WATER PRODUCTIVITY, ECONOMICS AND ENERGETICS OF GOBHI SARSON (*Brassica napus* L.) AS INFLUENCED BY DRIP IRRIGATION AND FERTIGATION SCHEDULES

Thesis

Submitted to the Punjab Agricultural University
in partial fulfillment of the requirements
for the degree of

MASTER OF SCIENCE
in
AGRONOMY
(Minor Subject: Soil Science)

By

Divya S Kumar
(L-2016-A-5-M)

Department of Agronomy
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LUDHIANA – 141 004

2019

CERTIFICATE – I

This is to certify that the thesis entitled, **"Water productivity, economics and energetics of *gobhi sarson* (*Brassica napus* L.) as influenced by drip irrigation and fertigation schedules"** submitted for the degree of **M.Sc.** in the subject of **Agronomy** (Minor Subject: **Soil Science**) of the Punjab Agricultural University, Ludhiana, is a bonafide research work carried out by **Divya S Kumar (L-2016-A-05-M)** under my supervision and that no part of this thesis has been submitted for any other degree.

The assistance and help received during the course of investigations have been fully acknowledged.

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CERTIFICATE II

This is to certify that the thesis entitled, **"Water productivity, economics and energetics of *gobhi sarson* (*Brassica napus* L.) as influenced by drip irrigation and fertigation schedules"** submitted by **Divya S Kumar (L-2016-A-05-M)** to the Punjab Agricultural University, Ludhiana, in partial fulfillment of the requirements for the degree of **M.Sc.** in the subject of **Agronomy** (Minor Subject: **Soil Science**) has been approved by the Student's Advisory Committee along with Head of the Department after an oral examination on the same, in collaboration with an External Examiner.

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ABSTRACT

The present investigation entitled "Water productivity, economics and energetics of *gobhi sarson* (*Brassica napus* L.) as influenced by drip irrigation and fertigation schedules" was conducted to find out water and energy efficient drip irrigation and fertigation schedules to increase the productivity and profitability of *gobhi sarson (Brassica napus* L.). The experiment was conducted at the Student's Research Farm, Department of Agronomy, Punjab Agricultural University, Ludhiana, during the *rabi* seasons of 2016-17 and 2017-18. It was laid out in randomized complete block design (RCBD) comprising combinations of three drip irrigation levels (60% of CPE, 80% of CPE and 100% of CPE) and three fertigation levels (60% RDF, 80% RDF and 100% RDF) along with one absolute control (flood irrigation and manual application of recommended dose of nutrients). Drip irrigation at 100% of CPE recorded highest values for growth parameters and yield attributes which were statistically at par with 80% of CPE but significantly higher than 60% of CPE during both the crop seasons. Drip irrigation with 100% of CPE recorded 19.5%, 16.1% and 23.1%, 20.3% higher seed and oil yield than 60% of CPE during 2016-17 and 2017-18, respectively whereas 80% of CPE recorded 15.5%, 13.0% and 19.0%, 17.5% higher seed and oil yield than 60% of CPE during 2016-17 and 2017-18, respectively. Highest gross returns, net returns, B:C, energy use efficiency and energy productivity were also obtained with drip irrigation at 100% of CPE followed by 80% of CPE. However, apparent and total water productivity obtained was lowest in 100% of CPE and highest in 80% of CPE resulting in saving of 12.7% and 14.5% irrigation water as compared to 100% of CPE during 2016-17 and 2017-18, respectively. Fertigation schedules at 100% RDF recorded highest growth parameters, oil and seed yield which were statistically at par with 80% RDF but significantly higher than 60% RDF. However, an inverse relationship between increased fertilizer doses and oil content was observed. Fertigation at 100% RDF resulted in maximum gross (76445 and 94310 Rs ha^{-1}) and net returns (39851 and 57769 Rs ha^{-1}) followed by 80% RDF and 60% RDF although, B:C was highest in 80% RDF (1.15 and 1.65) as compared to 100% RDF (1.09 and 1.58) during 2016-17 and 2017-18, respectively. Maximum energy use efficiency and energy productivity was obtained with fertigation at 60% RDF followed by 80% RDF. Drip irrigation at 100% of CPE or 80% of CPE with 100% RDF or 80% RDF produced significantly higher seed and oil yield, economics, water productivity and energetics as compared to absolute control. Hence, *gobhi sarson* should be irrigated through drip irrigation at 80% of CPE with 80% RDF to obtain higher net returns, water productivity and energy productivity than absolute control.

Keywords: *gobhi sarson*, drip irrigation, fertigation, seed yield, oil yield, water productivity, net returns, energy productivity

Signature of Major Advisor **Signature of the Student**

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ਮੁੱਖ ਸਲਾਹਕਾਰ ਦੇ ਹਸਤਾਖਰ **ਵਿਦਿਆਰਥੀ ਦੇ ਹਸਤਾਖਰ**

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CHAPTER – I

INTRODUCTION

Oilseeds are the second most important component of Indian agriculture after cereals. The oil extracted forms an important part of human diet, besides providing raw material for manufacturing of large number of industrial products such as paints, soaps, cosmetics, varnishes, lubricants etc. Oil cake which is residue after oil extraction from oilseeds is also used as cattle feed and manure. There are two major groups of oilseed crops in India, namely edible and non-edible oilseeds. Groundnut (*Arachis hypogaea* L.), rapeseed and mustard (*Brassica* spp.), sesame (*Sesamum indicum* L.), safflower (*Carthamus tinctorius* L.), niger (*Guizotia abyssinica* L.), soybean (*Glycine max* L.), and sunflower (*Helianthus annuus* L.) are edible, while linseed (*Linus usitatissimum* L.) and castor (*Ricinus communis* L.) are categorized under non-edible oilseed group.

India has the fourth largest oilseed economy in the world after USA, China and Brazil (Reddy and Immanuelraj 2017) with 7.4 per cent of world's oilseed production; 5.8 per cent of vegetable oil production; 11.2 per cent of oil import and 9.3 per cent of edible oil consumption (Anonymous 2015). To meet the nutritional requirement of projected population of 1685 million by 2050, India needs to produce 17.8 million tonnes of vegetable oil and this target is difficult to achieve with the current status of technology and resource management (Hegde 2012). Therefore, the present cultivation practices of oilseeds have to be improved to enhance productivity and to meet the present and future demand of edible oil as well as oil for other uses.

In India, rapeseed and mustard ranks the second important oilseed crop after soybean and accounted for 24.2 per cent of the oilseed production during 2012-13 (Anonymous 2015). Hence, rapeseed and mustard are the key edible oilseeds, which account for nearly one fourth of the vegetable oil produced in our country. In India, 6.3 million hectares area was under its cultivation with production of 7.9 million tonnes having 1251 kg ha^{-1} productivity during 2016-17 (Anonymous 2017). While in Punjab, its production was 44.8 thousand tonnes from 31.7 thousand hectares with 1413 kg ha^{-1} productivity during 2016-17 (Anonymous 2018).

Brassica napus L., also referred to as oilseed rape, is an important member of the *Brassica* family. This crop is an amphidiploid species (2n=19) originating from the natural interspecific hybridization between *Brassica oleracea* (n=9) and *Brassica rapa* (n=10). *B. napus* is mainly cultivated for its seeds however, all the parts are useful. The seeds are used for the production of edible oil as well as for biodiesel and its leaves are consumed as vegetable, particularly in Northern India. The oilseed cake is used as animal feed after processing. Moreover, its dried stalk can also be used as domestic fuel.

In India, the production of quality vegetable oil is the need of the hour as the traditional cultivars of rapeseed and mustard have low preference in international market due to higher contents of erucic acid and glucosinolates. Higher amount of erucic acid in oil causes health problems while high glucosinolates in the oil cake are undesirable for animal feed (Kumar *et al* 2009). But the newly released *Brassica napus* L. cultivars known as canola have low erucic acid (<2% in oil), glucosinolates (<30 micro moles per gram of defatted meal) (Anonymous 2018) and higher oleic acid (>60%) content in the seed (Kaur *et al* 2017). Depending upon the species and cultivar *Brassica* seeds contain 30-40 per cent oil and 35-40 per cent protein (Zafar *et al* 2015). The elimination of long chain erucic acid in the canola cultivars is accompanied by increase in the proportion of desirable MUFA (monounsaturated fatty acid) from 10-20 to 60-65 per cent. Hence, the oil of canola cultivars is healthy for human consumption (Anonymous 2018).

The production of oilseeds has not been increasing with the same pace in the country as in cereals. One of the main reason for its low acreage is the overlapping of its sowing time with that of wheat, which is the main staple food of the nation. *Brassica* species is mostly cultivated on marginal and rainfed lands. Although, the area under canola varieties is increasing at a faster rate due to increasing health awareness among the consumers in the country, but average yield is still low as compared to its potential yield. Thus, our main focus is to increase the production of oilseeds from shrinking land resources through increasing input use efficiency. By the efficient management of agronomic practices such as water and nutrients, input use efficiency can be increased. Maintenance of proper soil moisture is a pre-requisite to reap the harvest of rapeseed-mustard as it has been adopted for growth in falling temperature regime during its early phase followed by sharp rise in temperature during the peak vegetative and reproductive phase. Delay in irrigation during this period can lead to moisture stress resulting in drastic reduction in the yield.

Under current scenario, it is expected that the share of water for agriculture is going to decrease with further increase in demand from other sectors. The National Commission for Integrated Water Resources Development (NCIWRD) estimated a total withdrawal of 1180 billion cubic meters (BCM) water for all purposes, in 2050. Out of which irrigation will be accounted for nearly 68 per cent followed by domestic use 9.5 per cent, industries 7 per cent, power development 6 per cent, and other activities claimed about 9.5 per cent (Central Water Commission 2014). To counter this deficit for sustainable production targets, adoption of micro-irrigation systems like drip and sprinkler irrigation are recommended (DOAC 2004).

Even though, 75.5 per cent of the total area under rapeseed and mustard in India is irrigated, but the faulty irrigation practices and schedules lead to its low productivity (Rathod *et al* 2014a). The limited water is mainly applied through check basin method, where water use efficiency seldom exceeds above 35-40 per cent (Rathod *et al* 2014b). Besides this, one-time application of irrigation water at one growth stage increases moisture stress at other stages. Moreover, water saving from drip irrigation system varied from 12 to 84 per cent for different crops besides increasing the productivity of crops (Ramah 2008). Thus, drip irrigation was introduced as water saving technology that not only increases the water productivity but also significantly increases the crop yield. Drip irrigation is one of the most efficient irrigation method, which reduces water requirement by reducing the application losses, reduces weed growth along with providing the water and nutrients beneath the root zone of the crop (Kaur and Brar 2016). Furthermore, it also helps to save electricity cost and takes lesser number of pumping hours of water, hence, easier application of irrigation. It is also being viewed as a promising technology for its ability to support farmers in raising their income by increasing production of the crop.

Among nutrients, nitrogen and phosphorous play a vital role in enhancing canola yield whereas sulphur has a major role in increasing its seed oil content (Chaudhary *et al* 1992). But nitrogen use efficiency (NUE) is very low (i.e. 30-40%) under check basin irrigation system, where water supply exceeds the evapo-transpiration (Katyal *et al* 1985). On the other hand, phosphorous gets fixed into the soil and is not readily available to the plants. Thus, nutrients must be made available to the plants at proper growth stage so as to avoid their excessive loss. Fertigation is a technique of applying soil amendments, fertilizers and other water-soluble product required by the plant during its growth stages through drip irrigation. This technique saves fertilizer, increases fertilizer use efficiency and limits excessive use of expensive fertilizers. Through fertigation, fertilizers can be applied at critical growth stages when the nutrients demand is high. It ensures regular and timely supply of nitrogen without contaminating the environment through leaching (Asad *et al* 2002).

In view of this, it is pertinent to evaluate the performance of canola *gobhi sarson* under different irrigation and fertigation schedules for higher productivity, profitability and sustaining soil health. Thus, the present study entitled 'Water productivity, economics and energetics of *gobhi sarson* (*Brassica napus* L.) as influenced by drip irrigation and fertigation schedules' was planned and executed with the following objectives.

i. To study the effect of drip irrigation and fertigation schedules on growth and productivity of *gobhi sarson* (*Brassica napus* L.).

ii. To compute water productivity, economics and energetics of *gobhi sarson* (*Brassica napus* L.) under different drip irrigation and fertigation schedules.

CHAPTER – II

REVIEW OF LITERATURE

The literature related to the study entitled "**Water productivity, economics and energetics of *gobhi sarson* (*Brassica napus* L.) as influenced by drip irrigation and fertigation schedules**" has been reviewed and presented in this chapter under the following heads:

2.1 Effect of methods of irrigation

2.2 Effect of irrigation schedules

2.3 Effect of fertigation

2.1 Effect of methods of irrigation

With the increase in population and decrease in water availability for agriculture, it has become essential to increase the crop productivity with declining water resources. A higher crop water productivity results from either the same production from less water resources or a higher production from the same water resources (Zwart and Bastiaanssen 2004). According to Bajwa (2007), even a modest improvement (10%) in water use efficiency could release huge quantity of water that may add 14 million hectares of additional irrigation water in the country. With good management and adoption of appropriate practices, more efficient crop production has only been possible under both dryland and irrigated conditions (Wang *et al* 2004). Under Indian conditions, generally three types of irrigation methods are being practiced, these are surface, sub-surface and pressurized irrigation or micro-irrigation. The surface irrigation methods mainly consist of flood irrigation, check basin, furrow irrigation and border strip irrigation. The overall efficiency of surface irrigation is considerably very low (33%) and around 67 per cent of water is being wasted. This low efficiency could be account of losses due to seepage, evapo-transpiration and poor water application technology (Himanshu *et al* 2012). Moreover, a considerable portion (10-15 %) of land is also wasted in bunds and channels in this method of irrigation (Kushwah and Dwivedi 2013). But in sub-surface irrigation method water is applied through perforated or porous pipes laid below the soil surface and provides adequate drainage. The pressurized irrigation systems mainly include drip and sprinkler irrigation methods and up to 50 per cent irrigation water can be saved whereas the remaining quantity of water can be utilized for intensification of cropping system (Rathod *et al* 2014b). Likewise, there was reduction in water consumption by 30–70 per cent by use of drip system over surface method with a considerable gain in productivity by 20–30 per cent for different crops (Thind *et al* 2008; Singh *et al* 2009; and Jayakumar *et al* 2014). Further, significantly increase in yield and water saving using drip irrigation over furrow method has also been reported (Sharanappa and Gowda 1995; Srivastava and Chauhan 1999).

2.1.1 Effect on growth and development

Soni and Raja (2017) in their experiment evaluated two irrigation levels (100% and 75% pan evaporation i.e. PE), two fertigation levels (100% and 75% recommended doses of fertilizer i.e RDF), two irrigation systems (drip and micro sprinkler) and one surface irrigation with soil application of RDF in groundnut. Significantly greater leaf area index (LAI), plant height and dry weight per plant were recorded under drip irrigation at 100 per cent PE with fertigation at 100 per cent RDF, as compared to rest of the treatments and lowest under surface irrigation. Further, Rathod *et al* (2014b) conducted an experiment on micro-irrigation and fertigation in Indian mustard (*Brassica juncea*) and revealed that pressurized irrigation through sprinkler and drip irrigation and their combination with check basin irrigation resulted in higher above ground dry matter, increased plant height and chlorophyll content than check basin alone. In the similar line, Buttar *et al* (2006) studied three methods of irrigation (flood, furrow and alternate furrow) in oilseed rape and concluded that furrow irrigated crop had 3.0 per cent higher plant height, 6.0 per cent higher primary branches, 4.3 per cent higher secondary branches and 6.1 per cent higher number of pods per plant than conventional irrigation method.

In 2000, Wang *et al* investigated the effect on soybean emergence and seedling growth under two irrigation regimes (drip irrigation and sprinkler irrigation). They observed that soil water content was relatively more uniform across the whole soil surface under drip irrigation than sprinkler irrigation. Although, five times more water was used in sprinkler than in drip plot but the soil water content at the root zone was found similar. Further they noticed that soil temperature was significantly higher in drip irrigated plot than in sprinkler, which led to higher emergence rate and enhanced seedling growth. So, it could be concluded that drip irrigation not only conserved water but also maintained the soil profile at a higher temperature more favorable for plant emergence and seedling development.

2.1.2 Effect on yield and yield attributes

Irrigation has direct impact on yield and yield contributing attributes of any crop. In spring sunflower (*Helianthus annuus* L.), Sinha *et al* (2017) studied the impact of drip irrigation levels (100%, 80% and 60% of crop evapotranspiration i.e. ETc) and fertigation schedules (100%, 80% and 60% of RDF) and compared them with an absolute control (furrow irrigation and manual application of fertilizers). Their data showed that, the seed yield recorded was statistically at par in both 100 per cent and 80 per cent ETc but significantly higher than 60 per cent ETc. Further, the crop irrigated with 80 per cent ETc produced 397g more seed yield per cubic meter of water which was 27.8 per cent higher than absolute control. They concluded that drip irrigation either at 100 per cent ETc or 80 per cent ETc, along with fertigation at 100 per cent RDF or 80 per cent RDF produced significantly higher seed yield as compared to absolute control. Similarly, Soni and Raja (2017) obtained significantly higher pod yield (3495 kg ha^{-1}) of groundnut under drip irrigation at 100 per cent PE with fertigation at 100 per cent RDF than surface irrigation method. But according to Singh *et al* (2017) sprinkler irrigation resulted in significantly higher yield attributes, seed and straw yield of soybean as compared to check basin method of irrigation. Sprinkler irrigation recorded 8.3 per cent higher seed yield over check basin method. Qureshi *et al* (2015) studied the comparison between drip and furrow irrigation methods and revealed that drip irrigation produced 26 per cent more seed yield of sunflower due to precise irrigation management, that produced radial distribution pattern and effective utilization of nutrient fertigation in the wetted soil volume. Rathod *et al* (2014b) obtained highest seed and oil yield were in micro-sprinkler system, which was statistically at par with drip system and also with combination of micro- sprinkler and check basin system, but significantly higher than check basin alone in *Brassica juncea*.

Kushwah and Dwivedi (2013) proved that drip irrigation @ 4 liter per hour at 60 per cent available soil moisture (ASM) yielded 82.4 per cent higher than furrow irrigation in *Brassica oleracea* L. var. capitate. Further, Senzen *et al* (2017) proved that irrigation treatments significantly influenced sunflower seed and oil yield and oil quality under both drip irrigation and sprinkler irrigation regimes. Significant linear relationships (R2 =0.96) between evapotranspiration (ET) and oil yield (Y) were obtained during both the years of study. The seed yield response factors (kyseed) were 1.24 and 0.86 for the sprinkler and 1.19 and 1.06 for drip irrigation system in 2006 and 2007, respectively. The response factor for oil yield (kyoil) was found to be 1.08 and 1.49 for the sprinkler and 1.36 and 1.25 for drip systems, in both the years, respectively. The results revealed that, in drip irrigation system partial root zone drying was an acceptable practice to increase sunflower yield and quality under water scarcity condition. In Punjab, Buttar *et al* (2006) also revealed that furrow irrigation gave the highest grain yield (873 kg ha^{-1}) as compared to flood irrigation method (811 kg ha^{-1}) in oilseed rape.

