

Productivity, nutrient uptake and profitability of hybrid sunflower (*Helianthus annuus*) as influenced by irrigation and fertilizer-management practices under sub-tropical climate of West Bengal

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ABSTRACT

An experiment was conducted at farmer's field at Madandanga, Gayeshpur, Nadia, West Bengal during the winter seasons 2011–12 and 2012–13, to study the effect of water and nutrient-management practices on growth and yield of hybrid sunflower (*Helianthus annuus* L.). The experiment was laid out in split-plot design, assigning 3 irrigation levels in the main plot and 7 fertilizer treatments in the sub-plots. The experiment consisted of 21 treatment combinations replicated thrice. Results revealed that $N_{80}P_{40}K_{40}B_{1.5}S_{25}$ (80, 40, 40, 1.5 and 25 kg/ha of N, P_2O_5 , K_2O , B and S respectively) treatment significantly and synergistically increased plant height at 100 days after sowing (DAS), leaf-area index at 75 DAS, total dry-matter accumulation at 100 DAS, crop-growth rate during 50–75 DAS, basal girth at harvesting and capitulum diameter of hybrid sunflower (9.6, 65.1, 49.7, 49.0, 11.6 and 11.9% higher values than the crop in farmer fertilizer practice (FFP) plot respectively). The yield attributes, namely filled seeds/capitulum, filled seed weight/capitulum, total seed weight/capitulum and 100-seed weight, were significantly higher by 52.8, 63.5, 38.6 and 16.9% when grown with 3 irrigations, given at 30, 60 and 80 days after sowing ($I_{30/60/80}$) than the plants receiving 1 irrigation (I_{30}) and 75.7, 73.2, 97.8 and 30.0% with $N_{80}P_{40}K_{40}B_{1.5}S_{25}$ treatment than the FFP plots. Average seed and stalk yield of sunflower 'Aditya' was the highest in $I_{30/60/80}$ treatment, accounting 44.1 and 78.8% more than the crop yield obtained under I_{30} treatment, respectively. Application of $N_{80}P_{40}K_{40}B_{1.5}S_{25}$ resulted in significantly higher seed and stalk yield (38.6 and 48.1% more than the values in FFP plots). Irrigation with $I_{30/60/80}$ resulted 1.2% more oil percentage compared to the I_{30} treatment. The oil content of tested cultivar was significantly and synergistically increased by the application of $N_{80}P_{40}K_{40}B_{1.5}S_{25}$, accounting 6.4% more than that obtained with FFP. Irrigation × fertilizer interaction had significant effect on oil content and the highest value was observed to be in seeds obtained in plots fertilized with $N_{80}P_{40}K_{40}B_{1.5}S_{25}$ under 2 irrigations ($I_{30/60}$). The maximum net return and benefit: cost ratio were recorded with the crop irrigated thrice ($I_{30/60/80}$), accounting 118 and 35%, respectively, more over the crop irrigated once (I_{30}). Irrespective of irrigation levels, combined application of NPK and B ($N_{80}P_{40}K_{40}B_{1.5}$) resulted in the highest net returns and benefit: cost ratio among all fertilization practices, accounting 52 and 23%, respectively more over the crop fertilized with $N_{60}P_{30}K_{30}$ (FFP).

Key words: Irrigation water productivity, Nutrient uptake, Oil content, Sunflower, Yield

Sunflower is second most important oilseed crop after mustard in the eastern parts of India and has also been cultivated on significant area since last two and a half decades. In West Bengal, 15,000 ha of land was under sunflower, producing 22,000 tonnes, while the productivity

was 1.48 t/ha during 2016–17 (Indiastat, 2017). At the turn of the century, West Bengal share only 2.5 and 5.1% in countries area and production respectively. Though there have been considerable advancements in the productivity of oilseed crops in West Bengal, the total internal supply of edible vegetable oils in the state has always being less than ever-increasing demand. By and large non-traditional areas of West Bengal are considered for cultivation of oilseeds, sunflower in particular and the scenario is alarming. Of late, sincere efforts have been initiated from the Directorate of Agriculture, Government of West Bengal, to popularize the cultivation of sunflower in the state. Such exercise brought about a formidable rise in the production

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of sunflower in just 2 to 3 years time which has been primarily the result of area expansion and growing of hybrid cultivars, but the production could not reach the desired levels.

