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Genetic improvement for deficit irrigation in bread wheat (*Triticum aestivum* L.)

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Abstract

A study was conducted for four years in the central and peninsular India to examine the route to yield under deficit irrigation in bread wheat and devise suitable selection criteria for variety development. Yield components and genotypes were compared at two irrigation levels (zero and one) in the first two years whereas trials were conducted in the following two years to realize the yield potential and genotype specificity under supplementary irrigation. Majority of the yield governing traits responded to the supplementary irrigation but the magnitude of realized advantage varied vividly in the associated traits. In yield determinants; biomass, stem elongation rate, spike weight and a disincentive to plant height was common in both treatments. Delayed heading in zero irrigation and longer duration but quick grain ripening for one-irrigation were additional attributes of selection. Proper site selection and screening of the germplasm was found crucial to raise prospects of high genetic yield potential under deficit irrigation.

Key words: Deficit irrigation, limited irrigation, moisture tolerance, yield parameters, selection criteria, Indian wheat

Introduction

Efficient use of restricted water resources under irrigated agriculture is paramount in tropical or semiarid environments. Studies in Turkey and Iran have revealed that exposing wheat crop to water stress at specific growth stages may not cause significant yield reduction [1, 2]. Response to limited irrigation in wheat had been examined in several countries and water saving strategies had been suggested/ formulated in China, WANA region and Australia [3-5]. Specific wheat varieties for limited irrigation (Promontory, TAM 107 and Thunderbolt) have been recommended in USA, too. In central and peninsular India, nearly 4.0-4.5 m ha area of this prominent winter cereal i.e. bread wheat (*Triticum aestivum* L.) falls in the water deficit area. Wheat in this part of the country is either grown on residual moisture or irrigations are restricted to just one or two and the irrigation source is mostly a well which usually goes dry after 2-3 months of monsoon rains. This water source is often utilised by the farmers to apply irrigation at the most crucial time which is identical to CRI stage, the most crucial stage in wheat under deficit irrigation [6]. This kind of abiotic stress, occurring predominantly in the vegetative phase adversely affects tillering, biomass production, grain number and poor grain filling. To strengthen wheat breeding for such situations, it is essential to access the character response of supplementary irrigation and define the plant type required for restricted irrigation so that effective selection could be exercised in the segregating materials. The route to yield under moisture stress conditions should also be investigated to identify the key components of grain yield. The present investigation focused these issues in the targeted area so as to develop the kind of wheat genotypes, truly essential to harness advantages of restricted irrigation.

Material and methods

The study conducted at three locations during 2000-04, involved an experiment in the first two years, which was conducted to compare crop performance under moisture stress conditions. A multilocation trial was conducted in the next two years to access the genetic yield potential under one irrigation situation and select the desirable genotypes. The material used in the study was selected on the basis of preliminary screening under restricted condition at Karnal. The experiment was laid in split plot design with two irrigation levels (zero and one) as main plots and twelve genotypes as sub-plots. The experiment was planted at Powarkheda in Madhya Pradesh, Pune in Maharshtra and Vijapur in Gujarat. With pre-sown irrigation, planting was done under normal conditions by the middle of November and dose was also reduced to 80kg N (two splits) and 40kg P. Under zero irrigation, no irrigation was applied after germination whereas restricted irrigation crop received one after 20-25 days of sowing i.e. CRI stage. Irrigation source at each site was wells only and the standing crop received no rain. Besides grain yield, data were recorded on ten other important yield components. Based upon grain yield, an elite group was formed in the test materials by roping in the genotypes covered in the first non-significant group. While identifying the promising genotypes for limited irrigation, drought susceptibility index (DSI) suggested by Fischer and Maurer [7] was also taken into consideration. The replication mean was further utilized for multiple regression analysis where step-up method was applied to identify the most important yield contributing traits. The trials conducted for two years during 2002-04 were similar to one irrigation experiment but they involved 36 entries in 6X6 lattice design. In that multilocation trial, Niphad located in Maharashtra was added to replace Vijapur location.

