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Research Paper

# Influence of irrigation schedule and nutrient-management practice on dry matter accumulation and grain yield of quality protein maize (*Zea mays*) in new alluvial zone of West Bengal

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## ABSTRACT

A 2-year field experiment was conducted during the winter (*rabi*) season of 2017–18 and 2018–19 at Kalyani Nadia, West Bengal, to study the response of 'HQPM1' quality protein maize (*Zea mays* L.) to irrigation schedule and nutrient-management practice. Three irrigation schedules, viz. irrigation water: cumulative pan evaporation or (IW : CPE) of 0.5 ($I_1$), 0.75 ($I_2$) and 1.0 ($I_3$) constituted main plots and 4 nutrient management practices, viz. control ($N_1$), 100% recommended dose of fertilizer (120 kg N, 60 kg $P_2O_5$ and 60 kg $K_2O$/ha) ($N_2$), 75% RDF+ 2 t/ha vermicompost ($N_3$) and 75% RDF + 2 t/ha vermicompost + 25 kg/ha $ZnSO_4$ ($N_4$), subplots a split plot design with 3 replications. The results revealed that interaction of an IW : CPE 1.0 and 75% RDF + 2 t/ha vermicompost + 25 kg/ha $ZnSO_4$ ($I_3N_4$) excelled the other treatment combinations in terms of total dry-matter accumulation (1,509.8 g/m$^2$), grain yield (6.76 t/ha), net returns (76,886 ₹/ha) and B : C ratio (2.50). The interaction effect of irrigation regimes and nutrient-management practices on stress degree-days and number of stress-days was insignificant. Both stress degree-days (SDD) and numbers of stress days were significantly and negatively correlated to dry-matter accumulation and grain yield and they showed a polynomial relationship with SDD. Therefore, an interaction of IW : CPE 1.0 and 75% RDF + 2 t/ha vermicompost + 25 kg/ha $ZnSO_4$ ($I_3N_4$) can be recommended to the farmers for recording less moisture stress condition and improving dry-matter accumulation, grain yield and benefit: cost ratio of quality protein maize in new alluvial zone of West Bengal.

***Key words*** : Dry matter accumulation, Grain yield, Irrigation, Nutrient, Quality protein maize, Stress degree days

Maize is emerging as an important cereal crop in the world agricultural economy as food, feed and industrial raw material after wheat and rice. This crop provides nutrients for humans and animals, serves as basic raw materials for production of starch, oil, alcoholic beverages, and more recently fuel. In spite of several important uses, maize has an in-built drawback of being deficient in 2 essential amino acids, namely lysine and tryptophan, that lead to poor protein utilization and low biological value of traditional maize genotypes. To overcome this problem and to minimize the prevalence and persistence of malnutrition in developing countries, breeders have modified maize to produce a vitreous endosperm resembling that of conventional maize at the Purdue University, USA, in 1963 and named as quality protein maize (QPM) by incorporating *opaque-2* mutant gene, which is particularly responsible for enhancing lysine and tryptophan content of maize endosperm.

It is clear that future increase in food production requires keeping pace with the burgeoning world population that must be achieved without depleting our natural resource base of soil, water and air. Probably the greatest issue in maintaining sustainable agricultural production over the next few decades will be the availability of water. Irrigated QPM grown in *rabi* season requires ample volume of irrigation water, and availability of water is a limiting factor particularly in water scarce regions. Therefore, quantifying the crop response to irrigation schedules is an important invention for proper utilization of water resources and higher water use efficiency. Undoubtedly, being heavy feeder of nutrients and high productivity potential, maize crop also requires continuous and assured nutrient supply

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throughout the growing period from germination to grain-filling stage. Thus, proper nutrient management for QPM hybrid is important to realize higher yields.

The winter season in the Indo-Gangetic Plains (IGP) of West Bengal is short, spanning from November to February, the January being the coolest month. Temperature change invites a great attention (Das and Lohar, 2005; Sivakumar, 2006) with a greater look on changes in the agricultural productivity. Changes in maximum and minimum temperatures in the IGP of Eastern India reduce the duration of different phenophases and adversely affect the growth processes in maize. A change in temperature invites the change in canopy temperature, which affects the growth and productivity of the crop. It is well known that the variation in crop productivity is not based only on a single weather parameter change, but it is based on the collaborative effect of all different meteorological variables (Kingra, 2016). The canopy temperature measurement is necessary to understand the plant water status at a particular phenophase of a crop. Idso *et al*. (1977) first worked out the stress degree-day (SDD) by subtracting the mid-day air temperature from mid-day canopy temperature. Both the canopy temperature and SDD negatively affect the dry matter production and yield (Chakravarti *et al*., 2010) and may be used for identification of soil moisture stress as well as crop water status. Among the different phenophases of a crop, some are highly sensitive and some are less sensitive to moisture stress. Identification of highly moisture sensitive phenophase has an important effect on crop productivity. A few reports are available in some crops (Chakravarti *et al*., 2010). However, no systematic study has been carried out on quality protein maize, which is one of the most important cereal crops in Eastern India. Hence to address this lacuna, a comprehensive field experiment was conducted to determine the integrated effect of different irrigation schedule and nutrient management practices on dry matter accumulation, yield, profitability and yield response of QPM to water stress and evapotranspiration.

