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Yield, quality, water productivity and economic assessment of sweet corn under irrigation and nitrogen management in humid tropical climate

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Abstract
A field experiment was conducted during three consecutive winter seasons of 2013-14 to 2015-16 in the Indo-Gangetic plains encompassing humid tropical climatic region to study four irrigation regimes (gravity drip at 1.0, 0.8 and 0.6 ETc and surface irrigation) and four nitrogen management (100% RDN, 75% RDN + 25% RDN as vermicompost, 75% RDN + 25% RDN as FYM and 75% RDN + 25% RDN as mustard oilcake) on sweet corn. The results showed that surface irrigation with 75% RDN + 25% RDN as vermicompost was found the best treatment combination for maximum yield and economic realization which being competitive with drip irrigation at 1.0 ETc with 75% RDN + 25% RDN as vermicompost. Relatively higher quality parameters and moderate water productivity were observed with drip irrigation schedule at 1.0 ETc. The findings portray the precise planning and efficient management of available water and nitrogen resources for sweet corn growers.

Keywords: Surface and drip irrigation, sweet corn, crop evapotranspiration, water productivity, economics

Introduction
Sweet corn (*Zea mays* L var. *saccharata* Sturt) also known as sugar corn is a hybridized variety of maize having higher sucrose content, kernel protein and many minerals with delicious taste. It is the most versatile high value crop grown extensively in temperate to tropical climatic regions of the world throughout the year. It is gaining popularity among the rural and peri-urban farmers due to its short duration and high economic returns. The sweet corn industry is flourishing because of increasing domestic consumption, national and international demand. Besides providing green cobs, it also produces good quality palatable fodder for milch animals (Abebe *et al*., 2016) [1]. It occupies an area of 11.9 million hectares with production of 22.3 million tonnes in India. However, the crop productivity is only 2.5 tonnes per hectare which is much below the global average. It an exhaustive deep rooted crop and consumes high quantities of water and nutrients from soil. The corn plant is very sensitive to water stress and water excess as well as nitrogen constraint during any physiological stages which eventually reflects in reduced yield (Mathukia *et al*., 2014; Datta *et al*., 2019) [12,7]. The judicious use of limited water and nutrient resources is the key to meet the daily water and nutrient demands for sustainable crop production (Okumura *et al*., 2011) [15]. Drip irrigation is an advanced water management technology because it directly applies precise amounts of water in several splits in the vicinity of crop root zone to maintains optimum soil water balance matching the daily requirement of water and increases higher water use efficiency (Abd El-Wahed and Ali, 2013) [2]. It is superior to other methods of irrigation owing to minimal soil evaporation and deep percolation loss (Vijayakumar *et al*., 2010; Deshmukh and Hardaha, 2014) [19,8]. Among the nutrient inputs, nitrogen is the key macro element due to its profound impact on vegetative and reproductive growth of the sweet corn and its adequate availability in soil throughout the growing stages is indispensable for sustaining yield (Chauhan and Patel, 2011) [6]. Nitrogen plays an important role in synthesis of chlorophyll, amino acids and other organic compounds of physiological significance in plant system (Havlin *et al*., 2005) [10]. The increase in mineral nitrogen supply can improve yield, but simultaneously reduces its use efficiency and can have adverse impacts on the environment in relation to soil, air and groundwater pollution (Muhumed *et al*., 2014) [14]. In view of increasing cost of nitrogenous fertilizers, the organic manures can be partially substituted to

mitigate the crop nitrogen demand and to curtail the cost on the investment of expensive chemical fertilizers (Rodríguez *et al*., 2008) [18]. The integrated nitrogen management comprising both mineral fertilizer and organic manure is an alternative viable option to achieve the sustained yield and quality, besides improving soil health and economic profitability (Wailare, 2014) [20]. The acceptance or rejection of any adoptable technology to the farming community is primarily dependent on its simplicity to handle and high monetary returns in terms of net returns and benefit-cost ratio.