Results and discussion

The results of the experiment were directed to first examine the yield pattern under moisture stress conditions, the interactions between locations, treatments and the genotypes. Further investigation was aimed to identify the key component traits and formulate selection criteria for moisture stress conditions. Evaluation of genotypes in the form of trials aimed at looking into potential of genotypes and the type of materials that excel under one-irrigation.

(A) Performance under moisture stress conditions

i) Location specificity

Growing wheat under moisture stress conditions was highly location specific (Table 1). Powarkheda proved to be congenial site as abiotic stress noted on plant height, crop duration, ripening period and grains per ear were minimal and consequently biomass production was good. On the contrary, expression was very poor at Vijapur as small height, poor tillering and early heading added to poor biomass production. Location effect at that site was also visible on grain weight and grain number per ear, which ultimately resulted in poor yield. Situation was slightly different at Pune where abiotic stress forced early heading, shrank the ripening period and added to non-effective tillering. Location specific performance is not uncommon in wheat and has been reported by several wheat workers [8, 9].

ii) Response to supplementary irrigation

Significant improvement was noticed in each trait with just an irrigation applied at CRI stage (Table 2). Even though treatment differences were highly prominent, the magnitude varied in the associated traits. A 27 to 32% margin in yield, grain number per unit area and biomass was reduced to around 12% in case of tillers and grains per ear; 6 to 8% in height and grain weight and below 5% in phenological traits like ripening period, maturity days and days to heading. Pronounced effect of moisture stress on spikes/m^2, biological yield, grains/m^2, grain weight, grains/spike, height and duration of grain filling has been established in wheat [3, 10-13].

Table 1. Performance at individual locations

Characteristic	Location			
	Pune	Powarkheda	Vijapur	LSD*
Grain yield (q/ha)	19.39	25.67	10.38	1.28
Biomass (q/ha)	57.07	65.33	40.04	2.60
Grains/ m^2 ('000)	5.32	5.77	2.86	0.28
Grain weight (mg)	36.60	44.41	36.21	0.81
Plant height (cm)	70.46	80.08	65.40	1.94
Tillers per metre row	64.14	49.71	50.70	3.88
Heading (days)	59.88	69.77	60.91	0.46
Maturity (days)	92.82	122.31	100.34	0.56
Ripening period (days)	32.93	52.35	39.46	0.58
Grains per spike (#)	37.30	40.09	33.28	0.86

*Least significance difference at P 0.01

Table 2. Irrigation response in yield components

Characteristic	Zero irrigation	One irrigation	% improvement
Grain yield (q/ha)	15.9	21.0***	32.3
Biomass (q/ha)	47.6	60.7***	27.1
Grains/m^2 ('000)	4.07	5.23***	28.5
Grain weight (mg)	38.0	40.2***	5.82
Plant height (cm)	69.3	74.6***	7.69
Tillers per metre row	51.8	57.9***	11.9
Heading (days)	63.2	63.8***	0.87
Maturity (days)	103.9	106.4***	2.35
Ripening period (days)	40.6	42.6***	4.97
Grains per spike (#)	34. 8	39.0***	12.1

***Significant at P 0.001

Studies on supplementary irrigation have shown an increment of 36% in Iran [12]. In this study also, yield was raised from 22.7 to 28.6 q/ha at Powarkheda and 17.2 to 21.6 q/ha at Pune and the yield gain at both the places was 25 to 26%. In first year of the experiment, an additional site Indore was included and the average yield of one irrigation crop was as high as 36.25 q/ha with matching yield advantage i.e. 32%. It was a different situation at Vijapur where yield was very poor under zero irrigation (7.82 q/ha) and one-irrigation thereafter could only raise it to 12.95 q/ha. It showed that even to have productivity of 1.5 t/ha, additional irrigation and different irrigation scheduling was required for the sandy soils as that of Vijapur.

iii) Route to yield

A pronounced impact of supplementary irrigation was bound to affect the contribution of associated traits to grain yield. Majority of the traits stayed positively correlated with grain yield and high multiple regression coefficients were achieved in zero (R^2: 0.95) as well as one-irrigation (R^2: 0.79) treatments (Table 3). Differences, however, could be noted in the percent contribution of individual traits to R^2 value, which were too wide especially in case of phenological traits. The study amply demonstrated that even though certain degree of commonality could exist between the irrigation levels, characters of importance under moisture stress conditions depend upon the level of stress.

