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Productivity and water-use efficiency of macaroni (*Triticum durum*) and bread wheats (*T. aestivum*) under varying irrigation levels and schedules in the Vertisols of central India

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ABSTRACT

A field experiment was conducted during the winters of 1998–99 and 1999–2000, to evaluate the performance of macaroni or *durum* (*Triticum durum* Desf.) and bread or *aestivum* wheat (*Triticum aestivum* L. emend. Fiori & Paoi.) under varying irrigation levels and schedules, under limited water availability situations in central India. Performance of wheat under varying irrigation levels revealed that the grain yield of *durum* and *aestivum* cultivars increased significantly with increasing levels of irrigation and the maximum grain yield of 5,397 and 5,960 kg/ha was obtained during 1998–99 and 1999–2000, respectively, when 6 irrigations [in addition to come up irrigation (CUI)] were applied based on physiological growth stages. *Durum* wheat cultivars performed better than *aestivum* wheat with an yield advantage of 4.5 to 8.1% at all levels of irrigations except at I_0 (CUI) and I_1 (CUI + CRI), where yield levels of both wheats were at par. The effective tillers/plant were 55 and 17% higher in *aestivum* than *durum*, while 1,000-grain weight was 22 and 14.2% higher in *durum* over *aestivum* during 1998–99 and 1999–2000 respectively. Significant increase in grain yield with an advantage of 12.4 and 22.5% was recorded by shifting/delaying irrigation at crown-root initiation to late tillering and late jointing (LJ) respectively. The maximum grain yield of 3,350 kg/ha and water-use efficiency of 11.72 kg/ha-mm were obtained when 1 irrigation (in addition to CUI) was applied at late jointing. The *durum* varieties 'HI 8498' and 'HD 4672' gave the maximum grain yield of 4,046 and 3,968 kg/ha, respectively, when 2 irrigations were applied at CRI and LJ in addition to CUI. The maximum WUE of 12.15 kg/ha-mm was recorded in 'Lok 1', followed by 'HI 8498' (12.06 kg/ha mm) and 'HD 4672' (11.85 kg/ha-mm).

Key words : Bread and macaroni wheat, Vertisols, Irrigation, Water-use efficiency, Varieties

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In the Vertisols of Indore (Madhya Pradesh) under irrigated high fertility, early and normal sowing conditions, macaroni wheat performed better than bread wheat. The former wheat varieties 'Malavshakti' and 'Malavshree' were found suitable with high grain yield, economic returns and disease resistance. These 2 varieties perform better than bread wheat under limited (2–4) irrigation conditions (Behera and Thakur, 1999). Hence an experiment was conducted to evaluate the performance of macaroni or *durum* and bread or *aestivum* wheat under varying levels of irrigation and study the effect of irrigation schedules on wheat productivity under limited water availability situations in central India.

MATERIALS AND METHODS

A field experiment was conducted during winter (*rabi*) 1998–99 and 1999–2000 involving *durum* and *aestivum* wheat cultivars under varying irrigation levels (Trial-1) and schedules (Trial-2) based on growth stages under limited water availability situations. The soil was Vertisols (fine, smectitic, hypothermic, Typic Haplusterts) with pH 7.8, organic cabon 0.5%, sand 13%, silt 34% and clay 53%. The available nitrogen and phosphorus contents were low and medium respectively. But the available potassium was high in the soil. The soil water content of the top 60 cm soil measured by pressure plate was 32.5% by weight at 33 kpa and 17.5% by weight at 1500 kpa.

Trial 1 comprised 5 irrigation levels (4 during 1998–99); I_0, come-up irrigation given immediately after sowing (CUI); I_1, CUI + (CRI) (crown-root initiation); I_2, CUI + CRI + FL (flowering); I_3, CUI + CRI + LJ (late jointing) + ML (milk); I_4, CUI + CRI + LT (late tillering) + LJ+FL+ ML+D (dough) in the main plot; and 8 wheat varieties or cultivars consisting of 4 *durum* and 4 *aestivum* in subplots (Table 1). The experiment was conducted during the winter 1998–99 and 1999–2000 in split-plot design with 3 replications.

