



Improvement of physiological and productivity traits of Indian mustard (*Brassica juncea*) through micro-irrigation and fertigation under hot semi-arid eco-region

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ABSTRACT

The efficient irrigation and nutrient management was done through micro-irrigation along with fertigation and the effect was evaluated on gas exchange traits, photosynthesis, growth, yield attributes and seed productivity of Indian mustard [*Brassica juncea* (L.) Czernj and Coss.] crop during *rabi* season of 2010-11 and 2011-12 respectively, under semi arid conditions. The micro-sprinkler system (MS), drip irrigation (DS) and check basin (CB) irrigation systems were experimented with variable N fertigation levels (0, 40, 80 and 120 kg/ha). The micro irrigation systems, i.e. MS, DS significantly influenced dry weight, chlorophyll concentration, photosynthetic rate, internal CO₂ concentration (ICC), primary and secondary branches, main shoot length, total siliquae and 1000 seed weight. Micro-sprinkler irrigation (MS) irrigated mustard was observed on an average increase of 34 % and 23 % increase in seed yield was resulted due to drip irrigation over the two years. N-fertigation from N₀ to N₁₂₀ had significantly improved mustard yield attributes, seed and oil yield. Micro irrigations were also found economically viable option for irrigation in Indian mustard because of higher B: C ratio. Improvement in growth, physiological and yield attributes of mustard were ultimately enhanced seed and oil yield, irrigation water use efficiency, sustainability, yield index and production efficiency. Thus micro irrigation systems at every level of N fertigation out yielded the effect of check basin irrigation.

Key words: Agronomic efficiency, *Brassica juncea*, Drip irrigation, Irrigation water use efficiency, Micro-irrigation, Micro-sprinkler, Sustainability

Edible oil production in India meets only half of the domestic requirement. By 2050, India needs to produce 28.5 mt of vegetable oil for direct consumption (Vision 2050) and it is difficult to achieve at current status of resources, technology and management in Indian agriculture (Hegde 2012). Rapeseed-mustard is contributing maximum (32%) in edible oil production in the country with an area, production and productivity of 5.8 Mha, 6.3 mt and 1089 kg/ha respectively during 2014-15 (Anonymous 2016). The potential productivity of the improved varieties of is more than 2000 kg/ha, therefore huge untapped opportunities exist for doubling the seed productivity rapeseed-mustard. Efficient management of the water and nutrient is critical in achieving sustainably high edible oil production in the country. The decreasing availability of water to agriculture sector has become a serious limitation in many areas and the share of water for agriculture is expected to reduce further with the increasing

demand from other sectors. And to counter the irrigation water deficit without missing the production targets, micro-irrigation in oilseeds crops has already been recommended by the task force on micro irrigation. The faulty irrigation management led to low mustard productivity and water use efficiency from irrigated area. In mustard growing areas, the limited available water is applied mainly through check basin, where water use efficiency hardly exceeds 35-40% (Rathore *et al.* 2014 a). One time application of irrigation water resulted in excess water supply at one stage and moisture stress at other growth stages which affects growth, reduced photosynthesis, primary and secondary branches, main shoot length, number and length of siliqua and seed yield of Indian mustard (Rathore *et al.* 2014b). Adaptive advantages of irrigation management to mustard has been well documented, but the effects of use of limited water through micro irrigation and different levels of N fertigation on growth, yield attributes, yield and water use efficiency had not reported adequately. Keeping these points in view the field experiments were conducted to evaluate the effect of on micro irrigation and N-fertigation on growth, yield attributes, seed, oil yield, production efficiency, sustainability and irrigation water use efficiency of Indian mustard [*Brassica juncea* (L.)

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Czernj and Coss] var Rohini during 2010-11 and 2011-12 under semi-arid conditions.