## MATERIALS AND METHODS

The field trial was carried out on quality protein maize (cv. 'HQPM 1') during the *rabi* seasons (November–March) of 2017–18 and 2018–19 at District Seed Farm, Bidhan Chandra Krishi Viswavidyalaya, Kalyani, Nadia, encompassing the new alluvial zone of West Bengal, India. The experiment was laid out in a split-plot design with 3 irrigation treatments in main plots, viz. irrigation water: cumulative pan evaporation (IW : CPE) 0.5 ($I_1$), IW : CPE 0.75 ($I_2$) and IW : CPE 1.0 ($I_3$), and 4 nutrient management treatments in subplots, viz. control ($N_1$) 100% recommended dose of fertilizer (RDF) (120 kg N, 60 kg $P_2O_5$ and 60 kg $K_2O$/ha) ($N_2$), 75% RDF + 2 t/ha vermicompost ($N_3$) and 75% RDF + 2 t/ha vermicompost + 25 kg/ha $ZnSO_4$ ($N_4$), replicated thrice. Irrigation scheduling based on IW : CPE ratio was given when cumulative pan evaporation (CPE) from an USWB class A open pan evaporimeter reached to a particular value. The depth of each irrigation was fixed at 5 cm with the help of a 'V' notch and the ridge and furrow method of irrigation was followed. Irrigations at IW/CPE 0.5, 0.75 and 1.0 were given when CPE reached 100, 67 and 50 mm, respectively, if no rain occurred between 2 irrigations. Fertilizer doses were calculated as per treatment and applied to each plot using urea, single superphosphate (SSP) and muriate of potash (MoP). Entire dose of phosphorus and potassium and 50% recommended dose of nitrogen were applied basal and remaining 25% N at knee-high stage (30-35 days after sowing) and 25% N at tasseling. Other nutrient sources, namely, $ZnSO_4$ @ 25 kg/ha and vermicompost @ 2 t/ha were given at the time of land preparation. Seed rate for QPM was 20 kg/ha to ensure desired plant population. A row-to-row spacing was maintained at 45 cm and plant-to-plant spacing was adjusted to 20 cm.

Five random plants were taken from each plot at 30, 60, 90 days after sowing (DAS) and at harvesting and the accumulated dry matter was recorded in g/m$^2$. At maturity cobs were harvested from 5 random and tagged plants from each plot and then grain weight (in kg) was recorded per net plot and finally expressed in t/ha. Canopy temperature was measured during mid-day (13:35 hours) for each treatment on weekly basis from 8$^{th}$ DAS onwards with the help of infrared thermometer (Model No.T-4, METRAV) held at 1 m away from the canopy top from four sides at 60$^o$ angle with the horizontal plane.

### *Stress degree-days (SDD)*

A means for evaluating water status by remote measurement could open the way to improved yield predictions and, in irrigated areas, to improved scheduling times. The difference between the temperature of a plant canopy and the temperature of the surrounding air ($T_c - T_a$) may be an indicator of the water status of a crop because water stress causes partial stomatal closure, thus reducing transpiration and allowing sunlight leaves to warm above ambient air temperature. Idso *et al*. (1977) originally developed stress degree day concept and defined as:

$$SDD = \sum_{i=1}^{n} (T_c - T_a)$$

Where $T_c$ is the canopy temperature and $T_a$ is the air temperature in °C. In general, if a plant has adequate water, ($T_c - T_a$) will be near zero or negative; if it is water stressed, ($T_c - T_a$) will be greater than zero. Thus, the sum of the positive values of ($T_c - T_a$) may serve as an index of when to irrigate. The SDD values were measured for crop growth stages of each and every treatment and then average was made to note down the mean SDD value corresponding to the crop growth stage. Finally, from those average SDD values, mean SDD value throughout the total crop growing season was calculated for each treatment.

### *Number of stress days*

From the positive canopy air temperature difference values, number of stress days was noted treatment wise. Number of stress days was counted at different crop-growth stages of each treatment and then summed up to calculate the total number of stress days in each treatment throughout the total crop growing season for each study year.

### *Economics*

The prices of inputs in rupees that were prevailing at the time of their use were taken into account to work out the cost of cultivation (₹/ha). The gross return was calculated by considering the prices of QPM grain and stover prevailed during the harvest of the crop. The net returns (₹/ha) were calculated by deducting the cost of cultivation from gross return. The benefit: cost ratio was calculated dividing the gross returns by cost of cultivation.

Data obtained on various variables were analyzed by analysis of variance (ANOVA) method (Panse and Sukhatme, 1967).

## RESULTS AND DISCUSSION

### *Dry matter accumulation*

The pooled data of 2 years exhibited that the total dry-matter accumulation varied significantly with irrigation regimes across the stages of observations, except the initial stage of the crop (up to 30 DAS). The pooled results showed that, the maximum dry matter accumulation was registered under $I_3$ treatment, followed by $I_2$ and the lowest accumulation were observed in case of $I_1$ at 60 DAS, 90 DAS and at harvesting (Table 1). The periodical increase in growth attribute like dry matter accumulation with increasing levels of irrigation was owing to the beneficial effect of water on plant growth. Actually during early stage, no irrigation was applied and the crop growth was supported only by the residual soil moisture. The greater accumulation of aerial dry matter under higher number of irrigations could be explained by the fact that adequate moisture supply in root zone might have reduced the stomatal inhibition and facilitated the photosynthesis rate, which contributed to more translocation as well as accumulation of photosynthates in plants. The higher rate of photosynthesis was also associated with higher leaf-area index (LAI), leaf chlorophyll content and more interception of solar radiation under optimum level of irrigation. In fact, the irrigation water acted as a medium for dissolving nutrients in soil and enhanced the uptake of nutrients. Therefore, the higher uptake of nutrients, particularly of N and Zn under sufficient moisture availability (IW : CPE 1.0) might be associated with better synthesis of chlorophyll and greater assimilation of photosynthates. In moisture-stressed plants resulting from limited water supply, the photosynthetic rate might be decreased by the reduced diffusion of $CO_2$ to the chloroplast and due to metabolic constrains, hence, increased the respiration rate (Pinheiro and Chaves, 2010). As a consequence, the dry-matter accumulation was affected greatly which led to reduction in the rate of cell division and cell enlargement.