In the Indo-Gangetic plains region, the sweet corn is an emerging crop and its popularity is fast growing due to its sweet taste and high nutritional quality. The farmers usually grow the crop with conventional surface irrigation and inadequate mineral nitrogenous fertilization resulting in low marketable yield and quality of produce. Keeping these points in view, the present investigation was undertaken with the objective of finding out the best treatment combination of irrigation and nitrogen management for obtaining higher yield, quality and income of sweet corn.

Materials and Methods

A field experiment was conducted on sweet corn during the three consecutive winter season of 2013-14 to 2015-16 at Central Research Farm, Bidhan Chandra Krishi Viswavidyalaya, Gayeshpur, West Bengal, India belonging to the Indo-Gangetic plains region under humid tropical climate. The area is located at 22^{0}58'31" N latitude and 88^{0}26'20" E longitude with an altitude of 9.75 m above the MSL. The mean monthly temperature varied from 37.6 to 25.4 ^{0}C in summer and 23.7 to 10.5 ^{0}C in winter. Mean annual rainfall is 1500 mm and pan evaporation loss ranged from 1.1 to 4.9 mm day^{-1}. The soil is sandy loam in texture (Typic Fluvaquept) with bulk density 1.49 Mg m^{-3}, organic C 5.6 g kg^{-1}, pH 6.9, EC 0.25 dS m^{-1} and low in available N (169.6 kg ha^{-1}), medium in available P (32.5.3 kg ha^{-1}) and available K (148.5 kg ha^{-1}).

The experiment comprised sixteen treatment combinations consisting of four irrigation regimes (gravity drip irrigation at 1.0, 0.8, 0.6 of the crop evapotranspiration (ETc) and conventional surface irrigation at 50 mm depth) allotted in the main plots and four nitrogen management (100% RDN as mineral fertilizer, 75% RDN as mineral fertilizer + 25% RDN as vermicompost, 75% RDN as mineral fertilizer + 25% RDN as FYM and 75% RDN as mineral fertilizer + 25% RDN as mustard oilcake) in sub-plots was laid out in a split plot design with three replications. The gross plot size was 5.5 m × 4.0 m and net plot size was 4.5 m × 3.0 m. Disease free healthy seeds of sweet corn hybrid 'Sugar 75' @ 10 kg ha^{-1} were sown at a depth of 2-3 cm with 75 cm × 30 cm geometry during first week of November and harvested during second week of March in each experimental year. The uniform dose of 60 kg P_2O_5 ha^{-1} and 40 kg K_2O ha^{-1} was applied in all plots as basal in the form of single superphosphate and muriate of potash, respectively at the time of sowing. The recommended dose of nitrogen (RDN) @ 120 kg N ha^{-1} as urea was applied as per prescribed schedules in three equal splits i.e., first at sowing, second at vegetative (30 days after sowing) and third at flowering (60 DAS) stage. The organic sources of N viz., vermicompost (1.44% N, 1.5% P_2O_5 and 1.2% K_2O), farmyard manure (0.5% N, 0.2% P_2O_5 and 0.5% K_2O) and mustard oilcake (5.2% N, 1.9% P_2O_5 and 1.2% K_2O) were incorporated during the final land preparation and mixed up well with the soil. The standard agronomic and plant protection measures were adopted uniformly in all plots. The total soluble solids (TSS) of cobs were determined using a hand refractometer while the total and reducing sugar contents of corns were estimated by the standard method (AOAC, 1990) [4].

Surface irrigation each of 5 cm depth at 12-13 days interval and gravity drip irrigation scheduling at 1.0, 0.8 and 0.6 of ETc every 3 days interval was imposed. A common irrigation at 2 cm depth was applied in all treatments just after sowing for proper seed germination and uniform plant establishment. The irrigation water requirement for drip system was computed on the basis of pan evaporation, crop coefficient, canopy area and wetted area factor. Irrigation was given when ETc reached at the desired level. The seasonal actual crop evapotranspiration (ETa) was computed using the field water balance equation as $ETa = I + Re \pm \Delta S$; where, ETa is the actual crop evapotranspiration (mm), I is the irrigation water applied (mm), Re is the effective rainfall (mm) and $\pm\Delta S$ the change in soil water storage in rooting depth (mm). Water productivity (WP) was determined to evaluate the benefit of the applied water through economic crop production. The value of WP (kg m^{-3}) was computed by dividing green cob yield (kg ha^{-1}) with seasonal actual crop evapotranspiration (m^3 ha^{-1}).