2.1.3 Effect on water productivity, water use efficiency (WUE) and other soil moisture studies

In broccoli (*Brassica oleracea* L.), Jeelani *et al* (2017) concluded that drip irrigation based scheduling resulted in higher water use efficiency (WUE) (44.7% to 54.8%) and saving of irrigation water (43.3% to 48.9%) in comparison to conventional method of irrigation. Furthermore, Senzen *et al* (2017) revealed that the partial root zone drying treatment resulted in maximum water productivity (1.0 kg m^{-3}) and irrigation water productivity (IWP) (1.4 kg m^{-3}) in sunflower. In the same crop Sinha *et al* (2017) found that irrigation at 80 per cent ETc saves 33.3 per cent more water than the absolute control (furrow irrigation and RDF). But, apparent water productivity and energy productivity was higher in drip irrigation at 80 per cent ETc than 100 per cent or 60 per cent ETc. They also concluded that, drip irrigation at 80 per cent ETc and fertigation at 80 per cent RDF had higher water and energy productivity and was economically more viable than absolute control. While in groundnut Soni and Raja (2017) noticed that under drip and micro irrigation, the moisture content was near to the field capacity with little fluctuation between before and after irrigation. Whereas, under surface irrigation from 48 hours after irrigation, there was sharp decline in soil moisture content with time. But, Singh *et al* (2017) found that sprinkler irrigation resulted in significantly higher water productivity of soybean than check basin method. Experiments of Jain and Meena (2015) in groundnut crop exhibited application of water soluble fertilizers through drip saved 36-38 per cent water over check basin method of irrigation. According to Rathod *et al* (2014b), the higher water use efficiency was obtained with micro- sprinkler system over check basin irrigation system in *Brassica juncea*. Kushwah and Dwivedi (2013) proved that drip irrigation @ 4 liter per hour at 60 per cent available soil moisture (ASM) saved 31.0 per cent water and 164.6 per cent more WUE than irrigation with furrow method in *Brassica oleracea* L. var. capitata. Kumar and Sahu (2013) found that up to 50 per cent water saving was possible due to micro- irrigation as well as higher available soil moisture and lower water tension during entire growing period. WUE was found higher under drip irrigation at 40 per cent PE (9.8 q ha^{-1} cm^{-1}) over furrow irrigation at 1.2 IW:CPE (8.1 q ha^{-1} cm^{-1}) in *Brassica oleracea*. Maisiri *et al* (2005) conducted an on-farm evaluation of low cost drip irrigation as compared to conventional irrigation method in *Brassica napus* L. It was recommended that low cost technologies should be used in conjunction with good water and nutrient management if higher water and crop productivity were to be realized than surface irrigation systems. Aujla *et al* (2003) studied the effect of modified furrow irrigation (irrigation to each furrow, irrigation to same alternate furrow, irrigation to alternate furrow irrigated alternately, irrigation to furrow after skipping 2 rows and irrigation to furrow after skipping 3 rows) as compared to flood irrigation. The modified methods saved irrigation water than flooding. Irrigation to furrow after skipping 3 rows and irrigation to furrow after skipping 2 rows being the best treatments. The modified methods showed water expense efficiency of 30.8, 36.7, 46.0 and 54.7 kg $ha^{-1}cm^{-1}$, respectively, compared to 21.5 kg $ha^{-1}cm^{-1}$ under flooding method in case of *gobhi sarson*.

2.2 Effect of irrigation scheduling

Water deficit is a limiting factor in crop production, under such circumstances crop water use efficiency should be increased. This can be made possible through proper irrigation scheduling i.e. by providing the water as per the crop evapo-transpiration requirements and at critical growth stages (Wang *et al* 2001; Norwood and Dumler 2002 and Kar *et al* 2005).

Irrigation scheduling is providing water at right amount and at right time. Moreover, the relationship between crop water use and yield has been examined by numerous researchers. Development of an ideal irrigation schedule is necessary for efficient utilization of irrigation water and maximum yield realization (Matsunaka *et al* 1992)

2.2.1 Effect on growth and development

In broccoli (*Brassica oleracea* L.var. italica), Jeelani *et al* (2017) concluded that drip irrigation at 80 per cent PE resulted in better shoot and root growth, higher relative leaf water content and NPK uptake with respect to drip irrigation at 60 per cent and 40 per cent PE. While in soybean, Montoya *et al* (2017) studied the effect of supplemental irrigation treatments along with rainfed treatment on growth and yield. Soybean growth and development was positively influenced by supplemental irrigation during reproductive stage. The total dry matter and leaf area index (LAI) were 8 and 40 per cent higher in irrigation treatments than in rainfed conditions. Moreover, rainfed treatment recorded 35 per cent yield reduction in comparison to irrigation treatments. Taia A Abd Elmageed (2017) conducted field experiment on soybean grown under three irrigation regimes 100 per cent, 85 per cent and 70 per cent of ETc combined with three potassium (K_2O) levels (90, 120 and 150 kg ha^{-1}). Relative water content and chorophyll fluorescence were significantly affected by irrigation and potassium application. Singh *et al* (2014) stated that, plant height (cm), leaf area index and dry matter accumulation (g $plant^{-1}$) of mustard crop were significantly higher with irrigation at 0.7 IW:CPE ratio than all other irrigation intervals, in Indian mustard (*Brassica juncea* L). Rushima *et al* (2014) observed that the crop raised by 40 cumulative pan evapotranspiration i.e. CPE had maximum secondary branches which was statistically at par with 60 CPE, but significantly higher than 80 CPE and two irrigation schedules (at four weeks after sowing and at flowering) for Indian mustard (*Brassica juncea* L.). Rad *et al* (2014) also verified that maximum relative leaf water content and chlorophyll a and b content was obtained under normal irrigation i.e. under no stress in case of spring rapeseed (*Brassica napus* L.).

Kumar and Sahu (2013) carried out a field trial with 25 treatment combinations involving 5 irrigation levels (furrow irrigation at 1.2 IW:CPE, drip irrigation at 100, 80, 60 and 40% PE) and 5 nitrogen levels (50, 75, 100, 125 and 150% of recommended dose of nitrogen) through fertigation in cabbage (*Brassica oleracea* L. var. capitata). They indicated that all the growth parameters viz, plant height, number of leaves, head diameter, gross and net weight of cabbage were significantly influenced by irrigation and fertigation treatments. Greater plant height and leaves per plant was obtained from drip irrigation at 100 per cent PE and fertigation at 150 per cent recommended dose of nitrogen. According to Seyedmohammadi *et al* (2011), the highest plant height and dry matter accumulation was produced in RGS003 cultivar of spring canola under 6 days irrigation interval as compared to 8 and 10 days interval. The results of the experiment conducted by Piri *et al* (2011) in Indian mustard (B. *juncea* var. Pusa Jagannath) revealed that application of two irrigations (45 DAS and 90 DAS) significantly increased plant height and number of primary branches per plant over one irrigation (45 DAS). Application of two irrigations were statistically at par with one irrigation and also significantly increased net assimilation rate (NAR) and relative growth rate (RGR) over no irrigation at all plant growth stages. Sindhu *et al* (2008) concluded that in case of hybrid canola (*Brassica napus* L.) maximum root density was obtained in CPE 40 followed by recommended irrigation, CPE 60 and then in CPE 80. Tahir *et al* (2007) studied the performance of canola (*Brassica napus L*) under different irrigation levels. They revealed that maximum crop growth rate (CGR) and NAR were observed with three irrigations (21, 56 and 93 DAS). Al-Barrak (2006) concluded that in case of canola (*Brassica napus* L.), the highest stem diameter and plant height were obtained with irrigation at every 7 or 14 days, respectively. Prabhakaran and Lourdurai (2004) founded that various IW:CPE ratios ranging from 0.7 to 1.2 were attributed for higher growth attributes of soybean. Higher plant height, dry matter production and leaf area index were recorded under adequate moisture due to more absorption and utilization of nutrients. Shahin *et al* (2000) studied the effect of irrigation cycles on the growth of rapeseed *(Brassica napus* L.) and they concluded that decreasing the duration of irrigation cycles from 41 to 18 days significantly increased the plant height. The studies conducted by Mahal and Singh (2000) exhibited that growth characteristics like dry matter accumulation and leaf area index in hybrid *gobhi sarson* (*Brassica napus* L.) were optimum at nitrogen application at 150 kg ha^{-1} and irrigation at 75 CPE.

2.2.2 Effect on yield and yield attributes

Jeelani *et al* (2017) concluded that drip irrigation at 80 per cent PE produced higher yield in broccoli (*Brassica oleracea* L.var. italica) as compared to drip irrigation at 60 per cent and 40 per cent PE. Singh *et al* (2017) revealed that scheduling sprinkler irrigation at 0.6 IW:CPE resulted in significant increase in yield and yield attributes of soybean as compared to 0.4 and 0.8 IW:CPE. Irrigation at 0.6 IW:CPE showed 51.3 per cent and 39.0 per cent higher seed yield of soybean over 0.4 and 0.8 IW:CPE. In addition to irrigation, supplying of 75 per cent RDF + 2.5 t FYM ha^{-1} also achieved higher productivity. Results of experiment conducted by Taia A Abd Elmageed (2017) indicated that potassium application of 150 and 120 kg ha^{-1} significantly increased seed yield by 29.6 per cent and 13.9 per cent, respectively when compared with 90 kg ha^{-1}. Saud *et al* (2016) obtained maximum seed yield in Indian mustard (*Brassica juncea* L.) (1582 kg ha^{-1}) with one irrigation at flowering stage over no post sowing irrigation (1269 kg ha^{-1}). Singh *et al* (2014) recorded highest yield attributes like number of siliquae per plant, number of seeds per siliqua, length of siliqua (cm) and seed

(16.4 q ha^{-1}) and stover yield with irrigation at 0.7 IW:CPE ratio than all other irrigation intervals, in Indian mustard (*Brassica juncea* L). Moreover, Verma *et al* (2014) evaluated the response of Indian mustard (*Brassica juncea* L.*)* to irrigation (no irrigation, one irrigation at branching, one irrigation at siliqua formation, two irrigations at branching + siliqua formation) and they concluded that all the yield attributes were increased significantly with irrigations at branching + siliqua formation which were significantly higher over rest of the treatments. Rad *et al* (2014) considered two levels of irrigation [i.e. normal irrigation (non water stress) and interruption of irrigation from the pod formation stage (water stress)] in spring rapeseed (*Brassica napus* L.) and observed that highest seed yield, biomass yield and seed oil content was obtained under normal irrigation. Kumar and Sahu (2013) revealed that, highest yield in cabbage (*Brassica oleracea* L. var. capitata), (30.6 t ha^{-1}) was obtained with drip irrigation at 100 per cent PE. Kingra and Kaur (2012) studied three irrigation treatments (I_1, I_2 and I_3 with one, two and three post-sowing irrigations, respectively) in *Brassica* species, viz *Brassica juncea* and *Brassica napus.* Seed and straw yield were highest in I_3 followed by I_2 and I_1 in decreasing order in both the species. Furthermore, Himanshu *et al* (2012) found that, highest yield of cabbage (*Brassica oleracea*) i.e. 90.5 t ha^{-1} was recorded under drip irrigation at 175 per cent of PE with 1.0 m lateral spacing. The drip irrigation levels were 25, 75, 125, 175 and 225 per cent of PE replenishment.

Seyedmohammadi *et al* (2011) the highest number of total siliqua, seed yield, biological yield and oil yield was produced in RGS003 cultivar of spring canola under 6 days irrigation interval as compared to 8 and 10 days interval. Futhermore, Singla *et al* (2011) undertook work on fertigation in cauliflower (*Brassica oleracea* var. botrytis Linn.) with three nitrogen rates (100%, 75% and 50% of recommended dose) applied in three splits i.e. 50 per cent at planting time, 25 per cent at 30 days after planting and remaining 25 per cent at 60 days after planting along with three irrigation levels (IW:CPE= 0.5, 0.75 and 1.0) in case of two greenhouse conditions (fan pad cooled greenhouse and naturally ventilated greenhouse), respectively. The studies revealed that the yield obtained i.e. 120.7 q ha^{-1} and 105.0 q ha^{-1} of early cauliflower, were maximum under irrigation schedule based on IW:CPE 0.5 and 100 per cent of recommended nitrogen dose, respectively. Similarly, Patel *et al* (2009) indicated that irrigation scheduling at 40 mm CPE significantly increased the yield attributing characters, quality, pod and haulm yield in groundnut crop. Sindhu *et al* (2008) determined that maximum seed yield of hybrid canola (*Brassica napus* L.) (15.9 q ha^{-1}) was obtained with recommended irrigation schedule which was significantly superior over CPE 80 but was statistically at par with CPE 40 and 60. Daneshvar *et al* (2008) experimented on rapeseed which comprised of 4 irrigation levels (I_{60}, I_{90}, I_{120} and I_{150}) and 4 nitrogen levels (N_0, N_{70}, N_{140} and N_{210} kg N ha^{-1}). As rate of nitrogen increased, seed oil percentage decreased and seed oil yield increased significantly. Likewise, Al-Barrak (2006) concluded that irrigating canola every 7 or 14 days and fertilizing with 120-180 kg N ha^{-1} produced the highest seed and oil yield. It was also observed that irrigating canola plants at the regular interval of 14 days with irrigation water 650 m^{3} ha^{-1} resulted in highest seed and oil yield. Singh *et al* (2001) also found that application of two irrigations, one at initiation of branching (40 DAS) and the other at flowering (60 DAS) or pod development stage (100 DAS) resulted in statistically similar yields with three irrigations in Indian mustard. Water stress during the initiation of branching through pod development stage caused 28 per cent yield reduction, whereas water stress throughout the crop growth period resulted in yield reduction of 35 per cent as compared to no water stress.

Bhalerao (2001) concluded that irrigation scheduling at 0.8 IW:CPE significantly increases the seed and oil yield in Indian mustard (*Brassica juncea* L.) as compared to 0.6 and 0.4 IW:CPE. Shahin *et al* (2000) studied the effect of irrigation cycles (18-22 29-30 and 41 days) on seed yield and soil water plant relation for rapeseed *(Brassica napus* L.) and concluded that decreasing the duration of irrigation cycles from 41 to 18 days increased 1000 seed weight, number of pods plant^{-1} and seed yield. Mahal and Singh (2000) found that yield attributes such as harvest index, number of siliquae per plant, test weight and seed yield in hybrid *gobhi sarson* (*Brassica napus* L.) were optimum at 150 kg N ha^{-1} and irrigation at 75 CPE, although yield was significantly higher at 200 kg N ha^{-1} and irrigation at 90 CPE. Garnavak *et al* (2000) also revealed, that irrigation at IW:CPE of 0.8 produced significantly higher seed (15.7 q ha^{-1}), oil (592 kg ha^{-1}) and biomass (80.4 q ha^{-1}) yields as well as removed higher amount of nutrients as compared to IW:CPE of 0.4 and unirrigated control on *B. carinata* and *B. juncea* under late-sown conditions. Likewise, nitrogen application significantly increased the harvested biomass up to 120 kg ha^{-1} but yield attributes, seed and oil yield as well as nutrients uptake were increased only up to 80 kg ha^{-1}. Kumar *et al* (1996) experimented on *Brassica juncea* cultivar RH-30 and *B. campestris var. toria* cultivars TH-68 and TCH-2 and evaluated four N levels (0, 30, 60 or 90 kg N ha^{-1}) with or without irrigation at 40 DAS. They reported that irrigation increased the seed yield (1474 vs. 1316 kg ha^{-1}) as compared to no irrigation but increase in seed yield was observed up to 60 kg N ha^{-1} only. Siag *et al* (1993) achieved maximum seed yield (1.35 t ha^{-1}) of toria (*Brassica campestris* var toria) with irrigation at branching + siliqua development whereas seed yield without irrigation was 0.67 t ha^{-1}. Among single irrigation treatments, yield was highest (1.04 t ha^{-1}) with irrigation at peak flowering than rest of the treatments. Similarly, Gill and Narang (1993) conducted a field experiment to determine the yield *in gobhi sarson* (*Brassica napus* L.) The field was irrigated once at 28 DAS, 28 DAS+ CPE 120 mm and 28 DAS+ twice at 80 mm CPE. Dry matter production and seed yield were highest with a combination of three irrigations and application of 150 kg N ha^{-1}. Narang *et al* (1993) experimented on *Brassica napus*, to study the effect of irrigation (50, 60 and 70% depletion of available soil moisture) and nitrogen, sulphur and phosphorous fertilization. With increase in irrigation frequency and increase in N rate up to 17.4 kg P and S application the seed yield also increased. The highest seed yield of 1.81 t ha^{-1} was obtained with 120 kg N + irrigation at 50 per cent depletion of available soil moisture.

2.2.3 Effect on water productivity and water use efficiency and other soil moisture studies

Jeelani *et al* (2017) indicated that drip irrigation at 80 per cent PE had higher soil water content, profile water recharge and soil water stock in comparison to drip irrigation at 60 per cent and 40 per cent PE. Rushima *et al* (2014) stated that water use was higher with irrigation scheduling at 40 CPE and deceased with increase in CPE, while WUE increased with increase in CPE in Indian mustard. Himanshu *et al* (2012) evaluated the effect of five drip irrigation levels (25, 75, 125, 175 and 225% of PE replenishment) in cabbage (*Brassica oleracea*) and observed that irrigation at 25 per cent of PE replenishment produced highest water productivity of 61.6 kg m^{-3} with 1.0 m lateral spacing and decreased significantly with increasing irrigation levels. They also concluded that drip irrigation method was highly profitable for cabbage production with 1.0 m lateral spacing. Fanaei *et al* (2009) observed potassium fertilization and irrigation levels effect on WUE and grain yield of two *Brassica* species (Hyola 401 hybrid and a landrace of Indian mustard). Three irrigation levels were [irrigation after 50% (S_1) (control), 70% (S_2), 90% (S_3) depletion of soil water] were tested against potassium fertilizer and they concluded that with increasing stress intensity grain yield decreased and water use efficiency increased significantly. Grain yield in severe water stress treatment (S_3) was 27 per cent lower than the control (S_1), however, there was 16 per cent increase in WUE. Increasing water use efficiency reduced water used in S_2 and S_3 treatments by 7 per cent and 39 per cent as compared with control (S_1). Irrigation and potassium interaction was significant for WUE, grain yield and number of aborted siliquae per plant, but not for the other traits. Patel *et al* (2009) obtained maximum WUE with irrigation schedule of 50 mm CPE. Daneshvar *et al* (2008) experimented on rapeseed, comprising of 4 irrigation levels (I_{60}, I_{90}, I_{120} and I_{150}) and 4 nitrogen levels (N_0, N_{70}, N_{140} and N_{210} kg N ha^{-1}). As N rate increased, seed oil percentage decreased and seed oil yield increased significantly. Both WUE and dry matter remobilization efficiency (DMRE) were increased by decreasing water supply in treatments I_{90} to I_{150}. But N_0 and N_{210} resulted in the lowest WUE and DMRE, respectively. Sindhu *et al* (2008) revealed that for hybrid canola (*Brassica napus* L.) WUE was maximum (35.4 kg ha^{-1} cm^{-1}) in recommended irrigation schedule followed by CPE 40, 60 and 80.

Kar *et al* (2007) observed a significant increase in water use efficiency of mustard by increasing irrigations from two to three. Al-Barrak (2006) stated that in canola crop (*Brassica napus* L.), optimum WUE was obtained with irrigation after every 14 days, particularly with the addition of 180 kg N ha^{-1}. Singh *et al* (2001) also concluded that by increasing the number of irrigations, the consumptive use of water increased but WUE reduced. Similarly, Kumar *et al* (1996) reported that irrigation increased the total water use, but decreased WUE. Siag *at el* (1993) recorded that total water use of 137 mm without irrigation, 184-191 mm with one irrigation and 242-250 mm with two irrigations. WUE was highest from single irrigation at peak flowering stage in Toria (*Brassica campestris* var. toria). Choudhary *et al* (1990) studied the response of rapeseed (*Brassica napus* L.) to irrigation schedules (no irrigation, irrigation at 50% flowering or early siliqua formation) and determined that the WUE was highest with no irrigation and lowest with irrigation at 50 per cent flowering.

2.3 Effect of fertigation

Efficient use of water and fertilizer is crucial to sustain agricultural production. Therefore, the goal of soil fertility research should be to develop practices to achieve crop nutrient requirement by higher nutrient absorption through minimal use of fertilizers. Fertigation is an efficient method of applying nutrients through irrigation water as a carrier and distributor of crop nutrients (Bachchhav 2005). This improves fertilizer use efficiency (FUE), minimize volatilization and leaching losses as well as ground water contamination. Moreover, resource use efficiency and yield gets improved with fertigation (Jat *et al* 2011).

