.75	3.51	35.1
January	2	Deve/Mid	1.02	4.83	48.3
January	3	Mid	1.15	5.62	61.8
February	1	Mid	1.15	5.81	58.1
February	2	Mid	1.15	6.00	60.0
February	3	Mid/late	1.06	5.73	45.9
March	1	late	0.79	4.42	44.2
March	2	late	0.46	2.49	24.9
Total					443.8

Table 4. Irrigation Water Requirement, IR, of Irrigated Wheat at Werer.

Irrigation Water Requirement, IR, of Irrigated Wheat at Werer					
Eto Station: Werer			Crop: Spring Wheat Planting Date: 21/11		
Month	Decade	Et crop (mm/dec.)	Eff. Rain (mm/dec.)	IR (mm/day)	IR (mm/dec.)
November	3	14.7	0.0	1.47	14.7
December	1	14.2	0.0	1.42	14.2
December	2	13.6	0.0	1.36	13.6
December	3	23.0	0.0	2.09	23.0
January	1	35.1	0.0	3.51	35.1
January	2	48.3	0.0	4.83	48.3
January	3	61.8	0.0	5.62	61.8
February	1	58.1	0.0	5.81	58.1
February	2	60.0	0.0	6.00	60.0
February	3	45.9	0.1	5.72	45.8
March	1	44.2	1.6	4.26	42.6
March	2	24.9	2.4	2.25	22.5
Total		443.8	4.1		439.7

Irrigation Scheduling: Criteria –I: Based on the ideal criteria of irrigation scheduling, Table 6, which applies provision of irrigation water at critical soil moisture depletion level with a depth of water just enough to refill soil moisture to FC, it was determined that irrigated wheat growing in the Middle Awash Valley region requires four irrigation application events of net depths irrigation water of 46.7mm, 90.8mm, 110.5 mm, and 110.3 mm on 14th, 47th, 69th, and 88th after planting (Table 5).

Table 5. Irrigation scheduling at critical depletion to refill soil moisture.

Irrigation Scheduling at critical Depletion to refill soil moisture to FC					
Irrigation Schedule Timing: Irrigate at Critical Depletion Application: Refill soil to FC; Field Efficiency: 60%			Crop: Spring Wheat Planting Date: 21/11 Harvest Date: 20/03 Yield Reduction: 0.0%		
Date	Day	Stage	Depletion (%)	Net IR (mm)	GIR(mm)
4 December	14	Initial	51.0	46.7	77.9
6 January	47	Development	50.0	90.8	151.4
28 January	69	Mid	51.0	110.5	184.2
16 February	88	Mid	51.0	110.3	183.8
21 March	END	Late	55.0		
Total Gross Irrigation		597.2 mm	Total rainfall		31.0 mm
Total Net Irrigation		358.3 mm	Effective Rainfall		31.0 mm
Total Irrigation Losses		0.0 mm	Total Rain losses		0.0 mm
Efficiency schedule		100.0 %	Efficiency rain		100.0 %

Irrigation Scheduling: Criteria –II: Data mentioned in Table 7 indicates that based on the fixed interval with fixed depth of application criteria, it was determined that irrigated wheat growing in the Middle Awash Valley region requires 14 irrigation applications with 425.0 mm total net depth at 7 days interval (Table 6), twelve (12) irrigation applications with 432 mm total net depth at 10 days (Table 7), and 8 irrigation applications with 464 mm total net depth at 15 days interval as depicted in Table 8. In these fixed interval-depth irrigation scheduling, it was possible to achieve scheduling efficiencies of 94.9 %, 94.7%, and 92.6% for the 7 days, 10 days, and 15 days interval, respectively.

Table 6. Irrigation scheduling for wheat at 7 days Interval.