Besides, the pooled results showed that the maximum increase in total dry matter at different stages was under the treatment $N_4$ (75% RDF + 2 t/ha vermicompost + 25 kg/ha $ZnSO_4$). This $N_4$ treatment was followed by $N_3$ (75% RDF + 2 t/ha vermicompost). The minimum accumulation was observed under treatment $N_1$ (Control) at 60, 90 DAS and at harvesting respectively. The integrated treatment excelled others due to the synergetic effects of inorganic nutrients (primary and micro elements) applied with vermicompost, as the nutrients from fertilizers helped in the promotion of growth during the early stages while organic sources of nutrients improved crop growth during later stages. The favourable effect of vermicompost on growth parameters might be attributed to the presence of relatively readily available plant nutrients, growth enhancing substances and number of beneficial organisms like nitrogen fixing, phosphate solubilizing, cellulose decomposing and other microbes as well as antibiotics, vitamins and hormones etc. (Nehra *et al*., 2001). Increase in availability of nutrients to the plants for a longer period owing to slow release of nutrients from vermicompost as well as higher uptake of nutrients under integrated nutrient management practices might have favoured the all round cell growth and cell division within plants. The application of vermicompost in conjugation with chemical fertilizers produced significantly higher dry matter than chemical fertilizers (100% RDF) owing to the fact that the addition of vermicompost created favourable growing conditions by increasing soil porosity, water holding capacity and aeration, and enhanced the uptake of nutrients and nutrient use efficiencies along with the adequate supply of nutrients for longer period, which resulted in increased photosynthetic assimilates in plants that finally pushed for increasing dry-matter accumulation. Moreover, the additive effect of Zn on the biosynthesis of carotenoids and chlorophyll ultimately helped the photosynthetic mechanism and production of assimilates (Aravind and Prasad, 2003). As maize is a nutrient exhaustive crop, the poor increase in dry-matter production was observed in control plots due to nutrient-starved situations. However, this growth parameter of QPM was relatively less favoured by the full recommended dose of chemical fertilizer (100% RDF) than integrated nutrient sources and it might be owing to higher solubility of inorganic fertilizers that led to more losses of nutrients through leaching, volatilization, fixation and other mechanisms, and hence, failed to avail the essential nutrients in required quantity synchronizing with crop demands.

The data pertaining to total aerial dry matter accumulation at various stages of crop growth were influenced significantly by the interaction of irrigation regimes and nutrient management, except at 30 DAS. The pooled results indicated that the maximum aerial dry-matter accumulation was noticed in case of $I_3N_4$ at 60 DAS, 90 DAS and at harvesting, followed by $I_3N_3$ which was significantly superior to all other treatment combinations whereas the minimum values were recorded in $I_1N_1$ (irrigation at IW : CPE of 0.5 with the control). Significantly higher dry-matter accumulation obtained in the combination of IW : CPE 1.0 and 75% RDF + 2 t/ha vermicompost + 25 kg/ha $ZnSO_4$ might be ascribed to the increased uptake of nutrients under adequate availability of moisture in root zone that eventually accelerated the assimilation and partitioning of photosynthates towards linear growth leading to greater improvement of plant vigour. Balanced nutrition and optimum moisture status during growth period of the crop might favour the rapid cell division and elongation of meristematic plant tissues. Additionally, the correction of zinc deficiency by soil application of $ZnSO_4$ might have improved the chlorophyll formation and efficiency of photosynthesis process, resulting in higher accumulation of dry matter and

**Table 1.** Effect of irrigation and nutrient management on dry matter accumulation and grain yield of quality protein maize (HQPM1) in winter season (pooled data of 2 years)

| Treatment | Dry-matter accumulation (g/m$^2$) | | | | Grain yield (t/ha) |
|---|---|---|---|---|---|
| | 30 DAS | 60 DAS | 90 DAS | At harvesting | |
| *Irrigation (I)* | | | | | |
| $I_1$ (IW : CPE 0.5) | 51.6 | 301.3 | 633.4 | 781.4 | 3.74 |
| $I_2$ (IW : CPE 0.75) | 52.1 | 352.9 | 772.0 | 1002.3 | 4.60 |
| $I_3$ (IW : CPE 1.0) | 54.1 | 394.2 | 918.7 | 1200.2 | 5.33 |
| SEm± | 2.1 | 4.8 | 9.0 | 15.8 | 0.06 |
| CD (P=0.05) | NS | 15.5 | 29.3 | 51.6 | 0.19 |
| *Nutrient management (N)* | | | | | |
| $N_1$ (Control) | 46.1 | 269.7 | 571.8 | 714.7 | 2.74 |
| $N_2$ (100% RDF) | 51.6 | 335.3 | 733.9 | 946.6 | 4.44 |
| $N_3$ (75% RDF + 2 t/ha vermicompost) | 56.8 | 380.1 | 852.0 | 1092.4 | 5.29 |
| $N_4$ (75% RDF + 2 t/ha vermicompost + 25 kg/ha $ZnSO_4$) | 55.8 | 412.8 | 941.1 | 1224.7 | 5.76 |
| SEm± | 1.8 | 3.9 | 8.7 | 12.8 | 0.04 |
| CD (P=0.05) | 5.1 | 11.2 | 24.6 | 36.6 | 0.12 |
| *Interaction (Irrigation × nutrient management)* | | | | | |
| $I_1N_1$ | 46.2 | 234.7 | 475.6 | 581.8 | 2.22 |
| $I_1N_2$ | 47.7 | 292.8 | 585.5 | 722.5 | 3.64 |
| $I_1N_3$ | 53.0 | 323.5 | 716.3 | 871.3 | 4.36 |
| $I_1N_4$ | 59.5 | 354.3 | 756.3 | 949.8 | 4.77 |
| $I_2N_1$ | 46.9 | 267.7 | 580.3 | 733.4 | 2.82 |
| $I_2N_2$ | 52.4 | 350.2 | 741.2 | 977.2 | 4.48 |
| $I_2N_3$ | 59.0 | 390.0 | 831.9 | 1083.9 | 5.34 |
| $I_2N_4$ | 50.0 | 403.9 | 934.4 | 1214.5 | 5.75 |
| $I_3N_1$ | 45.1 | 306.7 | 659.4 | 828.9 | 3.19 |
| $I_3N_2$ | 54.8 | 363.0 | 875.0 | 1140.0 | 5.21 |
| $I_3N_3$ | 58.5 | 427.0 | 1007.9 | 1321.9 | 6.16 |
| $I_3N_4$ | 57.9 | 480.3 | 1132.7 | 1509.8 | 6.76 |
| | I × N  N × I | I × N N × I | I × N  N × I | I × N  N × I | I × N  N × I |
| SEm± | 3.1 | 6.7 | 15.0 | 22.1 | 0.07 |
| | 3.4 | 7.5 | 15.8 | 24.8 | 0.09 |
| CD (P=0.05) | NS | 19.3 | 43.0 | 63.3 | 0.21 |
| | NS | 22.8 | 47.3 | 75.1 | 0.27 |