2.3.1 Effect on growth and development

Jeelani *et al* (2017) conducted an experiment on broccoli (*Brassica oleracea* L.var. italic). The treatments consisted of three drip irrigation levels ($I_{0.4}$, $I_{0.6}$ and $I_{0.8}$ i.e. drip at 40% ,60% and 80% CPE) and three fertilizer application levels (F_{100} -100% RDF through fertigation, $F_{C25+F75}$ -25% RDF through conventional method as a basal dose and 75 % through fertigation and F_{CF} -100% RDF through conventional method and fertilizers, along with control -flood irrigation of 4 cm at 8-10 days interval + 100% RDF) and an absolute control- no fertilizer and flood irrigation of 4 cm at 8-10 days interval. Likewise, F_{100} and $F_{C25+F75}$ treatment obtained higher root and shoot growth, chlorophyll content, relative leaf water content, NPK uptake and WUE in comparison to F_{CF}**.** Jain and Meena (2015) indicated that maximum SPAD chlorophyll meter reading (SCMR) in case of groundnut (*Arachis hypogaea* L.) was recorded with the application of water soluble fertilizer (WSF) through drip irrigation at 150 kg ha^{-1} (at 50 DAS), while the plant height, dry matter accumulation per plant and number of nodules per plant (at 75 DAS) were found higher in the treatment receiving WSF at 226.5 kg ha^{-1}. Daleshwar *et al* (2014) studied three drip irrigation level (100, 80 and 60% of evapotranspiration i.e. ET) and three fertigation levels (100, 75 and 50%

recommended N and K through drip irrigation system) and one control (surface irrigation at 1.0 IW:CPE and recommended dose of fertilizer as in farmers practice) in cabbage (*Brassica oleracea* L. var capitate). The maximum plant height, diameter of curd and plant spread was obtained with drip irrigation at 80 per cent ET and fertigation at 75 per cent of recommended N and K. Likewise, Rathod *et al* (2014b) revealed that fertilization of N substantially increased productivity of mustard by increasing leaf area index and the efficiency of converting intercepted light into biomass of the individual plant. Behera *et al* (2014) also observed that fertigation level of 100 per cent of RDF (150:60:60 kg ha^{-1}) resulted in significantly higher accumulation of dry matter of menthol mint (*Mentha arvensis* L.) as compared to 75 and 50 per cent RDF. Kumar and Sahu (2013) obtained greater plant height and leaves per plant with fertigation at 150 per cent recommended dose of nitrogen

2.3.2 Effect on yield and yield attributes

Soni and Raja (2017) obtained significantly higher pod yield (3495 kg ha^{-1}) under drip irrigation at 100 per cent PE with fertigation at 100 per cent RDF in groundnut crop. Jeelani *et al* (2017) stated that the curd yield obtained in broccoli (*Brassica oleracea* L.var. italica) under drip irrigation at 40 per cent PE and fertigation with 100 per cent RDF was statistically at par with drip irrigation 60 per cent PE and fertigation with 100 per cent RDF, which resulted in saving of 20 per cent irrigation water. Sinha *et al* (2017) in sunflower recorded that among the fertigation treatments, 100 per cent RDF produces highest seed and oil yield as well as net returns and energetics, which was significantly higher as compared to 80 per cent and 60 per cent RDF. Patel *et al* (2017) conducted an experiment comprising of four scheduling of irrigation (0.6, 0.8 and 1.0 alternate days fraction of pan evaporation (ADFPE)) through drip system and surface method and three nitrogen fertigation (50%, 75% and 100% RDN (i.e. 80 kg ha^{-1}). The result revealed that to achieve profitable yield from semi *rabi* castor, irrigation followed at 1.0 ADFPE through drip in conjunction with fertigation of nitrogen at 60 kg ha^{-1} through urea in four equal splits at 30, 60, 90 and 120 DAS, respectively. Jain and Meena (2015) revealed that in groundnut crop (*Arachis hypogaea* L.) maximum pod yield (2.7 t ha^{-1}), kernel yield (1.8 t ha^{-1}), oil yield (0.9 t ha^{-1}), haulm yield (5 t ha^{-1}), protein yield (0.5 t ha^{-1}), oil content (50.3%),) and nutrient uptake (200.1 kg NPK ha^{-1}) were obtained with application of water soluble fertilizer through drip irrigation at 226.5 kg ha^{-1}. The maximum actual N (36.0 kg ha^{-1}), P (8.5 kg ha^{-1}) and K (31.4 kg ha^{-1}) gains were recorded when water soluble fertilizer was applied @ 250 kg ha^{-1} through drip irrigation as compared to rest all other treatments. Rathod *et al* (2014b) observed that increase in N fertigation levels from 0 to 120 kg ha^{-1} significantly improved mustard yield attributes, seed and oil yield, however was found statistically at par with 80 kg N ha^{-1}. Also, Daleshwar *et al*

(2014) gained highest yield (338.4 q ha^{-1}) in cabbage (*Brassica oleracea* L. var capitate) when treated with drip irrigation at 80 per cent ET and fertigation at 75 per cent RDF (N and K).

Vasu and Reddy (2013) conducted an experiment to study the effect of fertigation in cabbage (*Brassica oleracea*) and they reported that highest yield (16.9 t ha^{-1}) was observed under daily fertigation of N and K at 100 per cent RDF followed by 125 per cent RDF. Highest N (100.5 kg kg^{-1}) and K (131.4 kg kg^{-1}) fertilizer use efficiency was obtained by daily fertigation of 75 per cent of RDF. Kumar and Sahu (2013) determined that fertigation at 150 per cent of recommended dose of nitrogen significantly increased the yield of cabbage (*Brassica oleracea* L. var. capitata) to 29.7 t ha^{-1}. The maximum uptake of nitrogen (296.2 kg ha^{-1}), phosphorus (26.9 kg ha^{-1}) and potassium (309.7 kg ha^{-1}) were also observed at fertigation with 150 per cent of recommended dose of nitrogen. Brahma *et al* (2010) showed that there was significant improvement in growth, yield and fertilizer use efficiency of broccoli (*Brassica oleracea* L. var. italica) under drip irrigation and fertigation. Drip irrigation at 100 per cent evaporation replenishment with 100 per cent supplementation of recommended dose of nitrogen (200 kg ha^{-1}) through fertigation was found to be significantly higher in terms of yield and yield attributes over conventional method of fertilizer application with recommended dose of nitrogen. Fertigation saved fertilizers to the tune of 40 per cent as compared to conventional method for the same yield levels. Furthermore, fertigation with 100 per cent recommended doses of N was the most efficient treatment with fertigation efficiency of 55.4 per cent and 57.3 per cent respectively (for two years). Therefore, it was concluded that fertigation with the present recommended dose of N (200 kg ha^{-1}) at 4 days can be practiced for profitable cultivation of broccoli. Patel *et al* (2010) performed experiment on castor (*Ricinus communis* L.) and the levels for fertilizer application were 100 per cent recommended dose of nitrogen (RDN) through spot application, 50 per cent RDN through fertigation and 100 per cent RDN through fertigation. They observed that application of 100 per cent RDN through fertigation obtained significantly highest seed yield (3037 kg ha^{-1}) as compared to rest of the treatments.

2.3.3 Effect on water productivity and water use efficiency

According to Sinha *et al* (2017), the apparent water productivity recorded was significantly higher in sunflower crop for 100 per cent RDF than 80 per cent and 60 per cent RDF. Jain and Meena (2015) experimented on groundnut crop and observed maximum water productivity (787 g m^{-3}) from application of water soluble fertilizer at the rate of 226.5 kg ha^{-1} through drip irrigation. Daleshwar *et al* (2014) observed that in cabbage (*Brassica oleracea* L. var capitate) maximum water saving (53.7%) and highest WUE of 176.9 kg ha^{-1} mm^{-1} could be obtained from irrigating the crop at 60 per cent of ET through drip system and fertigating it against 75 per cent of recommended dose of N and K. N and K use efficiency was recorded to be highest in drip irrigation at 80 per cent of ET and fertigation at 50 per cent of recommended dose of N and K. Vasu and Reddy (2013) found out that the highest water productivity (7.9 kg m^{-3}) was obtained with daily fertigation with 100 per cent RDF in *Brassica oleracea*. Kumar and Sahu (2013) recorded highest WUE with fertigation at 150 per cent of recommended dose of nitrogen (9.7 q ha^{-1} cm^{-1}) in cabbage (*Brassica oleracea)*. Similarly, Abdelraouf *et al* (2013) concluded that reducing fertigation levels from 100 to 50 per cent recommended NPK fertilizer significantly increased irrigation WUE of wheat cultivar. WUE increased from 0.9 to1.2 kg m^{-3} for 100 and 50 per cent recommended NPK fertigation treatments, respectively.

CHAPTER – III

MATERIAL AND METHODS

The present investigation entitled "**Water productivity, economics and energetics of *gobhi sarson* (*Brassica napus* L.) as influenced by drip irrigation and fertigation schedules**" was conducted at the Student's Research Farm, Department of Agronomy, Punjab Agricultural University, Ludhiana, during the *rabi* seasons of 2016-17 and 2017-18. The details of the materials used and methods adopted during the course of investigation are presented in this chapter.

3.1 Location and climate

Ludhiana is situated at 30^0 54' N latitude and 75^0 48' E longitude at the mean height of 247 m above mean sea level in the central plain region of Punjab state under the trans-gangetic agro-climatic zone of India. The region is characterized by semi-arid and sub-tropical climate. Hot and dry summers prevails during April to June, hot and humid conditions from July to September, November to January is characterized by cold winters and mild winters during February and March. There is considerable fluctuation in the mean maximum and minimum temperatures during summer and winter. The average annual rainfall of Ludhiana is 755 mm and greater portion (> 75 %) of it is received as monsoon from July to September. The rains are scanting during winter, but few showers of cyclonic rains are received during December-January or late spring. The *rabi* season is marked with gradual decrease in temperature during December–January and after that the temperature start to increase, which is suitable for the growth and development of *gobhi sarson.*

3.2 Weather during the crop season

The mean weekly meteorological data was recorded from the Meteorological Observatory of Punjab Agricultural University, Ludhiana during crop season of *rabi* 2016-17 and 2017-18 and presented in Figure 3.1 and 3.2 and in appendix I and II. The weekly maximum mean air temperature ranged from 16˚C to 34.5˚C and 17.1˚C to 31.3˚C during crop season 2016-17 and 2017-18, respectively. The weekly minimum mean air temperature ranges from 3.5˚C to 19.3˚C and 5.3˚C to 16.2˚C during crop season 2016-17 and 2017-18, respectively. The maximum and minimum weekly mean temperature of 34.5˚C and 3.5˚C were recorded during 13th and 2nd week of crop season 2016-17 whereas for crop season 2017-18 the maximum and minimum weekly mean temperature of 31.3˚C and 5.3˚C were recorded during 43rd and 2nd week, respectively. The maximum 80% and 84.5% weekly mean relative humidity was recorded during 50th and 4th week of crop season of 2016-17 and 2017-18, respectively. The minimum 58% and 57.3% weekly mean relative humidity was recorded during 13th and 11th week of crop season of 2016-17 and 2017-18, respectively. The total rainfall of 93.7 and 76.4 mm was recorded during 2016-17 and 2017-18, respectively.

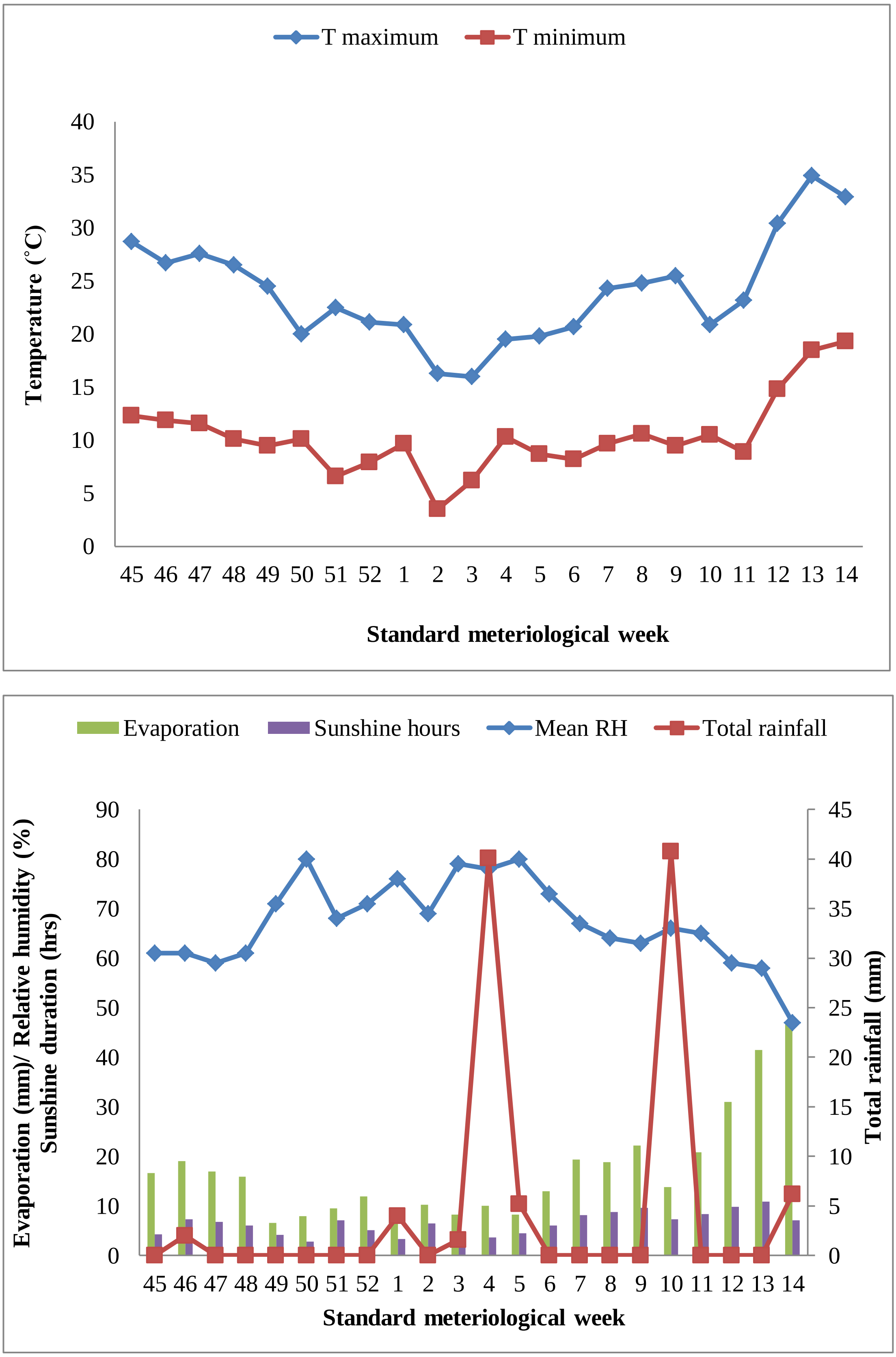
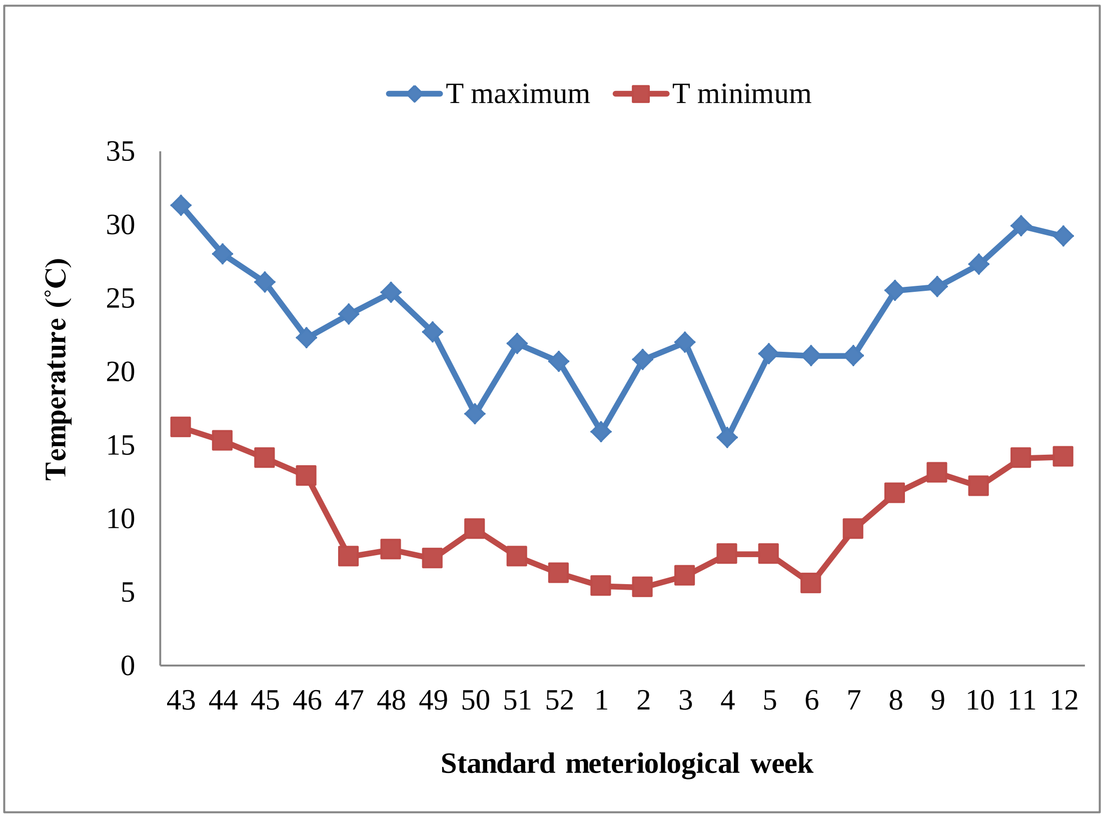


Fig 3.1: Weekly mean meteorological data recorded during the crop season (November 2016 - April 2017) at Meteorological Observatory, Department of Climate Change and Agricultural Meteorology, PAU Ludhiana



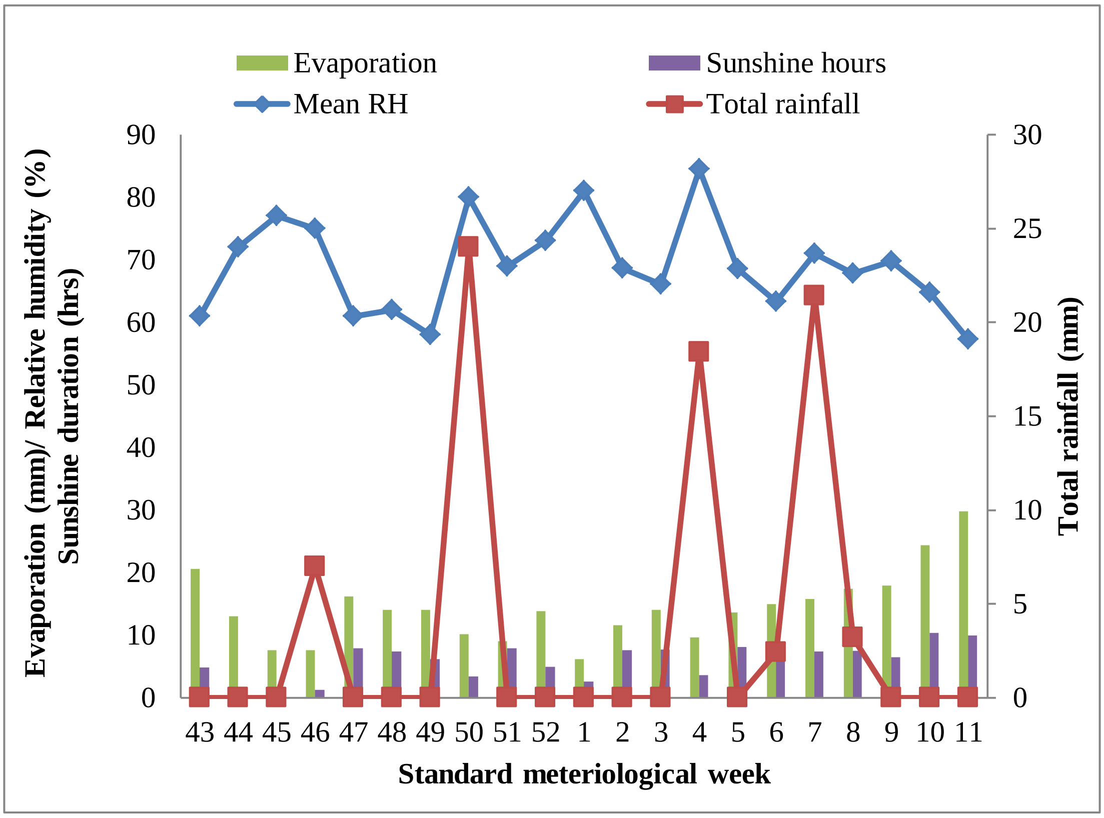


Fig 3.2: Weekly mean meteorological data recorded during the crop season (October 2017 - April 2018) at Meteorological Observatory, Department of Climate Change and Agricultural Meteorology, PAU Ludhiana

3.3 Cropping history

Cropping history of the experimental field is given below in Table 3.1

Table 3.1: Cropping history of the field under experiment

Year	***Kharif***	***Rabi***
2015-16	Rice	Wheat
2016-17	Rice	*Gobhi sarson* (Experimental crop)
2017-18	Fallow	*Gobhi sarson* (Experimental crop)

3.4 Soil characteristics

Five randomly selected sites in the experimental field were chosen to collect composite soil samples from 0-15 and 15-30 cm soil depth before sowing of the experimental crop. The soil samples after collection were dried in shade, grinded and then sieved through 2 mm sieve. The physico-mechanical and chemical analysis were done to evaluate the inherent fertility and texture of the experimental plot. The values obtained with respect to various properties are as follows:

3.4.1 Physico-mechanical properties

The data with respect to physico-mechanical analysis of soil is presented in Table 3.2. The soil texture of the experimental field was loamy sand with an average bulk density of 1.58 g cm^{-3} from 0-30 cm soil profile.