MATERIALS AND METHODS

The experiment on micro-irrigation and fertigation methods for Indian mustard under semiarid conditions was conducted at DRMR research farm located at 77.30° E longitudes, 27.15° N latitude and 178.37 m of altitude. The climate is sub-tropical and semi-arid. The weather during crop growth period was moderate with range in minimum and maximum temperature of 3.5-19.7 °C and 18.5-35.8°C and total rainfall received was 51.6 and 61.4 mm respectively during (October to March) 2010-11 and 2011-12, the sunshine throughout the crop growth period ranged from 4.0-8.1 hr, comparatively lesser sunshine was recorded in November, December and January, while remaining months were received with bright and full sunshine. The experiment was conducted in split plot design (SPD) with three replications during *rabi* season 2010-11 and 2011-12. The treatments consist of micro-sprinkler system (MS), micro sprinkler and check basin irrigation in main plot and fertigation of N levels, viz. Control (0 N), 40, 80 and 120 kg N/ha in subplot. The irrigation water was applied 60mm and 20 mm in each check basin and micro-irrigation system respectively. Two irrigations were provided though check basin one at 35-40 days and another at 65-70 days after sowing coinciding with critical stages of growth in mustard crop. Under micro-irrigation, irrigation is scheduled based on water requirement and soil moisture balance. The initial soil pH and EC were 8.5-9.5 and 2.5-3.5 dS/m. The soil was poor in available N (126 kg/ha), medium in P (21.2 kg/ha) and K (255.0 kg/ha). The micro-sprinkler head was operating at 2.5 kg/cm² pressure and single micro sprinkler head covered 9 m of diameter. These are installed in the field to work in overlapping manner. Indian mustard (Cv. Rohini) was sown on 20 and 25 October and harvested on 10th and 12th March during 2010-11 and 2011-12 respectively. Photosynthesis and gas exchanges activities of mustard were measured using a portable photosynthesis system during 1000-1300 hr under clear sunshine conditions at 40 and 80 days after sowing. The fully expanded leaves on two-third above part of plants were selected randomly in each experiment. The yield attributes and yield observations were recorded at maturity of the crop. Observations on yield attributes were recorded by selecting five random plants from each plot. Minimum guaranteed yield that could be obtained relative to maximum observed yield over the years of fallow-mustard cropping system was quantified through sustainability yield index (SYI), which was calculated by the following mathematical equation $Y_{\text{mean}} - SD / Y_{\text{max}}$ (Singh *et al.* 1990). The data were statistically analyzed using Fisher's analysis of variance technique and the treatments means were compared by Duncan's Multiple Range (DMR) test at level of 0.05 probabilities. The standard analysis of variance (ANOVA) test was performed using SPSS 17.0 statistical software to compare the treatment means for each year separately.

RESULTS AND DISCUSSION

Physiological and growth parameters

The physiological parameters of Indian mustard (Cv. Rohini) were significantly influenced by the irrigation systems and levels of N fertigation. MS recorded significantly higher internal CO₂ concentration. The higher photosynthetic rate 30.9 % and 23.0 % under micro sprinkler and drip irrigated crop compared to check basin was observed with higher internal CO₂ concentration. This may be due to the increase CO₂ assimilation with higher CO₂ concentrations. Transpiration was higher under MS compared to check basin due to better vegetative growth, while stomatal resistance was higher under combination of CB and MS. Contrary, rate of evaporation was higher under CB. The similar trend was observed during second year on physiological parameters under irrigation systems. Successive increase in N fertigation gradually and significantly increased physiological parameters and higher values were recorded at 120 kg N/ha (Table 1). The plant growth traits were also increased significantly under micro irrigation (Table 1), the plant height and dry matter accumulation was observed significantly higher under micro sprinkler and drip irrigated mustard, this was probably due to the fact of higher photosynthetic rate. Further precise need based irrigation scheduling and better N fertigation increased the better growth in mustard crop (Rathore *et al.* 2014b). The higher photosynthetic rate and efficient portioning of photosynthates in to sink due to congenial environmental conditions led to higher seed productivity of Indian mustard under micro irrigation and fertigation (Sharma and Ramachandra 1990, Rathore *et al.* 2014b).