IW : CPE, Irrigation water: cumulative pan evaporation; RDF, Recommended dose of fertilizer; 120 kg N, 60 kg $P_2O_5$ and 60 kg $K_2O$/ha; DAS, days after sowing; NS, non-significant faster crop-growth rate per unit time per unit ground area. However, the minimum dry-matter observed under IW : CPE 0.5 coupled with control condition was due to the abiotic stresses (water and nutrient) imposed to plants by limited irrigation and unfertilization. The effect of prolonged moisture stress along with nutrient deficiencies inhibited growth by closure of leaf stomata and restricting sink-source nutrient supplementation and finally reduction in dry-matter production (Meena *et al.,* 2017).

### *Grain yield*

The grain yield of QPM plants recorded under different irrigation regimes and nutrient levels varied significantly in case of pooled data. The pooled analysis stated that $I_3$ (IW : CPE 1.0) treatment resulted in the highest grain yield of 5.33 t/ha which was followed by $I_2$ (IW : CPE 0.75) (4.60 t/ha) and the lowest grain yield (3.74 t/ha) in $I_1$ (IW : CPE 0.5) treatment. As the yield components largely depend on total dry-matter production, the substantial increase in yield components under adequate supply of water could be ascribed to greater cell turgidity, better opening of stomata and higher rate of photosynthesis, and finally increase in partitioning of photosynthates to reproductive structure (Pandey *et al*., 2000). However, the QPM plants grown under limited irrigation (IW : CPE 0.5) exhibited lower yield attributes over the years due to poor grain setting as well as improper grain filling caused by the water starved condition in plants. It was reported that the moisture stress in crops caused a decrease in translocation of carbohydrates and growth substances, disturbance in nutrients uptake and metabolism, forced loss of turgour and consequently, the reduction in sink size. Significant increase in grain yield under IW : CPE 1.0 over other irrigation regimes was owing to the marked improvement in yield attributes. This treatment resulted in 5.33 t/ha grain yield which was nearly 14 and 30% higher than that obtained from IW : CPE 0.75 and IW : CPE 0.5 respectively.

The pooled results showed that the maximum increase in grain yield was under the treatment $N_4$ (75% RDF + 2 t/ha vermicompost + 25 kg/ha $ZnSO_4$) (5.76 t/ha) which showed significant variation from all other treatments. This $N_4$ treatment was followed by $N_3$ (75% RDF + 2 t/ha vermicompost) and $N_2$ (100% RDF), where the grain yields of 5.29 t/ha and 4.44 t/ha, respectively, were observed, but the lowest value of 2.74 t/ha was observed under the treatment $N_1$ (control). It was found that the application of 75% RDF + 2 t/ha vermicompost + 25 kg/ha $ZnSO_4$ resulted in significantly higher yield because it could provide the necessary nutrients from initial stage, and increased the supply and uptake of N, P, K and Zn in a more synchronized way through integration of organic manure and inorganic fertilizers, which seemed to have resulted in increased yield attributes by virtue of increased photosynthetic efficiency, greater availability of photosynthates and efficient partitioning of metabolites to develop reproductive organs. It was also reported that, the application of organic manure with optimal level of fertilizers increased the yield which might be associated with better amelioration of soil, and adequate supply and absorption of nutrients (Kannan *et al*., 2013). Moreover, the positive effects of Zn application on yield attributing characters of maize such as higher number of grains/cob and more grain weight might be because of the involvement of zinc in stimulating various enzymatic and metabolic processes which helped to catalyze the reactions for dry matter production and finally led to more source translocation towards sink and consequently, better yield. Nonetheless, the QPM plants grown in the control conditions, i.e. without addition of any fertilizers/ organic manure exhibited a drastic reduction in yield attributes over the years. The insufficient supply of essential plant nutrient elements only from inherent soil source was unable to meet the nutrient requirements of this exhaustive crop that finally resulted in poor development of yield attributes. The application of 75% RDF + 2 t/ha vermicompost + 25 kg/ha $ZnSO_4$ recorded significantly the highest grain yield of 5.76 t/ha, which was approximately 9, 23 and 52% higher than 75% RDF + 2 t/ha vermicompost, 100% RDF and control treatments respectively.

