Indian Journal of Agronomy **65** (3): 324—330 (September 2020)

Research Paper

Response of summer pearl millet (*Pennisetum glaucum*) to irrigation, fertility and hydrogel under semi arid tropics

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Received: June 2020; Revised accepted: September 2020

ABSTRACT

A field experiment was conducted on loamy sand soil during two consecutive summer seasons (*Zaid*) of 2016 and 2017 at Sardarkrushinagar, Gujarat, to evaluate the effect of irrigation, fertilizer and hydrogel on growth, yield and economics of summer pearl millet (*Pennisetum glaucum*). The result revealed that all growth traits, yield components, grain and straw yield of pearl millet increased significantly with an increase level of irrigation up to 1.0 irrigation water: cumulative pan evaporation (IW : CPE) ratio with water application 541 mm, fertility of 125% recommended dose of fertilizer (RDF) and hydrogel application @ 5 kg/ha on pooled basis. The highest water productivity was recorded with an IW : CPE ratio of (1.0) 125% RDF and hydrogel application @ 5 kg/ha on pooled basis. The highest net returns and benefit: cost ratio were recorded with IW : CPE ratio of 1.2 and 125% RDF. However, increasing level of hydrogel application from 0 kg to 5 kg/ha, benefit: cost ratio was not increased in both the years of study.

Key words **:** Fertility, Hydrogel, Irrigation, Pearl millet, Yield

Pearl millet is an important drought-hardy millet crop and satiates the nutritional security for poor people in a short period. India is the largest producer of pearl millet, the crop occupied an area of 8.69 million ha, annual production of 10.05 million tonnes with an average productivity of 1,156 kg/ha. (DES, MoA, 2016). Irrigation and fertilization are two most important crop-management factors through which farmers can control crop development, yield and quality.

Pearl millet has the capacity to survive in rainfed areas because of its drought-escaping mechanism, but still responds well to all inputs including irrigation and fertilizers. There is a tremendous pressure on agriculture sector to reduce its share of water and at the same time to improve total water productivity with increased water-use efficiency. Scheduling irrigation on the basis of evaporative demand results not only in efficient utilization of water, but also in considerable water saving. Among different approaches for scheduling irrigation, climatological approach based on the ratio between depth of irrigation water (IW) and cumulative pan evaporation (CPE) is found the most appropriate and practicable, as it integrates all the weather parameters giving their natural weightage in a given soil-water-plant continuum.

Likewise, pearl millet is very sensitive to insufficient fertility level and results gives low yields and shows significantly reduced profits compared to a properly fertilized crop (Singh *et al.,* 2003). Fertilizer-use efficiency is closely related to soil-moisture content. In general, farmers apply medium to high doses of fertilizers with less irrigation water compared to its requirement. This causes low yield due to less availability of water as well as fertilizers to the plants (Saren and Jana, 2001). To increase the productivity level of pearl millet, there has been a tendency to apply higher level of fertilizers and irrigation water, often together.

Apart from irrigation and fertilizer under water-scarcity situation, improved water-conservation techniques are required for conserving soil moisture and increasing water-holding capacity under limited water resources. Hydrogel is water-absorbing product, may be used to enhance water-use efficiency (Huttermann *et al.,* 2006). It is a synthetic three-dimensional, hydrophilic polymer, loosely cross-linked networks capable of imbibing large amounts of water or biological fluids. 'Pusa Hydrogel' is a novel semi-synthetic super absorbent polymer developed by the Indian

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Agricultural Research Institute (IARI) and it has shown the potential to realize more yield per unit of input. This product displayed a swelling potential of minimum 350 times, often exceeding 500 times its weight in pure water. It enhances the crop productivity per unit available water and nutrients, particularly in moisture-stress condition. It improves physical properties of soil, seed germination, seedling emergence rate, root growth and density that help plants to prolonged moisture stress (Ekebafe *et al*., 2011).

Research work on use of hydrogel in field crops is very meager. Input information on optimal schedules for irrigation and fertigation to summer pearl millet will have to be generated with water-conservation technology. Therefore, the present investigation was conducted to study the different levels of irrigation, fertility and hydrogel on pearl millet under semi-arid tropical region of India.