iv) Selection criteria

Step-wise regression analysis was done, deleting the least significant character one by one, to derive the key components of yield at individual irrigation level. Ultimately, 5-6 traits were left in each treatment with multiple R^2 value matched to the original ones (Table 4). Four characters remained common under both the situations i.e. biomass, ear weight, plant height and stem elongation rate. Plant height recognized as a good yield contributor under rainfed or residual moisture stress conditions, proved a disincentive under deficit irrigation even though its correlation with yield was significantly positive. Instead of height, it was stem elongation rate (per day height increase till heading) that assumed significance in both treatments, implying that fast initial growth rate was paramount in deficit irrigation. Role of Rht alleles across a range of moisture level had been recognized in spring wheat [14]. Tillering failed to register

Table 3. Correlation between yield and yield contributing traits

Character	Correlation coefficient		% contribution to yield	
	Zero irrigation	One irrigation	Zero irrigation	One irrigation
Biomass	0.863***	0.830***	44.40	67.99
Plant height	0.631***	0.521***	–167.42	–116.23
Stem elongation rate	0.489***	0.233*	116.22	47.59
Ear weight	0.830***	0.462***	49.99	13.39
Grains per spike	0.578***	0.306**	–4.86	–0.10
1000-grain weight	0.713***	0.310**	–6.62	–4.48
Tillering	0.086	0.266**	1.17	3.85
Heading	0.376***	0.507***	59.29	–43.15
Maturity	0.533***	0.568***	3.89	263.37
Ripening period	0.522***	0.450***	3.94	–132.23

*,**,*** Significant at P 0.05, 0.01 and 0.001, respectively

Table 4. Key yield determinants

Character	Zero irrigation (Multiple R^2 : 0.89)		One irrigation (Multiple R^2 : 0.77)	
	Regression value	% contribution	Regression value	% contribution
Biomass (q/ha)	0.27	50.78	0.36	71.75
Plant height (cm)	–1.47	–169.47	–1.28	–131.05
Stem elongation rate (cm)	95.40	118.85	83.88	54.29
Ear weight (g)	7.88	39.73	3.27	9.43
No. of grains per spike	NS	-	NS	-
1000-grain weight (g)	NS	-	NS	-
Tillers per meter	NS	-	NS	-
Heading (days)	1.61	60.11	NS	-
Maturity (days)	NS	-	1.57	194.46
Ripening period (days)	NS	-	–1.46	–98.88
Intercept a	–112.56	-	–114.05	-

*,**,***Significant at P 0.05, 0.01 and 0.001, respectively. NS: Non-significant

any significant effect on yield under deficit irrigation. Specificity for irrigation levels existed only for phenological parameters as late flowering assumed importance in case of zero irrigation whereas long duration but quick grain ripening were favourable for supplementary irrigation. These traits had assumed importance in several studies focused on deficit irrigation in wheat [3, 12, 15-16]. The investigations suggested that when breeders aim to develop varieties of wider adaptation for an area as large as central-peninsular India, the above mentioned 5-6 parameters could be decisive in regulating 89% yield in zero irrigation and 77% in one-irrigation.

v) Breeding prospects

Pronounced location specificity is bound to effect prospects of any breeding initiative. Multiple regression coefficients were taken a tool to gauge efficacy of such programmes at individual site. Even with ten yield-contributing traits, significant F value could not be derived at Vijapur under any irrigation level. It implied that selection based upon those traits would fail to register any significant impact on grain yield in Vilapur or similar type of environments. In contrast, highly significant F values at Powarkheda suggested that selection could produce desired results for both irrigation levels and the characters of importance were biomass, grains/spike and heading in zero irrigation (R^2: 0.82) and just biomass and grains/spike in one irrigation (R^2: 0.65). On that account, Pune could be rated suitable only for zero irrigation as F value was not significant in one irrigation. Key traits for selection in zero irrigation were ear weight, tillering and grain filling period (R^2: 0.70).