The pooled results revealed that, the maximum grain yield was registered in the plots treated with irrigation at IW : CPE 1.0 and 75% RDF + 2 t/ha vermicompost + 25 kg/ha $ZnSO_4$ (6.76 t/ha), followed by irrigation at IW : CPE 1.0 and 75% RDF + 2 t/ha vermicompost, while the minimum was recorded in treatment $I_1N_1$ (irrigation at IW : CPE 0.5 with control). The synergistic effect of this combined treatment could be attributed to the better proportions of NPK and Zn, required for the promotion of meristematic and physiological activities such as plant height, leaf spread, root development, dry matter production etc. that led to an efficient absorption and translocation of water and nutrients, interception of solar radiation and assimilation of carbon dioxide. These activities promoted higher photosynthesis leading to the production of enough assimilate for subsequent translocation to various sinks and hence resulted in the production of higher yield and yield components of maize.

### *Stress degree days and number of stress days*

The pooled analysis of stress degree days (SDD) values presented in Table 2 clearly depicted that, the more negative value of SDD and lesser number of stress days were recorded in the treatment $I_3$ (IW : CPE 1.0) in early vegetative; grand growth; tasseling, silking, milking and dough; dent and maturity stage as well as during total crop duration. Besides, the higher positive value of SDD along with the maximum number of stress days were registered in the treatment $I_2$ (IW : CPE 0.75) in early vegetative stage and in $I_1$ (IW : CPE 0.5) during grand growth; tasseling, silking, milking and dough stage; dent and maturity stage as well as in case of total duration. The positive values of SDD indicated the soil moisture stress during different phenophases. The cumulative values of SDD based on the differences of canopy and ambient air temperatures during the crop-growth period clearly indicated that the plants irrigated with IW : CPE 0.5 were exposed to longer stress period. However, the shortest period of stress during the crop duration was experienced with IW : CPE 1.0 owing to higher number of irrigations. The low canopy temperature and the negative values of SDD were conducive for cellular photosynthesis as well as dry matter production and crop yield (Chakravarti *et al.,* 2010). Moreover, the more exposure to stresses during the critical stages of crop water requirement (active vegetative and flowering stages) reduced the growth and yield of QPM under IW : CPE 0.5 treatment. This

**Table 2.** Effect of irrigation and nutrient management on stress degree days (SDD) and number of stress days of quality protein maize (HQPM 1) in winter season (pooled data of 2 years)

| Treatment | Early vegetative stage (15–30 DAS) | | Grand growth stage (31–60 DAS) | | Tasseling, silking, milking and dough (61–90 DAS) | | Dent and maturity (91-125 DAS) | | Total duration (110 days) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | SDD | No. of stress days | SDD | No. of stress days | SDD | No. of stress days | SDD | No. of stress days | SDD | No. of stress days |
| *Irrigation (I)* | | | | | | | | | | |
| $I_1$ (IW : CPE 0.5) | –1.41 | 7 | 1.71 | 21 | 2.75 | 20 | 2.39 | 23 | 5.43 | 70 |
| $I_2$ (IW : CPE 0.75) | 0.23 | 7 | –1.85 | 14 | 1.54 | 16 | 0.12 | 18 | 0.04 | 54 |
| $I_3$ (IW : CPE 1.0) | –1.78 | 6 | –3.11 | 10 | –2.02 | 11 | –1.61 | 15 | –8.51 | 41 |
| SEm± | 0.39 | 0.32 | 0.75 | 0.53 | 0.57 | 0.46 | 0.41 | 0.39 | 1.26 | 1.10 |
| CD (P=0.05) | 1.28 | NS | 2.46 | 1.72 | 1.85 | 1.51 | 1.35 | 1.26 | 4.11 | 3.58 |
| *Nutrient management (N)* | | | | | | | | | | |
| $N_1$ (Control) | –0.51 | 7 | -1.17 | 15 | 0.89 | 15 | 0.26 | 17 | –0.54 | 54 |
| $N_2$ (100% RDF) | –2.36 | 7 | 0.51 | 15 | 1.43 | 16 | 0.89 | 19 | 0.47 | 55 |
| $N_3$ (75% RDF+ 2 t/ha vermicompost) | –0.74 | 7 | -2.01 | 15 | 0.55 | 15 | –0.96 | 18 | –3.15 | 54 |
| $N_4$ (75% RDF + 2 t/ha vermicompost + 25 kg/ha $ZnSO_4$) | –0.34 | 6 | -1.67 | 14 | 0.17 | 15 | 1.01 | 18 | -0.84 | 53 |
| SEm± | 0.56 | 0.35 | 0.80 | 0.37 | 0.65 | 0.41 | 0.72 | 0.48 | 1.18 | 0.82 |
| CD (P=0.05) | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS |
| *Interaction (Irrigation × Nutrient management)* | | | | | | | | | | |
| $I_1N_1$ | –1.31 | 7 | 4.49 | 22 | 2.93 | 19 | 3.30 | 22 | 9.41 | 69 |
| $I_1N_2$ | –1.74 | 6 | 5.62 | 21 | 3.25 | 20 | 2.67 | 23 | 9.80 | 70 |
| $I_1N_3$ | –1.00 | 7 | –2.46 | 21 | 4.12 | 18 | 1.14 | 23 | 1.80 | 68 |
| $I_1N_4$ | –1.62 | 6 | –0.82 | 20 | 0.68 | 20 | 2.44 | 22 | 0.68 | 67 |
| $I_2N_1$ | 1.20 | 8 | –2.82 | 14 | 3.05 | 16 | –0.22 | 17 | 1.22 | 54 |
| $I_2N_2$ | –2.35 | 7 | –2.15 | 13 | 1.32 | 15 | 1.37 | 19 | –1.82 | 54 |
| $I_2N_3$ | 0.28 | 7 | –1.42 | 13 | 0.85 | 16 | –1.77 | 17 | –2.06 | 53 |
| $I_2N_4$ | 1.81 | 6 | –1.00 | 13 | 0.95 | 16 | 1.09 | 17 | 2.85 | 51 |
| $I_3N_1$ | –1.42 | 5 | –5.17 | 9 | –3.34 | 11 | –2.30 | 14 | –12.22 | 39 |
| $I_3N_2$ | –2.99 | 6 | –1.94 | 9 | –0.29 | 12 | –1.37 | 14 | –6.58 | 41 |
| $I_3N_3$ | –1.48 | 7 | –2.15 | 10 | –3.32 | 11 | –2.25 | 16 | –9.19 | 43 |
| $I_3N_4$ | –1.21 | 6 | –3.20 | 10 | –1.13 | 11 | –0.50 | 14 | –6.04 | 40 |
| | I × N | I × N | I × N | I × N | I × N | I × N | I × N | I × N | I × N | I × N |
| | N × I | N × I | N × I | N × I | N × I | N × I | N × I | N × I | N × I | N × I |
| SEm± | 0.97 | 0.61 | 1.39 | 0.64 | 1.12 | 0.71 | 1.24 | 0.83 | 2.04 | 1.43 |
| | 0.92 | 0.62 | 1.42 | 0.77 | 1.12 | 0.77 | 1.15 | 0.82 | 2.17 | 1.65 |
| CD (P=0.05) | NS | NS | 3.98 | NS | NS | NS | NS | NS | 5.85 | NS |
| | NS | NS | 4.23 | NS | NS | NS | NS | NS | 6.51 | NS |

