



Yield and quality of hybrid sunflower (*Helianthus annuus*) as affected by irrigation and fertilization

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ABSTRACT

Present study was carried out to evaluate the effects of varying levels of irrigation and fertilizers, as well as their interaction on the yield, oil quality and nutrient uptake by hybrid sunflower (*Helianthus annuus* L.) (cv. Aditya) at farmer's field, Nadia, West Bengal. Results revealed that average seed yield, stalk yield, oil percentage and oil yield of Aditya was the highest with three irrigations. These parameters were also significantly and synergistically increased by the application of $N_{80}P_{40}K_{40}B_{1.5}S_{25}$. The values of linoleic acid and oleic acid concentrations were greatest in seeds obtained with $N_{80}P_{40}K_{40}B_{1.5}S_{25}$ under single irrigation and double irrigations, respectively. In contrary, the proportions of palmitic acid and stearic acid were lowest with same fertilizer management practices under three irrigations and single irrigation, respectively. The lowest saponification value and maximum iodine value of sunflower oil was obtained with $N_{80}P_{40}K_{40}B_{1.5}S_{25}$ under single irrigation and three irrigations, respectively. The increase in irrigation frequency from one to three brought about significant increase in nutrient uptake by tested cultivar. Total N and S uptake was significantly higher when the tested cultivar grown with $N_{80}P_{40}K_{40}B_{1.5}S_{25}$; however, total P and K uptake was higher with $N_{80}P_{40}K_{40}S_{25}$. Application of $N_{80}P_{40}K_{40}B_{1.5}$ exerted higher boron (B) uptake. Thus fertilization with RDF (80 kg N, 40 kg P_2O_5 and 40 kg K_2O /ha) in combination with 1.5 kg B and 25 kg S/ha under controlled irrigation at 30, 60 and 80 DAS can be used to sustain hybrid sunflower production during winter in West Bengal.

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

Sunflower (*Helianthus annuus* L.) is a warm-season crop whose cultivation in winter period imposes irrigation in Gangetic plains of West Bengal, where rainfall from November to March is rare. Hence, the adoption of sustainable irrigation strategies has become a priority which maximise water use efficiency while maintaining satisfactory yields. 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). In addition, under- or over-supply of irrigation water may affect growth, seed yield and oil quality of the crop. Moisture stress, especially at the most critical stages like seedling, flowering bud initiation and seed filling, results sharp decline in sunflower productivity (Moitra *et al.* 2012). 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 and the crop is characterized by high plasticity under different nutrient availability. An estimate showed that hybrid sunflower crops remove about 47, 10 and 54 kg N, P and K, respectively to produce one tonne of seed (Bhattacharyya *et al.* 2015). 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). The glaring non-responsiveness to application of recommended or elevated levels of NPK is due to the growing hidden hunger for secondary and micronutrients. There is general agreement on the nature of the responses of sunflower to variations in NPK supply, but little emphasis has been placed on documenting the combined effect of macro and micro-nutrient supply (either from inorganic or organic sources). Hence, the present experiment was conducted to assess the effect of major, secondary, micronutrients and organic sources of nutrients in different combinations under varied irrigation levels to achieve sustainable hybrid sunflower productivity during winter in Gangetic plains of West Bengal.

MATERIALS AND METHODS

The experiment was conducted during winter of 2011-12 and 2012-13 on well drained alluvial soil (Entisols) at

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farmer's field of Madandanga village under Chakdaha block of Nadia district in West Bengal (23°22.221'N latitude, 88°22.221'E longitude and 12.0 m amsl) under typical sub-tropical climate. Maximum and minimum temperature fluctuated between 33.9 and 10.1°C in winter 2011-2012 and 36 and 6.9°C in winter 2012-2013. Relative humidity prevailed between 99 and 33% in winter 2011-2012, and 98 and 31% in winter 2012-2013. The rainfall during the experimental period (November to March) was 68.8 (4 rainy days) and 18.2 mm (3 rainy days) in winter 2011-2012 and winter 2012-2013, respectively. The soil (0-30cm) of the experimental site was clay loam in texture, non-saline (EC 0.29 dS/m) with pH 6.89, organic carbon 0.42%, available N 175.4 kg/ha, available P 27.5 kg/ha, available K 108.1 kg/ha, available S 27.0 kg/ha and available B 1.89 kg/ha.