Sunflower cultivation on rice-fallow lands during November-March is gaining popularity. This growing season (winter) of sunflower is characterized by cool-dry climate and very low or zero rainfall necessitating irrigation for good harvest. This crop, with high water requirement, grows well in fertile soil with at least 500-600 mm (annual) rainfall or with irrigation in less fertile soil (Banerjee *et al.*, 2014). Both the productivity and quality of produce largely depend on a proper balance between soil air and soil-moisture available in the plant root zone throughout the crop-growth period, which can only be achieved by adopting a sound water-management practices. In addition, under- or over-supply of irrigation water may affect growth, seed yield and oil quality of the crop. Inadequate water in rainfed cultivation results in greater seed yield reduction (104%) and marginal decrease (1.1%) in oil content than those obtained from optimally irrigated crop at irrigation water: cumulative pan evaporation (IW: CPE) ratio of 1.00 (Moitra *et al.*, 2012). They added that moisture stress, especially at the most critical stages like seedling, flowering, bud initiation and seed filling, results in the sharp decline in sunflower productivity. Therefore, an adequate water supply is required from seedling stage till the maturity for higher seed yield and good oil quality.

In general, nutrient requirement of hybrid sunflower is high for all the nutrients and the crop need to be supplied in adequate quantities for achieving high yields. An estimate showed that hybrid sunflower crop removes about 47, 10 and 54 kg N, P and K, respectively, to produce 1 tonne of seed (Banerjee *et al.*, 2014). In order to produce same amount of seed, the removal of S and B was estimated at 6 and 0.5 kg/ha respectively (Shekhawat and Shivay, 2008). On the other hand, there is a growing deficiency of secondary and micronutrients such as S, Ca, Zn, Fe and B due to intensive cropping with the use of high-analysis fertilizers. The glaring non-responsiveness to application of recommended or elevated levels of NPK is due to the growing hidden hunger for secondary and micronutrients. Hence meeting the higher nutrient need of hybrid sunflower through site-specific balanced fertilization is the focus for reducing the cost, increasing nutrient-use efficiency and increasing the profitability besides maintaining soil fertility. Therefore, the present experiment was conducted to assess the effect of major, secondary, micro-nutrients and organic sources of nutrients in different combinations under varied irrigation levels to achieve sustainable hybrid sunflower productivity during winter (dry) season in Gangetic plains of West Bengal.

MATERIALS AND METHODS

The experiment was conducted in farmer's field at Madandanga, Gayeshpur (23°22.221'N, 88°22.221'E, 12.0 m above mean sea-level), Nadia, West Bengal for 2 winter seasons 2011-12 and 2012-13 under typical subtropical climate. Maximum and minimum temperature fluctuated between 33.9 and 10.1°C in winter of 2011-12 and 36 and 6.9°C during the winter 2012-13. Relative humidity prevailed between 99 and 33% during the winter of 2011-12, and 98 and 31% during the winter of 2012-13. The rainfall during the experimental period (November to March) was 68.8 (4 rainy days) and 18.2 mm (3 rainy days) in the season of winter 2011-12 and 2012-13 respectively. The soil was clay loam, having pH 6.89, organic carbon 0.42%, available N 175.4 kg/ha, available P₂O₅ 27.5 kg/ha, available K₂O 108.08 kg/ha, available S 27.0 kg/ha and available B 1.89 kg/ha. The experiment was laid out in a split-plot design, assigning 3 irrigation levels [I₃₀, one irrigation at 30 days after sowing (DAS); I_{30/60}, 2 irrigations at 30 and 60 DAS; I_{30/60/80}, 3 irrigations at 30, 60 and 80 DAS] in the main plot and 7 fertilizer treatments [F₁, farmer fertilizer practice (FFP) (60-30-30 kg N-P₂O₅-K₂O/ha); F₂, Recommended dose of fertilizer (RDF) (80-40-40 kg N-P₂O₅-K₂O/ha); F₃, RDF + boron @ 1.5 kg/ha; F₄, RDF + sulphur @ 25 kg/ha; F₅, RDF + boron @ 1.5 kg/ha + sulphur @ 25 kg/ha; F₆, RDF + farmyard manure @ 5 t/ha; F₇, RDF + vermicompost @ 5 t/ha] in the subplots. The experiment consisted of 21 treatment combinations, replicated thrice. The hybrid sunflower variety 'Aditya' was grown as test crop under irrigated medium land situation with good drainage facility. Seeds were sown @ 6 kg/ha on 19 November in year 1 and 20 November in year 2, at a spacing of 60 cm × 30 cm (55,555 plants/ha). The net plot size was 4 m × 3 m. The nutrients (NPK) were provided to the crop as per treatment details through urea (46% N), diammonium phosphate (18% N and 46% P₂O₅), muriate of potash (60% K₂O), zinc sulphate (ZnSO₄, 7H₂O with 11% S), Granubor® Natur (Disodium Tetraborate Pentahydrate; Granular with 15% B), farmyard manure (0.56% N, 0.24% P₂O₅ and 0.59% K₂O) and vermicompost (1.6% N, 0.98% P₂O₅ and 1.1% K₂O) respectively. All P, K, B and Zn fertilizers were applied to the soil before sowing in each plot. The N fertilizer was applied in 3 splits-50% before sowing, 25% at 30 DAS and 25% at 45 DAS. The FYM and vermicompost were surface broadcast during final land preparation (as basal). Diesel-operated water lifting pump (5 HP) was used for 15 h to irrigate the crop with 50 ha-mm water under each irrigation. Two hand-weedings (HW) were done at 20 and 40 DAS to promote early crop growth, maintain a good crop canopy and keep the plots more or less weed free. As a prophylactic measure,

