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Growth and Yield Response of Pea (*Pisum sativum* L.) Crop to Classical and Regulated Deficit Irrigation along with Nitrogen Fertilization under Drip Irrigation

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ABSTRACT

Background: The conventional methods of applying water and nutrient results lot of wastage and negatively affect the soil, environment and crop response of pea.

Methods: The experiments were conducted at Lovely Professional University, Punjab during two years. The five drip irrigated treatments having full irrigation, classical deficit irrigation and regulated deficit irrigation in combination same level of nitrogen fetigation @90% recommended dose of nitrogen (RDN) were taken in 4 replications. One control plot (having flood irrigation with soil application of nitrogen @100% RDN through broadcasting) was taken for comparison.

Result: Plant growth, yield contributing parameters, pod yield and water use efficiency (WUE) were significantly affected by drip irrigation in combination with 90% RDN through fetigation over conventional method of irrigation and fertilizer application. Among all the drip irrigated treatments, the increment in crop yield, WUE and irrigation water saving varied from 27.6 to 65.7%, 63.6 to 99.7% and 26.1 to 44.6%, respectively over control plot. In case of same nitrogen fertigation level, the yield and water use efficiency of drip irrigated pea crop can be improved by adoption of moderate water deficit level (which is 15% less than full IWR) under regulated deficit irrigation approach over full irrigation approach. The findings of the work can be utilized by farm managers for irrigation planning and nitrogen management for pea crop and by policy makers to conserve available fresh water resources in water scares regions.

Key words: Classical and regulated deficit irrigation, Legume, Nitrogen fertilization, Pea, Pod yield, Water use efficiency.

INTRODUCTION

Pulses are proved as unique jewels of Indian farming. Pulses are an essential part of Indian's diet. Pulses have the potential to significantly enhance human health, soil health by nitrogen fixation, save the environment and support global food security. The average fresh green pea yield was recorded as 9686.1 kg/ha (FAOSTAT, 2018). Water and nitrogen act as critical factors in green pea production. In Punjab, farmers are using conventional methods for irrigation and fertilizer application which results in more water and nutrient losses (Devi *et al.*, 2021). Improper irrigation scheduling and poor water management under various irrigation methods has led to water stress in pea production. Numerous studies have noted the detrimental impacts of inefficient water management, including over- and under-watering, the impact of water on soil salinity, water stress and a lack of study to determine the ideal amount of water for pea production at different growth stages. The use of modern irrigation methods can improve crop yield and water use efficiency (Jadav *et al.*, 2021; Changade *et al.*, 2023). The upcoming challenge in future agriculture is how to use irrigation water efficiently. Adoption of drip irrigation technique for irrigating crops could overcome this problem. In water scares regions of Punjab, along with drip irrigation; deficit irrigation approach can be a batter option to conserve use of fresh surface and ground water in pea production. Deficit irrigation (DI) refers to the application of irrigation water below the actual crop water requirements, either during the full growing period of crop (Classical deficit irrigation; CDI) or at some specific phonological/growth stages (regulated deficit irrigation; RDI). Crop response to DI varies with the exposure durations and severity of water stress exerted on plants at different growth stages (Chai *et al.*, 2016). DI levels can vary with type of crop so it is crop

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specific. Therefore, DI involves thorough understanding of how crops respond to water stress in terms of yield and quality. Hence, the appropriate level of deficit irrigation should be ensured for high production of pea crop. Now days, farmers are supplying 100% recommended dose of nitrogen (RDN) through direct soil application (broadcasting) in pea cultivation which results nitrogen losses. So along with water conservation some nitrogen amount can save by drip fertigation which will provide a supply of nitrogen uniformly and timely without polluting the environment by the leaching process. The drip fertigation decreases the requirement of fertilizer by 40-60% and enhances the crop yield by 15-50% over conventional method (Loganathan and Latha, 2016). The integrated application of irrigation water and nutrient (fertigation) to plants boosts the photosynthesis process so they produce new tissues to increase production of biomass. However; there is a gap in the study of integrated water and nitrogen management in the cultivation of green pea. Research works on deficit irrigation along with nitrogen fertilization in green pea are also scant under existing climatic condition of Trans-gangetic region of Punjab. Therefore, the present research work was undertaken.