MATERIALS AND METHODS

A field experiment was carried out during the summer season (*zaid*) of 2016 and 2017 at S. D. Agricultural University, Sardarkrushinagar, Gujarat. The site is geographically situated at 24°–19' N and 72°–19' E with an elevation of 154.52 m above the mean sea-level in the North Gujarat Agro-climatic Zone IV (AES-I) of Gujarat. The region is characterized by tropical and semi-arid with fairly dry and hot summer. The rise in temperature starts from February and reaches the maximum during April–May and considered as the hottest months of the year in North Gujarat Agro-climatic Zone. Average daily pan evaporation ranged from 4.27 to 11.06 mm and 3.70 to 11.94 mm per day (Fig. 1) and cumulative pan evaporation was 665 mm during 2016 and 757 mm during 2017 in the crop season. Soil of experimental plot is loamy sand in texture (83.90% sand, 5.55% silt and 9.84% clay), slightly alkaline in reaction with *p*H 7.41 and EC 0.13 dS/m. It was moderately fertile being low in organic carbon (2.5 g/kg) and low in available nitrogen (167 kg/ha), medium in available phosphorus (39.5 kg/ha) and high in available potassium (270 kg/ha). Initial bulk densities of the soil were 1.44 and 1.45 Mg/m^3

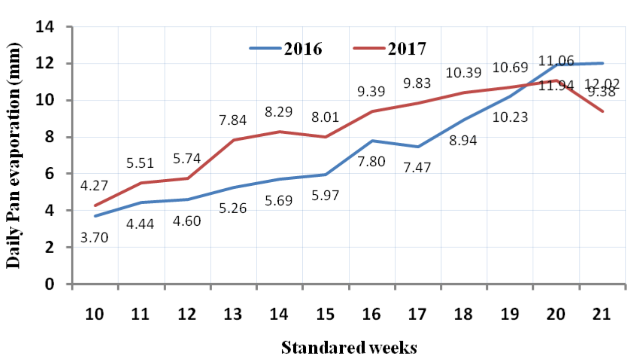

Fig. 1. Daily pan evaporation data in standard week during crop growth period (2016 and 2017)

in 0–15 and 15–30 cm depth, respectively. The soil moisture-retention capacity at field capacity and at permanent wilting point of the experimental site was 7.38% and 2.58% (0–60 cm) estimated by the standard procedure.

'GHB 732' variety of pearl millet @ 3.75 kg/ha was sown at 45-cm-row spacing on 2 March in 2016 and 1 March 2017. The experiment was laid out in a split-plot design with 18 treatment combinations and replicated thrice. The main treatment comprised 3 levels of irrigation [surface check basin irrigation of 0.8, 1.0 and 1.2 irrigation water: cumulative pan evaporation (IW : CPE ratio), 2 fertility levels (100% RDF, 120 N : 60 P : 0 K Kg/ha and 125% RDF, 150 N : 75 P : 0 K kg/ha) in main plots and 3 hydrogel levels (0.0, 2.5 and 5.0 kg/ha) as sub-plots treatments. The measured quantity of fertilizers and hydrogel was drilled in the soils at 5 cm below the seed according to treatments. The gross plot size was 5.0 m × 4.5 m and net plot size was 4.0 m × 2.7 m.

Daily evaporation data were recorded with the help of USWB Class 'A' open pan evaporimeter installed at the meteorological observatory of the farm in Agro-meteorological station at farm. Surface-check basin irrigations scheduled on climatologically approach (IW : CPE ratio) and it was given as per treatments using 50 mm depth of irrigation water.

The volume of water required in case of 50 mm water was calculated as:

$$W = A \times d \times 1{,}000$$

where, W, quantity of water (litre/ha); A, plot area in m^2; d, depth (m) of irrigation water in meters.

Water productivity (WP) is the economic yield/unit of irrigation water consumed by the crop and expressed in kg/m^3.

$$WP = \frac{Y}{IR}$$

where WP, water productivity in kg/m^3; Y, marketable crop yield in kg/ha; IR, applied irrigation water in m^3.

Crop yield (dependent variable) was assumed as a function of various growth traits, yield components and nutrient uptake (independent variable) and the following straight line model was established by least-square technique (Gomez and Gomez, 1984) as follows:

$$Y = a + b\,(x)$$

The data obtained on the different growth and yield components and yield were analyzed statistically by the method of analysis of variance as per the procedure outlined for split-plot design given by Gomez and Gomez (1984). Statistical significance was tested by P-value at 0.05 level of probability and critical difference was worked out wherever the effects were significant.