Table 3.2: Physico-mechanical properties of the experimental plot soil

Soil depth (cm)	**Sand (%)**	**Silt (%)**	**Clay (%)**	**Textural class**	**Bulk density (g cm^{-3})**
0-15	75.0	13.0	12.0	Loamy sand	1.57
15-30	76.0	12.6	11.4	Loamy sand	1.59
Method used	**International Pipette method (Piper 1966)**				**Core Sampler method (Bodman 1942)**

3.4.2 Chemical properties

The composite soil samples from 0-15 cm and 15-30 cm profile layers from five spots of experimental field were taken prior to sowing of crop and subjected to mechanical and chemical analysis. The data exhibited that the soil from experimental site has normal pH and EC but found low in organic carbon. Further, it has been observed that soil has low available N, medium available P and S and high available K. The data pertaining to chemical properties are presented in Table 3.3.

Table 3.3: Chemical properties of soil of the experimental field

Characters	Soil depth (cm)		Rating	Method used
	0-15	**15-30**		
pH	7.3	7.4	Normal	1:2 soil: water suspension (Jackson 1967)
EC (dSm^{-1}) at 23 ^0C	0.45	0.36	Normal	1:2 soil: water supernatant Solu-bridge conductivity meter (Jackson 1967)
Organic carbon (%)	0.34	0.24	Low	Walkley and Black's rapid titration method (Piper 1966)
Available nutrients (kg ha^{-1})				
N	187.0	164.0	Low	Modified alkaline potassium permanganate method (Subbiah and Asija 1956)
P	22.0	18.7	Medium	0.5 N Sodium bicarbonate extractable P by Olsen's method (Olsen *et al* 1954)
K	341.2	320.6	High	Ammonium acetate extractable K (Jackson 1967)
S	21.5	19.1	Medium	Turbidimetric method (Chesnin and Yien 1950)

3.5 Experimental details

The field experiment was conducted in randomized complete block design (RCBD) keeping combination of three irrigation levels (60%, 80% and 100% of CPE), and three fertigation levels (60%, 80% and 100% RDF). Thus, nine treatments (T_1 to T_9) were applied through drip irrigation and fertigation along with T_{10} (absolute control) that consist of flood irrigation and manual application of recommended dose of fertilizers (Table 3.4). The gross size of the experimental plot was 5.6 m x 2.7 m. In each plot, six rows of *gobhi sarson* were sown at a spacing of 45 cm and for drip irrigation and fertigation lateral pipes of 12 mm were placed between two rows of the crop. Thirty outline drippers in each lateral line were placed with dripper to dripper spacing of 20 cm. Discharge rate of dripper was 4 litre per hour.

Table 3.4: Details of treatments applied to *gobhi sarson* under different irrigation and fertigation schedules during *rabi* 2016-17 and 2017-18.

Symbols	Treatments
T1	60 % of CPE*, 60 % RDF**
T2	60 % of CPE, 80 % RDF
T3	60 % of CPE, 100 % RDF
T4	80 % of CPE, 60 % RDF
T5	80 % of CPE, 80 % RDF
T6	80 % of CPE, 100 % RDF
T7	100 % of CPE, 600 % RDF
T8	100 % of CPE, 80 % RDF
T9	100 % of CPE, 100 % RDF
T10	**PAU recommendation** – flood irrigation and manual application of recommended dose of fertilizers

*CPE: Cumulative Pan Evapo-transpiration

**RDF: Recommended Dose of Fertilizers (150 kg N and 30 kg P_2O_5 per hectare)

3.6 Methodology

Crop : *Brassica napus* L.

Variety : GSC 7

Experimental Design : Randomized Complete Block Design (RCBD)

Total Number of Treatments : 10

Number of Replication : 3

Total Number of Plots : 30

Gross Plot Size : 15.12 m^2 (5.6 m x 2.7 m)

Wettable Area : 12.09 m^2

Net Plot Size : 8.28 m^2 (4.6 m x 1.8 m)

3.7 Layout

The layout plan of the experimental field is depicted in Fig 3.3

Fig :3.3 Layout of the experimental field

3.8 Agronomic practices

3.8.1 Pre-sowing irrigation

A heavy pre-sowing irrigation (10 cm) was applied to the whole experimental field before seed bed preparation to ensure adequate moisture in the soil profile at the time of sowing.

3.8.2 Seedbed preparation

A fine seed bed was prepared by ploughing the field with disc harrow and once with tractor drawn cultivator followed by planking after the field came to proper moisture condition.

3.8.3 Sowing

The crop cultivar GSC 7 was sown on 7th November, 2016 and on 27th October 2017, during 2016-17 and 2017-18, respectively. The seed was sown at optimum soil moisture at the rate of 3.75 kg ha^{-1} with hand drill in rows 45 cm apart and was then covered with light soil.

3.8.4 Thinning and gap filling

Thinning and gap filling of crop was done after one month of sowing by keeping plant to plant distance of 10 cm.

3.8.5 Fertilizer schedule

As per university recommendation, 150 kg N (325 kg ha^{-1} urea) and 30 kg P_2O_5 (187.5 kg ha^{-1} SSP) per hectare in flood irrigated plots were applied. Nitrogen was applied through urea (46% N) and phosphorous through single super phosphate (16% P_2O_5 and 12% S), no dose of potassium was applied as the soil test showed high K levels. In flood irrigated plot (T_{10}) half dose of N and full dose of P_2O_5 was applied before sowing and the remaining ½ dose of N was applied with first irrigation. For drip irrigated plots (T_1 to T_9), 150 kg N was applied in the form of urea (312.5 kg ha^{-1}), 30 kg P_2O_5 was applied in the form of mono ammonium phosphate (MAP @ 50 kg ha^{-1}) and S through elemental sulphur (25 kg ha^{-1}). The fertigation schedules were started after 15 days of sowing and were completed in 10 splits with an interval of 6 days through venture system. Fertilizer doses as well as the date of fertigation is presented in the Table 3.5 and 3.6, respectively.

Table 3.5: Fertilizer doses applied to *gobhi sarson* under different irrigation and fertigation schedules during *rabi* 2016-17 and 2017-18.

Area	**Urea**	**MAP**	**Sulphur**
Per hectare	312.5 kg	50 kg	25 kg
Per plot	420 g	67 g	33.6 g
Per split (10 splits)	42 g	6.7 g	3.3 g
100% RDF (9 plots per split)	378 g	60 g	30 g
80% RDF (9 plots per split)	302 g	48 g	24 g
60% RDF (9 plots per split)	227 g	36 g	18 g

Table 3.6: Dates of fertigation applied to *gobhi sarson* under different irrigation and fertigation schedules during *rabi* 2016-17 and 2017-18.

No of fertigation	**2016-17**	**2017-18**
1	23rd November	11th November
2	30th November	18th November
3	7th December	25th November
4	14th December	2nd December
5	21th December	9th December
6	28th December	16th December
7	4th January	23rd December
8	11th January	30th December
9	18th January	6th January
10	25th January	13th January

3.8.6 Weed control

One manual weeding was carried out with the help of a *kasaula* after 40 -45 days of sowing

3.8.7 Irrigation schedule

Irrigations through drip system were applied at six days interval (fixed) and volume of each irrigation kept equal to cumulative pan evapo-transpiration (CPE) of the respective treatments and required amount of irrigation water was measured through water metre. Irrigation schedules were started one month after sowing and thereafter irrigation was applied after every 6th day. The data regarding rainfall and pan evaporation was obtained from metrological observatory at Punjab Agricultural University, Ludhiana. Irrigation water applied was equal to 60% of CPE, 80% of CPE and 100% of CPE for different treatments. In flood irrigated plots, first irrigation was given one month after sowing, the second irrigation was carried out at the end of December and the third and last irrigation was given during the second fortnight of February upto the depth of 7.5 cm. A total of 11 irrigations through drip and 3 irrigations through flood were applied during crop season 2016-17 and 2017-18. The volume of irrigation water applied per wettable area per plot are presented in appendix IV.

Table 3.7: Dates of irrigation applied to *gobhi sarson* under different irrigation and fertigation schedules during *rabi* 2016-17 and 2017-18.

Irrigation	2016-17		2017-18	
	Drip	Flood	Drip	Flood
1	8th December	8th December	27th November	27th November
2	15th December	31st December	4th December	27th December
3	22nd December	15th February	11th December	15th February
4	29th December		3rd January	
5	5th January		10th January	
6	12th January		17th January	
7	19th January		24th January	
8	25th January		7th February	
9	23rd February		21st February	
10	2nd March		28th February	
11	9th March		7th March	

3.8.8 Plant protection

All recommended plant protection measures were adopted to protect the crop from major pests like mustard aphid and leaf eating caterpillar. A total of 4 sprays were carried out using a knapsack sprayer fitted with cone type nozzle, out of which two sprays of Rogor 30 EC @ 1 kg ha^{-1} to control aphid infestation, one spray of Confidor @1 kg ha^{-1} to control aphid infestation and one spray of Malathion 50 EC @ 1 kg ha^{-1} for the control of leaf eating caterpillar were done during crop season 2016-17. While for crop season 2017-18, a total of 4 sprays were carried out, out of these two sprays of Rogor 30 EC @1 kg ha^{-1} to control aphid infestation, and two sprays of Ekalux 25 EC @1 kg ha^{-1} to control leaf eating caterpillar.

3.8.9 Harvesting

The crop was harvested on 7th April and 20th March of 2017 and 2018, respectively. Harvesting was done with sickles when the colour of stem, branches and siliqua changed from

Plate 1: Photographs of experiment

Plate 2: Irrigation at 60% of CPE and fertigation at 60% RDF

Plate 3: Irrigation at 60% of CPE and fertigation at 80% RDF

Plate 4: Irrigation at 60% of CPE and fertigation at 100% RDF

Plate 5: Irrigation at 80% of CPE and fertigation at 60% RDF

Plate 6: Irrigation at 80% of CPE and fertigation at 80% RDF

Plate 7: Irrigation at 80% of CPE and fertigation at 100% RDF

Plate 8: Irrigation at 100% of CPE and fertigation at 60% RDF

Plate 9: Irrigation at 100% of CPE and fertigation at 80% RDF

Plate 10: Irrigation at 100% of CPE and fertigation at 100% RDF

Plate 11: PAU recommendation – flood irrigation and manual application of fertilizers

green to light yellow. The harvested crop was tied in bundles, labelled and kept for sun drying for few days before threshing.

3.8.10 Threshing

Threshing was done manually with the sticks separately for each plot. The produce of each plot was cleaned by proper winnowing.

3.9 Field studies

3.9.1 Emergence count

The number of emerged plants of each experimental plot was counted after 10 days of sowing and was expressed as number of emerged plant m^{-2}.

3.9.2 Plant height

Periodic plant height was recorded at 30, 60, 90, 120 days after sowing and at harvest. Five plants from each of the experimental plot were randomly selected and their height was measured from the base of the plant i.e. ground level to the base of fully opened leaf in each plot. The mean plant height of five plants were computed and expressed in cm.

3.9.3 Dry Matter Accumulation (DMA)

Periodic DMA was recorded at 30, 60, 90 and 120 days after sowing and at harvest. Two representative plant samples from each experimental unit were cut at ground level and their dry weight were recorded after drying the samples in oven at a temperature of 60^0 C till constant weight was achieved. The dry matter was represented as dry matter accumulation and expressed as q ha^{-1}.

3.9.4 Leaf Area Index (LAI)

LAI was recorded at 30, 60, 90 and 120 days after sowing and at harvest using the Sun Scan Canopy Analyzer.

3.10 Phenological observations

3.10.1 Days taken to emergence

The number of emerged plants in one-meter row length were counted from two randomly selected places in each plot. The data was recorded daily from 3 days to 10 days after sowing.

3.10.2 Days taken to 50% flowering

Ten plants were randomly selected from each crop row to determine days taken to 50% flowering. It is the date at which at least one fully opened flower appeared on 5 of the 10 selected plants. The number of days were counted from sowing to this date and referred to as days taken to 50% flowering.

3.10.3 Days taken to 50% siliqua formation.

Days taken to 50% siliqua formation is the date at which one or more siliqua appeared on 5 of the 10 randomly selected plants from each crop row. The number of days were counted from sowing to this date and referred to as days taken to 50% of the siliqua formation.

3.10.4 Days taken to physiological maturity

The physiological maturity of crop was indicated when seeds became brown to black in colour, siliquae turned to lemon yellow in colour and stem and branches turned from pale yellow to brown. The number of days from sowing to this date was counted and referred to as number of days taken to physiological maturity.

3.11 Yield attributes:

3.11.1 Primary branches per plant

Five plants were randomly selected from each plot and number of primary branches these plants were counted and average was expressed in per plant basis.

3.11.2 Secondary branches per plant

The number of secondary branches of five randomly selected plants from each plot were counted and average was expressed in per plant basis.

3.11.3 Number of siliquae per plant

Five plants were randomly selected from each treatment and the number of siliquae on whole plant was counted separately at the time of maturity and computed as mean number of siliquae per plant.

3.11.4 Number of seeds per siliqua

Twenty-five siliquae were randomly collected from each treatment at maturity and hand threshed. Total number of seeds were counted and mean number of seeds per siliqua were calculated.

3.11.5 Test weight

After threshing the crop and cleaning the produce (seeds), a representative sample of seeds from each treatment was obtained from bulk produce of the whole plot. One thousand seeds were counted and weighed to give 1000-seed weight and their weight was recorded in grams.

3.11.6 Seed yield

Seed yield was recorded from net plot area of 8.28 m^2 (4.6 x 1.8 m) during both the years and expressed as q ha^{-1}.

3.11.7 Stover yield

The stover yield was calculated by weighing individual bundle weight of the stover from net plot area of 8.28 m^2 (4.6 x 1.8 m) and expressed as q ha^{-1}.

3.11.8 Harvest Index (HI)

Donald (1976) gave the concept of harvest index as a ratio of seed yield to the biological yield. HI is related to ability of crop to produce economically valuable output. HI was calculated by formula given below:

$$\text{Harvest index} = \frac{\text{Economic yield}}{\text{Biological yield}} \times 100$$

3.11.9 Oil content

Gobhi sarson seed oil content was determined by NMR (Nuclear Magnetic Resonance) Analyser (dry) extraction method and expressed in percentage.

3.11.10 Oil yield

Oil yield was calculated by multiplying oil content with seed yield and expressed as q ha^{-1}.

3.11.11 Protein content

Protein content was determined by determining nitrogen content in the seeds. The N content in the seed samples were estimated by Micro Kjeldahl's Distillation Method, as given by Piper (1966). Protein content in seed samples were determined directly by multiplying the nitrogen content in the seed by a factor of 6.25 and expressed in percentage.

3.11.12 Protein yield

Protein yield was calculated by multiplying protein content with seed yield and expressed as q ha^{-1}.

3.12 Water use studies

3.12.1 Soil moisture determination

Soil sample was collected from each treatment at periodic intervals from 0-15, 15-30, 30-45, 45-60 and 60-100 cm of soil depth to determine the soil moisture content. The per cent moisture on dry weight basis was calculated as per Standard Thermo-gravimetric method (Dastane 1967).

3.12.2 Apparent Water Productivity (AWP)

The apparent water productivity was calculated by formula as reported in literature (Sinha *et al* 2017 and Brar *et al* 2012).

$$\text{AWP (kg m}^{-3}\text{)} = \frac{\text{Seed yield (kg ha}^{-1}\text{)}}{\text{Irrigation water applied (m}^{3}\text{ ha}^{-1}\text{)}}$$

3.12.3 Total Water Productivity (TWP)

Total water productivity was calculated by formula as reported in literature (Sinha *et al* 2017 and Brar *et al* 2012).

$$\text{TWP (kg m}^{-3}\text{)} = \frac{\text{Seed yield (kg ha}^{-1}\text{)}}{\text{Irrigation water applied (m}^{3}\text{ ha}^{-1}\text{) + precipitation (m}^{3}\text{ ha}^{-1}\text{)}}$$

3.12.4 Consumptive water use

Consumptive water use was calculated using water balance equation (Sahoo *et al* 2018).

$$\text{ETa} = \text{I} + \text{P} - \text{R} - \text{D} \pm \Delta\text{S}$$

Where, I is irrigation water applied (mm), P is precipitation (mm), R is surface runoff (mm), D is deep drainage (mm) and ΔS is change in soil profile moisture storage (mm).

3.12.5 Water Use Efficiency (WUE)

Water use efficiency was computed by the formula given by Perry *et al* (2009).

$$\text{WUE (\%)} = \frac{\text{ETa}}{\text{I + P}} \times 100$$

Where, I is irrigation water input (m^3 ha^{-1}), P is precipitation (m^3 ha^{-1}), and ETa is the actual crop evapotranspiration (m^3 ha^{-1}).

3.13 Energetics

3.13.1 Energy input

The total energy used in one hectare was calculated by addition of partial energies of human labour, diesel and petrol fuel, machinery, irrigation, chemical fertilizer and agrochemicals, expressed as MJ ha^{-1}. Energy input of various inputs and agronomic practices are given in appendix III

3.13.2 Energy output

The energy output of bio energy gained from the economic product and by-product was calculated using their energy equivalents. It is expressed as MJ ha^{-1}.

3.13.3 Energy Use Efficiency (EUE)

EUE was calculated by the formula given by Demircan *et al* (2006).

$$\text{EUE} = \frac{\text{Energy output (MJ ha}^{-1}\text{)}}{\text{Energy input (MJ ha}^{-1}\text{)}}$$

3.13.4 Energy productivity (EP)

EP was also calculated by the formula given by Demircan *et al* (2006) and expressed as g MJ^{-1}.

$$EP = \frac{\text{Seed yield (g ha}^{-1}\text{)}}{\text{Energy input (MJ ha}^{-1}\text{)}}$$

3.14 Economics

3.14.1 Cost of cultivation

The cost of cultivation of *gobhi sarson* has been obtained from Department of Economics and Sociology, PAU, Ludhiana.