MATERIALS AND METHODS

Study area

A field experiment was conducted at research field of Lovely Professional University, Punjab (Plate 1) during *rabi* 2021-22 (Y1) and 2022-23 (Y2). The site was facilitated with drip irrigation system along with fertigation system.

The experimental site is located at latitude 31.25°N and longitude 75.70°E along with altitude of 280 m above mean sea level). The region has a humid subtropical climate. The annual mean temperature and precipitation are 23.1°C and 957 mm. The soil type in study area is sandy loam. The available nitrogen, phosphorus (P) and potassium (K) contents in the 0-20 cm soil layer before transplantation were 256.8, 6.1 and 246.8 kg/ha, respectively.

Experimental details

The raised beds were prepared with 75 cm width, 15 m long and 30 cm height from ground surface. The total six treatments (including control plot) were arranged in random block design with four replications. As per treatments, full dose of phosphorus and potash (as per recommended dose of fertilizer) were applied as basal dose (prior to sowing of seeds) to the respective plot through soil application (broadcasting). The recommended dose of nitrogen (by urea fertilizer) was supplied to respective plots (as per treatments) in 8 equal splits at 6 day interval through drip fertigation. In control plot, RDF (including nitrogen) was supplied as per farmer's practice through broadcasting. Pure and healthy seeds of pea were sown in paired row at spacing of 30×15 cm and 4-5 cm depth.

Treatments details

In this study, the following treatments were taken in random block design with four replications as given in Table 1.

Calculation of crop water requirement

In drip irrigated plots, irrigation water (as per treatments) was given on the basis of following equations. The pan coefficient (K_p) for calculating crop evapotranspiration was taken as 0.7.

$$ET_C = E_{pan} \times K_p \times K_C \quad \dots (1)$$

$$IWR = Ep \times Kc \times Kp \times Sr \times Sp \times WP \quad \dots (2)$$

Where,
IWR = Irrigation water requirement (litre/day/plant).
Epan = Pan evaporation (mm/day).
Kc = Crop factor/coefficient.
Kp = Pan coefficient, m.
Sr = Row spacing, m.
Sp = Plant spacing.
Wp = Percentage wetted area, 90%.

In order to calculate the total amount of water supplied, on the monthly basis, the effective rainfall (ER) was calculated by following equation (Sharma *et al*, 2021):

$$ER = P_t \left[\frac{125-0.2 \times Pt}{125}\right] \text{ for } Pt < 250 \text{ mm} \quad \dots (3)$$

Where,
P_t = Total rainfall, mm.

Standard package of practices (given by Punjab Agricultural University) was followed for rest of the operations to grow the crop.

Crop observation

In every plot, five plants were selected. Plant height, number of branches/plant and leaf area index (LAI) were recorded at flowering stage of the crop in both the years. Pods per plant (numbers), grains per pod (numbers), total weight of 100 seeds and yield (kg/ ha) of pea crop were recorded at harvesting. Analysis of variance (ANOVA) procedures were used to statistically analyze the data gathered from the current field experiment, with a 5% threshold of significance.

Plate 1: Experiment view.

Table 1: Treatment details.

Treatment	Explanation
T_1	FI i.e irrigation at 100% of IWR (based on daily Epan) during whole growing stages through drip irrigation + 90% RDN through drip fertigation.
T_2	CDI i.e irrigation at 85% of IWR (based on daily Epan) during whole growing stages through drip irrigation + 90% RDN through drip fertigation.
T_3	CDI i.e irrigation at 70% of IWR (based on daily Epan) during whole growing stages through drip irrigation + 90% RDN through drip fertigation.
T_4	RDI i.e irrigation at 85% of IWR (based on daily Epan) during initial, development and mid growth stages through drip irrigation + 90% RDN through drip fertigation
T_5	RDI i.e irrigation at 85% of IWR (based on daily Epan) during initial, development and late growth stages through drip irrigation + 90% RDN through urea under drip fertigation
T_6	Irrigation through flood irrigation (irrigation at 50% depletion in field capacity) and 100% RDN by broadcasting method.