IW : CPE, Irrigation water: cumulative pan evaporation; RDF, Recommended dose of fertilizer; 120 kg N, 60 kg $P_2O_5$ and 60 kg $K_2O$/ha; DAS, days after sowing; NS, non-significant might be due to high leaf temperature because of plant water stress during vegetative and reproductive stages that led to higher stomatal diffusion resistance which in turn reduced the $CO_2$ fixation by the leaf with the resultant reduction in photosynthetic activities. The more number of stress days and higher positive value of SDD recorded during the vegetative growth stage (15–60 DAS) under irrigation at an IW : CPE of 0.5 clearly indicated that the plant growth was inhibited due to lack of available soil moisture in rhizospheric region. On the contrary, the lesser number of stress days or more negative value of SDD during this period was obtained due to the optimum moisture condition in case of irrigation scheduling at IW : CPE ratio of 1.0. The irrigation scheduling at IW : CPE of 0.75 exhibited the intermediate values of all the growth parameters probably because of the moderate level of water application.

The pooled results clearly depicted that the nutrient-management practices did not pose any significant impact on stress degree days and number of stress days. More negative values of SDD with less stress days were recorded in the treatment $N_2$ (100% RDF) at early vegetative; in $N_3$ (75% RDF + 2 t/ha vermicompost) at grand growth; in $N_4$ (75% RDF + 2 t/ha vermicompost + 25 kg/ha $ZnSO_4$) during tasseling, silking, milking and dough; in $N_3$ at dent and maturity stage and in treatment $N_3$ also in the case of total duration. It might be explained that the combined application of different nutrient sources could not modify the moisture status in the root zone significantly to eliminate the stress effects on crop growth and yield.

The interaction effect of irrigation regimes and nutrient-management practices on stress degree days and number of stress days was insignificant. The pooled results indicated that the more negative value of SDD with less number of stress days were recorded in the treatment combination $I_3N_2$ at early vegetative; in $I_3N_1$ at grand growth; in $I_3N_1$ during tasseling, silking, milking and dough; $I_3N_1$ in dent and maturity stage and in $I_3N_1$ also in the case of total duration. Besides the higher positive value of SDD along with higher stress days were registered in the treatment $I_2N_4$ at early vegetative stage; in $I_1N_2$ at grand growth stage; in $I_1N_3$ during tasseling, silking, milking and dough stage; in $I_1N_1$ at dent and maturity stage and in combination $I_1N_2$ for total duration. The less number of stress days under irrigation at an IW : CPE of 1.0 and 75% RDF + 2 t/ha vermicompost + 25 kg/ha $ZnSO_4$ indicated that, the sufficient moisture level maintained in the rhizospheric region during crop period by the combined effect of optimum irrigation scheduling and increased moisture holding through vermicomposting might have mitigated the stress effects on plants. On the other hand, the maximum stress effects in terms of higher number of stress days under irrigation at an IW : CPE of 0.5 were obtained by the virtue of prolonged watering intervals coupled with nutrient deficient situations (control treatment). As a result, an inadequate supply of water during different phases of plant growth, particularly at reproductive stage, was very harmful to develop the reproductive tissues and grains due to general starvation for the substrates.

### *Relationship of stress degree days with grain yield of quality protein maize*

In order to study the variation in grain yield in relation to stress degree days, relationships between grain yield and SDD were developed which showed that the yield developed polynomial relationship with SDD during different phenophases (Fig. 1). The results obtained from pooled analysis during early vegetative stage; grand growth stage; and tasseling, silking, milking and dough stage as well as dent and maturity stage were not significant ($R^2 = 0.003$, $R^2 = 0.150$, $R^2 = 0.230$ and $R^2 = 0.160$ respectively) hence not considered. Thus, it was observed that the model was able to explain 0.3, 15, 23 and 16% of the total variation in yield through a polynomial function.