Neemazal-T/S (Azadirachtin 1% EC) was sprayed twice (35 and 42 DAS) @ 1 ml/litre water. In addition, Pride (Acetamiprid 20% SP) was sprayed @ 3 g/10 litres water at 50 DAS for controlling white fly. The plants were cut at the base after attaining harvest maturity (120 DAS). The capitula were sun-dried for 23 days, and then seeds were separated.

Observations on plant height, leaf-area index (LAI), total dry-matter accumulation (TDMA) and crop-growth rate (CGR) were recorded at 100, 75, 100 and 50–75 days after sowing (DAS). Yield components namely basal girth, capitulum diameter, number and weight of filled seeds/capitulum, 100-seed weight (seed index), seed and stalk yields were recorded at harvesting (120 DAS). Irrigation water productivity was determined by dividing seed yield with amount of irrigation water use. Plant samples from each treatment were collected, oven-dried, and ground for analyzing total recoveries of N, P, K, B and S at harvesting following standard procedures. The economic assessment in terms of net return and benefit: cost (B : C) ratio of hybrid sunflower cultivation was worked out on the basis of prevailing market prices of inputs and outputs.

Data obtained on the different growth, yield and nutrient uptake were analyzed statistically by the method of analysis of variance (ANOVA) as per the procedure outlined for split-plot design (Gomez and Gomez, 1984). Statistical significance was tested by P-value at 0.05 level of

probability and critical difference (CD) was worked out wherever the effects were significant. Principal component analysis (PCA) based upon correlation matrix involving measured growth and yield parameters were used to diagnose the similarity among all treatment combinations.

RESULTS AND DISCUSSION

Growth parameters

The crop receiving 3 irrigations ($I_{30/60/80}$) attained the maximum height at 100 days after sowing (DAS), LAI at 75 DAS, TDMA at 100 DAS and CGR at 5075 DAS (11.7, 24.8, 23.3 and 61.5% more than the crop irrigated once respectively) (Table 1). At harvest maturity (120 DAS), basal girth and capitulum diameter of tested sunflower hybrid was greater when grown with $I_{30/60/80}$ (20.6 and 11.6% more than that the crop receiving I_{30} respectively). High frequency water management by $I_{30/60/80}$ might have provided at least daily requirements of water to a portion of the root zone of each plant, and maintain a high soil metric potential in the rhizosphere to reduce plant water stress. Further, ample irrigation water might have enhanced the plant growth with higher biomass associated with more leaves, and larger stem girth with increased shoot water content. In contrast, poor response of the growth parameters to drought stress (I_{30}) might be due to reduction in leaf cell hydraulic conductivity, which in turn, decreases water transport and hinders both cell enlarge-

Table 1. Effect of irrigation and fertilizer levels on growth characteristics of sunflower hybrid ‘Aditya’ (mean data of 2 years)

Treatment	Plant height (cm) at 100 DAS	Leaf-area index at 75 DAS	Total dry-matter accumulation (g/m ²) at 100 DAS	Crop-growth rate (g/m ² /day) at 50-75 DAS	Basal girth (cm) at harvesting	Capitulum diameter (cm) at harvesting
<i>Irrigation levels (I)</i>						
I_{30}	196.4	4.12	1333	25.7	10.7	17.2
$I_{30/60}$	209.8	5.11	1445	33.7	11.9	18.2
$I_{30/60/80}$	219.4	5.14	1644	41.6	12.9	19.2
SEm±	2.61	0.11	37.89	2.23	0.11	0.25
CD (P=0.05)	8.54	0.36	123.57	7.29	0.36	0.81
<i>Fertilizer levels (F)</i>						
$N_{60}P_{30}K_{30}$ (FFP)	198.1	4.23	1110	26.6	11.2	17.2
$N_{80}P_{40}K_{40}$ (RDF)	204.3	4.63	1457	28.1	11.5	17.4
$N_{80}P_{40}K_{40}B_{1.5}$	210.7	5.00	1539	36.6	12.1	18.5
$N_{80}P_{40}K_{40}S_{25}$	212.7	4.97	1569	37.4	12.3	19.0
$N_{80}P_{40}K_{40}B_{1.5}S_{25}$	217.1	5.22	1662	39.7	12.5	19.3
$N_{80}P_{40}K_{40}FYM_5$	207.7	4.79	1475	32.4	11.7	17.8
$N_{80}P_{40}K_{40}VC_5$	209.4	4.69	1509	34.9	11.8	18.4
SEm±	2.71	0.11	51.83	2.32	0.19	0.27
CD (P=0.05)	7.64	0.32	146.12	6.56	0.56	0.78