FI: Full irrigation [amount of irrigation water supplied will be equal to daily irrigation water requirement (IWR)].

CDI: Classical deficit irrigation [i.e Same level of deficit irrigation (amount of irrigation water supplied will be some percentage of daily IWR] will supply during whole growth stages of crop.

RDI: Regulated deficit irrigation (i.e A specific level of deficit irrigation will supply during certain or specific growth stages of crop while for remaining growth stages, irrigation water will supply as per full IWR).

Epan: Pan Evaporation (mm/day)

RDN: Recommended dose of Nitrogen

Water use efficiency

It is defined as the ratio of yield to the total quantity of irrigation water applied. It was calculated by equation 4.

$$\text{Field water use efficiency (\%)} = \frac{\text{Crop yield (t/ha)}}{\text{Total depth of irrigation (mm)}} \times 100 \quad \text{... (4)}$$

RESULTS AND DISCUSSION

Crop evapotranspiration and irrigation water requirement

In study area, the uneven trend of daily pan evaporation was found during year 2021-22 and 2022-23 which varies from 0.1 to 3.1 and 0.4 to 4.2 mm/day, respectively (Fig 1 and 2). This variation emphasis on adoption of modern approaches of irrigation scheduling which is based on daily irrigation water requirement (IWR) of pea crop under drip irrigation. Poor irrigation scheduling results water stress instigating reduction in the growth and pea yield. In case of full irrigation under drip irrigation method, the minimum and maximum IWR were estimated 0.368and 1.8 l/plant during initial and mid stages respectively (Fig 3). It was mainly due to variation in daily weather parameters. In RDI treatments, the total IWR during whole growing period was found 3.2 and 3.3 l/plant/season for T_4 and T_5, respectively. While, the total IWR under CDI treatments *i.e* T_2 and T_3 were estimated 3 and 2.5 liter/plant/season, respectively (Fig 4) which was slightly lesser than RDI treatments (T_4 andT_5) but it gives continuous water stress for pea plant during whole growing period over full irrigation as well as RDI approaches and consequently affects pea production and water use efficiency. Legume crops are very sensitive to water so in case of DI approach, the over and under irrigation during whole growing period (FI or CDI) will affect crop response so RDI will be a better approach to improve the crop performance under drip irrigation.

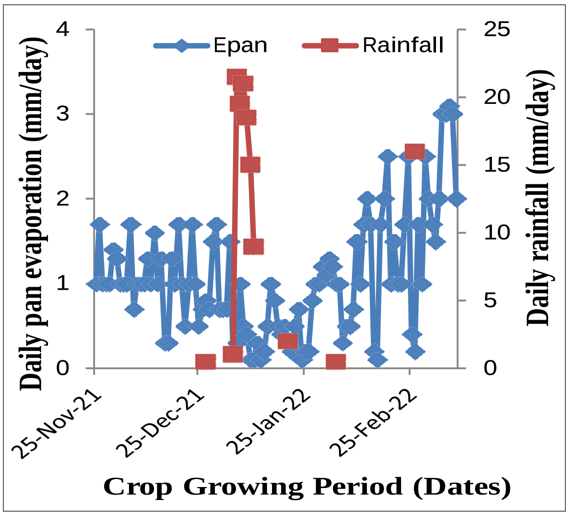

Fig 1: Trend of daily pan evaporation and rainfall during season 2021-22.