RESULTS AND DISCUSSION

Yield attributes

Pooled results indicated that irrigation at an IW : CPE of 1.2 revealed the highest values of yield attributing characters, viz. number of ears, girth of ear (12.76 cm), length of ear, (24.72 cm), grains weight/ear, (13.0 g), 1,000-grain weight (Table 1). The higher performance of these attributes over IW: CPE of 0.8 and 1.0 might be owing to increase in number of irrigations applied at shorter intervals. This situation avoids moisture stress and provided a favourable condition for moisture and nutrient availability to the crop. Sonawane *et al.* (2010) also reported similar findings. The availability of adequate moisture with 1.0 and 1.2 IW : CPE might be resulted in better translocation and partitioning of these photosynthates from source to sink and increased the grains weight/ear, 1,000-grain weight. Patel *et al.* (2013) also observed increased in yield attributes with higher irrigation over lower one in pearl millet.

Application 125% RDF significantly improved the yield attributes. Significantly higher values of yield attributes, viz. number of ear, girth of ear (11.56 cm), length of ear, grain weight/ear (12.82 g), 1,000-grain weight over 100% RDF, were recorded. Better growth under 125% RDF might have produced and converted more photosynthates into numerous metabolites needed for such yield attributes. Sharma *et al.* (2000) found that the increase in 1,000-seed weight for higher fertility level was owing to the better filling of seeds, which resulted in bold-sized seeds and consequently higher 1,000-seed weight.

Hydrogel application @ 5.0 kg/ha showed its significant superiority in case of number of ears (15.34/m row), girth of ear (11.24 cm), length of ear (23.27 cm), grain weight/ear (12.65 g), 1,000-grain weight (13.02 g) over the treatment without hydrogel application and hydrogel application @ 2.5 kg/ha. Our results showed that an increase in hydrogel level significantly increased the girth of ear. As the water content of the plant decreases, cell shrinks and turgour pressure against cell walls relaxes. This decrease in cell volume resulting from lower turgour pressure subsequently concentrates solutes in cells. SAPs increase the turgour pressure inside the cells by maintaining sufficient amount of water as per plant need and thus causing increase in yield attributes and other related parameters (Yazdani *et al*., 2007).

Yield

The result with respect to seeds and stover yields indicated that irrigation level had appreciably influenced the seed and stover yields of pearl millet (Table 2). The irrigation at an IW : CPE of 1.2 resulted in significantly highest seed and stover yields as compared with an IW : CPE of 0.8 and remained at par with IW : CPE of 1.0. The increase in seed yield with an 1.2 IW : CPE of 1.2 over 0.8 was 7.17% and of 1.0 was 27.93%, while that of stover was 13.43 and 39.63%, respectively. The higher seed and sto-

Table 1. Yield attributes of pearl millet as influenced by irrigation, fertility and hydrogel levels (pooled mean of 2 years)

Treatment	Ears/m	Length of ear (cm)	Girth of ear (cm)	Grain weight/ ear (g)	1,000-grain weight (g)
Irrigation levels					
I_1, 0.8 IW : CPE	13.9	19.0	9.0	11.5	12.1
I_2, 1.0 IW : CPE	14.8	23.8	11.2	12.4	12.3
I_3, 1.2 IW : CPE	15.6	24.7	12.7	13.0	12.4
SEm±	0.40	0.35	0.12	0.22	0.04
CD (P=0.05)	1.16	1.02	0.34	0.63	0.11
Fertility levels					
F_1, 100% RDF	13.4	21.4	10.4	11.8	12.2
F_2, 125% RDF	16.3	23.6	11.5	12.8	12.3
SEm±	0.33	0.29	0.09	0.18	0.03
CD (P=0.05)	0.95	0.83	0.28	0.51	0.09
Hydrogel levels (kg/ha)					
H_0, No hydrogel	14.0	21.7	10.7	11.8	11.5
H_1, 2.5 hydrogel	14.8	22.5	11.0	12.5	12.3
H_2, 5.0 hydrogel	15.3	23.2	11.2	12.6	13.0
SEm±	0.20	0.17	0.07	0.14	0.03
CD (P=0.05)	NS	0.49	0.20	0.38	0.09
CV%	7.97	4.63	3.46	6.64	1.56

IW : CPE, Irrigation water : cumulative pan evaporation; RDF, recommended dose of fertilizer

ver yields with 1.2 and 1.0 IW: CPE could be attributed to increased soil moisture coupled with accelerated nutrients uptake, which helped the plant to put optimum growth. The harvest index of pearl millet was not significantly influenced by irrigation, fertility and hydrogel levels in both the years. It is a well-established fact that, harvest index is more or less governed by genetical make up of a plant and is not influenced much more by input-supply system if crop is raised under recommended practices. Our results also follow the same pattern.