Trial 2 comprised 5 irrigation treatments: I_0, come-up irrigation (CUI); I_1, CUI+CRI; I_2, CUI + LT; I_3, CUI +LJ; I_4, CUI + CRI + LJ in the main plot and 8 wheat varieties or cultivars (4 *durum* and 4 *aestivum* cultivars including iso-genic lines) in subplot (Table 3) with 4 replications. The experiment was conducted in split-plot design during winter 1999–2000.

In both the trials, crop was raised using recommended package of practices. A fertilizer dose of 120, 60 and 40 kg N, P_2O_5 and K_2O/ha was applied in Trial 1, while it was restricted to 60, 30 and 20 kg N, P_2O_5 and K_2O/ha in Trial 2. A rainfall of about 60 mm was received during flowering period of the crop in 1998–99.

Observations were recorded on grain yield from a net plot area of 16 m^2 and 10 m^2 in Trial 1 and 2 respectively. Yield attributes were recorded from the representative sample area of 1 m^2 in each treatment. The soil moisture studies were made using gravimetric method up to a depth of 160 cm at an interval of 20 cm. The consumptive use of water was estimated using the formulae given by Mishra and Ahmed (1987).

RESULTS AND DISCUSSION

Effect of irrigation levels on grain yield and its attributes

The grain yield was significantly

influenced by the irrigation levels. The maximum grain yield was obtained during 1998–99 and 1999–2000 when 6 irrigations (I_4) were applied at various physiological growth stages. The significant yield increase was observed up to I_3 during 1998–99, but it increased significantly up to I_4 in 1999–2000 (Table 1). The *durum* wheat varieties 'Raj 1555' and 'HI 8498' yielded significantly better than other wheat cultivars except 'GW 273' during 1998–99. During 1999–2000, the highest grain yield was also recorded in 'Raj 1555', followed by 'HI 1479' and 'HI 8498' (Table 1). The difference in I_3 and I_4 during 1998–99 was reduced due to the occurrence of rain (6.0 cm) during flowering.

Interaction effect of irrigation levels and varieties revealed that with the increase in irrigation level from I_1 to I_2, the grain yield of all the cultivars increased significantly in

Table 1. Grain yield and yield attributes of wheat as influenced by varying levels of irrigation during 1998–99 and 1999–2000

Treatment	Grain yield (kg/ha)		Spikes/m^2		Grains/spike		1,000-grain weight	
	1998–99	1999–2000	1998–99	1999–2000	1998–99	1999–2000	1998–99	1999–2000
I_0		1,416		232		29.20		37.82
I_1	2,460	2,523	208	241	36.73	35.18	43.13	41.30
I_2	3,362	3,685	214	283	39.98	38.80	48.50	50.27
I_3	4,773	4,170	282	277	45.31	38.21	44.84	51.88
I_4	5,397	5,960	342	355	44.92	42.89	45.03	52.71
Mean	3,998	3,013	261	282	41.73	31.41	45.37	39.48
CD (P=0.05)	682	383	48.1	302	5.84	4.19	2.02	2.903
Macaroni wheat								
'HI 8498'	4,306	3,625	247	246	34.03	33.05	51.64	54.36
'GW 1139'	3,715		260		33.66		52.24	
'RAJ 1555'	4,399	3,837	251	265	42.37	40.41	48.07	48.84
'PDW 273'	4,011	3,484	253	253	37.72	37.99	47.64	47.37
'HI 8381'		3,524		247		40.86		49.03
Mean	4,108	3,617	253	253	36.94	38.07	49.89	49.9
Dread wheat								
'GW 273'	4,120	3,465	229	242	49.54	44.77	41.44	39.50
'Lok 1'	3,723	3,488	365	342	30.01	28.79	48.70	50.46
'NIAW 200'	3,932		227		54.18		39.14	
'GW 303'	3,778		261		52.37		34.13	
'HI 1479'		3,726		319		31.53		47.05
'HI 1077'		3,256		308		37.45		37.76
Mean	3,888	3,483	270	303	46.52	35.63	40.85	43.69
CD (P=0.05)	269	234	28.2	24.9	3.32	3.10	1.54	1.79

Details of treatments are given in text

both the years expect for the cultivar 'GW 1139' during 1998–99. Further increase in irrigation level from I_2 to I_3 significantly increased grain yield in all the cultivars during 1998–99. But during 1999–2000, only 'HI 8381' and PDW 273' exhibited significantly superior performance in I_3 compared to I_2. Further increase in irrigation levels from I_3 to I_4 resulted in significant increase in grain yield in all the varieties during both the years except 'HI 8498' during 1998–99 (Table 2).