Growth parameters

The results showed that the plant growth, yield attributes parameters and pod yield were significantly affected by drip irrigation in combination fetigation over conventional methods of irrigation and fertilizer application. The data given in Table 2 indicated that the plant height was recorded as highest in drip irrigated plot (T_1) and lowest in control plot. The similar result was reported by Jadhav *et al.* (2021); Sharma *et al.* (2021). Among all the drip irrigated treatments, the plant height was highest as 49 cm under treatment T_1 followed by T_5 (45.5 cm). The plant height under treatment T_2 (43 cm) and T_3(42 cm) was recorded at par, which

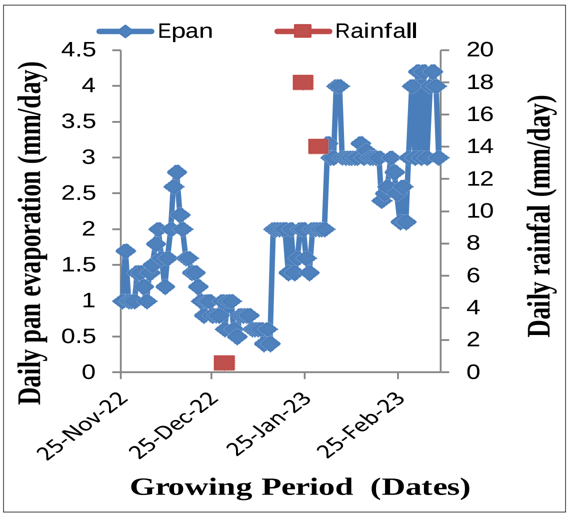

Fig 2: Trend of daily pan evaporation and rainfall during season 2022-23.

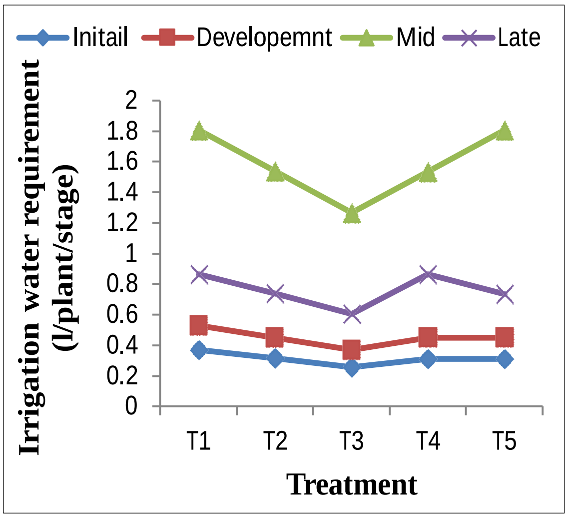

Fig 3: Irrigation water requirement (liter/plant/stages) for different treatments (on Mean data basis).

indicates non-significant effect of classical deficit irrigation (CDI) level on plant height. As compared to treatment T_2, the plant height was significantly higher in T_5 which shows that, for same level of deficit irrigation (*i.e* 85% of daily IWR) the batter plant height was recorded under regulated deficit irrigation (water stress *i.e* 15% of daily IWR during initial, development and late stage) over CDI (continuous water stress *i.e* 15% of daily IWR during whole crop period). When nitrogen fertilization strategies and water stress level was same, the plant height under T_4 (43.5 cm) and T_5 (45.5 cm) shows the significant affects of regulated deficit irrigation (RDI) during specific growth stages (Chai *et al*, 2016). This is clearly indicates that, the water stress during mid growth stage of plant results poor plant growth. Minimum plant height was recorded under T_6 (39 cm) which were significantly less as compared to all other treatments in both the years. It was due to leaching of nitrogen amount through flood irrigation. Better plant height under drip irrigation treatments can be attributed to favorable soil moisture level and minimum losses of nitrogen due to frequent application of irrigation water, nitrogen fertilization and suitable microclimate. This suggests that the seedlings of legumes require a root zone environment that is continually moist and having optimal microclimate. The leaf area index (LAI) was estimated maximum as 1.15 under treatment T_1 followed by T_5 (0.91). The LAI under T_4 (0.88) and T_5 (0.91)indicated the significant effect of same level of RDI during different growth stages. The water stress during mid stage will significantly reduce the LAI. The results are similar with Singhal *et al.* (2021). Minimum LAI were recorded under control plot (0.71).