The experiment was laid out in split-plot design, assigning three irrigation levels (I_{30} , one at 30 DAS; $I_{30/60}$, two at 30 and 60 DAS; $I_{30/60/80}$, three at 30, 60 and 80 DAS) in the main plot and seven fertilizer treatments [F_1 , Farmer fertilizer practice/ FFP (60-30-30 kg N-P₂O₅-K₂O/ha); F_2 , Recommended dose of fertilizer/ RDF (80-40-40 kg N-P₂O₅-K₂O/ha); F_3 , RDF + boron @ 1.5 kg/ha; F_4 , RDF + sulphur @ 25 kg/ha; F_5 , RDF + boron @ 1.5 kg/ha + sulphur @ 25 kg/ha; F_6 , RDF + farmyard manure @ 5 t/ha; F_7 , RDF + vermicompost @ 5 t/ha] in the sub-plots. 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 19th November in first year and 20th November in second year, at a spacing of 60 cm × 30 cm (55555 plants/ha). The net plot size was 4m × 3m. The nutrients (NPK) were provided to the crop as per treatment details through urea (46% N), di-ammonium 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 prior to sowing in each plot. The N fertilizer was applied in three splits; 50% before sowing, 25% at 30 DAS and 25% at 45 DAS. Both FYM and VC were surface broadcasted 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. Two hand weeding (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 of water. In addition, Pride (Acetamiprid 20% SP) was sprayed @ 3 g/10 litres of water at 50 DAS for controlling white fly. The plants were cut at the base after attaining harvest maturity (120 DAS).

For determination of oil and fatty acid content, standard procedures were followed (AOAC 2005). Saponification value and iodine value were estimated following the

standard methods given by Association of Official Analytical Chemists (AOAC 2005). Plant samples from each treatment were collected, oven dried, and ground for analysing total recoveries of N, P, K, S and B at harvest, as per standard methods.

The data obtained on the different growth, yield and nutrient uptake were analysed 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.

RESULTS AND DISCUSSION

Yield, irrigation water productivity (IWP) and oil content of hybrid sunflower: 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 1). In contrary, the water applied through single irrigation probably was not enough to fully compensate the crop water requirement for normal plant production. Application of $N_{80}P_{40}K_{40}B_{1.5}S_{25}$ produced 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 1). Full irrigation ($I_{30/60/80}$) produced 45.2% more oil yield compared to the deficit-irrigated treatment (I_{30}). The elevated yield level under ample moisture is a plausible explanation for the observed increased oil yield (Banerjee *et al.* 2014). The oil yield of tested cultivar (Aditya) was significantly and synergistically increased by the application of $N_{80}P_{40}K_{40}B_{1.5}S_{25}$, accounting 46.8% more than that obtained with FFP (Table 1); however, it was statistically at par with oil yields under treatments $N_{80}P_{40}K_{40}B_{1.5}$ and $N_{80}P_{40}K_{40}S_{25}$.

The severe drought stress treatment (I_{30}) had greater IWP than other irrigation treatments (Table 1). 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 might be due to increased deep water percolation and evaporation. 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 $N_{80}P_{40}K_{40}S_{25}$. Average seed oil percentage was greater when grown with three irrigations (0.6% more than that obtained with single irrigation, respectively), leaving no significant difference with $I_{30/60}$ levels (Table 1). 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 1). Irrigation × fertilizer interaction had significant effect on oil content (Table 1). The higher values of oil content were observed to be in seeds obtained in plots fertilized with $N_{80}P_{40}K_{40}B_{1.5}S_{25}$ under two ($I_{30/60}$) and three irrigations ($I_{30/60/80}$); however, the values were statistically at par among themselves.