The relationship between grain yield as well as total dry-matter accumulation with stress degree days and number of stress days is shown in the Table 3. From the correlation values obtained, it can be said that the grain yield and dry-matter accumulation during both the years of experimentation were negatively correlated with SDD and number of stress days, i.e. with the increase in stress days and higher positive SDD values, the yield and dry-matter accumula-

**Table 3.** Effects of SDD and number of stress days on grain yield and total dry-matter accumulation of quality protein maize (HQPM 1) based on correlation study

| Growth stages | Grain yield (t/ha) | | | | Total dry matter accumulation (g/m$^2$) | | | |
|---|---|---|---|---|---|---|---|---|
| | SDD | | No. of stress days | | SDD | | No. of stress days | |
| | 2017–18 | 2018–19 | 2017–18 | 2018–19 | 2017–18 | 2018–19 | 2017–18 | 2018–19 |
| $P_1$ | –0.51* | –0.66** | –0.38 | –0.42 | –0.57* | –0.55* | –0.49* | –0.46 |
| $P_2$ | –0.40 | –0.51* | –0.55* | –0.50* | –0.48* | –0.53* | –0.63** | –0.55* |
| $P_3$ | –0.49* | –0.68** | –0.45 | –0.52* | –0.61** | –0.79** | –0.55* | –0.56* |
| $P_4$ | –0.89** | –0.46* | –0.53* | –0.32 | –0.85** | –0.41 | –0.64** | –0.31 |

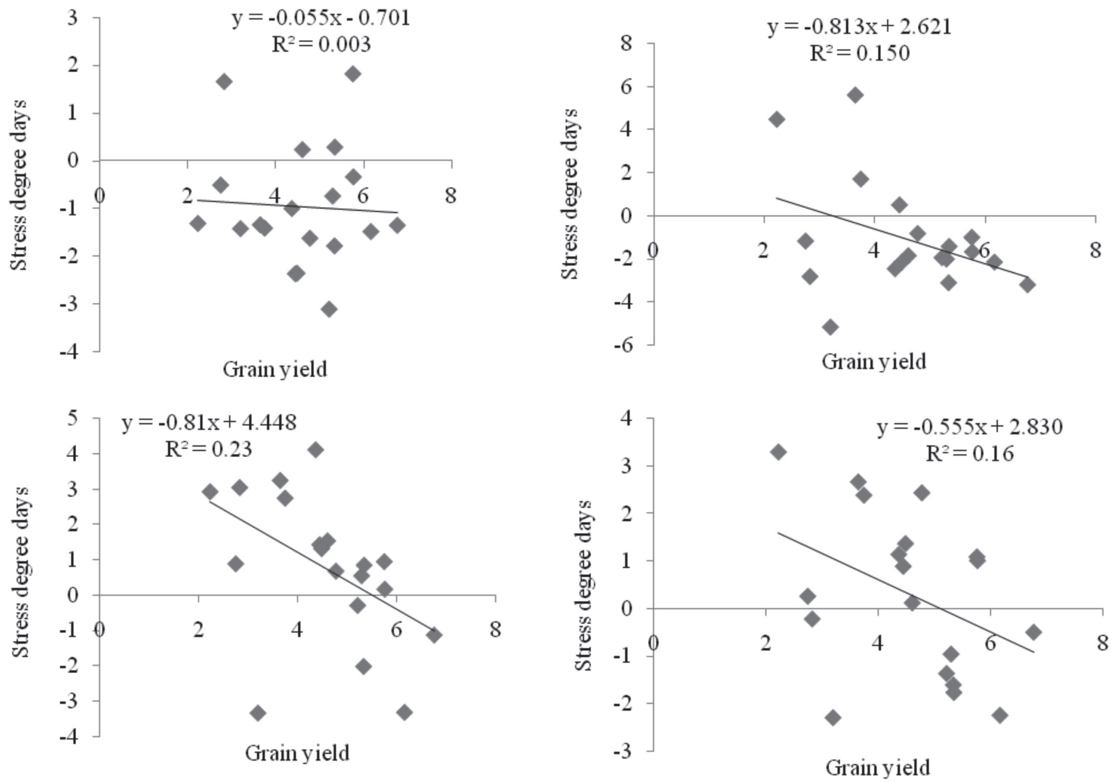


**Fig. 1.** Relationship of stress degree-days (°C) accumulated at early vegetative stage (a), grand growth stage (b), tasseling, silking, milking and dough stage (c), and dent and maturity stage (d) with grain yield of 'HQPM 1' quality protein maize (based on pooled data of 2 years)

tion were decreased. In case of total growth duration of the crop during 2017–18 and 2018–19, the grain yield showed very strong correlation with SDD which were significant at 1% level of significance and moderate correlation with number of stress days, significant at 5% level of significance. Similar trend was followed in case of total dry matter accumulation. The total dry matter accumulation also showed very strong correlations with stress degree days, which were significant at 1% level of significance during 2017–18 and 2018–19 while considering total duration of the crop. Moderate correlation was noticed between total dry matter accumulation and number of stress days during 2017–18, being significant at 1% level of significance and the correlation value –0.56 was achieved during 2018–19 which was significant at 5% level of significance.

### *Economics*

The analysis of economics (Table 4) of QPM production revealed that the treatment $I_3$ (IW : CPE 1.0) resulted in the highest gross returns (₹101,648/ha), net returns (₹56,192/ha) and benefit: cost (B: C) ratio (2.24), followed by the treatment $I_2$ (IW : CPE 0.75). The lowest gross returns, net returns and B : C ratio were recorded in treatment $I_1$ (IW : CPE 0.5). Application of irrigation at an IW : CPE 1.0 to QPM achieved the benefit of getting highest dividends in terms of gross returns, net returns, and benefit: cost ratio owing to the highest grain and stover yields, and relatively higher market price of QPM. However, among the irrigation-based treatments, the cost of cultivation was mainly varied with number of irrigations. Likewise, the lowest economic benefits recorded in case of irrigation at IW : CPE 0.5 were mainly associated with lower levels of QPM production.