Yield contributing parameters

The data related to yield contributing parameters are given in Table 3. The number of branches/plant in all the treatments (except T_5) were not significantly affecting by drip irrigation in combination with nitrogen fertigation over control plot. The significant difference for number of branches/plant was noted between full irrigation treatment T_1 (5) and CDI treatments (T_2 and T_3) under drip irrigation. Which is clearly indicates that, by supplying same dose of nitrogen (through fertigation), the deficit level of water (from full IWR) during

Table 2: Plant height, leaf area index and number of branches/plant under different treatments.

Treatments	Plant Height			Leaf Area Index			Number of branches		
	2021-22	2022-23	Mean	2021-22	2022-23	Mean	2021-22	2022-23	Mean
T_1	47	51	49	1.10	1.20	1.15	4	6	5
T_2	41	45	43	0.87	0.88	0.88	3	4	3.5
T_3	40	44	42	0.84	0.84	0.84	3	4	3.5
T_4	41	46	43.5	0.88	0.88	0.88	4	4	4
T_5	43	48	45.5	0.90	0.91	0.91	6	6	6
T_6	38	40	39	0.70	0.71	0.71	4	4	4
CD 5%	1.15	2.60	1.87	0.05	0.11	0.08	1.7	1.43	1.59
CV (%)	4.2	3.7	3.95	4.03	8.06	6.05	19.3	14.3	16.8

Table 3: Yield contributing parameters under different treatments.

Treatments	Number of pod/plant			Number of seed/pod			Weight of 100 seeds (gm)		
	2021-22	2022-23	Mean	2021-22	2022-23	Mean	2021-22	2022-23	Mean
T_1	19	20	19.5	7	8	7.5	26	26	26
T_2	16	17	16.5	6	6	6	21	20	21
T_3	14	16	15	6	5	5.5	20	20	20
T_4	16	16	16	8	6	7	24	25	24
T_5	17	21	19	9	9	9	27	31	27
T_6	12	14	13	6	6	6	21	22	21
Cd	1.557	1.522	1.539	1.078	0.950	1.014	2.419	2.867	2.019
CV	6.557	5.896	6.226	10.213	9.395	9.804	7.015	7.913	7.015

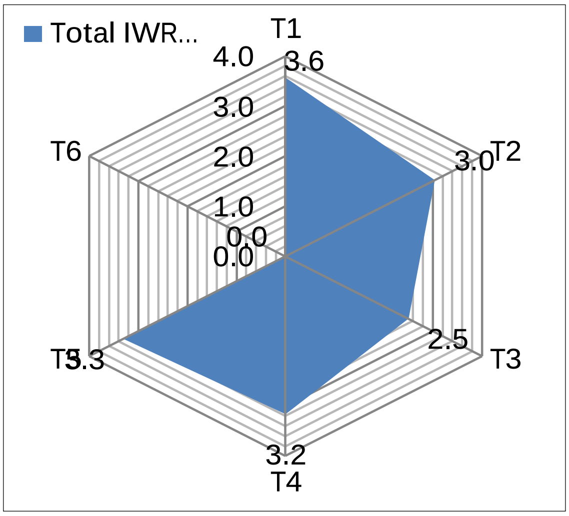

Fig 4: Total amount of irrigation water requirement under different treatment (on Mean basis).