3.14.2 Gross returns

It is the total amount of income or return including cost of production and expenditure. Gross return is obtained by multiplying the quantity of output and minimum support price (MSP). MSP of *gobhi sarson* was Rs 3700 q^{-1} and Rs 4000 q^{-1} during crop season 2016-17 and 2017-18 respectively.

3.14.3 Net returns

Net return was calculated by excluding cost of production and expenditure from the gross returns. The net return was calculated by subtracting the variable cost of cultivation from gross returns as given by Sinha *et al* (2017).

Net returns = Gross returns – Cost of cultivation

3.14.4 Benefit Cost Ratio (B:C)

The B:C ratio was calculated to access the feasibility of the treatments. It is the ratio between net returns obtained from any activity and the variable cost of cultivation. It was calculated by using the formula given below:

$$\text{Benefit: Cost} = \frac{\text{Net returns (Rs ha}^{-1}\text{)}}{\text{Cost of cultivation (Rs ha}^{-1}\text{)}}$$

3.15 Nitrogen (N), Phosphorous (P), Potassium (K) and Sulphur (S) content in seed and stover

3.15.1 Nitrogen (N)

The N content in seed and stover samples were estimated by Micro Kjeldahl's Distillation method, as given by Piper (1966). Sample of 0.5g was taken and digested with sulphuric acid. The solution that prepared after digestion was then placed in distillation for absorption of ammonia in presence of boric acid. After distillation the solution that contains absorbed ammonia was titrated against sulphuric acid.

3.15.2 Phosphorus (P)

The P content in seed and stover samples were determined by Vanado-phospho-molybdate Yellow Color method by digesting the samples with diacid. The intensity of yellow color was determined using spectrophotometer at 420 nm, as given by Piper (1966). A sample of 0.5g was taken in digestion tube and digested with diacid. After digestion volume was made by mixing vanado-phospho-molybdate yellow color solution and distilled water. The solution was kept undisturbed for half an hour for development of color. Then the intensity of color was determined using spectrophotometer at 420 nm.

3.15.3 Potassium (K)

The K content in seed and stover samples were estimated by using flame photometer which were digested in diacid mixture, as described by Muhr *et al* (1965). The sample digested with diacid was taken in volumetric flask and volume was made by adding distilled water to it. Then potassium content was determined using flame photometer.

3.15.4 Sulphur (S)

The S content in seed and stover were determined by Turbid Metric method by digesting the samples with diacid. The intensity turbidity was determined using colorimeter at 420 nm, as given by Chesnin and Yien (1950). The sample was digested with diacid and volume was made by adding barium chloride and gum acacia solution. The intensity of turbidity was determined by colorimeter at 420 nm.

3.16 Soil chemical properties

3.16.1 Soil pH

The soil pH was determined in 1:2 soil-water suspension using an elico-glass electrode pH meter (Jackson 1967).

3.16.2 Electrical Conductivity (EC)

Electrical conductivity of the soil samples was determined in 1:2 soil-water suspension equilibrated for 24 hours using a conductivity bridge.

3.16.3 Organic Carbon (OC)

The organic carbon was determined by Walkley and Black's rapid titration method as detailed by Piper (1950).

3.16.4 Available nitrogen

The total available N of the soil was determined by Alkaline Potassium Permanganate method given by Subbiah and Asija (1956). Excess of alkaline-$KMnO_4$ was added to the soil sample and ammonia thus evolved was absorbed in a standard acid. A standard alkali was used to titrate the excess acid by using methyl red as indicator. From the volume of standard acid used for absorption of ammonia, the amount of nitrogen in the soil sample was calculated.

3.16.5 Available phosphorus

Available P was determined by 0.5 M $NaHCO_3$ method suggested by Olsen *et al* (1954). Bicarbonate extract was added to the soil sample and shaken in an electric shaker for half an hour. The soil extract was filtered and then treated with ammonium molybdate, a complexing agent. The soil extract gave blue colour in the presence of a reducing agent (ascorbic acid). Colorimeter was used to measure the intensity of the blue color at a wavelength of 760 µm using red filter. From the standard curve, the amount of phosphorus present in soil was calculated.

3.16.6 Available potassium

The available K of the soil was determined by the method suggested by Muhr *et al* (1965). The sum of exchangeable and water-soluble K is the index of K availability. Neutral normal ammonium acetate solution was used as extracting agent. The extract was tested for potassium content with the help of flame photometer.

3.16.7 Available sulphur

The available S of the soil was determined by Turbid Metric Method given by Chesnin and Yien (1950). The filtrate was titrated with barium chloride in the presence of gum acacia solution. The turbidity that produced due to precipitation of sulphate as barium sulphate was measured with colorimeter, using a blue filter at a wavelength of 420 µm. The available sulphur in the soil was calculated by plotting the concentration against transmittance in the graph paper.

3.17 Statistical analysis

Statistical analysis of the data recorded was done as per factorial randomized complete block design using SAS 9.0. The split up of degrees of freedom (df) for different sources of variation are presented in Table 3.8.

Table 3.8: ANOVA

Sources of variation	**Degrees of freedom (df)**
Replications	2
Treatment	9
Factors	8
Fertigation	2
Irrigation	2
Irrigation x Fertigation	4
Control v/s Factor	1
Error	18
Total	29

CHAPTER – IV

RESULTS AND DISCUSSION

The results of the present study entitled "**Water productivity, economics and energetics of *gobhi sarson* (*Brassica napus* L.) as influenced by drip irrigation and fertigation schedules**" are presented and discussed in this chapter.

4.1 Field studies

4.1.1 Emergence count

Uniform emergence is pre-requisite for good plant establishment of a crop, which ultimately determines the crop yield. The data for emergence count was recorded at 3-10 days after sowing during 2016-17 and 2017-18 (Table 4.1). The data revealed that there were non-significant differences among all treatments *viz*. irrigation and fertigation schedules during both the years. This was due to the fact that no treatment was applied before sowing. The fertigation and irrigation treatments were applied only after 15 and 30 days after sowing (DAS), respectively.

Table 4.1: Effect of drip irrigation and fertigation schedules on emergence count (plants m^{-2}) of *gobhi sarson* during *rabi* 2016-17 and 2017-18

Year	**2016-17**					**2017-18**				
Fertigation schedules (FS)	**Irrigation schedules (IS)**				**Absolute control**	**Irrigation schedules (IS)**				**Absolute control**
	60% of CPE	**80% of CPE**	**100% of CPE**	**Mean**		**60% of CPE**	**80% of CPE**	**100% of CPE**	**Mean**	
60% RDF	23.0	22.7	21.3	22.3	24.0	25.7	25.7	24.3	25.2	25.0
80% RDF	23.3	23.3	24.0	23.6		24.3	25.7	24.0	24.7	
100% RDF	24.3	21.3	23.7	23.1		26.0	25.0	25.3	25.4	
Mean	23.6	22.4	23.0			25.3	25.4	24.6		
LSD (p=0.05)	IS=NS FS=NS ISxFS=NS ISxFS v/s absolute control=NS					IS=NS FS=NS ISxFS=NS ISxFS v/s absolute control=NS				

4.1.2 Plant height

Plant height is the determinant of vigour, strength and adaptability of a plant to the existing environmental conditions. It is an important parameter in determining the growth and developmental pattern of a crop. The data of plant height recorded at 30, 60, 90, 120 DAS and at harvest under different irrigation and fertigation schedules during both the years are presented in Table 4.2 and pooled data is graphically depicted in Fig 4.1. There was substantial increase in the plant height throughout the growing season and the rate of increase was maximum between 60-90 DAS, whereas maximum plant height was obtained at harvesting stage. Thus, 60-90 DAS period of *gobhi sarson* can be called as grand growth period.

Table 4.2: Effect of drip irrigation and fertigation schedules on periodic plant height (cm) of *gobhi sarson* during *rabi* 2016-17 and 2017-18

Year	2016-17					2017-18				
Fertigation schedules (FS)	Irrigation schedules (IS)				Absolute control	Irrigation schedules (IS)				Absolute control
	60% of CPE	80% of CPE	100% of CPE	Mean		60% of CPE	80% of CPE	100% of CPE	Mean	
At 30 DAS										
60% RDF	13.2	13.2	13.6	13.4	13.5	14.5	14.9	14.6	14.7	15.0
80% RDF	13.4	14.2	14.9	14.2		14.5	14.9	15.7	15.1	
100% RDF	13.7	14.4	14.8	14.3		14.8	15.1	15.9	15.3	
Mean	13.4	13.9	14.4			14.6	15.0	15.4		
LSD (p=0.05)	IS=NS FS=NS ISxFS=NS ISxFS v/s absolute control=NS					IS=NS FS=NS ISxFS=NS ISxFS v/s absolute control=NS				
At 60 DAS										
60% RDF	44.0	51.4	51.5	49.0	46.5	46.8	50.1	52.1	49.7	47.6
80% RDF	46.5	52.8	54.5	51.3		48.8	53.2	55.3	52.5	
100% RDF	51.4	56.2	57.7	55.1		50.1	56.5	57.6	54.7	
Mean	47.3	53.5	54.6			48.6	53.3	55.0		
LSD (p=0.05)	IS= 2.89 FS=2.89 ISxFS=NS ISxFS v/s absolute control= 3.49					IS=2.94 FS=2.94 ISxFS=NS ISxFS v/s absolute control=3.56				
At 90 DAS										
60% RDF	150.7	158.9	160.6	156.7	155.00	154.8	160.3	161.5	158.9	157.5
80% RDF	155.8	165.7	169.1	163.5		159.4	164.6	170.2	164.7	
100% RDF	159.7	168.7	169.5	166.0		161.6	169.2	172.4	167.8	
Mean	155.4	164.4	166.4			158.6	164.7	168.0		
LSD (p=0.05)	IS= 7.64 FS=7.64 ISxFS=NS ISxFS v/s absolute control= 10.3					IS=6.78 FS=6.78 ISxFS=NS ISxFS v/s absolute control=8.3				
At 120 DAS										
60% RDF	174.4	183.8	186.2	181.5	175.6	178.1	181.3	185.5	181.6	181.9
80% RDF	183.7	186.1	191.6	187.1		180.3	190.7	194.7	188.6	
100% RDF	184.3	193.7	195.1	191.0		182.3	194.8	196.1	191.1	
Mean	180.8	187.9	191.0			180.2	188.9	192.1		
LSD (p=0.05)	IS= 8.53 FS=8.53 ISxFS=NS ISxFS v/s absolute control= 11.4					IS= 5.60 FS=5.60 ISxFS=NS ISxFS v/s absolute control= 8.4				
At harvest										
60% RDF	178.4	184.6	187.6	183.0	182.3	181.7	185.7	189.7	185.7	181.5
80% RDF	182.3	192.0	196.4	190.2		183.9	194.2	195.5	191.2	
100% RDF	183.2	196.7	198.1	192.7		185.8	195.6	197.5	193.0	
Mean	181.3	191.1	194.0			183.8	191.8	194.2		
LSD (p=0.05)	IS= 7.04 FS=7.04 ISxFS=NS ISxFS v/s absolute control= 8.6					IS= 4.81 FS=4.81 ISxFS=NS ISxFS v/s absolute control= 7.3				

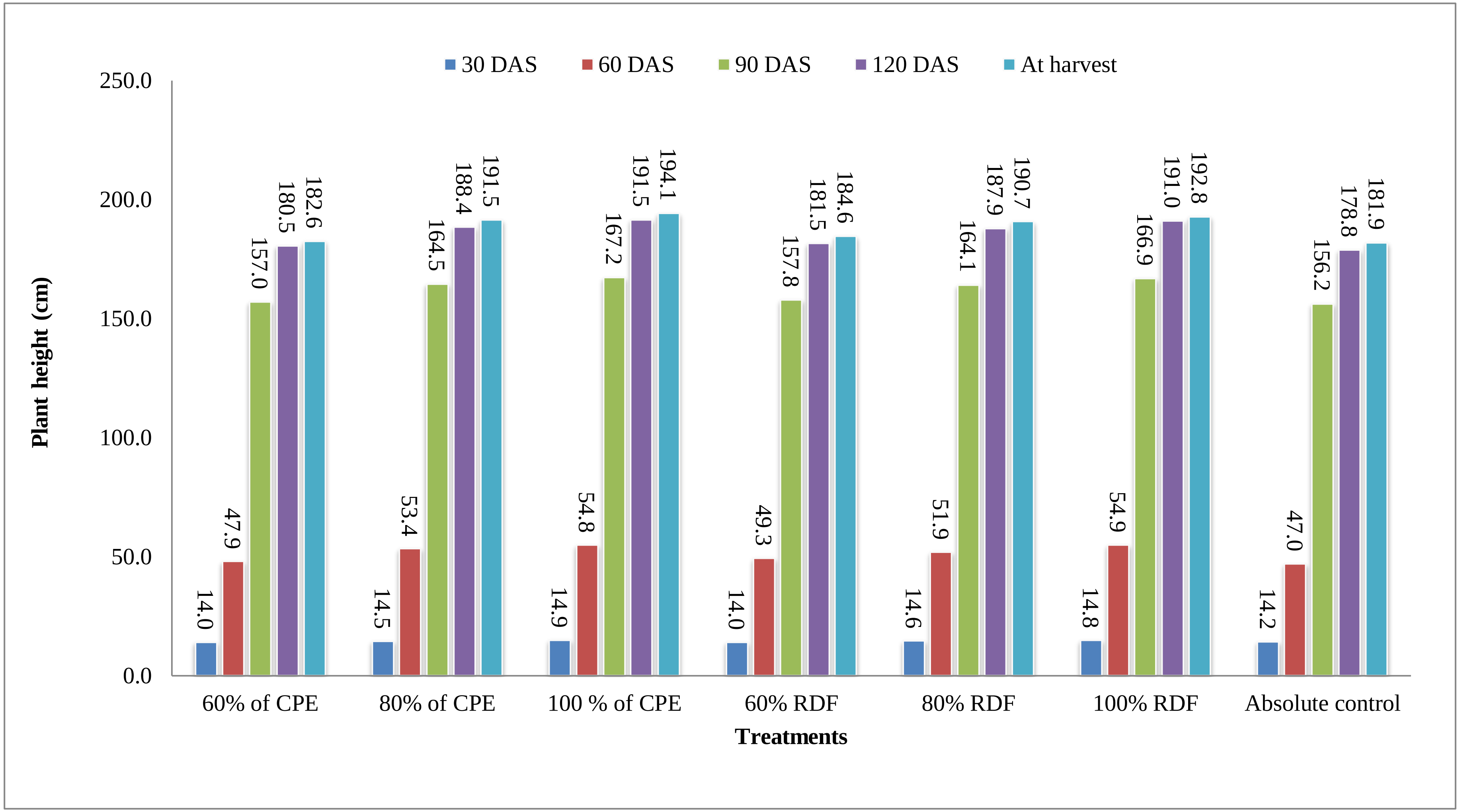


Fig 4.1: Effect of drip irrigation and fertigation schedules on periodic plant height (cm) of *gobhi sarson* (pooled mean of two years)

Irrigation scheduling at 100% of CPE recorded maximum plant height which was statistically at par with 80% of CPE but significantly higher than 60% of CPE at 60, 90, 120 DAS and at harvest. Drip irrigation schedules were non-significant at 30 DAS for both the crop seasons. At harvest drip irrigation at 100% of CPE and 80% of CPE recorded 7.0, 5.4 per cent and 5.7, 4.4 per cent taller plants than 60% of CPE during 2016-17 and 2017-18, respectively. Better plant height in drip irrigated crop could be due to more availability of moisture at the root zone and the crop was not under moisture stress.

Fertigation scheduling at 100% RDF obtained maximum plant height which was statistically at par with 80% RDF but significantly higher than 60% RDF for 90, 120 DAS and at harvest during both the crop seasons. In case of 60 DAS during 2016-17 fertigation schedules at 100% RDF was significantly greater than 80% RDF and 60% RDF, whereas in 2017-18 100% RDF was statistically at par with 80% RDF but significantly higher than 60% RDF. At harvest, fertigation at 100% RDF and 80% RDF recorded 5.3, 3.9 per cent and 3.9, 3.0 per cent taller plants than 60% RDF during 2016-17 and 2017-18, respectively. Better availability of water soluble fertilizers through drip irrigation increased their absorption by the crop which resulted in increased plant height.

Interaction between irrigation and fertigation schedules was non-significant during both the crop seasons. Whereas, interaction between treatment combinations and absolute control was significantly influenced at 60, 90, 120 DAS and at harvest. At harvest, maximum plant height was recorded with 100% of CPE and 100% RDF, which was statistically at par with rest of the treatment combinations but significantly better than absolute control during 2016-17 and 2017-18, respectively. The percent increase in plant height with 100% of CPE and 100% RDF is 8.7 and 8.8 per cent higher than absolute control during both the years. This result could be due to application of water soluble fertilizers through drip irrigation which increased absorption of nutrients by the crop. Therefore, combining both the factors of irrigation and fertigation, maximum plant height was obtained at higher doses. Similar results were also obtained by Soni and Raja (2017).

4.1.3 Dry Matter Accumulation (DMA)

Dry matter accumulation is an index to express the photosynthetic efficiency of the plant. DMA recorded at 30, 60, 90, 120 DAS and at harvest during both the years are presented in Table 4.3 and pooled data is graphically depicted in Fig 4.2. DMA progressively increased with age of the crop and maximum was obtained at harvest during both the years.