v) Selection for yield and moisture tolerance

Highly significant varietal differences for each trait made selection of superior genotypes quite easy. Genotype specificity for individual irrigation levels was amply demonstrated in grain yield (Table 5). However, a good genotype for moisture stress conditions could be the one that besides better yield, also possess moisture tolerance ability. It means that even if supplementary irrigation is not possible due to certain reasons, the yield loss drops to bare minimum and that could be quantified by deriving the drought sensitivity index (DSI), a parameter well demonstrated for yield potential under moisture stress conditions [15, 17]. Genotypes with high yield and DSI around one are preferred for deficit irrigation. Although three genotypes i.e. NIAW 215, MYL 396 and WH 147 belonged to the 1st non-significant group, NIAW 215 (20.2 q/ha) was the perfect genotype for moisture stress conditions with DSI 1.01 (Table 5) and the second best could be MYL 396 with overall yield ~20 q/ha. WH 147 (19.4 q/ha) could be used as check as it was a popular variety in the region with proven drought tolerance ability (DSI: 0.52). The three genotypes found suitable for limited irrigation were originally developed for irrigated condition. It had been amply demonstrated in several studies that potential yield in any environment depends not only on water and nitrogen but on cultivar as well [3, 7, 8].

Subjecting deficit irrigation in harsh environments

Table 5. Yield (q/ha) and moisture tolerance

Genotype	Zero irrigation	One irrigation	Variety mean	Drought susceptibility index
NIAW 215	17.39	23.08	20.23	1.01
MYL 396	16.97	22.84	19.90	1.05
WH 147 (check)	18.13	20.74	19.43	0.52
HW 2018	16.14	21.73	18.93	1.05
SUJATA (check)	15.84	21.88	18.86	1.13
AKAW 3862-2	16.06	21.65	18.85	1.06
MP 1121	16.80	19.56	18.21	0.58
JOB 151	14.68	21.51	18.10	1.30
RAJ 3993	14.90	20.89	17.90	1.17
HW 3004	15.21	20.18	17.74	1.02
LOK 1 (check)	14.20	19.69	16.94	1.14
HI 1477	14.58	18.74	16.66	0.91
Mean	15.91	21.05	18.48	

CD (5%) for yield; Treatment: 0.74, Variety: 1.26, Variety x Treatment: 1.79

resulted in all kind of possible interactions for all traits. No pattern or symmetry could be noted in the genotypes between the irrigation levels or the test sites. Rank correlation between zero and one irrigation was found insignificant and so was the case between different locations within the same treatment or across the treatments. Since highly significant interactions were noted in location x treatment x varieties, it was important to identify promising high yielding genotypes for individual locations. Applying the same selection criteria, suitable genotypes for deficit irrigation were NIAW 215, RAJ 3993 and LOK 1 at Pune; WH 147 and MYL 396 at Powarkheda, and NIAW 215, Sujata and LOK 1 at Vijapur. During one year testing at Indore also, WH 147 and NIAW 215 exhibited high yield potential under deficit irrigation.

(B) Genotypes for limited irrigation

i) Potential areas and the prospect

Location differences and their interaction with the varieties were too pronounced in the trials as well (Table 6). Trial mean during two years was highest at Powarkheda (27.2 and 28.6 q/ha) followed by Niphad (23.2 and 16.2 q/ha) and Pune (11.2 and 11.3 q/ha). Crop expression in the trials was also best seen at Powarkheda (plant height: 87 cm, heading: 63 days, grain ripening period: 50 days and grain weight: 49.7 mg). In comparison, the abiotic stress appeared to be high at Pune and Nipahd as height was reduced to 66-70cm, grain ripening periods was short (32-35 days) and consequently grain weight was reduced to 29.8 and 36.4 mg, respectively. It showed that locations like Powarkheda, which offer yield levels 2.5-3.0 t/ha, should be exploited to raise wheat production under restricted irrigation. At certain other sites like Nipahd or Pune, single irrigation was not enough and to get matching yield levels, one or two additional irrigation might be required and their scheduling has to be revised.