Biological, seed and oil yield of mustard

The micro-irrigation significantly improved biological, seed and oil yield of Indian mustard (Table 2) compared to the crop irrigated by check basin. Overall, there was 28.6 % increase in seed productivity of mustard crop during two years, however increase during 2011-12 was higher (38.6 and 49.6 %) than the seed productivity during 2010-11 under drip and micro sprinkler irrigation respectively. Thus various irrigation and N fertigation treatments significantly influenced biological, seed and oil yield in Indian mustard (Table 2 and Fig 1). The seed productivity increased significantly by 34.6, 53.1 and 72.1% under 40, 80 and 120 kg N/ha over control. During both the years every increasing levels up to 120 kg N/ha resulted in significant increase in seed yield (Table 2). While the increases in seed yield over 40 kg N/ha was 40.1% during 2010-11 and 28.5% during 2011-12. Further increasing the fertigation levels to 120 kg N/ha significantly enhanced the seed yield over 80 kg N/ha by 11.7 and 13.1% during 2010-11 and 2011-12 respectively. Increase in seed yield per unit N-fertigation resulted in higher nitrogen use efficiency and agronomic nitrogen use efficiency of Indian mustard under irrigation systems (Fig 2). The significant increase in seed yield at higher levels of N also indicates of huge N imbalance in the

Table 1 Gas exchange and growth traits of Indian mustard as influenced by irrigation methods and fertigation

Treatment	Internal CO ₂ concentration, ppm		Photosynthetic Rate, μ mol/m ² /S		Rate of transpiration, Mmol/m ² /S		Stomatal resistance, m ² s/ mol		Plant height, cm at harvest		Dry weight/ plant, g at harvest	
	2010-11	2011-12	2010-11	2011-12	2010-11	2011-12	2010-11	2011-12	2010-11	2011-12	2010-11	2011-12
<i>Irrigation</i>												
MS	352.7 ^a	365.2 ^a	11.2 ^a	15.5 ^a	21.8 ^a	25.2 ^a	48.2 ^a	49.2 ^a	196.3 ^a	196.5 ^a	69.0 ^a	78.2 ^a
DS	348.3 ^c	356.2 ^{ab}	10.3 ^c	14.8 ^a	22.1 ^a	22.3 ^b	46.6 ^c	51.2 ^{ab}	192.6 ^a	194.2 ^a	65.6 ^{ab}	65.3 ^b
CB	345.9 ^b	341.2 ^b	9.2 ^d	11.2 ^b	19.2 ^b	20.1 ^c	46.8 ^c	52.0 ^b	177.0 ^b	178.0 ^b	53.7 ^b	55.8 ^c
<i>Fertigation</i>												
Control	354.5 ^a	360.2 ^a	8.0 ^a	8.5 ^a	16.3 ^a	16.2 ^a	43.8 ^a	42.3 ^a	168.7 ^a	162.1 ^a	43.2 ^a	45.6 ^a
40 kg N/ha	350.6 ^b	347.2 ^b	9.2 ^b	10.2 ^b	19.1 ^b	20.1 ^{bc}	45.2 ^b	44.6 ^b	190.1 ^b	191.3 ^b	57.0 ^b	62.3 ^b
80 kg N/ha	345.7 ^c	340.2 ^c	11.1 ^c	14.5 ^c	22.7 ^c	23.0 ^c	49.7 ^c	50.2 ^c	191.5 ^b	199.6 ^b	70.8 ^c	65.2 ^{6b}
120 kg N /ha	338.7 ^d	341.2 ^c	13.3 ^d	15.5 ^c	25.2 ^d	26.5 ^d	54.1 ^d	56.2 ^d	197.2 ^c	205.1 ^b	73.6 ^c	79.5 ^c