Table 1 Yield, irrigation water productivity and oil content of hybrid sunflower cv. Aditya as influenced by irrigation and fertilizer levels (mean data of 2 years)

Treatment	Seed yield (t/ha)	Stalk yield (t/ha)	Oil yield (kg/ha)	IWP (kg/ha-mm)
<i>Irrigation levels (I)</i>				
I ₃₀	1.27	4.11	499.40	25.34
I _{30/60}	1.56	5.20	618.05	15.59
I _{30/60/80}	1.83	7.35	725.15	12.20
SEm±	0.03	0.34	15.53	0.41
CD (P = 0.05)	0.12	1.13	50.66	1.36
<i>Fertilizer levels (F)</i>				
N ₆₀ P ₃₀ K ₃₀ (FFP)	1.27	4.37	484.50	14.23
N ₈₀ P ₄₀ K ₄₀ (RDF)	1.42	5.03	545.45	16.32
N ₈₀ P ₄₀ K ₄₀ B _{1.5}	1.64	5.92	652.80	18.65
N ₈₀ P ₄₀ K ₄₀ S ₂₅	1.69	6.09	679.40	19.21
N ₈₀ P ₄₀ K ₄₀ B _{1.5} S ₂₅	1.76	6.47	711.35	20.23
N ₈₀ P ₄₀ K ₄₀ FYM ₅	1.54	5.38	606.45	17.51
N ₈₀ P ₄₀ K ₄₀ VC ₅	1.57	5.62	619.35	17.81
SEm±	0.05	0.24	22.10	0.79
CD (P = 0.05)	0.15	0.68	62.32	2.23
<i>Oil content (%)</i>				
<i>Fertilizer levels (F)</i>		<i>Irrigation levels (I)</i>		
	I ₃₀	I _{30/60}	I _{30/60/80}	Mean
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±	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; DAS, Days after sowing; IWP, Irrigation water productivity; NS, non-significant. Subscript digits signify respective timing of irrigation in DAS, dose of inorganic nutrients in kg/ha and organic manures in t/ha.

Oil quality of hybrid sunflower: The proportion of linoleic acid and palmitic acid was greater when provided with drought variant (I₃₀), and it was significantly 0.7 and 9.6% higher than ample irrigation (I_{30/60/80}), respectively (Table 2). The trend was just reversing for oleic acid and stearic acid concentrations, while the proportions of these two fatty acid constituents were generally greater at higher irrigation frequency (1.7 and 8.2% more than those values at single irrigation, respectively). Safer oil quality with respect to significantly lower saponification value and higher iodine value was obtained with ample irrigation (I_{30/60/80}), accounting 0.4% less and 0.4% more when provided with drought variant (I₃₀). Fertilizer also had significant effect on fatty acid compositions (Table 2). The proportions of both linoleic and oleic acids was greater when the tested cultivar (Aditya) grown with N₈₀P₄₀K₄₀B_{1.5}S₂₅, accounting 7.7 and 10.8% more than that obtained with FFP, respectively. At the same fertilizer management practice, the proportions of both palmitic and stearic acid were lowest (27.7 and 27.1% less when compared with FFP, respectively). Compared to FFP, fertilization with B, S and their combination significantly reduced saponification value and increased iodine value. Moreover, significantly lowest saponification value and highest iodine value was obtained with N₈₀P₄₀K₄₀B_{1.5}S₂₅ (2.7% less and 3.3% more when provided with FFP, respectively) while making the oil safe for human consumption.

The interaction of irrigation × fertilizer had a significant effect on fatty acid constituents (Table 2). The values were greatest in seeds obtained with N₈₀P₄₀K₄₀B_{1.5}S₂₅ under I₃₀ (for linoleic acid) and I_{30/60} treatments (for oleic acid). On the contrary, the proportions of SFAs were lowest with same fertilizer management practices under I_{30/60/80} (for palmitic acid) and I₃₀ treatments (for stearic acid). The other two quality indicators, viz. saponification value and iodine value were also significantly influenced by irrigation × fertilizer interaction. The lowest saponification value of sunflower oil was obtained with N₈₀P₄₀K₄₀B_{1.5}S₂₅ under three irrigations (I_{30/60/80}). The iodine value was found to be higher with N₈₀P₄₀K₄₀B_{1.5}S₂₅ at all irrigation levels, and the variation was non-significant. However, the maximum iodine value was obtained at I_{30/60/80} levels with N₈₀P₄₀K₄₀B_{1.5}S₂₅ which was statistically at par with N₈₀P₄₀K₄₀S₂₅. The higher value for this index was found when the crop fertilized with N₈₀P₄₀K₄₀B_{1.5}S₂₅ at all irrigation levels, in the order of I_{30/60/80} > I_{30/60} > I₃₀.