Irrigation Scheduling for wheat at 7 days Interval					
Irrigation Schedule Timing: Fixed Interval(7 days) Application: Fixed depth Field Efficiency: 60%			Crop: Spring Wheat Planting Date: 21/11 Harvest Date: 20/03 Yield Reduction: 0.0%		
Date	Day	Stage	Depletion (%)	Net IR (mm)	GIR(mm)
27-Nov	7	Initial	43	25	0
4-Dec	14	Initial	24	25	0
11-Dec	21	Initial	13	25	0
18-Dec	28	Initial	10	25	0
25-Dec	35	Development	9	25	9.6
1-Jan	42	Development	9	25	9.4
8-Jan	49	Development	12	25	2.7
15-Jan	56	Development	14	25	0
22-Jan	63	Mid	18	25	0
29-Jan	70	Mid	23	25	0
5-Feb	77	Mid	30	25	0
12-Feb	84	Mid	37	25	0
19-Feb	91	Mid	45	25	0
26-Feb	98	Late	52	25	0
5-Mar	105	Late	54	25	0
12-Mar	112	Late	53	25	0
19-Mar	119	Late	45	25	0
21-Mar	END	Late	34		
Total Gross Irrigation		708.3 mm	Total rainfall		31.0 mm
Total Net Irrigation		425.0 mm	Effective Rainfall		31.0 mm
Total Irrigation Losses		21.7 mm	Total Rain losses		0.0 mm
Efficiency schedule		94.90%	Efficiency rain		100.00%

Table 7. Irrigation scheduling for wheat at 10 days Interval.

Irrigation Scheduling for wheat at 10 days Interval					
Irrigation Schedule-Timing: Fixed Interval(10 days) Application: Fixed depth; Field Eff: 60%			Crop: Spring Wheat Planting Date: 21/11 Harvest Date: 20/03 Yield Reduction: 0.0%		
Date	Day	Stage	Depletion (%)	Net IR (mm)	GIR(mm)
30-Nov	10	Initial	47	36	60
10-Dec	20	Initial	22	36	60
20-Dec	30	Initial	14	36	60

30-Dec	40	Development	12	36	60
9-Jan	50	Development	17	36	60
19-Jan	60	Development	20	36	60
29-Jan	70	Mid	28	36	60
8-Feb	80	Mid	38	36	60
18-Feb	90	Mid	49	36	60
28-Feb	100	Late	58	36	60
10-Mar	110	Late	58	36	60
20-Mar	120	Late	49		
21-Mar	END	Late	32		

Total Gross Irrigation `	720.0 mm	Total rainfall	31.0 mm
Total Net Irrigation	432.0 mm	Effective Rainfall	31.0 mm
Total Irrigation Losses	23.1 mm	Total Rain losses	0.0 mm
Efficiency schedule	94.60%	Efficiency rain	100.00%

Table 8. Irrigation scheduling for wheat at 15 days Interval.

Irrigation Scheduling for wheat at 15 days Interval

Irrigation Schedule: Timing: Fixed Interval(15 days); Application: Fixed depth; Field Eff: 60%

Crop: Spring Wheat
Planting Date: 21/11
Harvest Date: 20/03
Yield Reduction: 0.0%

Date	Day	Stage	Depletion (%)	Net IR (mm)	GIR(mm)
5 December	15	Initial	52.0	58.0	96.7
20 December	30	Initial	22.0	58.0	96.7
4 January	45	Development	20.0	58.0	96.7
19 January	60	Development	28.0	58.0	96.7
3 February	75	Mid	39.0	58.0	96.7
18 February	90	Mid	53.0	58.0	96.7
5 March	105	Late	60.0	58.0	96.7
20 March	120	Late	49.0	58.0	96.7
21 March	END	Late	22.0		

Total Gross Irrigation	773.3 mm	Total rainfall	31.0 mm
Total Net Irrigation	464.0 mm	Effective Rainfall	31.0 mm
Total Irrigation Losses	33.6 mm	Total Rain losses	0.0 mm
Efficiency schedule	92.8 %	Efficiency rain	100.0 %

Field trial validation of optimal irrigation scheduling for irrigated wheat: Result indicated that grain yields were significantly affected by irrigation levels. Irrigation regime of Treatment T4 produced higher grain yield 2400 kg/ha, 20 q/ha in 2015 and 2016 respectively. This indicated that yield of wheat decrease with decreasing water amount and short interval frequency (Table 9 & 10).The highest mean yield of wheat (2200 kg/ha) was obtained from critical moisture refill application. Whereas, the lowest mean yield (1872 kg/ha) was obtained from 15 days irrigation interval and 65mm irrigation application.