Table 2 Effect of irrigation methods and fertigation on yield attributes, yield, protein and oil content of Indian mustard

Treatment	Biological yield (kg/ha)		Seed Yield (kg/ha)		Oil yield (kg/ha)		Sustainability index		Production efficiency (kg/ha/day)		Irrigation water use efficiency (kg/ha-mm)	
	2010-11	2011-12	2010-11	2011-12	2010-11	2011-12	2010-11	2011-12	2010-11	2011-12	2010-11	2011-12
<i>Irrigation systems</i>												
CB	8374 ^b	6992.1 ^c	1759 ^a	1684.5 ^c	716.0 ^a	673.8 ^a	0.46	0.32	11.3 ^a	11.70 ^c	14.9 ^e	14.1 ^a
DS	8451 ^b	8350.4 ^b	1897 ^{ab}	2334.5 ^b	779.0 ^b	957.1 ^b	0.51	0.51	12.2 ^{ab}	15.78 ^b	31.6 ^c	38.7 ^b
MS	8812 ^b	10119.5 ^a	2086 ^{bc}	2519.4 ^a	859.0 ^c	1020.4 ^c	0.58	0.56	13.5 ^b	16.90 ^a	34.8 ^a	42.0 ^c
<i>Fertigation of N, Kg/ha</i>												
Control	6296 ^a	6365.9 ^a	1360 ^a	1619.4 ^a	534.0 ^a	665.6 ^a	0.32	0.31	9.3 ^a	11.02 ^a	17.8 ^a	23.6 ^a
40 kg N/ha	7943 ^b	8713.2 ^b	1914 ^b	2080.2 ^b	785.0 ^b	850.8 ^{ab}	0.52	0.44	12.3 ^b	14.17 ^b	24.3 ^b	30.1 ^b
80 kg N/ha	9118 ^c	8831.4 ^b	2187 ^c	2354.7 ^c	915.0 ^c	970.1 ^b	0.61	0.52	14.0 ^c	16.01 ^c	28.0 ^c	34.1 ^c
120 kg N /ha	10082 ^d	10038.9 ^c	2443 ^d	2663.6 ^d	1000.0 ^d	1086.7 ^b	0.71	0.60	15.5 ^d	17.98 ^d	31.6 ^d	38.5 ^d

Within column, value represents with different letter indicate significant difference (P=0.0)

soil due to continuous mining of nitrogen. Biological yield and oil yield followed almost similar trend (Table 2 and Fig 1). Mustard crop experienced water stress in check basin

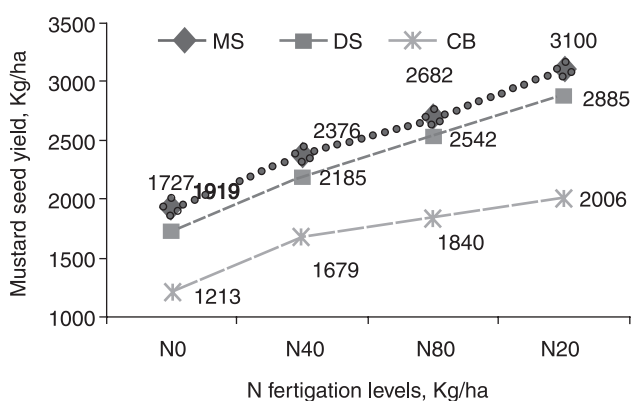


Fig 1 Significant interaction of irrigation systems and N fertigation on Indian mustard (2011-12)