FFP, Farmer’s fertilizer practice; RDF, recommended dose of fertilizer; details of irrigation and fertilizer levels are given under Materials and Methods; Subscript digits signify respective timing of irrigation in DAS, dose of inorganic nutrients in kg/ha and organic manures in t/ha

ment and cell division, and finally leaf development (Gholamhoseini *et al.*, 2013). The water stress results in less evapotranspiration (ET) by closure of the stomata, reduced assimilation of carbon and biomass production (Demir *et al.*, 2006).

The treatment $N_{80}P_{40}K_{40}B_{1.5}S_{25}$ significantly and synergistically increased plant height (at 100 DAS), LAI (at 75 DAS), TDMA (at 100 DAS), CGR (during 50-75 DAS), basal girth (at harvesting) and capitulum diameter (at harvest) over the other treatments (9.6, 23.4, 49.7, 49.0, 11.0 and 11.9% higher values than the crops in FFP plots respectively) (Table 1). However, the values were statistically at par with the values recorded with $N_{80}P_{40}K_{40}B_{1.5}$ and $N_{80}P_{40}K_{40}S_{25}$ treatments. Similar positive responses to sulphur (Sheoran *et al.*, 2013) and boron (Bhattacharyya *et al.*, 2015) application in respect of plant height, stem girth and head diameter in sunflower had also been reported. An adequate supply of S might have resulted in higher rate of cell multiplication, elongation, expansion, production of photosynthates, and their translocation to sink, which ultimately increased the plant height and other growth attributes (Kumar *et al.*, 2011). Moreover, the present results support previous findings of Shekhawat and Shivay (2008), who reported increased dry mass of vegetative parts and well-developed capitulum associated with less conversion of sugars into starch where B sprays were applied, while the reproductive parts were small and deformed with lower B spray concentrations.

Yield components

The average values for yield components of tested cultivar, namely, filled seeds/capitulum, weight of filled seeds/capitulum and 100-seed weight, were significantly higher when grown in plots irrigated thrice (52.8, 63.5 and 16.9% more than the plants receiving single irrigation) (Table 2). Irrigation increased reserve soil-moisture content, which improved the water status and overall plant growth. Thus, higher rate of water flow from soil to atmosphere (*via* plant) due to less stomatal resistance and more leaf area helped to sustain better transpiration rate in sunflower, and ultimately improved the capitulum size and the number as well as weight of seeds/capitulum (Demir *et al.*, 2006).

The $N_{80}P_{40}K_{40}B_{1.5}S_{25}$ treatment showed significantly higher filled seeds/capitulum, filled seed weight/capitulum and 100-seed weight (75.7, 73.2 and 30.0% more than the values against FFP plots), and it was statistically at par with $N_{80}P_{40}K_{40}B_{1.5}$ and $N_{80}P_{40}K_{40}S_{25}$ treatments. The reason might be the timely application of S increases the plant growth by increasing the assimilating surface area. The higher photosynthate assimilation helped in net export of carbon to sink and thus increased the number of seeds/

capitulum (Sheoran *et al.*, 2013). A significant increase in seeds/capitulum was observed owing to influence of B on flowering, pollen germination, fertilization, cell division and water relationship. Boron regulates the intake of water into the cell, therefore B-deficient plants show decrease in moisture percentage, less succulence, less metabolic activity, low water potential, stomata pore opening, transpiration and a lower growth rate, in comparison to B-sufficient plants (Zahoor *et al.*, 2011). The number of seeds/capitulum increased with B application as it increased the pollen-producing capacity of anthesis and pollen-grain viability (Shekhawat and Shivay, 2008). Moreover, B application increased the 100-seed weight through enhanced activities of dehydrogenase and phosphatase enzyme and better translocation.