whole growing stages (crop period) will reduce the number of branches/plant. In RDI treatments (having same nitrogen fertilization strategies), the number of branches/plant were significantly higher in T_5 (6) as compared to T_4 (4). It is because of change in trend of same water stress during different growth stages. The minimum number of branches/ plant was recorded as 4 in T_6 (control plot). In drip irrigated treatments, the significant changes were recorded for number of pods/plant under full irrigation level T_1 (19.5) and CDI levels (T_2 and T_3). In RDI treatments (having same nitrogen fertilization strategies), number of pods/plant was recorded 18.8% higher in T_5 as over T_4. The highest number of pods/plant was recorded as 19.5 in T_1 which were at par with number of pods/plant under T_5. The significant effect of RDI at different growth stages was found on number of pods/ plant under drip irrigation. The minimum number of pods/ plant was recorded as 13 under control plot. The number of seeds/plant was significantly affected by drip irrigation (except CDI treatments) over flood irrigation method which were found maximum under T_5 (9) followed by T_1 (7.5). At same level of DI (85% of daily IWR) and nitrogen fertilization strategies under drip irrigation, the number of seed/pod was significantly affected by RDI (water stress during different growth stages) in T_4 and T_5 over CDI in T_2. In RDI plots (having same water deficit level and nitrogen fertilization strategies), the number of seeds/pod was recorded significantly lower in T_4 (7) over T_5 (9) which clearly shows that the water stress during mid stage retards the seed formation in pods. The minimum number of seeds/pod was recorded as 6 under control plot. It was due to more water and nutrient losses through leaching, infiltration and surface evaporation. Overall, it can be stated that drip irrigation (which offers a more favorable soil moisture regime than flood irrigation) led to improved grain development. The result is in line with Singhal *et al*. (2021) for pea performance under drip irrigation. The maximum weight of 100 seeds was measured under T_5 (27 gm) which was at par with weight of 100 seeds measured under T(26 gm). As compared to full irrigation level (T_1) under drip irrigation, the weight of 100 seeds was significantly changes with respect to classical (T_2 and T_3) and regulated deficit irrigation level (T_4 and T_5). Further, in case of RDI treatments the weight of 100 seeds/ plant was significantly (12.5%) higher in T_5 (27) over T_4 (24). It shows the direct impact of water stress on weight of seeds during different growth stages of pea crop. The minimum weight of 100 seeds was recorded under treatment T_6. It is probably due to that under control plot (T_6), the significant amount nitrogen leached downward along with excess volume of irrigation water.

Crop yield, irrigation water use, irrigation water saving and water use efficiency (WUE)

The data in Table 4 shows that, the amount of total irrigation water applied was estimated minimum for T_3 (66.5 cm) and maximum for control plot (120 mm). In same level of DI (85% of daily IWR), 10.2% quantity of irrigation water was saved through CDI (T_2) over RDI (T_5) but it was significant reducing the pod yield and WUE. In comparison of full irrigation (T_1) under drip irrigation, 6.1% amount of irrigation water was saved under RDI (having 15% water stress during initial, development and late growth stages). It was not significantly affecting the pod yield and water use efficiency. The data related to total water use, pod yield and water use efficiency are presented in Table 5. The pod yield and WUE were found

Table 4: Amount of irrigation water supplied, effective rainfall and water saving under different treatments.

Treatments	Amount of irrigation supplied			Effective rainfall			Irrigation water saving over control		
	2021-22	2022-23	Mean	2021-22	2022-23	Mean	2021-22	2022-23	Mean
T_1	58.24	119.11	88.67	99.38	31.1	65.24	41	16	26
T_2	49.51	101.24	75.37	99.38	31.1	65.24	49	29	37
T_3	43.68	89.33	66.50	99.38	31.1	65.24	55	37	45
T_4	51.85	105.01	78.43	99.38	31.1	65.24	47	26	35
T_5	53.74	112.52	83.13	99.38	31.1	65.24	45	21	31
T_6	98	142	120	99.38	31.1	65.24			

Table 5: Crop water use, pod yield and water use efficiency under different treatment.

Treatments	Crop water use (irrigation water plus effective rainfall)			Pod yield (t/ha)			Water use efficiency (t/ha-cm)		
	2021-22	2022-23	Mean	2021-22	2022-23	Mean	2021-22	2022-23	Mean
T_1	157.6	150.2	153.9	8.7	8.9	8.7	0.552	0.593	0.565
T_2	148.9	132.3	140.6	6..3	6.7	6.7	0.423	0.506	0.476
T_3	143.1	120.4	131.7	6	6.2	6.1	0.419	0.515	0.463
T_4	151.2	136.1	143.7	7.5	7.9	7.7	0.496	0.580	0.536
T_5	153.1	143.6	148.4	8.1	8.5	8.3	0.529	0.592	0.559
T_6	197.4	173.1	185.2	5.2	5.3	5.25	0.263	0.306	0.283
Cd				1.955	0.687	1.3			
CV				15.161	6.444	10.8			