at some of the critical crop growth stages but under micro irrigation, the soil due to comparatively low soil moisture tension created the favorable available water regime in the soil. Nitrogen plays an important role in protein balance, oil biosynthesis and maintaining oil: protein ratio among oilseed crops (Tripathy and Sawhney 1989, Rathore *et al.* 2014c). Extra available nitrogen enhanced degradation of carbohydrates (tricarboxylic cycle) to acetyl Co A, thereby processes of reductive amination and transamination to produce more amino acids (Satyanarayan *et al.* 1986) causing increased seed protein content with corresponding decrease in seed oil content (Premi *et al.* 2013). The seed yield of Indian mustard under micro irrigation increased because of increased growth and physiological activities which directly determine the yield attributes like 1000 seed weight, seeds/silique, total number of siliques and siliques on the main shoot. The dependence of seed yield on important yield attributing characters of *Brassica juncea* was also indicated by correlation matrix that was significant during both the

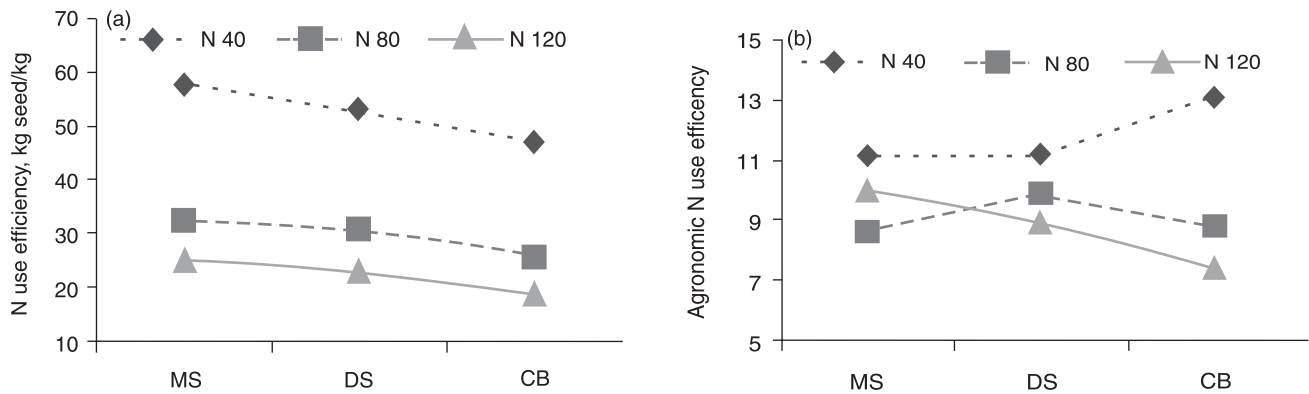


Fig 2 a and b Nitrogen use efficiency and agronomic nitrogen use efficiency of Indain msutard under irrigation systems

years (Table 3). The need based irrigation scheduling through micro irrigation improved internal CO₂ conc and thereby more chlorophyll development, higher photosynthesis rate and stomatal resistance resulting into more branches for enhanced fruiting and better translocation of photosynthates for larger sink (1000 seed weight). Various yield attributes, viz. primary branches/plant, total siliquae/plant and 1000 seed weight were found positively correlated to each other. Further, positive correlation of seed yield with siliquae on main shoot, total siliquae /plant, seeds/siliquae, 1000 seed weight was observed during both seasons confirms the findings and self explanatory for the reasons of improved productivity of *Brassica juncea* under micro irrigation systems (Table 3).

The benefits of micro-irrigation may include better crop growth and minimal yield variability and improved oil content and quality. Several experiments have shown positive responses of drip irrigation in many crops (Segal *et al.* 2000, Rathore *et al.* 2013). Almost similar and positive response of N fertigation under micro-irrigation systems

on seed yield was observed. Fertigation improves plant growth due to higher nutrient uptake and lower nutrient losses (Rathore *et al.* 2012). Fertigation permits improved efficiency of irrigation and nutrient use and reduces application costs. In general water supply at regular interval under micro-irrigation systems reduced sporadic water stress thereby improved soil-plant-water relationship and finally better yield attributes and seed productivity (Rathore *et al.* 2014b).