Seed yield and stalk yield

Average seed and stalk yield of 'Aditya' was the highest in full-irrigated treatment ($I_{30/60/80}$), accounting 44.1 and 78.8% more than the crop yield obtained under deficit-irrigation treatment (I_{30}) respectively (Table 2). This results indicated that maximum yield of hybrid sunflower could only be achieved if the soil's available water in the maximum activity root zone would not drop below deficit condition. Application of higher but optimum frequency of irrigation might have associated with an increase in accumulation and distribution of assimilated in the plant parts from seedling to maturity stage, and thereby improved all growth as well as yield attributes (Moitra *et al.*, 2012). In contrary, the water applied through single irrigation probably was not enough to fully compensate the crop water requirement for normal plant production. Therefore, water content in the soil profile might have dropped below the critical level and kept falling steadily to values approaching the soils permanent wilting point (PWP), resulting in low yields.

Application of $N_{80}P_{40}K_{40}B_{1.5}S_{25}$ resulted in significantly higher seed and stalk yield (38.6 and 48.1% more than the values in FFP plots) and it was found statistically at par with $N_{80}P_{40}K_{40}S_{25}$ and $N_{80}P_{40}K_{40}B_{1.5}$ (Table 2). The higher availability of nutrients, especially N and S, helped in better partitioning of photosynthates from source to sink which might have led to higher yield attributes, and finally resulted in higher seed yield of hybrid sunflower (Shekhawat and Shivay, 2008). The B application improved seed yield because it maintains good balance between photosynthesis and respiration. On the other hand, S-stress or deficiency causes disturbance in the balance of nutritional environment in plants, which has adverse effects on plant growth and ultimately reduces the yield of sunflower (Nasreen and Haq, 2002). Moreover, low B supply in the soil can lead to drastic yield reduction due to induction of pollen sterility and low

seed set (Krudnak *et al.*, 2013).

Irrigation water productivity

Crop yield/water-applied production function (IWP) was determined to assess how efficiently hybrid sunflower (cv. 'Aditya') used irrigation in the dry (winter) season. The severe drought stress treatment (I_{30}) had greater IWP than the other irrigation treatments (Table 2). In other words, IWP increased during conditions of limited water (I_{30}). For the no-stress ($I_{30/60/80}$) and mild stress treatment conditions ($I_{30/60}$), IWP decreased due to increased deep water percolation and evaporation (Gholamhoseini *et al.*, 2013). Effect of fertilizer management on IWP was found significant and the value of IWP with $N_{80}P_{40}K_{40}B_{1.5}S_{25}$ was significantly higher; however, it was statistically at par with the values obtained under $N_{80}P_{40}K_{40}B_{1.5}$ and $N_{80}P_{40}K_{40}S_{25}$. One practical way of assessing the likely benefits of irrigation in a given climatic environment and husbandry condition, is through the development of the relationship between seed yield and irrigation water supply (Fig. 1). As expected, the relationship between them was linear and the seed yield of hybrid sunflower was significantly correlated ($R^2 = 0.965$) to the amount of applied irrigation water.

Oil content

Average across years, oil percentage of sunflower was greater when grown with 3 irrigations (0.6% more than

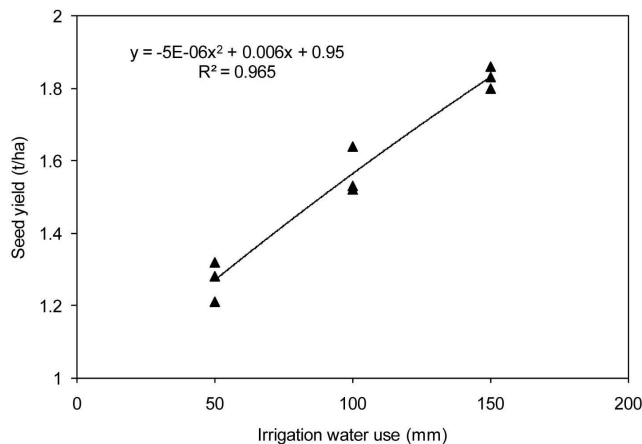


Fig. 1. Relationship between irrigation water use and seed yield of sunflower hybrid 'Aditya' (based on mean data of 2 years)

that obtained with single irrigation respectively), leaving no significant difference with $I_{30/60}$ levels (Table 3). Our findings correspond to those of Gholamhoseini *et al.* (2013), who reported that oil percentage increased with irrigation and the highest oil percentage may be obtained when irrigated at flowering and at the end of flowering.