Table 2. Interaction effect of cultivars and irrigation levels on grain yield (kg/ha) of wheat during 1998–99 and 1999–2000

Cultivar	Irrigation levels					
	I_0	I_1	I_2	I_3	I_4	Mean
			1998–99			
Macaroni wheat						
'HI 8498'		2,604	3,913	5,184	5,522	4,306
'GW 1139'		2,420	2,845	4,463	5,133	3,715
'Raj 1555'		2,614	4,128	5,097	5,758	4,399
'PWD 273'		2,113	3,066	5,069	5,794	4,011
Mean		24,38	3,488	4,953	5,552	4,108
Bread wheat						
'NIAW 200'		2,529	3,328	4,633	5,236	3,932
'GW 273'		2,706	3,246	4,904	5,625	4,120
'LOK 1'		2,475	3,470	4,365	4,581	3,723
'GW 303'		2,217	2,899	4,471	5,526	3,778
Mean		2,482	3,236	4,593	5,242	3,888
Grand mean		2,460	3,362	4,773	5,397	3,998
			1999–2000			
Macaroni wheat						
'HI 8498'	1,624	2,457	3,737	4,171	6,135	3,625
'HI 8381'	1,023	2,595	3,602	4,346	6,055	3,524
'Raj 1555'	2,125	2,581	4,022	4,443	6,016	3,837
'PDW 273'	888	2,522	3,660	4,374	5,977	3,484
Mean	1,415	2,539	3,755	4,333	6,046	3,617
Bread wheat						
'HI 1479'	1,887	3,068	3,755	4,127	5,795	3,726
'GW 273'	1471	2,429	3,592	3,855	5,977	3,465
'Lok 1'	1,365	2,722	3,517	3,968	5,870	3,488
'HI 1077'	948	1,807	3,598	4,075	5,853	3,256
Mean	1,418	2,506	3,615	4,006	5,874	3,483
Grand mean	1,416	2,523	3,685	4,170	5,960	3,551
CD (P=0.05)	*1998–99*	*1999–2000*				
For 2 sub-plot mean at same level of main plot				538	524	
For 2 main plot means at same or different levels of subplots				609	551	

The *durum* performed better than *aestivum,* with an yield advantage of 4.5 to 8.1% at all levels of irrigations except at I_0 and I_1, where yield levels of *aestivum* and *durum* wheats were almost same (Table 2). Similar findings were also reported by Behera and Thakur (1999).

With increase in irrigation levels, the yield attributes, viz. spikes/m^2, grains/spike, 1,000-grain weight, dry-matter accumulation/m^2 and effective tillers/plant were significantly influenced. The mean effective tillers/plant in *aestivum* wheat were 55% and 17% higher than *durum* wheat during 1998–99 and 1999–2000 respectively. However, 1,000-grain weight was higher in *durum* than *aestivum* wheat by 22% and 14.2% during 1998–99 and 1999-2000 respectively (Table 1). The grains/spike in *aestivum* wheat were 25% higher than *durum* wheat during 1998–99. This trend was not noted during next season. Thus it indicates that the higher yield of *durum* wheat was due to higher kernel weight.

There was a significant increase in kernel weight of all the wheat cultivars when irrigation levels increased from I_1 to I_2 during both the years of studies indicating that irrigation at reproductive phase of growth has great bearing in increasing the kernel weight of wheat. Further increase in irrigation levels did not show any increase in 1,000-grain weight during 1998–99, but marginal increase was observed during 1999–2000. The kernel weight of *durum* wheat was similar in both the seasons, indicating its stability under varying environments.