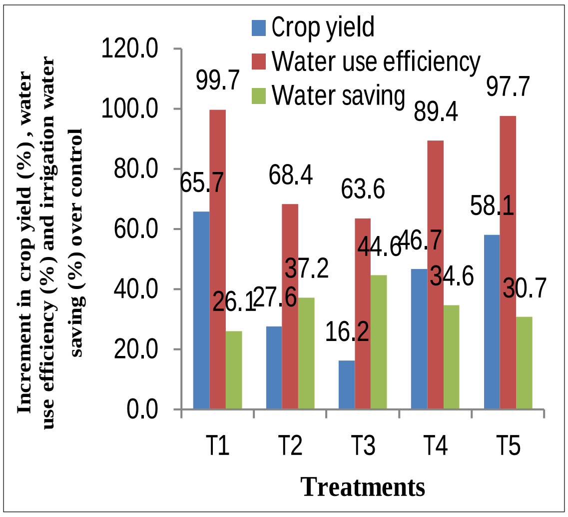

Fig 5: Increment in various parameters.

maximum under treatment $T_1$with values of 8.7 t/ha and 0.565 t/ha-cm respectively. The values of pod yield (8.53) and water use efficiency (0.559) under treatment T_5 which were at par with T_1. It clearly stated that, under limited water availability, the significant pod yield can get under drip irrigation by supplying deficit amount of irrigation water (15% less from daily IWR) in combination with deficit nitrogen level (90% RDN by fertigation) through RDI (water stress except mid growth stage) approach over full irrigation and same nitrogen levels.The minimum pod yield and water use efficiency were recorded under control plot (T_6)with values of 5.25 t/ha and 0.283 t/ha-cm respectively. It was because of the wastage of huge amount of water and nitrogen due to infiltration, seepage, evaporation and over wetting. The reduced pod yield in flood irrigated pea over drip irrigated is because of the fact that, the less concentration of oxygen in soil due to over wet conditions leading to stomatal closure of plants, thus decreasing the transpiration rate and later the yield. The water saving techniques can minimize the evaporation loss and can enhance the effective utilization of root zone water towards crop yield. The results of the study were found similar to Ranade *et al.* (2021). In case of full irrigation, the percentage of increase in yield over conventional irrigation was highest under T_1 (65.8%). The crop yield, water use efficiency and irrigation water saving was significantly higher in drip irrigation treatments as compared to control plot (flood irrigation). Further the increment level for all these parameters was significantly varies with full irrigation, CDI and RDI approaches under drip irrigation. Among all the drip irrigated treatments (having different water level and trend of water stress in combination with same nitrogen fertilization strategies *i.e* 90% RDN through fertigation), the increment in crop yield, water use efficiency and irrigation water saving was varies from 27.6 to 65.7%, 63.6 to 99.7% and 26.1 to 44.6% respectively over flood irrigation. The irrigation water saving was highest (44.6%) in T_3 over flood irrigation plot but in this treatment the percentage increase in crop yield and WUE were not significantly higher than other drip irrigation treatments. The increment in crop yield and WUE was highest in a treatment (T_1) where irrigation was done at 100% of daily IWR. Among all the CDI and RDI treatments under drip irrigation, the increment in crop yield, water use efficiency