Benefit-cost ratio analysis was carried out to examine the economic feasibility of different irrigation and nitrogen management treatment combinations. The seasonal cost of gravity drip system with 4 HP water pump included 4% depreciation, 10% interest rate and 2% for repair and maintenance calculated from the fixed cost. The life span of the gravity drip irrigation system was considered to be 10 years. The cost of cultivation accommodated the expenses incurred on field preparation, sowing, intercultural operation, harvesting and processing and cost of seed, mineral fertilizers, vermicompost, FYM, mustard oilcake including application, crop protection measures and irrigation charges. The gross returns were worked out by accounting the prevailing average market price of the produce during the experimental period. The net returns were estimated by deducting the total cost of cultivation from the gross returns. The benefit-cost ratio (BCR) of each treatment was calculated by dividing the net return with the cost of cultivation. The green cobs and green fodder yield data obtained were subjected to analysis of variance and the least significant difference (LSD) values were used to compare treatment means at $p < 0.05$.

Results and Discussions

Green cob yield

Differential irrigation regimes and application of fertilizer nitrogen either sole or in combination with various organic nitrogen sources and their mutual interactions had significant influences on the green cob yield in each experimental year (Table 1). Averaging over three years and nitrogen management, significantly the maximum cob yield (6.91 t ha^{-1}) was obtained with surface irrigation and gravity drip irrigation at 1.0 ETc and both the treatment were superior over that with moderate deficit drip irrigation at 0.8 ETc (6.22 t ha^{-1}) and higher deficit drip irrigation at 0.6 ETc (5.41 t ha^{-1}). Higher soil water stress due to deficit irrigation regime might have restricted the rate of transpiration, stomatal opening and reduced $^{14}CO_2$ fixation resulting into low photosynthetic activity, leaf area expansion and stunted growth, thereby led to decreased cob yield (Karam *et al*. 2002) [11]. On the other hand, no soil water stress due to the higher availability of soil water imposed through surface irrigation or drip irrigation at 1.0 ETc might have helped for keeping the plant photosynthetically active resulting into proper growth and development and ultimately reflects in maximum yield (Rathore and Singh, 2009; Acharya *et al*. 2013) [17,3]. The improvement in cob yield with adequate or excess irrigation level was reported by Dutta *et al*. (2015) [9]. Marked reduction in yield due to soil water deficit condition was also recorded (Moser *et al*., 2006) [13].

The combined application of 75% RDN as fertilizer + 25% RDN as vermicompost averaging over the irrigation regimes recorded significantly the maximum cob yield (6.96 t ha^{-1}). The values obtained with 100% RDN as fertilizer (6.23 t ha^{-1}) and 75% RDN as fertilizer + 25% RDN through FYM (6.38 t ha^{-1}) were moderate. Minimum cob yield (5.89 t ha^{-1}) was found with 75% RDN as fertilizer + 25% RDN as mustard oilcake (MOC). This amply suggests that the rate of nitrogen release from mineralization of farmyard manure and mustard oil cake is too slow and inadequate to meet the plant nitrogen requirement at all growth stages. However, chemical N fertilization along with vermicompost at 3:1 proportion rendered the highest cob yield, possibly due to steady and uninterrupted N release from the substrates used all through the growth stages (Rashedi and Ghosh, 2016) [16].