The data revealed that drip irrigation at 100% of CPE produced maximum DMA which was statistically at par with 80% CPE but significantly higher than 60% of CPE from 60 DAS to at harvest during both the years. At harvest, drip irrigated crop at 100% of CPE and 80% of CPE resulted in 48.6, 44.4 per cent and 28.0, 22.3 per cent higher DMA than 60% of CPE during 2016-17 and 2017-18, respectively. Crop irrigated with drip recorded higher dry matter

Table 4.3: Effect of drip irrigation and fertigation schedules on DMA (q ha^{-1}) of *gobhi sarson* during *rabi* 2016-17 and 2017-18

Periodic dry matter accumulation										
Year	**2016-17**					**2017-18**				
Fertigation schedules (FS)	**Irrigation schedules (IS)**				**Absolute control**	**Irrigation schedules (IS)**				**Absolute control**
	60% of CPE	**80% of CPE**	**100% of CPE**	**Mean**		**60% of CPE**	**80% of CPE**	**100% of CPE**	**Mean**	
At 30 DAS										
60% RDF	0.54	0.69	0.65	0.63	0.60	0.66	0.68	0.82	0.72	0.70
80% RDF	0.67	0.65	0.60	0.64		0.75	0.85	0.87	0.82	
100% RDF	0.67	0.70	0.70	0.69		0.86	0.81	0.87	0.85	
Mean	0.63	0.68	0.65			0.76	0.78	0.85		
LSD (p=0.05)	IS= NS FS=NS ISxFS=NS ISxFS v/s absolute control= NS					IS= NS FS= NS ISxFS=NS ISxFS v/s absolute control= NS				
At 60 DAS										
60% RDF	8.89	11.4	11.9	10.7	10.3	9.31	12.0	12.2	11.2	11.6
80% RDF	9.93	12.5	14.1	12.2		11.0	13.0	14.2	12.8	
100% RDF	10.2	14.0	15.1	13.1		12.4	14.1	15.9	14.1	
Mean	9.67	12.7	13.7			10.9	13.0	14.1		
LSD (p=0.05)	IS= 1.57 FS= 1.57 ISxFS=NS ISxFS v/s absolute control= NS					IS= 1.67 FS= 1.67 ISxFS=NS ISxFS v/s absolute control= NS				
At 90 DAS										
60% RDF	30.5	36.6	40.7	36.0	36.4	32.0	45.4	44.4	41.2	36.9
80% RDF	32.4	48.6	53.8	44.9		32.6	57.6	61.5	50.6	
100% RDF	34.7	55.2	57.9	49.3		43.7	60.4	63.0	55.7	
Mean	32.5	46.8	50.8			36.1	55.1	56.3		
LSD (p=0.05)	IS= 4.4 FS= 4.4 ISxFS=NS ISxFS v/s absolute control= 5.7					IS= 6.21 FS= 6.21 ISxFS=NS ISxFS v/s absolute control= 8.86				
At 120 DAS										
60% RDF	63.3	77.5	81.6	74.2	72.2	69.6	86.7	88.2	81.5	41.6
80% RDF	70.9	87.8	93.8	84.1		72.6	96.8	101.5	90.3	
100% RDF	73.0	93.4	96.9	87.8		82.2	100.0	103.3	95.2	
Mean	69.1	86.2	90.8			74.8	94.5	97.7		
LSD (p=0.05)	IS= 4.7 FS= 4.7 ISxFS=NS ISxFS v/s absolute control= 6.1					IS= 6.1 FS= 6.1 ISxFS=NS ISxFS v/s absolute control= 8.7				
At harvest										
60% RDF	77.8	95.5	96.7	90.0	97.0	98.5	113.9	115.3	109.2	103.4
80% RDF	76.3	116.7	120.7	104.6		101.5	128.9	138.5	123.0	
100% RDF	83.6	130.9	135.7	116.7		111.1	137.8	144.4	131.1	
Mean	79.2	114.4	117.7			103.7	126.8	132.7		
LSD (p=0.05)	IS= 10.8 FS= 10.8 ISxFS=NS ISxFS v/s absolute control= 14.5					IS= 8.9 FS= 8.9 ISxFS=NS ISxFS v/s absolute control= 11.4				

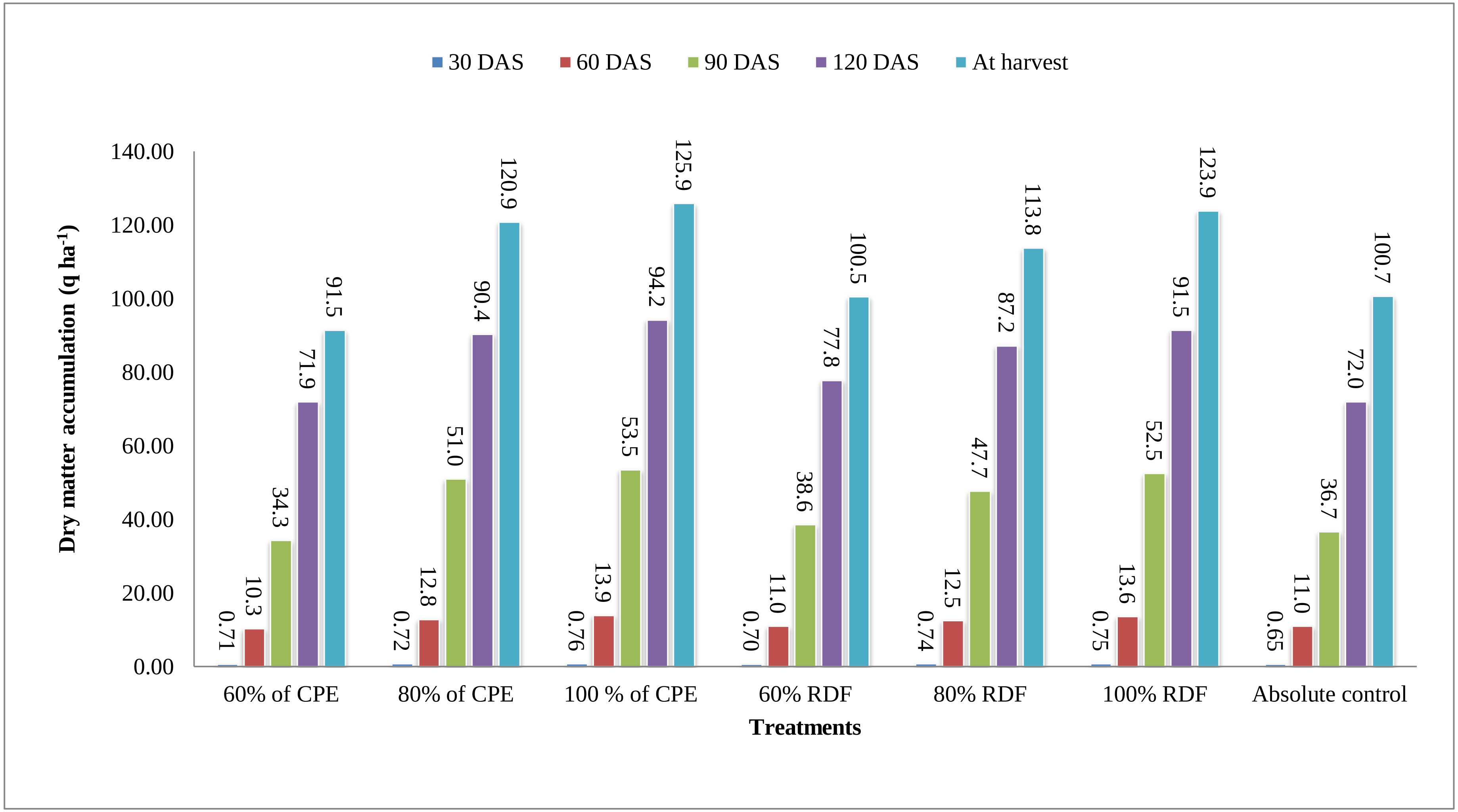


Fig 4.2: Effect of drip irrigation and fertigation schedules on DMA (q ha^{-1}) of *gobhi sarson* (pooled mean of two years)

which might be due to favourable soil moisture condition because of application of frequent and light irrigation to the root zone.

Among fertigation schedules, 100% RDF produced maximum DMA which was statistically at par with 80% RDF and significantly higher than 60% RDF from 60 DAS to harvest stage during both the crop seasons. At harvest drip irrigated crop at 100% and 80% of CPE resulted in 29.7, 16.2 per cent and 20.1, 12.6 per cent higher DMA than 60% RDF during 2016-17 and 2017-18, respectively. Higher DMA might be due to improvement in cell multiplication, cell elongation and cell expansion because of better availability of nutrients and moisture resulting in higher production of photosynthates and their translocation to sink (Kumar *et al* 2011).

Interaction between drip irrigation and fertigation schedules was noticed non-significant for all the growth stages under both the crop seasons. Whereas, interaction between treatment combinations and absolute control was found significant at 90, 120 DAS and at harvest. At harvest, drip irrigation and fertigation treatments at 80% of CPE with 80% RDF, 80% of CPE with 100% RDF, 100% of CPE with 80% RDF and 100% CPE with 100% RDF resulted significantly higher DMA than absolute control for 2016-17. Whereas, in 2017-18 treatment combinations 80% of CPE with 60% RDF and 100% of CPE with 60% RDF also recorded significant DMA as compared to absolute control. Lesser periodic dry matter accumulation in recommended practice might be due to less frequent application of irrigation and that too at longer intervals. Similar results were also obtained by Sinha (2015).

4.1.4 Leaf Area Index (LAI)

Leaf area index is an important determinant of plant growth. LAI was recorded at 30, 60, 90, 120 DAS and at harvest during both the years and are presented in Table 4.4 and pooled data is graphically depicted in Fig 4.3. Leaf area increased from 30 DAS to 90 DAS, reaching maximum at 90 DAS, afterwards it decreased on account of shedding of leaves for both the years.

Maximum LAI at 60, 90 and 120 DAS was obtained with drip irrigation at 100% of CPE which was statistically at par with 80% of CPE and significantly higher than 60% of CPE. At 90 DAS, drip irrigated crop at 100% of CPE and 80% of CPE recorded 25.8, 22.4 per cent and 18.1, 16.5 per cent higher LAI than 60% of CPE during 2016-17 and 2017-18, respectively.

Similarly, fertigation at 100% RDF resulted in maximum LAI, which was statistically at par with 80% RDF and significantly higher than 60% RDF, for both the crop seasons at 60, 90 and 120 DAS. At 90 DAS, drip irrigated crop at 100% of RDF and 80% of RDF recorded 20.9, 17.0 per cent and 17.6, 13.0 per cent higher LAI than 60% of RDF during 2016-17 and

2017-18, respectively.

Table 4.4: Effect of drip irrigation and fertigation schedules on periodic LAI of *gobhi sarson* during *rabi* 2016-17 and 2017-18

Year	2016-17					2017-18				
Fertigation schedules (FS)	**Irrigation schedules (IS)**				**Absolute control**	**Irrigation schedules (IS)**				**Absolute control**
	60% of CPE	**80% of CPE**	**100% of CPE**	**Mean**		**60% of CPE**	**80% of CPE**	**100% of CPE**	**Mean**	
At 30 DAS										
60% RDF	0.50	0.43	0.63	0.52	0.60	0.50	0.43	0.43	0.46	0.50
80% RDF	0.60	0.40	0.57	0.52		0.60	0.50	0.50	0.53	
100% RDF	0.40	0.50	0.53	0.48		0.47	0.60	0.50	0.52	
Mean	0.50	0.44	0.58			0.52	0.51	0.48		
LSD (p=0.05)	IS= NS FS= NS ISxFS=NS ISxFS v/s absolute control= NS					IS= NS FS= NS ISxFS=NS ISxFS v/s absolute control= NS				
At 60 DAS										
60% RDF	2.57	2.97	3.17	2.90	2.73	2.80	3.03	3.07	2.97	2.97
80% RDF	2.60	3.30	3.47	3.12		2.97	3.47	3.67	3.37	
100% RDF	2.80	3.43	3.50	3.24		3.03	3.57	3.77	3.46	
Mean	2.66	3.23	3.38			2.93	3.36	3.50		
LSD (p=0.05)	IS= 0.25 FS= 0.25 ISxFS=NS ISxFS v/s absolute control= 0.32					IS= 0.27 FS=0.27 ISxFS=NS ISxFS v/s absolute control= 0.33				
At 90 DAS										
60% RDF	3.23	3.87	3.83	3.64	3.53	3.67	4.00	3.90	3.86	3.77
80% RDF	3.67	4.40	4.70	4.26		3.80	4.57	4.70	4.36	
100% RDF	3.70	4.70	4.80	4.40		3.97	4.77	4.90	4.54	
Mean	3.53	4.32	4.44			3.81	4.44	4.50		
LSD (p=0.05)	IS= 0.35 FS= 0.35 ISxFS=NS ISxFS v/s absolute control= 0.43					IS= 0.28 FS=0.28 ISxFS=NS ISxFS v/s absolute control= 0.36				
At 120 DAS										
60% RDF	1.27	1.37	1.40	1.34	1.40	1.43	1.50	1.50	1.48	1.43
80% RDF	1.33	1.50	1.87	1.57		1.47	1.60	1.93	1.67	
100% RDF	1.37	1.83	1.87	1.69		1.40	1.87	1.97	1.74	
Mean	1.32	1.57	1.71			1.43	1.66	1.80		
LSD (p=0.05)	IS= 0.22 FS= 0.22 ISxFS=NS ISxFS v/s absolute control=NS					IS= 0.15 FS=0.15 ISxFS=NS ISxFS v/s absolute control= NS				
At harvest										
60% RDF	0.63	0.73	0.67	0.68	0.67	0.73	0.90	0.83	0.82	0.77
80% RDF	0.63	0.73	0.70	0.69		0.90	0.80	0.80	0.83	
100% RDF	0.67	0.73	0.77	0.72		0.80	0.83	0.90	0.84	
Mean	0.64	0.73	0.71			0.81	0.84	0.84		
LSD (p=0.05)	IS= NS FS= NS ISxFS=NS ISxFS v/s absolute control=NS					IS=NS FS=NS ISxFS=NS ISxFS v/s absolute control= NS				

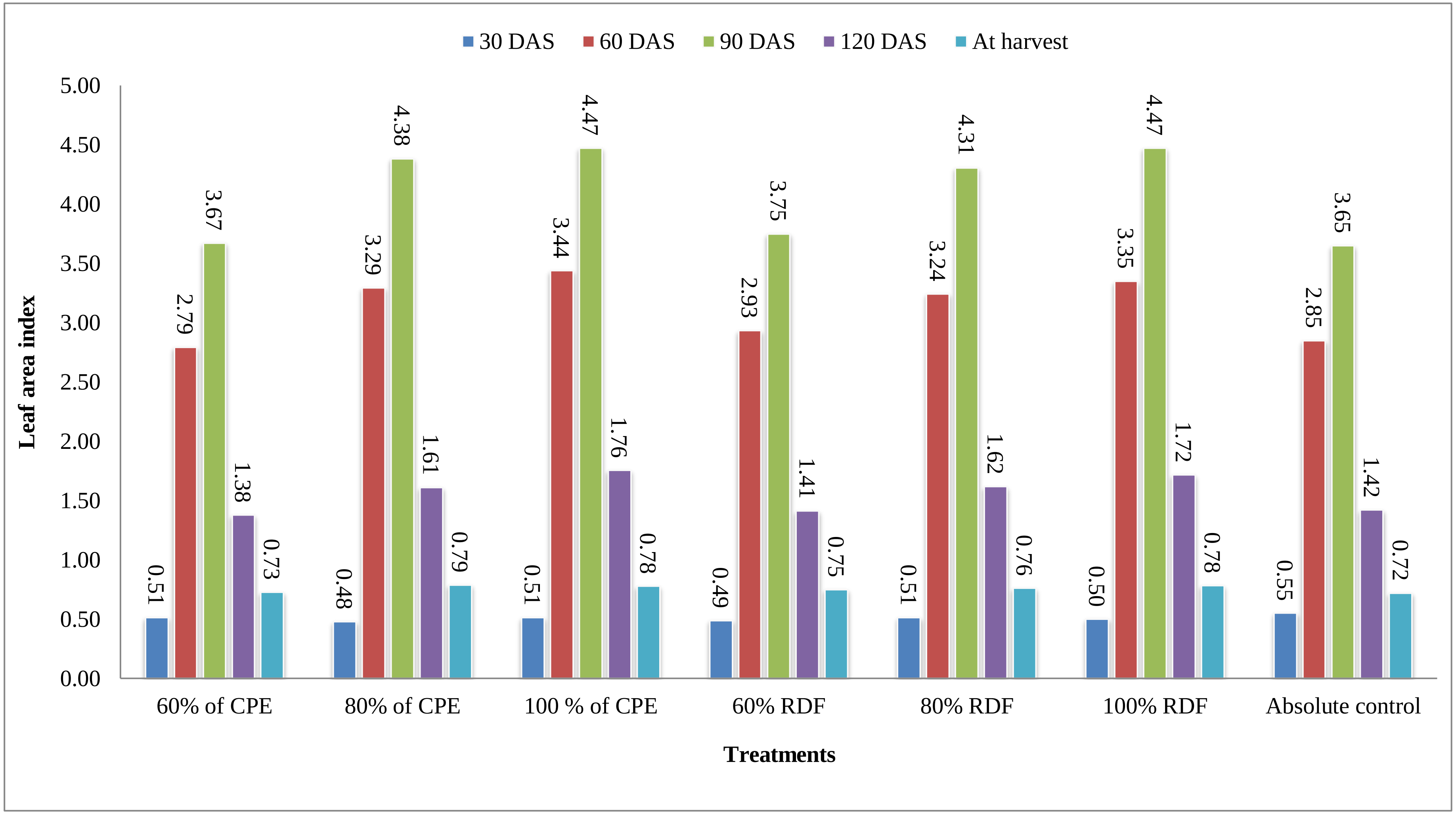


Fig 4.3: Effect of drip irrigation and fertigation schedules on LAI of *gobhi sarson* (pooled mean of two years)

Interaction between drip irrigation and fertigation schedules was found to be non-significant for all the growth stages under both the crop seasons. Whereas, interaction between treatment combinations and absolute control was found to be significant for both the crop seasons at 60 DAS and 90 DAS. At 90 DAS, for both the crop seasons, drip irrigation and fertigation treatments at 80% of CPE with 80% RDF, 80% of CPE with 100% RDF, 100% of CPE with 80% RDF and 100% CPE with 100% RDF were significantly higher than the absolute control. Higher availability of nutrients and moisture at proper growth stages might have resulted in production of maximum leaf area. Similarly, Mahal and Singh (2000) also reported increase in LAI of *gobhi sarson* with increasing levels of nitrogen. Furthermore, Soni and Raja (2017) also obtained maximum leaf area under drip irrigation at 100% PE (pan evaporation) and 100% RDF.

4.2 Phenological stages of crop

4.2.1 Days taken to emergence

Seedling emergence constitute the basis of plant population which will ultimately determine seed yield. Irrigation and fertigation scheduling had non-significant effect on number of days taken to emergence as none of the treatment was applied to the field and seeds at the time of sowing. The data recorded for days taken to emergence for both the crop seasons are presented in Table 4.5.

4.2.2 Days taken to 50% flowering

Flowering or beginning of the reproductive cycle is mainly governed by the genetic makeup, but it is also influenced by water and nutrient application. It took 80-86 days for *gobhi sarson* to reach 50% flowering for both the crop seasons. The data regarding days taken to 50% flowering for both the crop seasons are presented in Table 4.5

Crop irrigated at 100% of CPE took the maximum time for 50% of flowering which was statistically at par with 80% of CPE but significantly higher than 60% of CPE. Crop irrigated at lower level of irrigation might have been facing moisture stress therefore, to mitigate that stress it resulted in early flowering.

Fertigation schedule at 100% RDF took the maximum time to achieve 50% flowering which was statistically at par with 80% RDF but significantly higher than 60% RDF for 2016-17 and 2017-18 respectively. Crop raised at lower doses of fertigation might have been facing nutrient stress therefore to mitigate the stress it resulted in early flowering. Moreover, possible reason could be that nitrogen favoured late completion of vegetative phase of the plant and therefore, late mobilization of assimilates to the sink. In the similar line of action, Kaur (2017) also reported that higher doses of nitrogen resulted in delay in days taken to 50% flowering in *gobhi sarson*.