Oil content was significantly and synergistically increased by the application of $N_{80}P_{40}K_{40}B_{1.5}S_{25}$, accounting 6.4% more than that obtained with FFP (Table 3). This might be owing to the fact that S is an integral part of S-containing amino-acids (cysteine, cystine, and methionine), and 50-80% of total S in sunflower goes in making S-

Table 2. Effect of irrigation and fertilizer levels on yield components, yield, irrigation water productivity and annual economic benefits of hybrid sunflower (cv. 'Aditya') (mean data of 2 years)

Treatment	Filled seeds/capitulum	Weight of filled seeds/capitulum (g)	Seed index* (g)	Seed yield (t/ha)	Stalk yield (t/ha)	IWP (kg/ha-mm)	Net returns ($\times 10^3 \text{ ₹/ha}$)	Benefit: cost ratio
Irrigation levels (I)								
I_{30}	886.0	34.2	4.09	1.27	4.11	25.34	27.8	1.62
$I_{30/60}$	1062.2	46.0	4.45	1.56	5.20	15.59	43.8	1.90
$I_{30/60/80}$	1353.6	55.9	4.78	1.83	7.35	12.20	60.7	2.19
SEM \pm	55.76	2.65	0.08	0.03	0.34	0.41	-	-
CD (P=0.05)	181.85	8.66	0.28	0.12	1.13	1.36	-	-
Fertilizer levels (F)								
$N_{60}P_{30}K_{30}$ (FFP)	780.4	33.2	3.83	1.27	4.37	14.23	39.7	2.00
$N_{80}P_{40}K_{40}$ (RDF)	942.2	38.5	4.16	1.42	5.03	16.32	48.1	2.19
$N_{80}P_{40}K_{40}B_{1.5}$	1166.1	48.0	4.64	1.64	5.92	18.65	60.4	2.45
$N_{80}P_{40}K_{40}S_{25}$	1293.3	50.9	4.71	1.69	6.09	19.21	38.6	1.58
$N_{80}P_{40}K_{40}B_{1.5}S_{25}$	1371.2	57.5	4.98	1.76	6.47	20.23	41.8	1.62
$N_{80}P_{40}K_{40}FYM_5$	1048.3	43.1	4.34	1.54	5.38	17.51	47.7	1.99
$N_{80}P_{40}K_{40}VC_5$	1102.6	46.4	4.44	1.57	5.62	17.81	32.2	1.49
SEM \pm	79.19	3.58	0.14	0.05	0.24	0.79	-	-
CD (P=0.05)	223.27	10.10	0.41	0.15	0.68	2.23	-	-

FFP, Farmer's fertilizer practice; RDF, recommended dose of fertilizer; DAS, days after sowing; IWP, Irrigation water productivity; details of irrigation and fertilizer levels are given under Materials and Methods; Subscript digits signify respective timing of irrigation in DAS, dose of inorganic nutrients in kg/ha and organic manures in t/ha; *seed index, 100-seed weight

containing amino-acids and rest is required for other S-containing compounds, hence improved oil synthesis in sunflower (Karthikeyan and Shukla, 2008). Concordantly, increased oil content in response to B application might be attributed to enhanced B uptake and our results match with the results of Zahoor *et al.* (2011). Irrigation \times fertilizer interaction had significant effect on oil content (Table 3). The highest value of oil content was observed to be in seeds obtained in plots fertilized with $N_{80}P_{40}K_{40}B_{1.5}S_{25}$

Table 3. Main and interaction effect (irrigation \times fertilizer) on oil content (%) of hybrid sunflower 'Aditya' (mean data of 2 years)

Fertilizer levels (F)	Irrigation levels (I)			Mean
	I ₃₀	I _{30/60}	I _{30/60/80}	
$N_{60}P_{30}K_{30}$ (FFP)	38.07	38.21	38.10	38.13
$N_{80}P_{40}K_{40}$ (RDF)	38.40	38.60	38.23	38.41
$N_{80}P_{40}K_{40}B_{1.5}$	39.59	40.13	39.98	39.90
$N_{80}P_{40}K_{40}S_{25}$	40.07	40.43	40.43	40.31
$N_{80}P_{40}K_{40}B_{1.5}S_{25}$	40.44	40.72	40.55	40.57
$N_{80}P_{40}K_{40}FYM_5$	39.28	39.33	39.76	39.46
$N_{80}P_{40}K_{40}VC_5$	39.45	39.45	39.94	39.61
Mean	39.33	39.55	39.57	-
	SEm \pm	CD (P=0.05)		
I	0.02	0.09		
F	0.04	0.12		
F at same or different I	0.07	0.21		
I at same or different F	0.07	0.23		

FFP, Farmer's fertilizer practice; RDF, recommended dose of fertilizer; details of fertilizer levels are given under Materials and Methods; Subscript digits signify respective timing of irrigation in DAS, dose of inorganic nutrients in kg/ha and organic manures in t/ha

under 2 irrigations (I_{30/60}); however, it was statistically at par with 3 irrigations (I_{30/60/80}).