Production efficiency, irrigation water use efficiency, sustainability yield index

The irrigation systems and N fertigation resulted in significant variation in production efficiency (PE) and sustainability yield index. In general, production efficiency was higher during 2011-12 due to better weather conditions especially due timely occurrence of winter rains. The DS and MS increased the production efficiency significantly by 38.5% over CB. Overall, significantly higher production efficiency was recorded under micro-irrigation irrigation

Table 3 Correlations matrix of SPAD and light intensity with various yield attributing characters and yield of Indian mustard under micro irrigation and fertigation systems

Parameters	Biological yield	Seed yield	PB	SB	PH	SLMS	SLSB	MSL	SPAD 60T	SPAD 30T
Seed yield	0.82(**)									
PB	0.39(*)	.56(**)								
SB	0.51(**)	.66(**)	.45 (**)							
SLMS	0.68(**)	.79(**)	.42(*)	.73 (**)	.49 (**)					
SLQSB	0.65(**)	.81(**)	.452(**)	.84 (**)	.66(**)	.83 (**)				
MSL	0.66(**)	.75(**)	.32	.57(**)	.37(*)	.75(**)	.70 (**)			
SPAD60T	0.56(**)	.52 (**)	.45 (**)	.36 (*)	.29	.37(*)	.44 (**)	.24		
SPAD30T	0.57(**)	.51(**)	.42(*)	.35 (*)	.29	.37(*)	.42(*)	.27	.98(**)	
SPAD30B	0.49(**)	.62 (**)	.553(**)	.57 (**)	.47 (**)	.69(**)	.68(**)	.53(**)	.58(**)	.59(**)

PB: Primary branches, SB: Secondary branches, PH: Plant height, SLMS: Siliqua on main shoot, SLSB: Siliqua on SB, SPAD 60T: SPAD values at 60 days after sowing top leaves, SPAD 30T: SPAD values at 30 days after sowing top leaves, SPAD30B: SPAD values at 30 days after sowing basal leaves. ** Correlation is significant at the 0.01 level (2-tailed). * Correlation is significant at the 0.05 level (2-tailed).