Nutrient uptake in hybrid sunflower and available nutrient status in post-harvest soil: 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 I₃₀) (Table 3). Total N and S uptake was significantly higher when the tested cultivar grown with N₈₀P₄₀K₄₀B_{1.5}S₂₅ (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 N₈₀P₄₀K₄₀S₂₅ (Table 3). Furthermore, total P and K uptake was higher when the tested cultivar

Table 2 Interaction effect of irrigation and fertilizer levels on quality indicators of sunflower oil (mean data of 2 years)

Fertilizer levels (F)	Linoleic acid content (%)				Oleic acid content (%)				Palmitic acid content (%)			
	Irrigation levels (I)			Mean	Irrigation levels (I)			Mean	Irrigation levels (I)			Mean
	I ₃₀	I _{30/60}	I _{30/60/80}		I ₃₀	I _{30/60}	I _{30/60/80}		I ₃₀	I _{30/60}	I _{30/60/80}	
N ₆₀ P ₃₀ K ₃₀ (FFP)	62.16	62.86	62.07	62.36	19.53	19.26	19.82	19.54	8.86	8.54	8.17	8.52
N ₈₀ P ₄₀ K ₄₀ (RDF)	63.28	63.78	63.55	63.54	19.84	20.19	19.91	19.98	8.71	8.19	8.07	8.32
N ₈₀ P ₄₀ K ₄₀ B _{1.5}	66.24	64.99	65.22	65.48	20.43	20.92	21.43	20.93	7.18	7.01	6.71	6.97
N ₈₀ P ₄₀ K ₄₀ S ₂₅	67.41	66.67	66.00	66.69	21.57	21.64	21.50	21.57	7.05	6.87	6.42	6.78
N ₈₀ P ₄₀ K ₄₀ B _{1.5} S ₂₅	67.55	67.16	66.86	67.19	21.61	21.75	21.62	21.66	6.96	6.72	6.33	6.67
N ₈₀ P ₄₀ K ₄₀ FYM ₅	64.46	63.90	64.38	64.25	19.91	20.31	20.50	20.24	7.95	7.27	7.14	7.45
N ₈₀ P ₄₀ K ₄₀ VC ₅	64.56	63.96	64.41	64.31	20.27	20.58	20.73	20.53	7.84	7.12	6.94	7.30
Mean	65.09	64.76	64.64	-	20.45	20.66	20.79	-	7.79	7.39	7.11	-
	SEm±	CD (P = 0.05)			SEm±	CD (P = 0.05)			SEm±	CD (P = 0.05)		
I	0.009	0.028			0.008	0.027			0.004	0.012		
F	0.019	0.052			0.009	0.026			0.012	0.024		
F at same or different I	0.032	0.091			0.016	0.045			0.015	0.042		
I at same or different F	0.031	0.094			0.017	0.053			0.014	0.047		
Fertilizer levels (F)	Stearic acid content (%)				Saponification value (mg/g)				Iodine value (cg/g)			
	Irrigation levels (I)			Mean	Irrigation levels (I)			Mean	Irrigation levels (I)			Mean
	I ₃₀	I _{30/60}	I _{30/60/80}		I ₃₀	I _{30/60}	I _{30/60/80}		I ₃₀	I _{30/60}	I _{30/60/80}	
N ₆₀ P ₃₀ K ₃₀ (FFP)	5.30	5.37	5.63	5.44	194.15	194.45	193.80	194.13	147.65	148.40	147.60	147.88
N ₈₀ P ₄₀ K ₄₀ (RDF)	5.20	5.20	5.41	5.27	193.10	193.00	193.15	193.09	148.20	148.95	148.60	148.58
N ₈₀ P ₄₀ K ₄₀ B _{1.5}	4.22	4.36	4.86	4.48	190.30	190.15	189.55	190.00	150.75	151.75	151.50	151.33
N ₈₀ P ₄₀ K ₄₀ S ₂₅	4.19	4.27	4.68	4.38	190.05	189.60	189.35	189.67	151.95	152.05	152.75	152.25
N ₈₀ P ₄₀ K ₄₀ B _{1.5} S ₂₅	4.16	4.19	4.48	4.28	189.35	189.10	188.60	189.02	152.65	152.75	152.85	152.75
N ₈₀ P ₄₀ K ₄₀ FYM ₅	4.77	4.94	5.11	4.94	192.35	191.45	190.80	191.53	149.65	149.40	150.10	149.72
N ₈₀ P ₄₀ K ₄₀ VC ₅	4.70	4.83	5.01	4.84	191.35	191.05	189.90	190.77	149.75	150.35	151.30	150.47
Mean	4.65	4.74	5.03	-	191.52	191.26	190.74	-	150.09	150.53	150.67	-
	SEm±	CD (P = 0.05)			SEm±	CD (P = 0.05)			SEm±	CD (P = 0.05)		
I	0.003	0.011			0.043	0.140			0.054	0.174		
F	0.008	0.023			0.066	0.066			0.071	0.200		
F at same or different I	0.014	0.040			0.114	0.320			0.123	0.346		
I at same or different F	0.014	0.044			0.114	0.362			0.126	0.370		