Yield potential under limited irrigation was quite high (around 3t/ha) in certain genotypes at Powarkheda and Niphad. A couple of entries even touched the five-ton average at Kota, an additional site included in the

Table 6. Grain yield (q/ha) in the elite material

Location	Top 5 genotypes of the 1st non-significant group		Checks	
	Entries	Yield	WH 147	NI 5439
2002-03				
P'kheda	HP 1731, CAS 403, K 9993, MP 1135 & GW 326	32.1-35.9	27.2	28.3
Niphad	PBW 497,GW 284, NIAW 250, NI 5439 & NIAW 215	29.4-31.6	26.5	29.5
Pune	WH 147, HP 1731, CAS 400, HW 2048 & NIAW 215	13.0-15.4	15.4	11.1
Overall	HP 1731, CAS 403, NIAW 215, CAS 260 & NI 5439/ WH147	23.0-25.3	23.0	23.0
2003-04				
P'kheda	CAS 317, HI 1518, CAS 438, NW 2036 & CAS 434	34.4-37.1	30.8	30.8
Niphad	MP 1151, NIAW 215, PBW 435, CAS 436 & CAS 403	19.1-21.4	13.8	18.6
Pune	CAS 439, GW 343, HW 2044, PBW 512 & HP 1731	15.7-19.2	13.5	12.1
Kota	AP 885, CAS 439, MP 1151, HP 1731 & NI 5439	40.7-52.7	34.3	40.7
Overall	CAS 439, HI 1518, HP 1731, CAS 317 & NI 5439	25.6-26.9	23.1	25.6

second year trial. Yield advantage in the top five genotypes belonging to the 1st non-significant group was compared with checks for each location. Over the years, Powarkheda drew 17.6 and 19.8% yield advantage in that elite group in comparison to checks NI 5439 and WH 147, respectively. The top five registered just 6.16% yield advantage over the check WH 147 (14.45 q/ha) at Pune. In fact, WH 147 was the top yielder at that site in first year of the trial. The best check at Niphad was NI 5439 (24.05 q/ha) and only 5.28% yield gain could be noted in the elite group of best five. The yield levels and the yield advantage over checks revealed that advantage of limited irrigation could not be uniform all-around and the best results can be expected from Madhya Pradesh. Twelve promising genotypes were repeated in the second year trial and when their two years performance was compared, the best three (HP 1731, CAS 403 and CAS 317) collectively gathered 12 to14% higher yield advantage over checks WH 147 and NI 5439 at Powarkheda. In contrast, the checks themselves occupied top positions at Pune and Nipahd. Besides yield advantage, the prospects of finding new entries were also high at Powarkheda whereas both locations of Maharshtra registered very limited success.

The trial had seven released varieties in the first year and nine in the second. In the first year trials, only three of them (HP 1731, WH 147 and NI 5439) could occupy the 1st non-significant group whereas the other four which otherwise were rated high for abiotic stresses (MACS 2496, NIAW 34, PBW 373, WH 533) failed on that account. Similarly, HP 1731 and NI 5439 performed in the second year as well, whereas important varieties like GW 190, GW 322, RAJ 3765, HW 2044 lagged behind under restricted irrigation. It showed that the standard irrigated varieties may not be sufficient and churning the germplasm under limited irrigation therefore should be prioritised to identify useful materials.

Wheat research in the country warrants focussed efforts on limited irrigation. The study revealed that majority of the yield governing traits respond to the supplemental irrigation; the magnitude of the realized advantage however may vary in the associated traits. Height proved to be a disincentive in deficit irrigation but biomass, spike weight and fast early growth were certain desirable attributes. It was the crop phenology that could be used to select genotypes specific to the irrigation levels like long flowering for zero irrigation and delayed maturity but fast grain ripening in one-irrigation. Such an effort in wheat breeding can be better adopted in central India represented by Powarkheda in this study. To conduct an efficient breeding programme for deficit irrigation in wheat, intense germplasm screening and adoption of befitting sites should be prioritised with a focus on drought susceptibility index. Reviewing the limited source for better irrigation scheduling is also seen rewarding in raising wheat productivity under moisture stress conditions.

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