Effect of irrigation schedule on grain yield and its attributes

In addition to CUI, application of 2 irrigations at CRI and LJ gave the maximum grain yield. However, when only 1 irrigation was applied (in addition to CUI) either at CRI (I_1), LT (I_2) and LJ (I_3), the yield levels were 27.35, 30.74 and 33.50 q/ha respectively. Shifting of second irrigation from CRI to LT and LJ resulted significant increase in grain yield, with an advantage of 12.4% and 22.5% respectively (Table 3). The performance of *durum* and *aestivum* wheats was almost similar under 1 irrigation (in addition to CUI) at CRI or LT or LJ. However under 2 additional irrigations at CRI and LJ (I_4), *durum* exhibited superior performance to *aestivum* wheat.

Interaction effect of irrigation and cultivars revealed that with the increase in irrigation levels from I_0 to I_1, there was significant increase in grain yield of all the cultivars (Table 4). Significant increase in grain yield of most of the varieties or cultivars were also recorded with delaying in irrigation from I_1 to I_2. However, 'HD 4672' and 'Bechana' dwarf showed marginal increase in yield. Tall cultivars showed significant increase in grain yield owing to shift in irrigation from I_1 to I_2. Delaying of CRI irrigation restricted the excessive tiller growth in tall wheat which ultimately resulted in tiller mortality at later stages of crop growth. Further delay from I_2, to I_3, there was significant yield improvement in all the varieties or cultivars except for the cultivars 'HW 2004', 'Nesser Tall', 'Nesser Dwarf' and 'Bechana

Table 3. Grain yield and yield attributes of macaroni and bread wheat as influenced by varying irrigation schedules during 1999–2000

Treatment	Grain yield (kg/ha)	Spikes/ m^2	Grains/ spike	1,000-grain weight (g)	Dry-matter (g/m^2)	Harvest index	WUE (kg/ha-mm)	WUE (TDM, kg/ha-mm)
I_0	2,338	263	38.28	38.55	552	0.445	11.11	26.24
I_1	2,735	258	44.42	39.31	664	0.438	11.30	27.45
I_2	3,074	304	38.82	40.31	759	0.438	11.33	28.01
I_3	3,350	277	39.69	45.15	737	0.445	11.72	25.76
I_4	3,647	291	45.44	40.68	922	0.432	11.08	28.00
Mean	3,029	278	41.33	40.80	727	0.439	11.30	27.09
CD (P=0.05)	155	18.7	3.16	1.275	40.78		NS	1.81
Macaroni wheat								
'HI 8498'	3,238	222	38.14	53.26	669	0.478	12.06	24.81
'HD 4672'	3,177	257	41.90	44.23	701	0.45	11.85	26.04
'Bechana dwarf'	2,753	243	53.81	34.47	681	0.454	10.28	25.27
'Bechana Tall'	2,975	228	51.67	39.43	759	0.419	11.08	28.13
Mean	3,036	237	46.38	42.84	702	0.450	11.32	26.06
Bread wheat								
'HW 2004'	2,623	296	37.60	39.28	725	0.40	9.86	27.07
'LOK 1'	3,247	307	30.39	49.32	768	0.460	12.15	28.84
'Nesser Dwarf'	3,116	330	40.23	31.85	726	0.450	11.67	27.21
'Nesser Tall'	3,102	347	36.88	34.57	785	0.40	11.59	29.37
Mean	3,022	320	36.27	38.75	751	0.427	11.30	28.12
CD (P=0.05)	129	21.87	3.19	1.08	46.13		0.49	1.66

Details of treatments are given in text

Dwarf'. The highest grain yield was recorded in all the cultivars at I_4 irrigation. The *durum* wheat varieties 'HI 8498' and 'HD 4672' gave the maximum grain yield of 4,046 and 3,968 kg/ha, respectively, at this irrigation schedule. This treatment resulted in significantly higher grain yield over I_3 in cultivars, viz. 'HW 2004', 'HD 4672' 'Nesser Tall', 'HI 8498' and 'Bechana Dwarf'. The other cultivars showed a marginal increase.

The delay of irrigation from CRI to LT or LJ resulted in increase in effective tillers/plant, 1,000-grain weight, dry-matter accumulation (Table 3). The 1,000-grain weight and effective tillers were highest at I_3 in all the cultivars and it was significantly higher than I_2 in most of the cultivars. This indicates that irrigation application at late jointing may help in increasing the kernel weight.