The fertility level of 125% RDF resulted in significantly highest seed and stover yields as compared to 100% RDF. The extent of increase in seed and stover yields under 125% RDF was 15.46 and 11.98%, respectively, over the 100% RDF. This might be owing to adequately fertilized crop benefited from higher rates of nutrition that might have resulted in a more vigorous and extensive root-system of crop leading to increased vegetative growth means for more efficient sink formation and greater sink size, greater carbohydrate translocation from vegetative plant parts to the grains and longer and thicker ear, ultimately reflected in higher grain and stover yields of pearl millet. These findings corroborate the results of Parihar *et al*. (2010).

In case of hydrolgel application, the maximum grain yield (4,488 kg/ha) and stover yield (7,480 kg/ha) were registered under treatment H_2 (5.0 kg/ha) which was significantly superior to the yields obtained under other levels of hydrogel. Hydrogel, a hydrophilic or super absorbent polymer, has shown the potential to realize more yield per unit of input. Its application to the soil helped in retaining more moisture in the soil, increased water-holding capacity of polymer and decreased infiltration rate of soil. Increasing the levels of hydrogel has increased water-use efficiency over the control.

Consumptive use of water and water productivity

Among all irrigation levels, the lowest consumptive use of water was recorded with 0.8 IW : CPE ratio followed by 1.0 IW : CPE ratio and highest with 1.2 IW : CPE ratio during both the years of study on pooled basis. Further, each unit increased in irrigation level from 0.8 to 1.2 IW : CPE ratio decreased the water productivity (Table 2). The highest water productivity was recorded with 0.8 IW : CPE ratio while lowest was recorded with 1.2 IW: CPE ratio. The mean per cent increase in water productivity under 0.8 IW : CPE ratio, was 6.28 and 0.62 over 1.0 and 1.2 IW : CPE ratio, respectively. Similar findings were also reported by Kibe and Singh (2003) and Sonawane *et al.* (2010).

Fertility levels of 125% RDF resulted in the highest water productivity on pooled results basis, while the lowest value of water productivity was noticed in 100% RDF. Successive increase in fertility levels realized significant increase in water-use efficiency throughout the study. In case of hydrogel application, each unit increase in hydro-

Table 2. Effect of irrigation, fertility and hydrogel levels on yield, economics, consumptive use of water and water productivity of pearl millet (pooled mean of 2 years)

Treatment	Grain yield (t/ha)	Stover yield (t/ha)	Harvest index	Net return (₹/ha)	Benefit: cost ratio	Consumptive use of water (mm)	Water productivity (kg/m³)
Irrigation levels							
I_1, 0.8 IW : CPE	3.52	5.81	38.00	47,691	1.26	454	8.12
I_2, 1.0 IW : CPE	4.21	7.15	36.86	63,132	1.58	541	8.07
I_3, 1.2 IW : CPE	4.51	8.11	35.71	70,571	1.67	611	7.64
SEm±	0.07	0.06	0.658	-	-	-	-
CD (P=0.05)	0.32	0.98	NS	-	-	-	-
Fertility levels							
F_1, 100% RDF	3.79	6.62	36.38	54,364	1.38	532	7.40
F_2, 125% RDF	4.37	7.42	37.33	66,564	1.64	539	8.43
SEm±	0.06	0.13	0.537	-	-	-	-
CD (P=0.05)	0.18	0.37	NS	-	-	-	-
Hydrogel levels (kg/ha)							
H_0, No hydrogel	3.68	6.57	36.01	55,085	1.50	506	7.61
H_1, 2.5 hydrogel	4.07	7.02	37.00	60,298	1.51	541	7.83
H_2, 5.0 hydrogel	4.48	7.48	37.56	66,011	1.53	559	8.29
SEm±	0.07	0.11	0.589	-	-	-	-
CD (P=0.05)	0.19	0.31	NS	-	-	-	-
CV%	10.09	9.51	9.59	-	-	-	-

IW : CPE, Irrigation water : cumulative pan evaporation; RDF, recommended dose of fertilizer

gel application from 0 to 5 kg/ha recorded increased in water productivity in both the years. The highest water productivity was recorded with hydrogel application of 5 kg/ha, while lowest with no hydrogel application. Our finding confirm the results obtained by Dabhi *et al.* (2013) and Waly *et al.* (2015).