Factor analysis

Principal component analysis, a type of factor analysis, was used to reduce the large number of variables to a smaller number of compounds or factors that capture most of the variance in the observed variables. Each component or factor was estimated as being a linear weighted combination of the observed variables (Table 4). Selected 2 components explained greatest portion of total variance (95.48%). First component alone could explain 91.53% of total variance. Here, all measured growth parameters and yield components are highly loaded. Second component could explain only 3.95% of variance further. The remaining components explained very small portion of the total variance and hence they were discarded from the analysis. From the scatter diagram the homogenous situations can be detected if any at 2 dimensional space (Fig. 2). But

Table 4. Greatest portion of total variance in the observed variables as explained by selected 2 components through principal component analysis (PCA)

Variable	Component	
	1	2
Plant height (cm) at 100 DAS	0.985	0.128
Leaf-area index at 75 DAS	0.870	0.381
Total dry-matter accumulation (g/m ²) at 100 DAS	0.928	-0.265
Basal girth (cm) at harvesting	0.953	0.253
Capitulum diameter (cm) at harvesting	0.964	0.039
Filled seeds/capitulum	0.984	-0.128
Weight of total seeds/capitulum	0.938	-0.274
Weight of filled seeds/capitulum	0.989	0.015
Seed index (g)	0.957	-0.204
Seed yield (t/ha)	0.989	0.060
Stalk yield (t/ha)	0.961	0.013
Eigen value	10.069	0.435
% of variance	91.534	3.953
Cumulative %	91.534	95.488

DAS, Days after sowing

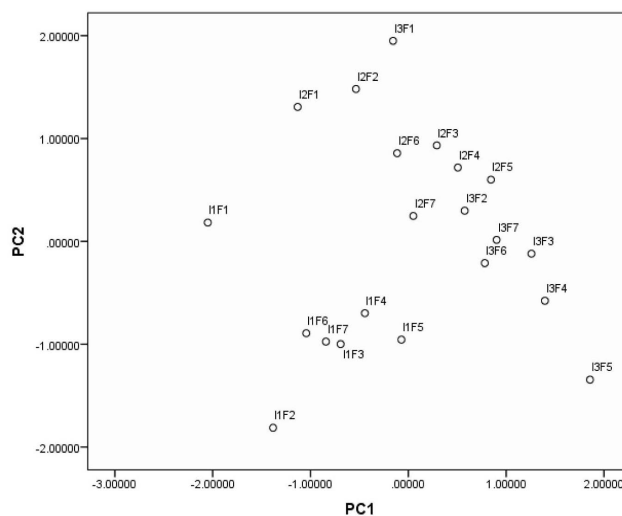


Fig. 2. Scatter diagram of regression factor scores for the first and second components produced by PCA in sunflower hybrid 'Aditya'; where I₁, I₂, I₃; I_{30/60}, I_{30/60/80}; F₁, $N_{60}P_{30}K_{30}$; F₂, $N_{80}P_{40}K_{40}$; F₃, $N_{80}P_{40}K_{40}B_{1.5}$; F₄, $N_{80}P_{40}K_{40}S_{25}$; F₅, $N_{80}P_{40}K_{40}B_{1.5}S_{25}$; F₆, $N_{80}P_{40}K_{40}FYM_5$; F₇, $N_{80}P_{40}K_{40}VC_5$

considering components it can be concluded that I₃F₅ treatment is always beneficial for growth and yield of hybrid sunflower, closely followed by I₃F₄ and I₃F₃. I₁F₁ and I₁F₂ manifested least expression for all the observed parameters.

Nutrient uptake

The higher frequency of irrigation (I_{30/60/80}) led significantly higher nutrient uptake compared to lower frequencies (92.4, 163.8, 82.2, 148.6 and 185.8% for N, P, K, B

and S, more than the values with I_{30}) (Table 5). This might be due to development of efficient root system with improved permeability, coupled with better absorption owing to better availability of nutrients in soil solution (Yadav *et al.*, 2009). In addition, 3 irrigations ($I_{30/60/80}$) might also have provided better conducive conditions for better uptake of nutrients and in turn helped the plants to boost their growth, leading to the development of yield attributes through supply of more photosynthates towards the reproductive sink (Moitra *et al.*, 2012).