FFP, Farmer's fertilizer practice; RDF, Recommended dose of fertilizer. Subscript digits signify respective timing of irrigation in DAS, dose of inorganic nutrients in kg/ha and organic manures in t/ha.

grown with N₈₀P₄₀K₄₀S₂₅ (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 N₈₀P₄₀K₄₀B_{1.5}S₂₅ and N₈₀P₄₀K₄₀VC₅. Total B uptake was higher when the tested cultivar grown with N₈₀P₄₀K₄₀B_{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 N₈₀P₄₀K₄₀B_{1.5}S₂₅.

The values for N, P, K, B and S content in soil at harvest in plots with three irrigations (I_{30/60/80}) were significantly higher than other values obtained with reduced irrigation (34.6, 42.6, 20.7, 29.7 and 9.1% more than the plots irrigated

with I₃₀ respectively). At harvest, the values for above chemical properties in soil were declined with reduced irrigation (I_{30/60}) and the differences being non-significant for available B content. The status of available N, P, K, B and S in soil was significantly influenced by different fertilizer levels (Table 3). Treatment with N₈₀P₄₀K₄₀B_{1.5} showed significantly higher available P and B content over other treatments (23.7 and 83.8% more than the FFP plots, respectively); however, it was statistically at par with N₈₀P₄₀K₄₀, N₈₀P₄₀K₄₀FYM₅ and N₈₀P₄₀K₄₀VC₅ for available P and N₈₀P₄₀K₄₀B_{1.5}S₂₅ for available B content in post-harvest soil. Application of N₈₀P₄₀K₄₀VC₅ showed

Table 3 Total nutrient uptake by hybrid sunflower and available nutrient content of post-harvest soil as influenced by different irrigation and fertilizer levels (mean data of two years)