Economics

The results pertaining to the benefit: cost analysis of the crop as influenced by irrigation levels indicated that application of irrigation at an IW: CPE of 1.2 resulted in the highest net returns (₹70,571/ha), with the maximum benefit: cost ratio of 1.67, whereas irrigating at an IW : CPE of 1.0 recorded the at par value of benefit: cost ratio (Table 2). The higher net returns/ha under 1.2 IW: CPE could be attributed to significantly higher seed and stover yield under this treatment as compared to other levels of irrigation. The fertility level of 125% RDF resulted in produced significantly highest net returns of ₹66,564/ha, with the highest benefit: cost ratio of 1.64. The higher net gain/ha under 125% RDF could be attributed to significantly higher yields as compared to 100% RDF. The highest net return (₹66,011/ha) was recorded in the treatment H_2 (5.0 kg hydrogel/ha), while different levels of hydrogel failed to exert any significant effect on benefit: cost ratio.

Soil physico-chemical status at the end of experiment

Data on physico-chemical status of the soil in terms of organic carbon (OC), available N, P, K, EC, *p*H and porosity are given in (Table 3). Significant improvement in fertility status of experimental soil was recorded in terms of organic carbon (OC), available nitrogen and phosphorus with increased level of irrigation, fertility and hydrogel. In contrary, availability of potassium was found statistically similar at each level of irrigation, fertility and hydrogel during both the years of investigation. Higher levels of inputs, i.e. application of irrigation at an IW : CPE ratio of 1.2, fertilization @ 125% RDF and mixing of hydrogel in soil @ 5.0 kg/ha proved the best by recording significantly higher organic carbon on pooled basis as compared to their lower levels. The organic carbon after harvesting of the crop was observed under higher input (irrigation, fertility and hydrogel) levels, as these inputs resulted in higher vegetative growth of crop plants that implies that profuse root-system has developed and thereby after harvesting of crop more amount of root debris remained in the soil which converted in carbon source reflected in terms of higher organic carbon in soil.

The irrigation level at 1.2 IW: CPE proved its superiority by recording significantly higher available nitrogen and phosphorus (Table 3). These values were followed by that recorded with 1.0 IW: CPE. The application of 125% RDF was found significantly superior by recording the highest available nitrogen and phosphorus at the end of the season during both years as well as in pooled data. The 100%

Table 3. Influence of irrigation, fertility and hydrogel levels on soil physico-chemical status at the end of experiment (pooled mean of 2 years)

Treatments	Organic carbon (%)	Available N (kg/ha)	Available P_2O_5 (kg/ha)	Available K_2O (kg/ha)	Electrical conductivity (dS/m)	*p*H	Porosity (%)
Irrigation levels							
I_1, 0.8 IW : CPE	0.26	168	43.9	276	0.11	7.1	43.7
I_2, 1.0 IW : CPE	0.29	175	48.7	277	0.11	7.1	43.6
I_3, 1.2 IW : CPE	0.32	190	50.8	280	0.11	7.1	43.0
SEm±	0.002	1.22	0.31	1.79	0.003	0.10	0.66
CD (P=0.05)	0.006	3.5	0.9	NS	NS	NS	NS
Fertility levels							
F_1, 100% RDF	0.22	172	45.8	277	0.11	7.1	43.5
F_2, 125% RDF	0.35	184	49.7	278	0.11	7.1	43.4
SEm±	0.002	1.00	0.25	1.46	0.002	0.08	0.54
CD (P=0.05)	0.005	2.9	0.7	NS	NS	NS	NS
Hydrogel levels (kg/ha)							
H_0, No hydrogel	0.24	173	46.6	276	0.11	7.1	43.6
H_1, 2.5 hydrogel	0.28	177	47.6	278	0.11	7.1	43.4
H_2, 5.0 hydrogel	0.34	184	49.1	280	0.11	7.1	43.4
SEm±	0.001	0.91	0.21	1.33	0.002	0.05	0.40
CD (P=0.05)	0.004	2.6	0.6	NS	NS	NS	NS
CV%	3.06	3.08	2.69	2.87	10.97	4.53	8.08
Initial status	0.25	168	39.5	270	0.12	7.4	46.0