Total N and S uptake was significantly higher when the tested cultivar grown with $N_{80}P_{40}K_{40}B_{1.5}S_{25}$ (94.7 and 85.2% more than the uptake by the crop grown with FFP, respectively); however, it was statistically at par with the values obtained under $N_{80}P_{40}K_{40}S_{25}$ treatment (Table 5). Sheoran *et al.* (2013) reported enhanced N and S concentrations in both seed and straw with S application up to 20 kg/ha, compared to without S application which might be higher owing to higher biomass and seed yield. Furthermore, total P and K uptake was higher when the tested cultivar grown with $N_{80}P_{40}K_{40}S_{25}$ (62.7 and 79.4% more than the uptake by the crop grown with FFP respectively); however, it was statistically at par with the values obtained under $N_{80}P_{40}K_{40}B_{1.5}S_{25}$ and $N_{80}P_{40}K_{40}VC_5$. This could be ascribed to synergistic effect of S in increasing the nitrate reductase activity and mobilizing the soil P for higher plant nutrient uptake (Kumar *et al.*, 2011). In the present study, total B uptake was higher when the tested cultivar grown with $N_{80}P_{40}K_{40}B_{1.5}$ (75.7% more than the uptake by

the crop grown with FFP); however, it was statistically at par with the values obtained under $N_{80}P_{40}K_{40}B_{1.5}S_{25}$. These results are in line with the findings of Ramulu *et al.* (2011), who opined that application of boron results in improvement in the uptake of all major- and micro-nutrients. Being a component in various enzymatic and other biochemical reactions, B plays a dominant role in improving the photosynthetic ability and assimilation capacity of crop.

Economic benefits

The economic benefit of hybrid sunflower cultivation was observed to increase with increasing levels of irrigation up to 3 times (Table 2). The maximum net returns (NR) and benefit: cost (B : C) ratio were recorded with the crop irrigated thrice ($I_{30/60/80}$), accounting 118 and 35% more over the crop irrigated once (I_{30}). Irrespective of irrigation levels, combined application of NPK and B ($N_{80}P_{40}K_{40}B_{1.5}$) resulted in the highest net returns and benefit: cost ratio among all fertilization practices, accounting 52 and 23% more over the crop fertilized with $N_{60}P_{30}K_{30}$ (FFP). The next best treatment was RDF ($N_{80}P_{40}K_{40}$). The poor response in net returns and benefit: cost ratio was recorded in crops treated with $N_{80}P_{40}K_{40}VC_5$ that might be due to higher input cost. These results are in partial agreement with the finding of Pattanayak *et al.* (2017), who reported that net returns and benefit: cost ratio were relatively low with FFP, and increased to a highest level at balanced fertilizer rate.

Table 5. Effect of irrigation and fertilizer levels on total nutrient uptake by hybrid sunflower (cv. ‘Aditya’) (mean data of 2 years)

Treatment	Total N uptake (kg/ha)	Total P uptake (kg/ha)	Total K uptake (kg/ha)	Total B uptake (g/ha)	Total S uptake (kg/ha)
<i>Irrigation levels (I)</i>					
I_{30}	34.4	11.6	34.9	124.4	13.4
$I_{30/60}$	51.7	18.2	44.0	167.5	21.5
$I_{30/60/80}$	66.2	30.6	63.6	309.3	38.3
SEM±	3.45	1.44	3.86	13.43	1.52
CD (P=0.05)	11.26	4.69	12.60	43.82	4.97
<i>Fertilizer levels (F)</i>					
$N_{60}P_{30}K_{30}$ (FFP)	34.0	15.0	33.5	139.5	16.9
$N_{80}P_{40}K_{40}$ (RDF)	41.7	16.7	35.9	195.3	20.1
$N_{80}P_{40}K_{40}B_{1.5}$	54.3	18.6	48.6	245.1	24.6
$N_{80}P_{40}K_{40}S_{25}$	60.9	24.4	60.1	198.3	29.5
$N_{80}P_{40}K_{40}B_{1.5}S_{25}$	66.2	21.6	55.6	242.3	31.3
$N_{80}P_{40}K_{40}FYM_5$	45.9	20.9	46.1	205.2	23.2
$N_{80}P_{40}K_{40}VC_5$	52.5	23.8	52.7	177.2	25.3
SEM±	2.47	1.09	3.39	9.62	1.08
CD (P=0.05)	6.98	3.07	9.56	27.12	3.07

FFP, Farmer’s fertilizer practice; RDF, Recommended dose of fertilizer; details of irrigation and fertilizer levels are given under Materials and Methods, Subscript digits signify respective timing of irrigation in DAS, dose of inorganic nutrients in kg/ha and organic manures in t/ha

Thus, it is inferred that fertilization with RDF (80 kg N, 40 kg P₂O₅ and 40 kg K₂O/ha) in combination with 1.5 kg B and 25 kg S/ha under controlled irrigation at 30, 60 and 80 days after sowing through channels can be used as a field management practice to sustain hybrid sunflower production in cooler (dry) climate of West Bengal. However, partial substitution of chemical fertilizer (RDF) through farmyard manure (FYM) or vermicompost is always beneficial not only for augmenting crop productivity but also for maintaining soil health.

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