Treatment	Total nutrient uptake					Available nutrient content		
	Total N (kg/ha)	Total P (kg/ha)	Total K (kg/ha)	Total B (g/ha)	Total S (kg/ha)	Available P (kg/ha)	Available K (kg/ha)	Available B (kg/ha)
<i>Irrigation levels (I)</i>								
I ₃₀	34.4	11.6	34.9	124.4	13.4	20.9	67.5	2.83
I _{30/60}	51.7	18.2	44.0	167.5	21.5	24.6	74.3	3.57
I _{30/60/80}	66.2	30.6	63.6	309.3	38.3	29.8	81.5	3.67
SEm±	3.45	1.44	3.86	13.43	1.52	1.15	1.96	0.16
CD (P = 0.05)	11.26	4.69	12.60	43.82	4.97	3.77	6.37	0.52
<i>Fertilizer levels (F)</i>								
N ₆₀ P ₃₀ K ₃₀ (FFP)	34.0	15.0	33.5	139.5	16.9	22.8	66.2	2.65
N ₈₀ P ₄₀ K ₄₀ (RDF)	41.7	16.7	35.9	195.3	20.1	24.8	75.6	2.59
N ₈₀ P ₄₀ K ₄₀ B _{1.5}	54.3	18.6	48.6	245.1	24.6	28.2	76.7	4.87
N ₈₀ P ₄₀ K ₄₀ S ₂₅	60.9	24.4	60.1	198.3	29.5	23.6	73.7	3.63
N ₈₀ P ₄₀ K ₄₀ B _{1.5} S ₂₅	66.2	21.6	55.6	242.3	31.3	24.2	74.3	4.28
N ₈₀ P ₄₀ K ₄₀ FYM ₅	45.9	20.9	46.1	205.2	23.2	25.4	77.9	2.78
N ₈₀ P ₄₀ K ₄₀ VC ₅	52.5	23.8	52.7	177.2	25.3	26.7	76.7	2.72
SEm±	2.47	1.09	3.39	9.62	1.08	1.39	2.25	0.28
CD (P = 0.05)	6.98	3.07	9.56	27.12	3.07	3.94	6.35	0.81
<i>Fertilizer levels (F)</i>								
<i>Available N (kg/ha)</i>					<i>Available S (kg/ha)</i>			
<i>Irrigation levels (I)</i>					<i>Irrigation levels (I)</i>			
<i>Mean</i>					<i>Mean</i>			
	I ₃₀	I _{30/60}	I _{30/60/80}		I ₃₀	I _{30/60}	I _{30/60/80}	
N ₆₀ P ₃₀ K ₃₀ (FFP)	109.1	133.0	154.9	132.3	21.60	22.55	19.85	21.34
N ₈₀ P ₄₀ K ₄₀ (RDF)	120.3	152.7	174.6	149.2	20.85	19.75	24.95	21.85
N ₈₀ P ₄₀ K ₄₀ B _{1.5}	127.6	151.9	168.5	149.3	20.25	22.45	25.10	22.60
N ₈₀ P ₄₀ K ₄₀ S ₂₅	128.8	158.1	167.5	151.5	24.80	29.45	28.05	27.44
N ₈₀ P ₄₀ K ₄₀ B _{1.5} S ₂₅	127.6	160.2	174.0	153.9	25.15	26.70	25.60	25.82
N ₈₀ P ₄₀ K ₄₀ FYM ₅	140.2	166.0	193.1	166.4	22.20	22.65	22.75	22.54
N ₈₀ P ₄₀ K ₄₀ VC ₅	156.2	170.8	192.9	173.3	20.60	20.90	23.30	21.60
Mean	130.0	156.1	175.0	-	22.21	23.50	24.23	-
	SEm±	CD			SEm±	CD		
		(P = 0.05)				(P = 0.05)		
I	0.28	0.92			0.06	0.06		
F	0.92	1.29			0.12	0.35		
F at same or different I	0.79	2.25			0.21	0.61		
I at same or different F	0.79	2.57			0.20	0.64		

FFP, Farmer's fertilizer practice; RDF, Recommended dose of fertilizer; NS, non-significant. Subscript digits signify respective timing of irrigation in DAS, dose of inorganic nutrients in kg/ha and organic manures in t/ha.

significant improvement in available N content in post-harvest soil over other fertilizer levels (31.0% more than the plots fertilized with FFP). All fertilizer levels exerted significant positive effect on available K content of post-harvest soil, and the values were statistically at par except FFP. However, the highest value was obtained in plots

receiving N₈₀P₄₀K₄₀FYM₅ (17.7% more than the plots fertilized with FFP), closely followed by its value in plots receiving N₈₀P₄₀K₄₀VC₅ and N₈₀P₄₀K₄₀B_{1.5}. Available S status was significantly improved with N₈₀P₄₀K₄₀S₂₅ and the value was 28.6% higher than the available S content in FFP plots (Table 3). The irrigation × fertilizer interaction

had a significant effect on available N and S content in post-harvest soil (Table 3). The available N content was highest in plots fertilized with $N_{80}P_{40}K_{40}FYM_5$ under highest irrigation frequency ($I_{30/60/80}$). However, the above treatment had no significant difference with $N_{80}P_{40}K_{40}VC_5$ with respect to available N content. The treatment with $N_{80}P_{40}K_{40}S_{25}$ in combination with two irrigations ($I_{30/60}$) showed significantly higher available S status of post-harvest soil.

Thus fertilization with RDF (80 kg N, 40 kg P_2O_5 and 40 kg K_2O /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 recommended to obtain higher grain yield and oil content with better quality in winter of West Bengal.

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