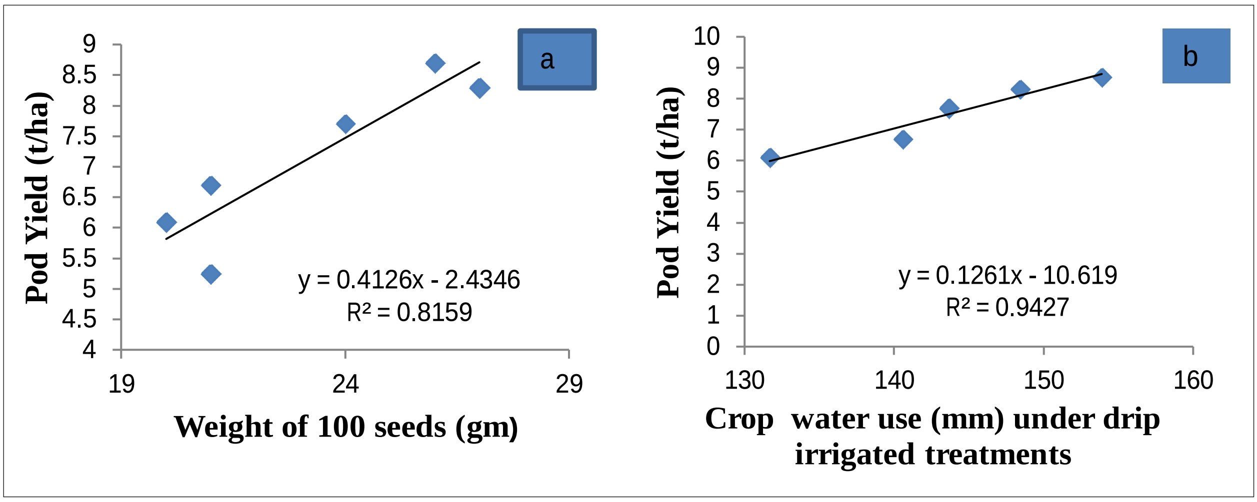

Fig 6: Correlation analysis between weights of 100 seeds (gm), crop water use (mm) and crop yield (t/ha-cm).

was recorded 58.1% and 97.7% respectively in treatment T_5 over control plot (flood irrigation) which was at par with T_1. The result presented in Fig 5 clearly shows that, the CDI approach for growing pea crop with same nitrogen fertilization strategies under drip irrigation will significantly reduce the crop yield and WUE over RDI. Among both the RDI treatments (T_4 and T_5), the irrigation water saving was higher (34.6%) in T_4 but it was significantly reducing the pod yield and WUE over T_5 which shows that a approach of RDI having water stress (15% less from full IWR) during mid stage of pea crop will retard significant plant growth and pod yield under drip irrigation. Consequently in water scare regions, a approach of RDI *i.e* irrigation at 85% of IWR (based on daily Epan) during initial, development and late growth stages through drip irrigation will surely enhance pod yield (58.1%), water use efficiency (97.7%) and will save 30.7% irrigation water over flood irrigation (irrigation at 50% depletion in field capacity). Along with above RDI approach, the nitrogen fertilization through drip fertigation can save 10% use of RDN over soil application method which will improve soil health without affecting pod yield and WUE of pea crop.

Correlation between yield and water use

There were positive linear co-relations between weight of 100 seeds verses yield (Fig 6a) with R^2= 0.815 and between crop water use verses yield (Fig 6b) with R^2= 0.942. From all these inter co-relations it can be stated that higher weight of 100 seeds and crop water use has a positive bearing on plant growth and yield.

CONCLUSION

Drip irrigation along with nitrogen fertigation results batter response of pea crop over conventional methods of water and fertilizer application. The classical deficit irrigation (continuous water stress during whole growth period) approach for growing pea crop under drip irrigation was significantly reduces the crop yield and water use efficiency over regulated deficit irrigation (water stress at specific growth stages). Overall results conclude that, among all selected approaches of irrigation scheduling (with same nitrogen fertilization level) under drip irrigation, the regulated deficit irrigation [where irrigation water supplied at 85% of daily irrigation water requirement (based on daily Epan) during initial, development and late growth stages] will surely enhance pod yield (58.1%), water use efficiency (97.7%) and will save 30.7% irrigation water over flood irrigation. In combination with this RDI approach nitrogen fertilization through drip fertigation can save 10% use of recommended dose of nitrogen which will improve soil health with significant plant growth and pod yield over flood irrigation with direct soil application of nitrogen (broadcasting). A cost effective irrigation and fertigation system could be developed as upcoming research for marginal landholdings. For implementation of this approach of irrigation and nitrogen management in pea on farm level, short term training programs and awareness camp for farmers could be conducted.

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Conflict of interest

The author(s) declare(s) that there is no conflict of interest.

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