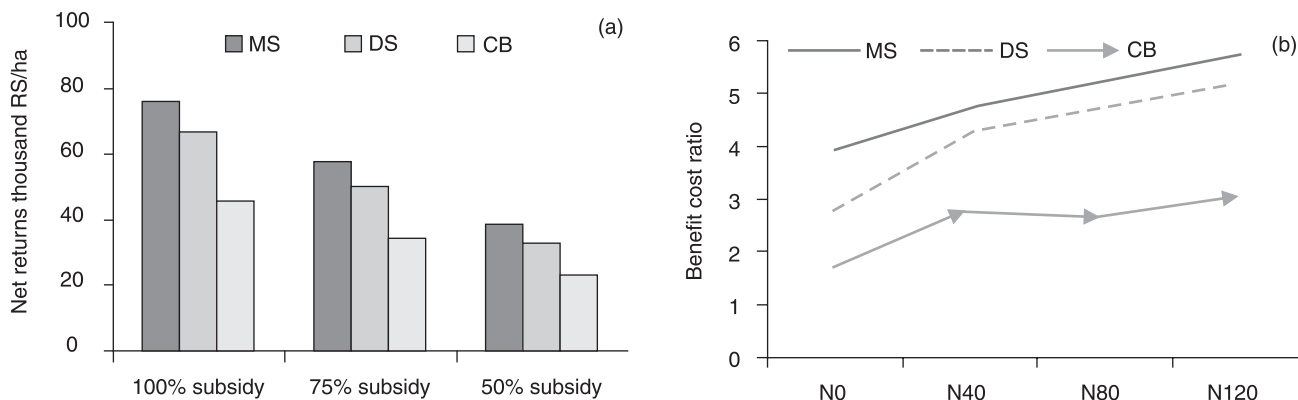


Fig 3 a and b. Economics of different irrigation system and N fertigation

systems compared to check basin irrigation systems. PE was increased significantly under MS and DS as compared to CB and in general higher PE was observed during 2011-12 than it was in 2010-11. On an average, micro irrigation increased the PE by 26.7 % over CB. Production efficiency increased with increase of levels of N/ha and maximum production efficiency was recorded at 120 kg N/ha during 2011-12 but statistically at par production efficiency was observed between 80 and 120 kg N/ha during 2010-11 (Table 3). For rapeseed-mustard, the response to micro-sprinkler irrigation is by and large better than that of drip irrigation. The pattern of configuration of laterals between the mustard rows (3:1) might be the reason for its poor performance compared to the micro-sprinkler system (Rathore *et al.* 2014b).

Irrigation water use efficiency (IWE) was also increased substantially due to micro irrigation systems and the increase in IWUE was higher during 2011-12 than in 2010-11 (Table 2). Micro irrigation resulted in IWUE between 35-38 kg/ha-mm and while under check basin it was only 14.5 kg/ha-mm over the years. The significantly higher IWUE of Indian mustard crop was observed under micro irrigation over check basin due to the fact of precise irrigation scheduling and considerably saving of irrigation water. Interaction for irrigation systems and levels of N fertigation was found significant for irrigation water use efficiency (Fig 1). With micro irrigation, water saving up to 50 per cent was possible through maintaining available soil moisture at low water tension and almost constant during entire growth period (Patel *et al.* 2006). Nazirbay *et al.* (2005) also reported high water use efficiency and water saving under micro irrigation systems when practised with fertigation of N. Irrigation scheduling in micro irrigation system provide water to the plants which matches the crop evapo-transpiration and providing irrigation at critical growth stages resulted in high water use efficiency (Kar *et al.* 2005). Similar sustainable yield index (SYI) was more than 0.5 under micro irrigation, which shows, the micro irrigation, was sustainable system of irrigation in terms of resource conservation and enhancing the productivity over CB. The increasing level of N fertigation also ensures better sustainability in the mustard production system due to consistent increase in seed yield. Thus higher the levels

of N fertigation, more was the sustainability in mustard production system (Table 2). The maximum net returns (₹/ha) was recorded under micro sprinkler system and followed by under drip irrigation (Based on subsidy provisions of 75-100 %). Similarly at every level of nitrogen, higher B:C ratio was observed under micro irrigation (Fig 3 a and b). Indian mustard responded better to fertigation with higher levels of N-fertilizer. Therefore, higher nitrogen use efficiency and agronomic NUE were recorded (Fig 2 a and b). The higher nutrient use efficiency led to higher mustard productivity. Rathore *et al.* (2014 b), also reported higher N use efficiency under fertigation due least pilferages of nutrient in supply channel. Over the period, yield levels are stably higher under micro irrigation systems, which resulted in sustainability more than 0.50 (Rathore *et al.* 2014c). The high sustainable yield index under micro irrigation is due to the fact that favourable soil moisture regimes are being maintained, which mitigates the risk of moisture stress to the crop plants. Apposite soil moisture along with better N nutrition ensure sustainably high seed productivity of Indian mustard.

Indian mustard is an important edible oilseed crop in north India especially under arid and semi arid areas. Due to its low water requirement, Indian mustard is mainly cultivated under limited irrigation conditions. The limited irrigation water could be suitably and efficiently utilized under micro irrigation and fertigation of soluble major elements especially nitrogen. The seed productivity of mustard crop and irrigation water use efficiency increased significantly due to the fact of optimum water regime under micro irrigation. The higher seed productivity is mainly attributed to higher increase in growth, yield attributes and physiological parameters of Indian mustard. Thus proper irrigation and nitrogen fertilizer scheduling under micro irrigation saves irrigation water, enhances nutrient use efficiency and gives better economics.

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