The mean data of 2 years revealed that the application of $N_4$ (75% RDF + 2 t/ha vermicompost + 25 kg/ha $ZnSO_4$) recorded the highest gross returns (₹109,573/ha), net returns (₹60,507/ha) and B : C ratio (2.23), followed by $N_3$ (75% RDF + 2 t/ha vermicompost) and $N_2$ (100% RDF). However, $N_1$ treatment (control) reported the lowest gross returns, net returns and B: C ratio (Table 4). The nutrient-management system involving organics like vermicompost @ 2 t/ha along with 75% recommended dose of chemical fertilizers supplying N, P and K and $ZnSO_4$ @ 25 kg/ha exhibited the highest economic advantages in terms of gross returns, net returns and benefit: cost ratio owing to higher yields. Higher cost of cultivation registered with the involvement of integrated nutrient-management practices was due to the cost of bulk quantity of vermicompost

**Table 4.** Effect of irrigation and nutrient management on production economics of quality protein maize (HQPM 1) in winter season (mean of 2 years)

| Treatment | Cost of cultivation (₹/ha) | Gross return (₹/ha) | Net return (₹/ha) | Benefit: cost ratio |
|---|---|---|---|---|
| *Irrigation (I)* | | | | |
| $I_1$ (IW : CPE 0.5) | 40,864 | 71,551 | 30,687 | 1.75 |
| $I_2$ (IW : CPE 0.75) | 43,160 | 87,668 | 44,508 | 2.03 |
| $I_3$ (IW : CPE 1.0) | 45,456 | 101,648 | 56,192 | 2.24 |
| SEm± | 0.01 | 1,071.57 | 1,072.05 | 0.03 |
| CD (P=0.05) | 0.02 | 3,494.58 | 3,495.23 | 0.09 |
| *Nutrient management (N) 0.09* | | | | |
| $N_1$ (Control) | 34,782 | 52,797 | 18,015 | 1.52 |
| $N_2$ (100% RDF) | 40,627 | 84,821 | 44,194 | 2.09 |
| $N_3$ (75% RDF + 2 t/ha vermicompost) | 48,166 | 100,631 | 52,465 | 2.09 |
| $N_4$ (75% RDF + 2 t/ha vermicompost + 25 kg/ha $ZnSO_4$) | 49,066 | 109,573 | 60,507 | 2.23 |
| SEm± | 0.01 | 770.42 | 770.87 | 0.02 |
| CD (P=0.05) | 0.03 | 2,209.69 | 2,210.35 | 0.05 |
| *Interaction (Irrigation × Nutrient management)* | | | | |
| $I_1N_1$ | 32,486 | 42,632 | 10,146 | 1.31 |
| $I_1N_2$ | 38,331 | 69,497 | 31,166 | 1.81 |
| $I_1N_3$ | 45,870 | 83,128 | 37,258 | 1.81 |
| $I_1N_4$ | 46,770 | 90,946 | 44,176 | 1.94 |
| $I_2N_1$ | 34,782 | 54,185 | 19,403 | 1.56 |
| $I_2N_2$ | 40,627 | 85,300 | 44,673 | 2.10 |
| $I_2N_3$ | 48,166 | 101,663 | 53,497 | 2.11 |
| $I_2N_4$ | 49,066 | 109,525 | 60,459 | 2.23 |
| $I_3N_1$ | 37,078 | 61,573 | 24,495 | 1.66 |
| $I_3N_2$ | 42,923 | 99,667 | 56,744 | 2.32 |
| $I_3N_3$ | 50,462 | 117,103 | 66,641 | 2.32 |
| $I_3N_4$ | 51,362 | 128,248 | 76,886 | 2.50 |
| | I × N N × I | I × N N × I | I × N N × I | I × N N × I |
| SEm± | 0.02 | 1,334.41 | 1,334.48 | 0.03 |
| | 0.02 | 1,575.99 | 3,827.50 | 0.04 |
| CD (P=0.05) | 0.05 | 3,827.29 | 3,827.61 | 0.08 |
| | 0.05 | 4,806.55 | 4,807.92 | 0.11 |

IW : CPE, Irrigation water: cumulative pan evaporation; RDF, Recommended dose of fertilizer; 120 kg N, 60 kg $P_2O_5$ and 60 kg $K_2O$/ha; DAS, days after sowing; NS, non-significant

needed to meet the nutrient requirement at recommended level, while the lower cost was incurred in case of 100% RDF as less quantity of chemical fertilizers could maintain the recommended dose of nutrients. However, the lowest production economics were shown in the control plots.

On the basis of mean of 2 years, the maximum gross returns of ₹128,248/ha and net returns of ₹76,886/ha were recorded under the treatment $I_3N_4$ (irrigation at IW : CPE 1.0 with 75% RDF + 2 t/ha vermicompost + 25 kg/ha $ZnSO_4$), followed by $I_3N_3$ (Irrigation at IW/CPE 1.0 with 75% RDF + 2 t/ha vermicompost). The treatment combination $I_1N_1$ (IW : CPE 0.5 with control) achieved the lowest gross returns. However, the benefit: cost ratio also followed the similar trend. The B: C ratio was maximum (2.50) in treatment combination $I_3N_4$ which was followed by $I_3N_3$ and $I_3N_2$. On the other hand, the application of $I_1N_1$ recorded the lowest benefit: cost ratio.

On the basis of our findings it may be recommended that irrigation scheduling at IW : CPE of 1.0 along with the application of 75% RDF + 2 t/ha vermicompost + 25 kg/ha $ZnSO_4$ can be recommended to the farmers for improving the growth and productivity of the crop and also profitability of quality protein maize (QPM) production in new alluvial zone of West Bengal. The equation developed in this experiment to predict the grain yield and dry matter accumulation as a function of stress degree-days (SDD) and number of stress days can be a useful tool to farmers and researchers in developing strategies and decision making for irrigation management under limited water conditions.

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