The interaction effect between irrigation and nitrogen management showed that maximum cob yield of 8.43 t ha^{-1} was obtained with surface irrigation coupling with 75% RDN as fertilizer and 25% RDN as vermicompost (I_4N_2) and the value was found to be superior over other treatment combinations. Next higher cob yield of 7.58 t ha^{-1} was recorded by surface irrigation in conjunction with 75% RDN as fertilizer and 25% RDN as FYM (I_4N_3) and of 7.38 t ha^{-1} by drip irrigation at 1.0 ETc accompanying with 75% RDN as fertilizer and 25% RDN as vermicompost (I_1N_2). The cob yield was found to be lowest (4.91 t ha^{-}) with higher deficit drip irrigation at 0.6 ETc complemented with 75% RDN as fertilizer and 25% RDN as MOC (I_3N_4). The higher availability of water in root zone under surface irrigation method provided with balanced supply of nitrogen through fertilizer-vermicompost combination might have stimulated the better root elongation and proliferation, thereby facilitating more water and nitrogen abstraction from soil and increased yield (Bozkurt *et al*., 2009) [5].

Cob quality

The quality parameters such as reducing sugar, total sugar and total soluble solids of corn were significantly affected by drip and surface method of irrigation and nitrogen management (Table 2). Relatively the higher reducing sugar (6.42%), total sugar (20.7%) and TSS (7.4%) contents was found with drip irrigation at 1.0 ETc whereas the lower quality attributes with the corresponding value of 5.92%, 18.9% and 6.5% was recorded with surface irrigation. Higher total soluble solid content in grains under drip irrigation at 1.0 ETc in comparison with surface irrigation was probably due to the relatively higher soil water stress condition. The results are in conformity with the observations of Datta *et al*. (2019) [7]. Likewise, relatively higher value of reducing sugar (6.29%) and TSS (7.31%) was obtained with 75% RDN as fertilizer + 25% RDN as vermicompost and that of total sugar (21.1%) with 75% RDN as fertilizer + 25% RDN as MOC. On the contrary, 100% RDN as mineral fertilizer produced the least quality parameters.

Seasonal crop water use and water productivity

The depth of irrigation water applied in conventional surface irrigation and gravity drip irrigation scheduling at 1.0, 0.8 and 0.6 of ETc was 270, 162, 134 and 105 mm, respectively. The seasonal actual crop evapotranspiration (ETa) including irrigation water, effective rainfall and soil profile water in gravity drip irrigation scheduling at 1.0, 0.8 and 0.6 of ETc was 245.6, 203.2 and 168.3 mm, respectively. The corresponding value for surface irrigation was 342.2 mm. The highest water productivity (3.22 kg m^{-3}) was obtained with drip irrigation at 0.6 ETc, whereas the lowest WP (2.02 kg m^{-3}) was found with surface irrigation. This indicates that WP of plant decreased with incremental water supply. The lesser WP in surface irrigation could be due to the loss of water in soil evaporation and deep percolation. Likewise, application of 75% RDN as fertilizer + 25% RDN as vermicompost recorded the highest WP (2.99 kg m^{-3}). The lowest WP (2.6 kg m^{-3}) was displayed with 75% RDN as fertilizer + 25% RDN as MOC. The interactive effects between irrigation and nitrogen management revealed that maximum WP (3.6 kg m^{-3}) was obtained with drip irrigation at 0.6 ETc with 100% RDN as fertilizer (I_3N_1) and minimum (1.64 kg m^{-3}) was recorded with surface irrigation along with 75% RDN as fertilizer + 25% N as MOC (I_4N_4).