Table 4.5: Effect of drip irrigation and fertigation schedules on phenological stages of *gobhi sarson* during *rabi* 2016-17 and 2017-18

Year	2016-17					2017-18				
Fertigation schedules (FS)	Irrigation schedules (IS)				Absolute control	Irrigation schedules (IS)				Absolute control
	60% of CPE	80% of CPE	100% of CPE	Mean		60% of CPE	80% of CPE	100% of CPE	Mean	
Days taken to emergence										
60% RDF	5.6	5.6	5.3	5.5	5.6	5.6	5.3	6.0	5.6	5.6
80% RDF	5.6	5.6	5.3	5.5		6.3	5.3	5.3	5.6	
100% RDF	6.0	6.0	5.3	5.7		6.3	5.6	5.3	5.7	
Mean	5.7	5.7	5.3			6.1	5.4	5.5		
LSD (p=0.05)	IS= NS FS= NS ISxFS=NS ISxFS v/s absolute control=NS					IS=NS FS=NS ISxFS=NS ISxFS v/s absolute control= NS				
Days taken to 50% flowering										
60% RDF	81.0	83.0	83.0	82.3	81.0	81.0	82.0	83.0	82.0	80.3
80% RDF	82.7	84.3	85.7	84.2		81.3	83.7	84.0	83.0	
100% RDF	83.3	85.3	86.0	84.9		81.7	84.0	85.7	83.8	
Mean	82.3	84.2	84.9			81.3	83.3	84.2		
LSD (p=0.05)	IS= 1.0 FS=1.0 ISxFS=NS ISxFS v/s absolute control=1.2					IS=0.9 FS=0.9 ISxFS=NS ISxFS v/s absolute control= 1.1				
Days taken to 50% siliqua formation										
60% RDF	98.7	99.7	99.3	99.2	98.7	91.0	92.0	94.0	92.3	91.7
80% RDF	99.0	100.0	102.0	100.3		91.7	94.7	95	93.8	
100% RDF	99.7	100.7	103.0	101.1		92.3	96	96	94.8	
Mean	99.1	100.1	101.4			91.7	94.2	95		
LSD (p=0.05)	IS= 1.5 FS=1.5 ISxFS=NS ISxFS v/s absolute control=NS					IS=1.7 FS=1.7 ISxFS=NS ISxFS v/s absolute control= NS				
Days taken to physiological maturity										
60% RDF	138.3	141.3	142.7	140.8	138.0	128.7	133.0	134.0	131.9	128.3
80% RDF	138.7	144.0	146.0	142.9		129.7	134.7	137.3	133.9	
100% RDF	140.0	145.0	146.7	143.9		131.0	135.3	137.3	134.6	
Mean	139.0	143.4	145.1			129.8	134.3	136.2		
LSD (p=0.05)	IS= 1.1 FS=1.1 ISxFS=NS ISxFS v/s absolute control=1.4					IS=1.2 FS=1.2 ISxFS=NS ISxFS v/s absolute control= 1.6				

Interaction between drip irrigation and fertigation schedules were found to be non-significant for days taken to 50% flowering under both the crop seasons. Whereas treatment combinations were found to have significant increase in days taken to 50% flowering as compared to absolute control (flood irrigation). In crop season 2016-17, all the drip irrigation and fertigation treatments recorded significantly higher days taken than the absolute control except 60% of CPE with 60% RDF, and in 2017-18 absolute control was statistically at par with only 60% of CPE with 60% RDF and 60% of CPE with 80% RDF and significantly lower than all the other treatments. The crop irrigated by flood irrigation might have faced moisture stress as water is available at one growth stage which might lead to moisture stress at the other stage. Therefore, crop irrigated by flood irrigation resulted in early flowering to mitigate moisture stress. Similar trend was obtained during both the years.

4.2.3 Days taken to 50% siliqua formation

Siliqua initiation indicates seed formation stage of the crop. The data pertaining to days taken to 50% siliqua formation for both the crop seasons are presented in Table 4.5. For crop season 2016-17, it took average 99 to 103 days to achieve 50% siliqua formation, but during 2017-18 it took average 91 to 96 days. This could be owing to late sowing of crop in 2016-17.

Drip irrigating the crop at 100% of CPE significantly delayed the days taken to 50% siliqua formation, which was statistically at par with 80% of CPE but significantly higher than 60% of CPE.

Fertigation also delayed the days taken to 50% siliqua formation during both the years. Fertigating the crop at 100% RDF was statistically at par with 80% RDF but significantly higher than 60% RDF. Application of fertilizer especially nitrogen might have increased the duration for days taken to 50% siliqua formation. This might be due to the fact that higher nitrogen increases vegetative growth and favours translocation of assimilates to the sink and thus late completion of vegetative phase.

Interaction between drip irrigation and fertigation schedules as well as drip irrigation and fertigation treatments and absolute control was found to be non-significant for days taken to 50% siliqua formation during both the crop seasons.

4.2.4 Days taken to physiological maturity

The change in siliqua colour from green to yellowish brown indicates its physiological maturity. Physiological maturity was significantly influenced by both irrigation and fertigation schedules. For crop season 2016-17, it took average 138 -147 days to reach maturity whereas for crop season 2017-18, it took average 128 to 137 days to reach physiological maturity. The data regarding days taken to physiological maturity for both the crop seasons are presented in Table 4.5.

Crop irrigated at 100% of CPE recorded maximum days taken to maturity followed by 80% of CPE and 60% of CPE. Similarly, fertigating the crop at 100% RDF recorded maximum number of days taken to maturity followed by 80% RDF and then 60% RDF. This might be due to the fact that higher nitrogen doses increased vegetative growth phase of the crop and hence delayed maturity. Similarly, Ahmad *et al* (2006) also reported that increasing nitrogen rate progressively delayed maturity and the maximum days taken to maturity obtained with application of nitrogen up to 160 kg ha^{-1}.

Interaction between drip irrigation and fertigation schedules was found to be non-significant during both the crop seasons. Whereas, drip irrigation and fertigation treatments significantly delayed days taken to maturity as compared to absolute control. Drip irrigation and fertigation significantly increased the duration of physiological maturity in all the treatments as compared to absolute control (flood irrigation) except in treatment 60% CPE with 60% RDF and 60% of CPE with 80% RDF. The crop irrigated by flood irrigation method might have faced moisture stress as availability of water at one growth might lead to moisture stress at other stage. Hence to mitigate moisture stress, the crop reached maturity earlier than the drip irrigated plots. The results were similar for both the seasons.

4.3 Yield attributing characters

4.3.1 Number of primary and secondary branches per plant

The number primary and secondary branches were counted before harvest. Data pertaining to number of primary and secondary branches per plant are presented in Table 4.6 and pooled data for 2016-17 and 2017-18 are graphically depicted in Fig 4.4.

Maximum number of primary branches per plant were obtained with irrigation at 100% of CPE and were statistically at par with 80% of CPE but was 13.1, 10.5 per cent and 12.6, 7.9 per cent higher than 60% of CPE during 2016-17 and 2017-18, respectively. Larger number of primary branches at higher levels of drip irrigation might be due to more availability of moisture to the crop which could might resulted in increased number of primary branches per plant. Likewise, Piri *et al* (2011) also indicated that, application of two irrigations significantly increased the number of primary branches per plant over one irrigation resulting in significant increase in seed yield.

There was no significant difference in fertigation schedules for both the years. The number of primary branches were statistically at par in both treatment combinations and absolute control. Interaction between drip irrigation and fertigation schedules were also found non-significant for both the crop seasons.

During both the crop seasons, secondary branches per plant were highest in drip irrigation at 100% of CPE which were statistically at par with 80% of CPE but were 60.0, 50.7 per cent and 85.9, 73.2 per cent higher than 60% of CPE during 2016-17 and 2017-18, respectively. Application of two irrigations significantly increased the number of secondary branches per plant over one irrigation Piri *et al* (2011).

In case of fertigation treatments, highest number of secondary branches per plant were obtained with fertigation at 100% RDF which were significantly higher than both 80% RDF and 60% RDF during 2016-17 and 2017-18, respectively. This implies that number of secondary branches increased with increase in application of fertilizer doses as well as with higher levels of irrigation. Similar results were also reported by Kumar (2000). He reported significant increase in secondary branches per plant of *gobhi sarson* with successive increment of nitrogen levels from 0 to 125 kg N ha^{-1}. Rathod *et al* (2014b) obtained gradual increase in secondary branches with increase in N fertigation from to 0 to 120 kg ha^{-1}.

Interaction between drip irrigation and fertigation schedules was found to be non-significant for both number of primary and secondary branches per plant during both the crop seasons but interaction between treatment combinations and absolute control was noticed to be significant. Maximum number of secondary branches were produced in treatment 100% of CPE and 100% RDF which exhibited 75.4 and 71.0 per cent higher than absolute control. Drip irrigation and fertigation treatments at 60% of CPE with 60%, 80% and 100% RDF were statistically at par with the absolute control and significantly lower than the rest of the treatments for both the crop seasons. Moisture availability at proper growth stage might have resulted in profuse branching in case of drip irrigation and fertigation treatments.

Table 4.6: Effect of drip irrigation and fertigation schedules on the number of primary and secondary branches per plant of *gobhi sarson* during *rabi* 2016-17 and 2017-18

Year	2016-17					2017-18				
Fertigation schedules (FS)	Irrigation schedules (IS)				Absolute control	Irrigation schedules (IS)				Absolute control
	60% of CPE	80% of CPE	100% of CPE	Mean		60% of CPE	80% of CPE	100% of CPE	Mean	
Number of primary branches										
60% RDF	4.22	4.56	4.56	4.44	4.44	4.22	4.89	5.00	4.70	4.67
80% RDF	4.22	4.67	4.78	4.56		5.00	5.11	5.33	5.15	
100% RDF	4.11	4.67	4.89	4.56		4.78	5.11	5.44	5.11	
Mean	4.19	4.63	4.74			4.67	5.04	5.26		
LSD (p=0.05)	IS= 0.51 FS=NS ISxFS=NS ISxFS v/s absolute control=NS					IS=0.41 FS=NS ISxFS=NS ISxFS v/s absolute control= NS				
Number of secondary branches										
60% RDF	4.00	5.56	5.94	5.17	4.56	4.67	8.11	8.89	7.22	6.56
80% RDF	4.50	7.33	7.67	6.50		5.56	10.00	10.67	8.74	
100% RDF	5.00	7.45	8.00	6.82		6.33	10.56	11.22	9.37	
Mean	4.50	6.78	7.20			5.52	9.56	10.26		
LSD (p=0.05)	IS=0.55 FS=0.55 ISxFS=NS ISxFS v/s absolute control=0.67					IS=0.88 FS=0.88 ISxFS=NS ISxFS v/s absolute control= 1.18				

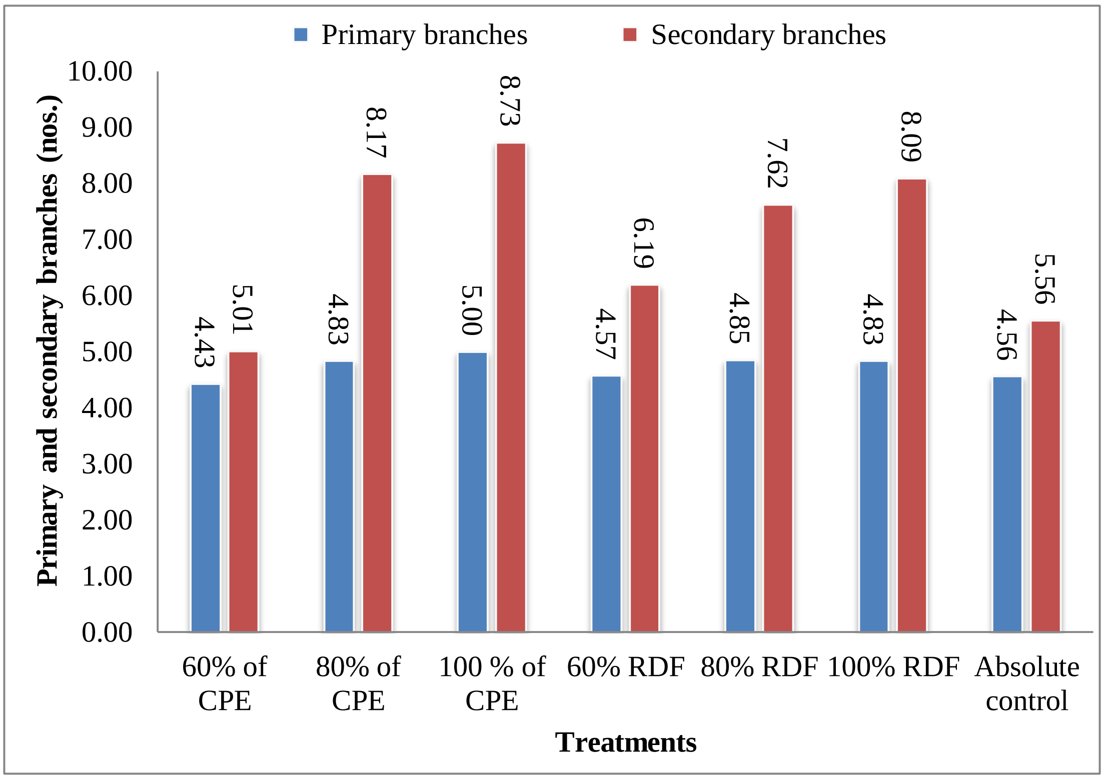


Fig 4.4: Effect of drip irrigation and fertigation schedules on number of primary and secondary branches per plant of *gobhi sarson* (pooled mean of two years)

4.3.2 Number of siliquae per plant

Number of siliquae per plant is considered to be a major yield contributing parameter in rapeseed-mustard on which seed yield of the crop depends. Results of number of siliquae per plant are presented in Table 4.7 and pooled data is graphically depicted in Fig 4.5

The highest number of siliquae per plant were found in drip irrigation at 100% of CPE and 80% of CPE, which was 24.6, 16.3 percent and 34.4, 31.2 percent higher than 60% of CPE during 2016-17 and 2017-18, respectively. Fertigating the crop at 100% RDF and 80% RDF resulted in 18.9, 13.7 and 18.7, 13.9 per cent increase in number of siliquae per plant as compared to 60% RDF during 2016-17 and 2017-18, respectively.

Interaction between drip irrigation and fertigation schedules was found non-significant for number of siliquae per plant under both the crop seasons but interaction between treatment combinations and absolute control was found significant. Drip irrigation and fertigation produced significantly higher number of siliquae as compared to the recommended practice. In crop season 2016-17, the highest number of siliquae were obtained in drip irrigation and fertigation treatments i.e. 100% of CPE with 100% RDF which was statistically at par with 100% of CPE with 80% RDF, 100% of CPE with 60% RDF, 80% of CPE with 80% RDF and 80% of CPE with 80% RDF as compared to absolute control. However, in 2017-18 absolute control was significantly lower than all other treatments except in treatments 60% of CPE with 60%, 80% and 100% RDF. Reduction in number of siliquae per plant under lower schedules of irrigation and fertigation as well as under recommended irrigation could be attributed to less number of primary and secondary branches per plant which bear siliquae. Moreover, increase in number of siliquae per plant with increased levels of nitrogen was also reported by Kumar (2000). Similarly, higher number of siliquae per plant was obtained with higher irrigation schedules (Tahir *et al* 2007 and Piri *et al* 2011).

Table 4.7: Effect of drip irrigation and fertigation schedules on number of siliquae per plant, number of seeds per siliqua and test weight (g) of *gobhi sarson* during *rabi* 2016-17 and 2017-18

Year	2016-17					2017-18				
Fertigation schedules (FS)	Irrigation schedules (IS)				Absolute control	Irrigation schedules (IS)				Absolute control
	60% of CPE	80% of CPE	100% of CPE	Mean		60% of CPE	80% of CPE	100% of CPE	Mean	
Number of siliquae per plant										
60% RDF	431.3	498.3	509.3	479.7	464.7	441.0	558.7	560.0	519.9	477.7
80% RDF	468.6	558.1	609.3	545.3		481.7	630.8	663.7	592.0	
100% RDF	491.3	605.3	615.2	570.6		496.3	672.7	683.3	617.4	
Mean	463.7	553.9	578.0			473.0	620.7	635.7		
LSD (p=0.05)	IS=32.9 FS=32.9 ISxFS=NS ISxFS v/s absolute control= 40.9					IS=58.5 FS=58.5 ISxFS=NS ISxFS v/s absolute control= 74.2				
Number of seeds per siliqua										
60% RDF	17.1	18.1	18.7	17.9	18.2	17.9	19.7	19.8	19.1	19.6
80% RDF	17.6	19.4	21.1	19.4		18.4	20.3	21.2	20.0	
100% RDF	18.1	20.8	21.2	20.0		19.4	22.1	22.7	21.4	
Mean	17.6	19.4	20.3			18.6	20.7	21.2		
LSD (p=0.05)	IS=1.8 FS=1.8 ISxFS=NS ISxFS v/s absolute control= NS					IS=1.6 FS=1.6 ISxFS=NS ISxFS v/s absolute control= NS				
Test weight (g)										
60% RDF	4.10	4.27	4.17	4.18	4.10	4.30	4.43	4.47	4.40	4.33
80% RDF	4.23	4.37	4.53	4.38		4.50	4.73	4.87	4.70	
100% RDF	4.33	4.40	4.60	4.44		4.43	4.83	4.93	4.73	
Mean	4.22	4.34	4.43			4.41	4.67	4.76		
LSD (p=0.05)	IS= NS FS= NS ISxFS=NS ISxFS v/s absolute control= NS					IS= NS FS= NS ISxFS=NS ISxFS v/s absolute control= NS				

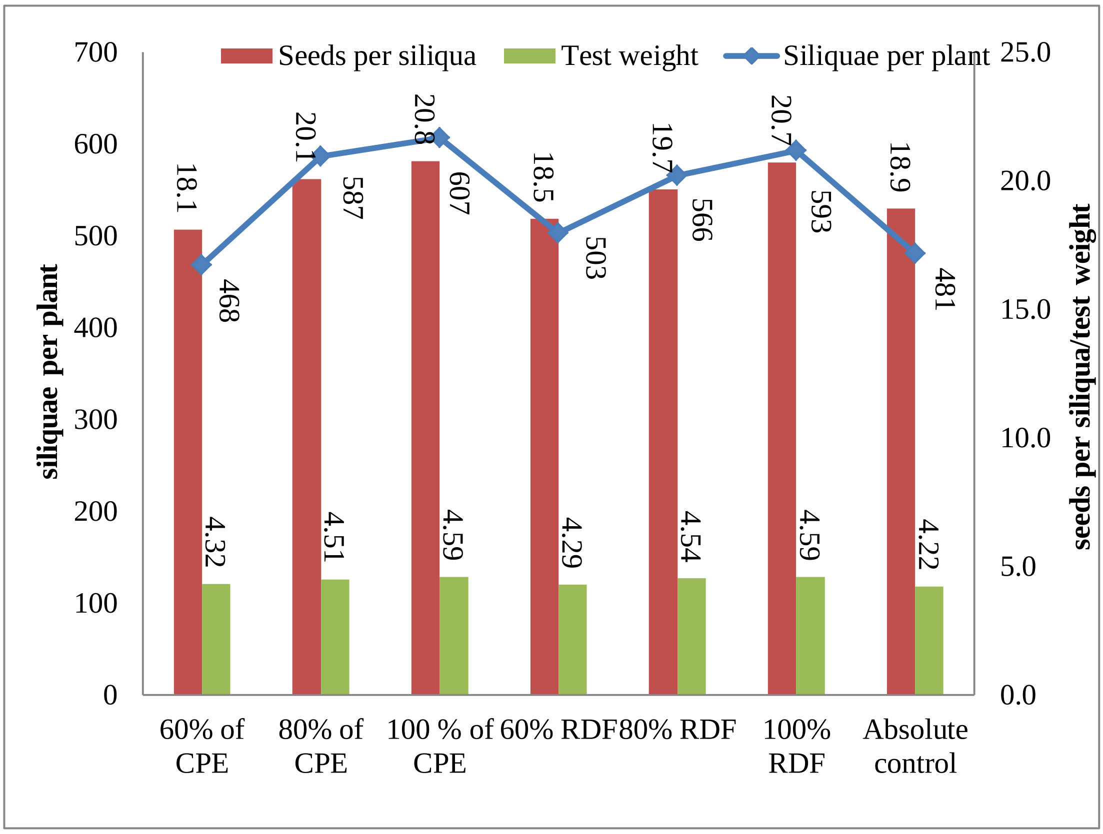


Fig 4.5: Effect of drip irrigation and fertigation schedules on number of siliquae per plant, number of seeds per siliqua and test weight of *gobhi sarson* (pooled mean of two years)

4.3.3 Number of seeds per siliqua

Number of seeds per siliqua is also a major yield contributing character. Results of number of seeds per siliqua are presented in Table 4.7 and pooled data is graphically depicted in Fig 4.5.

For both the crop seasons maximum number of seeds per siliqua were obtained under drip irrigation at 100% of CPE which exhibited statistically at par with 80% of CPE but were 15.3, 10.2 per cent and 13.9, 11.3 per cent higher than 60% of CPE in 2016-17 and 2017-18 respectively.

In case of fertigation, maximum number of seeds per siliqua was obtained under fertigation at 100% RDF which was statistically at par with 80% RDF but significantly higher than 60% RDF in 2016-17 and 2017-18, respectively. The percentage increase was 11.7, 8.4 per cent and 12.0, 4.7 per cent than 60% RDF in 2016-17 and 2017-18 respectively. Nitrogen being constituent of protein and nucleic acid plays an important role in seed development and has favourable effect on the number of seeds per siliqua (Singh 2016).