Table 9. Yield parameter result of wheat at Werer in 2015.

Treatment	Irrigation Amount and Interval		Plant height (cm)	Eff. Tiller number	Yield Q/ha
T-1	30mm	7 days	74.667a	5.667a	20.333b
T-2	40mm	10 days	75.667a	7.000a	22.000ba
T-3	65mm	15 days	76.333a	7.333a	19.667ba
T-4	Refill to FC	critical SMDL	73.000a	6.000a	24.000a
		Means	74.91	6.5	21.5
		LSD (0.05)	4.3797	2.1321	5.491
		Cv%	2.69	16.41	11.45

Table 10. Wheat grain yield and other parameters result in 2016.

TRM	APH	ATT	AET	SL	ANSS	ANKS	YKH	YQH
T1	72.43	6.27	6.27	8.40	15.97	35.25	1944.40	19.45
T2	68.03	5.93	5.93	8.07	14.80	28.33	1861.10	18.61
T3	68.17	6.20	6.20	8.40	15.03	33.17	1777.80	17.78
T4	73.83	5.77	5.77	9.43	16.43	35.50	2000.00	20.00
Mean	70.62	6.04	6.04	8.58	15.56	33.06	1895.83	18.96
LSD(0.05)	8.54	2.90	2.90	1.05	1.97	6.17	443.11	4.43
CV%	6.05	24.04	24.04	6.15	6.33	9.34	11.70	11.70

APH=Average Plant Height; ATT= Average Total Tiller; AET=Average Effective Tiller; SL= Spikelet Length; ANSS= Average Number Spike per Spikelet; ANKS =Average Number of Kentel per Spikelet; YQH=Yield kilogram per Hectare; YQH=Yield Quintal per Hectare.

Data arbitrated in Table 11, stated that the irrigation amount reflects the interaction between irrigation and crop yield (Table 11). Grain yield showed significant (P<0.05) effects for irrigation scheduling and irrigation treatments T1, T2, T3 and T4 (Table 9 & 10). Maximum mean yield (2200kg/ha) was obtained from T4 (refill to field capacity) and minimum (1872kg/ha) from T3 (65mm every 15 days) in two years. The wheat crop irrigated by monitoring soil moisture resulted maximum plant height (73.83 cm), spike length (9.43 cm) spikelets spike-1 (15.56), and grain yield (2000 kg ha-1) as compared to irrigations (40 mm at 10 days interval), (30mm irrigations at 7 days interval) and (65mm at 15 days interval) in 2015.

Table 11. Over years wheat grain yield comparison.

Treatment	Irrigation Amount	Irrigation interval	2015 Cool	2016 Cool	Combined
T1	30mm	7 days	20.33	19.45	19.89
T2	40mm	10 days	22.00	18.61	20.31
T3	65mm	15 days	19.67	17.78	18.72
T4	Refill to FC	critical SMDL	24.00	20.00	22.00
		Mean	21.5	18.96	20.23
		LSD0.05	5.491	4.43	4.96
		Cv%	11.45	11.70	11.57

SMDL: Soil moisture Depilation Level.

CONCLUSION

Wheat grown in the semi-arid area of Afar suffers seasonal water stress that results in lower grain yields 2200 kg/ha. Irrigation had a significant effect on grain yield of wheat grown in soil particularly when small amounts of water are added at critical growth stage (2200 kg/ha). The effective irrigation water application was highly effective in increasing grain yield by replenish the soil moisture and irrigate to field capacity. Hence, available water for irrigation is limited in arid areas, and practices for increasing yield at time of seeding are highly desirable. However, this study showed that irrigation by monitoring soil moisture greatly increased the amount of water used by the wheat and resulted in increased grain yields.

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