Economic analysis

The total cost of cultivation, gross monetary returns, net monetary returns and benefit-cost (BCR) analysis under different irrigation regimes and nitrogen management on sweet corn is presented in Table 3. The results in general showed that total cost of production increased with increase in irrigation water supply and nitrogen addition using different organic substrates. The cost of cultivation irrespective of nitrogen management was found maximum in drip irrigation at 1.0 ETc (₹25577 ha^{-1}) followed by 0.8 ETc (₹25449 ha^{-1}) and 0.6 ETc (₹25323 ha^{-1}), respectively. The corresponding figure for conventional surface irrigation was found minimum as ₹24722 ha^{-1}. The gross returns and net returns increased progressively due to increase in cob and fodder yields at each irrigation level supplemented with nitrogen addition through 75% RDN + 25% RDN as vermicompost, excepting drip irrigation at 0.6 ETc where 100% RDN through fertilizer registered the higher monetary returns than the other fertilizer-manurial N combinations. The gross returns as well as net returns values were comparatively lower at 1.0 ETc and 0.8 ETc under drip irrigation and in surface irrigation when complemented with 100% RDN or, 75% RDN + 25% RDN as FYM or MOC. Maximum gross returns (₹111734 ha^{-1}), net return (₹85585 ha^{-1}) and BCR (3.27) were obtained from surface irrigation with 75% RDN + 25% RDN as vermicompost (I_4N_2) which was followed by surface irrigation coupling with 75% RDN + 25% RDN as FYM (I_4N_3) with the corresponding value of ₹100747 ha^{-1}, ₹74667 ha^{-1} and 2.86, respectively. Drip irrigation at 1.0 ETc with 75% RDN + 25% RDN as vermicompost (I_1N_2) showed the moderate monetary values in respect of gross returns, net returns and BCR as ₹98084 ha^{-1}, ₹71102 ha^{-1} and 2.64, respectively. In drip irrigation system, comparatively higher BCR value (2.81) was obtained with irrigation schedule at 1.0 ETc in association with 100% RDN. The latter two treatments are likely to be useful under optimal to limited water supply condition. The higher monetary returns and BCR in surface irrigation supplemented with 75% RDN + 25% RDN as vermicompost was perhaps due to the sustenance of favourable water and nitrogen supply in root zone without soil water stress under uninterrupted N supply across the growth stages. Minimum values of gross returns, net returns and BCR were observed in higher soil water stress condition as a result of higher degree of deficit drip irrigation at 0.6 ETc endowed either with 75% RDN + 25% RDN through FYM (I_3N_3) or 75% RDN + 25% RDN through MOC (I_3N_4).

Table 1: Green cob yield, actual crop evapotranspiration (ETa) and water productivity (WP) of sweet corn under different irrigation schedules and nitrogen management for 2013-14 to 2015-16

Treatment	Green cob yield (t ha^{-1})				Average ETa* (mm)	Average WP (kg m^{-3})
	2013-14	2014-15	2015-16	Pooled		
Irrigation schedule (I)						
I_1	6.80	6.83	7.11	6.91	245.56	2.82
I_2	5.93	5.95	6.80	6.22	203.16	3.06
I_3	4.90	4.91	6.41	5.41	168.25	3.22
I_4	6.88	6.64	7.20	6.91	342.18	2.02
CD (0.05)	0.28	0.31	0.23	0.27	-	-
Nitrogen management (N)						
N_1	5.80	5.83	7.06	6.23	240.39	2.78
N_2	6.60	6.99	7.29	6.96	239.58	2.99
N_3	5.90	6.22	7.01	6.38	239.62	2.75
N_4	6.20	5.29	6.16	5.89	239.56	2.60
CD (0.05)	0.33	0.37	0.25	0.32	-	-
Interaction (I × N)						
I_1N_1	6.40	6.45	7.31	6.72	245.66	2.74
I_1N_2	7.20	7.41	7.53	7.38	245.55	3.01
I_1N_3	6.20	7.23	7.22	6.88	245.51	2.80
I_1N_4	7.40	6.22	6.40	6.67	245.52	2.72
I_2N_1	5.70	5.73	6.97	6.13	203.12	3.02
I_2N_2	5.10	7.33	7.17	6.53	203.18	3.21
I_2N_3	5.60	5.11	6.92	5.88	203.19	2.89
I_2N_4	7.30	5.62	6.14	6.35	203.14	3.13
I_3N_1	5.80	5.81	6.54	6.05	168.05	3.60
I_3N_2	4.80	4.92	6.81	5.51	168.36	3.27
I_3N_3	4.10	4.82	6.58	5.16	168.40	3.07
I_3N_4	4.90	4.11	5.72	4.91	168.20	2.92
I_4N_1	5.30	5.32	7.41	6.01	344.72	1.74
I_4N_2	9.30	8.32	7.66	8.43	341.25	2.47
I_4N_3	7.70	7.71	7.34	7.58	341.38	2.22
I_4N_4	5.20	5.22	6.41	5.61	341.38	1.64
CD (0.05)	0.48	0.50	0.46	0.48	-	-