IW : CPE, Irrigation water : cumulative pan evaporation; RDF, recommended dose of fertilizer

RDF resulted in 6.70 and 8.62% lower availability of nitrogen and phosphorus in comparison to 125% RDF. Increasing levels of NPK fertilization significantly increased the available N, P and K and organic carbon content in the soil. Incorporation of hydrogel @ 5.0 kg/ha resulted in significantly highest available nitrogen and phosphorus over its lower levels (without hydrogel application and hydrogel application @ 2.5 kg/ha) in pooled data. Similarly, Islam *et al.* (2011) also obtained higher available N, P_2O_5 and K_2O in soil with higher level of hydrogel. Different levels of irrigation, fertility and hydrogel did not exert any significant effect on electrical conductivity, *p*H and porosity of experimental soil during both the years as well as when pooled.

Thus, summer pearl millet sown in loamy sand soils of Gujarat region with 1.2 IW: CPE recorded the higher seed yield and gained the highest net returns and benefit: cost ratio over all the irrigation treatments. Fertility level of 125% RDF and hydrogel level 5.0 kg/ha seems to be optimum for getting higher seed yield and monetary returns. Therefore, irrigation at 1.2 IW: CPE along with application of 125% RDF and 5.0 kg/ha hydrogel could be applied for higher yield and economical realization from summer pearl millet along with improved nutrient status of soil.

Regression of growth traits, yield components and nutrient uptake on grain yield of pearl millet

All the independent variables showed a significant positive and linear relationship with grain yield (Table 4) indicating an increment in grain yield of pearl millet with the increase in given growth trait, yield component and NPK uptake. However, the magnitude of this reinforcement varied with the independent variable, viz. growth trait, yield component, nutrient uptake values and their units. The explained total variation as indicated by coefficient of determination (R^2) in grain yield by various growth traits (plant height, tiller production, dry-matter production and crop-growth, yield components (effective ears/m, ear length, girth of ear, grain weight/ear and test weight) and nutrient uptake (NPK uptake) chosen as independent variables individually ranged from 52.11 to 84.70%, 38.80 to 79.80% and 85.50 to 93.80%. The variance ratio for testing R^2 was highly significant (P=0.01) in all the relations. This indicates that the grain yield of pearl millet can be adequately predicted using the tested independent variables viz., growth traits, yield components and nutrient uptake.

CONCLUSION

Surface check basin irrigation at 1.0 irrigation water: cumulative panb evaporation (IW : CPE), 125% recommended dose of fertilizer and hydrogel application @ 5 kg/ha found superior in terms of yield components, grain and straw yield over 0.8 IW : CPE, but remained at par with 1.2 IW : CPE irrigation treatments in loamy sand soils of North Gujarat Agro-climatic conditions. The highest water productivity was recorded with 0.8 IW : CPE ratio, 125% RDF and 5 kg/ha hydrogel application. The results of study provide the useful information to farmers make irrigation and fertilizer decision along with hydrogel application for profit maximization and resource conservation.

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Table 4. Empirical estimates for the regression of growth traits, yield components and nutrient uptake on grain yield of pearl millet (pooled basis)

Relationship	Regression constant, coefficients and test statistics				
	a	b	SEb	R^2	F value for testing R^2
Yield-plant height (cm)	56.038	0.0287	0.0042	0.735	44.50
Yield-number of tillers/plant	1.275	0.0002	0.2493	0.521	17.38
Yield-dry matter/plant (g)	23.243	0.0128	0.0013	0.847	88.95
Yield-CGR (g/m^2/day)	14.397	0.0036	0.0005	0.736	44.65
Yield-number of effective ears/m	7.449	0.0018	0.0004	0.476	14.58
Yield-ear length (cm)	7.215	0.0037	0.0005	0.739	45.34
Yield-girt of ear	2.554	0.0020	0.0003	0.650	29.75
Yield-grain weight/ear (g)	7.226	0.0012	0.0001	0.798	63.47
Yield-test weight (g)	9.398	0.0007	0.0002	0.388	10.16
Yield-N uptake (kg/ha)	–36.859	0.0380	0.0024	0.938	243.66
Yield-P uptake (kg/ha)	–21.855	0.0143	0.0012	0.892	133.26
Yield-K uptake (kg/ha)	–49.958	0.048	0.0049	0.855	94.41

CGR, Crop-growth rate

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