Soil moisture and water-use efficiency

Soil moisture studies revealed that the moisture content in soil profile at maturity of crop for different irrigation treatments

were similar and it varied from 14.6 to 16.8% by weight for the upper soil layer up to a depth of 40 cm and 16.5 to 19.15% for 41 to 120 cm depth (Table 5). This shows that even at maturity, the moisture level goes below the permanent wilting point. The less difference in moisture content among the different irrigation treatments was due to cracking of soils up to a depth of 81–100 cm. The consumptive use of water for different irrigation treatments ranged from 21.05 to 32.95 cm and grain yield ranged from 2,238 to 3,647 kg/ha. The maximum water-use efficiency (WUE) was recorded when irrigation was applied at LJ (I_3), followed by I_2. The WUE of wheat cultivars differed significantly. The maximum WUE was recorded in 'LOK 1' followed by 'HI 8498' and 'HD 4672'. The lowest WUE was recorded in 'HW 2004'.

Shifting or delaying the irrigation at CRI to LT to LJ has definite advantage in grain yield under the Vertisols. The yield improvement by shifting the irrigation was 12.4% and 22.5% respectively. The CRI has been reported to be the most critical stage to obtain higher yield (Pandey *et al.*, 1997). But in swell and shrink Vertisols with high clay content and water-holding capacity, it retains higher percentage of moisture in soil and for this there remains enough soil moistue in the soil profile up to 30–40 days after wheat sowing. The cracks usually develops at this stage. Hence delaying CRI irrigation and applying the same when cracks start developing, helps closing these cracks and reducing soil-moisture evaporation loss. Thus, helps the crop to complete life-cycle with less water stress at reproductive stage, resulting increase in grain yield.

In the Vertisols of central India with

Table 4. Grain yield (kg/ha) of wheat cultivars under varying irrigation schedules during 1999–2000

Variety	Irrigation levels					
	I_0	I_1	I_2	I_3	I_4	Mean
Macaroni wheat						
'HI 8498'	2,435	2,911	3,213	3,585	4,046	3,238
'HD 4672'	2,460	2,896	3,047	3,513	3,968	3,177
'Bechana Dwarf'	2,154	2,485	2,756	2,961	3,410	2,753
'Bechana Tall'	2,253	2,590	2,880	3,518	3,635	2,975
Mean	2,325	2,720	2,974	3,394	3,765	3,036
Bread wheat						
'HW 2004'	2,026	2,413	2,899	2,705	3,071	2,623
'Lok 1'	2,527	2,936	3,280	3,706	3,785	3,247
'Nesser Dwarf'	2,411	2,882	3,266	3,495	3,525	3,116
'Nesser Tall'	2,435	2,771	3,249	3,320	3,738	3,102
Mean	2,350	2,750	3,137	3,306	3,530	3,022
Grand mean	2,338	2,735	3,074	3,350	3,647	3,029
CD (P=0.05)						
2 subplot means at same level of main plot				289		
2 main plot means at same or different level of subplots				296		

Table 5. Moisture-distribution pattern at the time of maturity in soil profile under wheat cultivation during 1999–2000

Treatment	Depth of soil profile (cm)					
	0–20	21–40	41–60	61–80	81–100	101–120
Macaroni wheat						
I_0	14.68	16.59	16.97	17.99	18.38	19.25
I_1	15.82	16.82	18.87	18.29	19.16	18.56
I_2	15.08	15.77	16.58	17.30	17.72	17.36
I_3	16.17	16.74	17.8	17.27	16.71	18.52
I_4	15.98	16.81	16.50	18.72	18.70	17.91
Mean	15.54	16.54	17.34	17.91	18.13	18.32

Details of treatments are given in text

high water-holding capacity and swell-shrink properties of soil, *durum* cultivars gave higher grain yield than *aestivum* wheat when more than 1 irrigations (in addition to CUI) were applied based on physiological growth stages. The durum wheat varieties 'HI 8498' and 'HD 4672' gave the maximum grain yield of 4,046 and 3,968 kg/ha, respectively, when irrigation was scheduled at CRI and LJ in addition to CUI. Shifting or delaying the CRI irrigation to LT to LJ improved the productivity of wheat by 12.4% and 22.5%, respectively, compared to irrigation applied at CRI.

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