I_1: drip irrigation at 1.0 ETc, I_2: drip irrigation at 0.8 ETc, I_3: drip irrigation at 0.6 ETc, I_4: conventional surface irrigation; N_1: 100% RDN as mineral fertilizer, N_2: 75% RDN as mineral fertilizer + 25% RDN as vermicompost, N_3: 75% RDN as mineral fertilizer + 25% RDN as FYM, N_4: 75% RDN as mineral fertilizer + 25% RDN as mustard oilcake; *including 20 mm pre-sowing irrigation for uniform seed germination, seedling emergence and crop establishment

Table 2: Effect of different irrigation schedules and nitrogen management on quality parameters of sweet corn (3-year pooled data)

Treatment	Reducing sugar (%)	Total sugar (%)	TSS (%)
Irrigation schedule (I)			
I_1	6.42	20.7	7.40
I_2	6.25	20.1	6.70
I_3	5.71	19.6	7.10
I_4	5.92	18.9	6.50
CD (0.05)	0.73	0.82	0.92
Nitrogen management (N)			
N_1	4.77	17.7	5.96
N_2	6.29	20.3	7.31
N_3	5.96	20.8	6.79
N_4	7.14	21.1	7.17
CD (0.05)	1.15	1.41	1.36

Table 3: Economic analysis of sweet corn under different irrigation schedules and nitrogen management

Treatment	Total cost of cultivation (₹ ha^{-1})	Gross returns from green cob (₹ ha^{-1})	Gross returns from green fodder (₹ ha^{-1})	Total gross returns (₹ ha^{-1})	Net returns (₹ ha^{-1})	Benefit-cost ratio
I_1N_1	23536	80640	8960	89600	66064	2.81
I_1N_2	26982	88560	9524	98084	71102	2.64
I_1N_3	26913	82560	8967	91527	64614	2.40
I_1N_4	24877	80040	8725	88765	63888	2.57
I_2N_1	23408	73596	8435	82031	58623	2.50
I_2N_2	26854	78372	7623	85995	59141	2.20
I_2N_3	26785	70512	7986	78498	51713	1.93
I_2N_4	24749	76224	8498	84722	59973	2.42

I_3N_1	23282	72612	8242	80854	57572	2.47
I_3N_2	26728	66120	7752	73872	47144	1.76
I_3N_3	26659	61968	7487	69455	42796	1.61
I_3N_4	24623	58908	7123	66031	41408	1.68
I_4N_1	22614	72132	8354	80486	57872	2.56
I_4N_2	26149	101100	10634	111734	85585	3.27
I_4N_3	26080	90984	9763	100747	74667	2.86
I_4N_4	24044	67284	7842	75126	51082	2.12

I_1: drip irrigation at 1.0 ETc, I_2: drip irrigation at 0.8 ETc, I_3: drip irrigation at 0.6 ETc, I_4: conventional surface irrigation; N_1: 100% RDN as mineral fertilizer, N_2: 75% RDN as mineral fertilizer + 25% RDN as vermicompost, N_3: 75% RDN as mineral fertilizer + 25% RDN as FYM, N_4: 75% RDN as mineral fertilizer + 25% RDN as mustard oilcake

Conclusion

Based on the above findings, it can be inferred that under plentiful water supply condition conventional surface irrigation with 5 cm depth each at 12-13 days interval in conjunction with 75% RDN as fertilizer and 25% RDN as vermicompost was found to be the best treatment combination for achieving maximum green cob yield, gross returns, net returns and benefit-cost ratio. However, under limited water supply condition gravity drip irrigation at 1.0 ETc coupling with 75% RDN as fertilizer and 25% RDN as vermicompost was the alternative option in deriving higher yield, monetary returns and moderate benefit-cost ratio. Drip irrigation system was found to improve the grain quality parameters in terms of TSS, total sugar and reducing sugar as compared with surface irrigation. The findings will portray the precise planning and efficient management of available water and nitrogen resources for sweet corn growers in this agro-climatic region.

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