Interaction between drip irrigation and fertigation schedules was found non-significant for number of seeds per siliqua during both the crop seasons and interaction between treatment combinations and absolute control was also observed to be non-significant.

4.3.4 Test weight

Development of the seed can be judged by the test weight also referred to as 1000 seed weight. The results regarding test weight are presented in Table 4.7 and pooled data is graphically depicted in Fig 4.5.

The data revealed that neither irrigation schedules nor fertigation schedules had any significant effect on 1000 seed weight, during both the crop seasons. Methods of irrigation also did not have any effect on test weight of the crop in any of the crop seasons. Interaction between drip irrigation and fertigation schedules was found to be non-significant during both the crop seasons.

4.3.5 Seed yield

Gobhi sarson responded significantly to both irrigation and fertigation treatments. The results pertaining to the seed yield of *gobhi sarson* under drip irrigation and fertigation schedules during 2016-17 and 2017-18 are presented in Table 4.8 and pooled data is graphically depicted in Fig 4.6

Table 4.8: Effect of drip irrigation and fertigation schedules on seed yield (q ha^{-1}) and stover yield (q ha^{-1}) of *gobhi sarson* during *rabi* 2016-17 and 2017-18

Year	2016-17					2017-18				
Fertigation schedules (FS)	Irrigation schedules (IS)				Absolute control	Irrigation schedules (IS)				Absolute control
	60% of CPE	80% of CPE	100% of CPE	Mean		60% of CPE	80% of CPE	100% of CPE	Mean	
Seed yield (q ha^{-1})										
60% RDF	16.4	17.8	18.3	17.5	17.4	17.7	20.9	21.7	20.1	19.2
80% RDF	17.6	20.9	21.8	20.1		20.2	24.1	24.9	23.1	
100% RDF	18.2	21.5	22.4	20.7		20.7	24.6	25.4	23.6	
Mean	17.4	20.1	20.8			19.5	23.2	24.0		
LSD (p=0.05)	IS=1.1 FS=1.1 ISxFS=NS ISxFS v/s absolute control=1.4					IS=1.5 FS=1.5 ISxFS=NS ISxFS v/s absolute control= 1.8				
Stover yield (q ha^{-1})										
60% RDF	59.4	63.8	67.2	63.5	64.9	70.6	77.4	81.3	76.4	75.6
80% RDF	61.8	69.2	74.7	68.6		76.3	83.1	87.3	82.2	
100% RDF	65.0	74.3	77.1	72.1		76.5	85.6	89.4	83.8	
Mean	62.0	69.1	73.0			74.5	82.0	86.0		
LSD (p=0.05)	IS=6.4 FS=6.4 ISxFS=NS ISxFS v/s absolute control= NS					IS=6.2 FS=6.2 ISxFS=NS ISxFS v/s absolute control= NS				

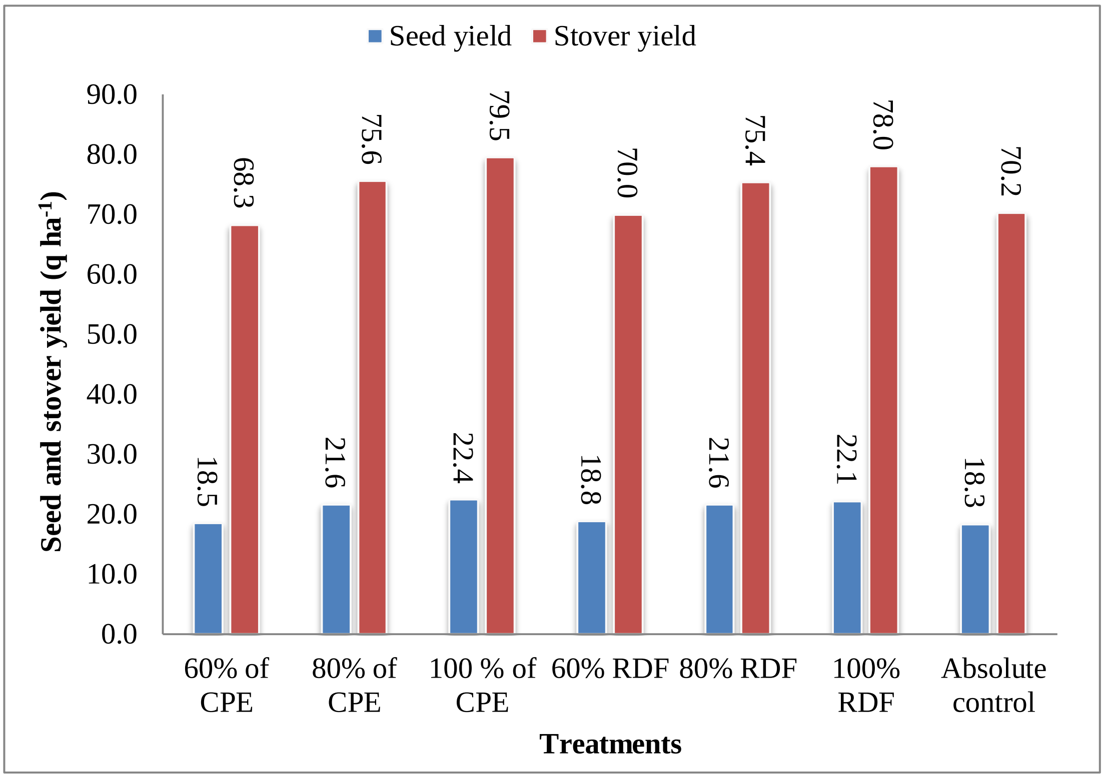


Fig 4.6: Effect of drip irrigation and fertigation schedules on seed and stover yield (q ha^{-1}) of *gobhi sarson* (pooled mean of two years)

Among irrigation schedules, drip irrigation at 100% of CPE resulted maximum seed yield, which was statistically at par with 80% of CPE and was 19.5, 15.5 per cent and 23.1, 19.0 per cent higher than 60% of CPE during 2016-17 and 2017-18, respectively. Drip irrigating the crop at 100% of CPE meant that the crop was exposed to greater availability of moisture at all the growth stages, whereas irrigating the crop at 60% of CPE might have caused moisture stress to the crop. Therefore, there is drastic reduction in yield at 60% of CPE as compared to irrigation at 100% of CPE and 80% of CPE. Moreover, drip irrigation at 100% of CPE and 100% RDF produced maximum leaf area, dry matter, secondary branches and siliquae per plant. The increased growth attributes as well as yield attributes might have resulted in production of higher yield. In the similar line of action, Jeelani *et al* (2017) concluded that drip irrigation at 80% PE produced higher yield as compared to drip irrigation at 60% and 40% PE.

In case of fertigation schedules, 100% RDF resulted in maximum yield which was statistically at par with 80% RDF but was 18.3, 14.9 and 17.4, 14.9 per cent higher than 60% RDF during 2016-17 and 2017-18, respectively. Fertigating the crop at 100% RDF provided all the nutrients to the crop, whereas fertigation at 60% RDF might have caused nutrient stress to the crop thereby reduced yield.

Interaction between drip irrigation and fertigation schedules obtained was non-significant whereas interaction between treatment combinations and absolute control was significant. Among treatment combinations maximum yield was produced under irrigation at 100% of CPE and fertigation at 100% RDF which was 28.7 and 32.5 per cent higher than absolute control during 2016-17 and 2017-18, respectively. Treatment combinations at 80% of CPE with 80% RDF, 80% of CPE with 100% RDF, 100% of CPE with 80% RDF and 100% of CPE with 100% RDF recorded significantly higher seed yield as compared to absolute control during 2016-17. Similar trend was also observed in case of pooled data and crop season 2017-18, except for treatment 100% of CPE with 60% RDF which also resulted in significant increase in seed yield than absolute control. Continuous moisture and nutrient availability to the plant in soluble form during all the growth stages of the crop might be the reason for higher yield under drip irrigation and fertigation schedules as compared to recommended irrigation and fertilizer application method (absolute control). Furthermore, lower yield in the absolute control might have caused moisture as well as nutrient stress during later part of growth period i.e. reproductive and maturity stages causing retardation of growth of floral parts and non-utilization of carbohydrates for synthesis of end product (Sinha 2015).

4.3.6 Stover yield

Stover yield is the measure of vegetative growth of the plant. The results pertaining to the stover yield of *gobhi sarson* under drip irrigation and fertigation schedules during 2016-17 and 2017-18 are presented in Table 4.8 and pooled data is graphically depicted in Fig 4.6.

The effect of irrigation schedules was significant on stover yield. The maximum stover yield was obtained with irrigation at 100% of CPE which was statistically at par with 80% of CPE, but were 17.7, 11.5 and 15.4, 10.1 per cent higher than 60% of CPE during 2016-17 and 2017-18, respectively. This increase in stover yield under higher irrigation levels might be due to higher availability of moisture for more dry matter production as well as greater number of primary and secondary branches per plant.

In case of fertigation schedules, 100% RDF resulted in maximum stover yield which was statistically at par with 80% RDF but was found 13.5, 8.0 and 7.6, 7.4 per cent higher than 60% RDF during 2016-17 and 2017-18, respectively. This increase in stover yield in higher fertilizer doses might be due to higher availability of nutrients for plant growth. Increase in stover yield of *gobhi sarson* with increase in nitrogen application was also reported by Singh *et al* (1997) and Singh and Kaistha (2006). Maximum stubble yield in castor was obtained by irrigating the crop at 50 mm CPE than at 100 mm CPE (Ramanjaneyulu *et al* 2013).

Interaction between drip irrigation and fertigation schedules as well as among treatment combinations and absolute control was non-significant during both the years.

4.3.7 Harvest index

Harvest index is obtained by dividing the economic yield to the biological yield. The results pertaining to the harvest index of *gobhi sarson* during 2016-17 and 2017-18 are presented in Table 4.9.

Table 4.9: Effect of drip irrigation and fertigation schedules on harvest index of *gobhi sarson* during *rabi* 2016-17 and 2017-18

Year	2016-17					2017-18				
Fertigation schedules (FS)	Irrigation schedules (IS)				Absolute control	Irrigation schedules (IS)				Absolute control
	60% of CPE	80% of CPE	100% of CPE	Mean		60% of CPE	80% of CPE	100% of CPE	Mean	
60% RDF	22.1	21.9	21.4	21.8	21.1	20.3	21.2	21.1	20.9	20.3
80% RDF	22.3	23.3	22.6	22.7		21.0	22.5	22.1	21.9	
100% RDF	22.0	22.5	22.5	22.3		21.4	22.4	22.1	22.0	
Mean	22.1	22.5	22.1			20.9	22.0	21.8		
LSD (p=0.05)	IS= NS FS= NS ISxFS=NS ISxFS v/s absolute control= NS					IS=NS FS=NS ISxFS=NS ISxFS v/s absolute control= NS				

The data revealed that neither irrigation schedules nor fertigation schedules had any significant effect on the harvest index of the crop. Similarly, non-significant effect on harvest index under different fertigation schedules were also obtained by Rathod *et al* (2014b). Furthermore, Ramanjaneyulu *et al* (2013) also reported non-significant harvest index despite having both significant seed and stubble yield in castor under different irrigation schedules.

Interaction between drip irrigation and fertigation schedules as well as between treatment combinations and absolute control was found non-significant during both the crop seasons.

4.3.8 Oil content

Oil content is the most important parameter in determining the quality of oilseed crops. The results pertaining to oil content of *gobhi sarson* during 2016-17 and 2017-18 are presented in Table 4.10 and pooled data is graphically depicted in Fig 4.7.

Irrigation treatments had no significant effect on oil content of the crop. Whereas, fertigation at 60% RDF recorded 2.5, 5.4 and 3.0, 3.6 per cent higher oil content than 80% RDF and 100% RDF during 2016-17 and 2017-18, respectively. Further, it was observed that oil per cent decreased with successive increase in fertilizer doses. The results showed that there is an inverse relationship between oil content and fertilizer doses, particularly nitrogen

Table 4.10: Effect of drip irrigation and fertigation schedules on oil content (%), oil yield (q ha^{-1}), protein content (%) and protein yield (q ha^{-1}) of *gobhi sarson* during *rabi* 2016-17 and 2017-18

Year	2016-17					2017-18				
Fertigation schedules (FS)	Irrigation schedules (IS)				Absolute control	Irrigation schedules (IS)				Absolute control
	60% of CPE	80% of CPE	100% of CPE	Mean		60% of CPE	80% of CPE	100% of CPE	Mean	
Oil content										
60% RDF	41.4	40.8	41.1	41.1	40.2	40.8	40.3	40.7	40.6	40.4
80% RDF	40.7	40.7	38.9	40.1		40.0	39.5	38.8	39.4	
100% RDF	39.9	38.3	38.7	39.0		39.6	39.4	38.7	39.2	
Mean	40.7	39.9	39.6			40.2	39.8	39.4		
LSD (p=0.05)	IS= NS FS= 1.58 ISxFS=NS ISxFS v/s absolute control= NS					IS=NS FS=0.83 ISxFS=NS ISxFS v/s absolute control= NS				
Oil yield										
60% RDF	6.81	7.25	7.53	7.20	6.98	7.23	8.42	8.85	8.17	7.81
80% RDF	7.18	8.54	8.46	8.02		8.10	9.53	9.65	9.09	
100% RDF	7.24	8.22	8.66	8.04		8.20	9.72	9.82	9.25	
Mean	7.08	8.00	8.22			7.85	9.22	9.44		
LSD (p=0.05)	IS= 0.59 FS= 0.59 ISxFS=NS ISxFS v/s absolute control= 0.73					IS=0.69 FS=0.69 ISxFS=NS ISxFS v/s absolute control= 0.85				
Protein content										
60% RDF	17.9	18.2	18.0	18.0	18.6	17.9	18.3	18.0	18.1	18.5
80% RDF	19.1	19.5	19.6	19.4		18.9	19.6	20.0	19.5	
100% RDF	20.7	20.9	21.1	20.9		21.1	20.9	20.4	20.8	
Mean	19.2	19.5	19.6			19.3	19.6	19.5		
LSD (p=0.05)	IS= NS FS= 0.3 ISxFS=NS ISxFS v/s absolute control= 0.5					IS=NS FS=0.6 ISxFS=NS ISxFS v/s absolute control= 0.8				
Protein yield										
60% RDF	2.95	3.23	3.29	3.16	3.23	3.18	3.83	3.92	3.64	3.57
80% RDF	3.36	4.09	4.27	3.91		3.82	4.73	4.97	4.51	
100% RDF	3.77	4.48	4.72	4.32		4.37	5.16	5.17	4.90	
Mean	3.36	3.94	4.09			3.79	4.57	4.69		
LSD (p=0.05)	IS= 0.22 FS= 0.22 ISxFS=NS ISxFS v/s absolute control= 0.26					IS=0.35 FS=0.35 ISxFS=NS ISxFS v/s absolute control= 0.43				

i.e. as the levels of fertilizer dose increases, the oil content decreases. This could be due to production of more proteinaceous substances in the seed as accounted for higher dose of nitrogen (Biswas *et al* 1995). The inverse relationship between oil content and higher dose of N might be due to a reduced availability of carbohydrates for oil synthesis at higher levels of N supply. The negative influence of N fertilization on the seed oil content is consistent with the findings of Asare and Scarisbrick, 1995; Kirkegaard *et al* 1997; Hocking *et al* 1997a; Mason and Brennan, 1998; Jackson, 2000; Cheema *et al* 2001 and Hao *et al* 2004.

There was no significant difference in oil content of treatment combinations when compared with absolute control. Interaction between drip irrigation and fertigation schedules was also non-significant during both the crop seasons.

4.3.9 Oil yield

Oil yield is obtained by multiplying the per cent oil content with the seed yield. The results regarding oil yield of *gobhi sarson* during 2016-17 and 2017-18 are presented in Table 4.10 and pooled data is graphically depicted in Fig 4.7

The data indicated that the maximum oil yield was obtained by drip irrigation with 100% of CPE which was statistically at par with 80% of CPE but were 16.1, 13.0 per cent and 20.3, 17.5 per cent higher than 60% of CPE during 2016-17 and 2017-18, respectively. Even though drip irrigation schedules had no significant effect on seed oil content but oil yield was significantly influenced by drip irrigation indicating that oil yield is a function of seed yield.

Fertigation at 100% RDF was statistically at par with 80% RDF. However, it was observed that 100% and 80% RDF produced 11.9, 11.7 per cent and 13.2, 11.3 per cent higher oil yield than 60% RDF during 2016-17 and 2017-18, respectively. Although the oil content in seed decreased with the application of fertilizers, especially nitrogen, the yield of oil increased significantly, indicating that oil yield was governed by the seed yield of *gobhi sarson* rather than its per cent oil content. Similarly, Daneshvar *et al* (2008) revealed that as the N rate increased, seed oil percentage decreased and seed oil yield increased significantly.

Interaction between treatment combinations and absolute control was significant. Maximum oil yield was obtained in drip irrigation at 100% of CPE and fertigation at 100% RDF which was 24.1 and 25.7 per cent higher than absolute control during 2016-17 and 2017-18, respectively. During crop season 2016-17, drip irrigation and fertigation treatments at 80% of CPE with 80% RDF, 80% of CPE with 100% RDF, 100% of CPE with 80% RDF and 100% of CPE with 100% RDF recorded significantly higher oil yield with respect to absolute control. For crop season 2017-18, drip irrigation and fertigation treatments at 80% of CPE with 80% RDF, 80% of CPE with 100% RDF, 100% of CPE with 80% RDF and 100% of CPE with 100% RDF along with 100% of CPE with 60% RDF recorded significantly higher oil yield as compared to absolute control. Drip irrigation and fertigation treatments resulted in significantly higher oil yield than the recommended practice, because of reduction in evaporation and leaching losses of water and nutrients from root zone which provided nutrients in adequate quantity to the crop.

Interaction between drip irrigation and fertigation schedules was non-significant during both the crop growing seasons as well as in pooled data.

4.3.10 Protein content

Protein content is also another parameter in determining the quality of oilseed crops. The results regarding the seed protein content of *gobhi sarson* seeds are presented in Table 4.10 and pooled data is graphically depicted in Fig 4.7.

Drip irrigation schedules had no significant effect on seed protein. Whereas, there was significant effect of fertigation schedules. The maximum protein content was obtained by fertigation at 100% RDF which was statistically at par with 80% RDF but 16.1, 7.7 per cent and 14.9, 7.7 per cent higher than 60% RDF during 2016-17 and 2017-18, respectively. Increase in rate of fertilizer application, especially N increases the production of amino acids which in turn increases the protein content in the seed. Likewise, Rathke *et al* 2005 stated that high oil content is generally correlated with low crude protein content and vice versa. They also revealed that by increasing the N rates there is decrease in oil content and a rise in crude protein content. Moreover, the synthesis of both fatty acids and amino acids require carbon compounds from the decomposition of carbohydrates. Since the carbon content of proteins is lower than that of oils, increased N supply intensifies the synthesis of proteins at the expense of fatty acids and thus, reduced seed oil content (Bhatia and Rabson, 1976; Lambers and Poorter, 1992).

Interaction between drip irrigation and fertigation schedules was found non-significant but there was significant difference in seed protein content between treatment combinations and absolute control. Drip irrigation and fertigation treatments at 60% of CPE with 100% RDF, 80% of CPE with 80% RDF, 80% of CPE with 100% RDF, 100% of CPE with 80% RDF and 100% of CPE with 100% RDF recorded significantly higher seed protein content with respect to absolute control under both the crop seasons and in pooled data also. Maximum protein content was found in treatment 100% of CPE with 100% RDF and was 13.4 per cent higher than absolute control during 2016-17, whereas in 2017-18 it was found to be highest in treatment 80% of CPE with 100% RDF and was 13.0 per cent higher than absolute control. Drip irrigated plots get more nutrients in soluble form as compared to flood irrigated plots where there are leaching losses. Therefore, drip irrigated crops have higher seed protein content than flood irrigated.

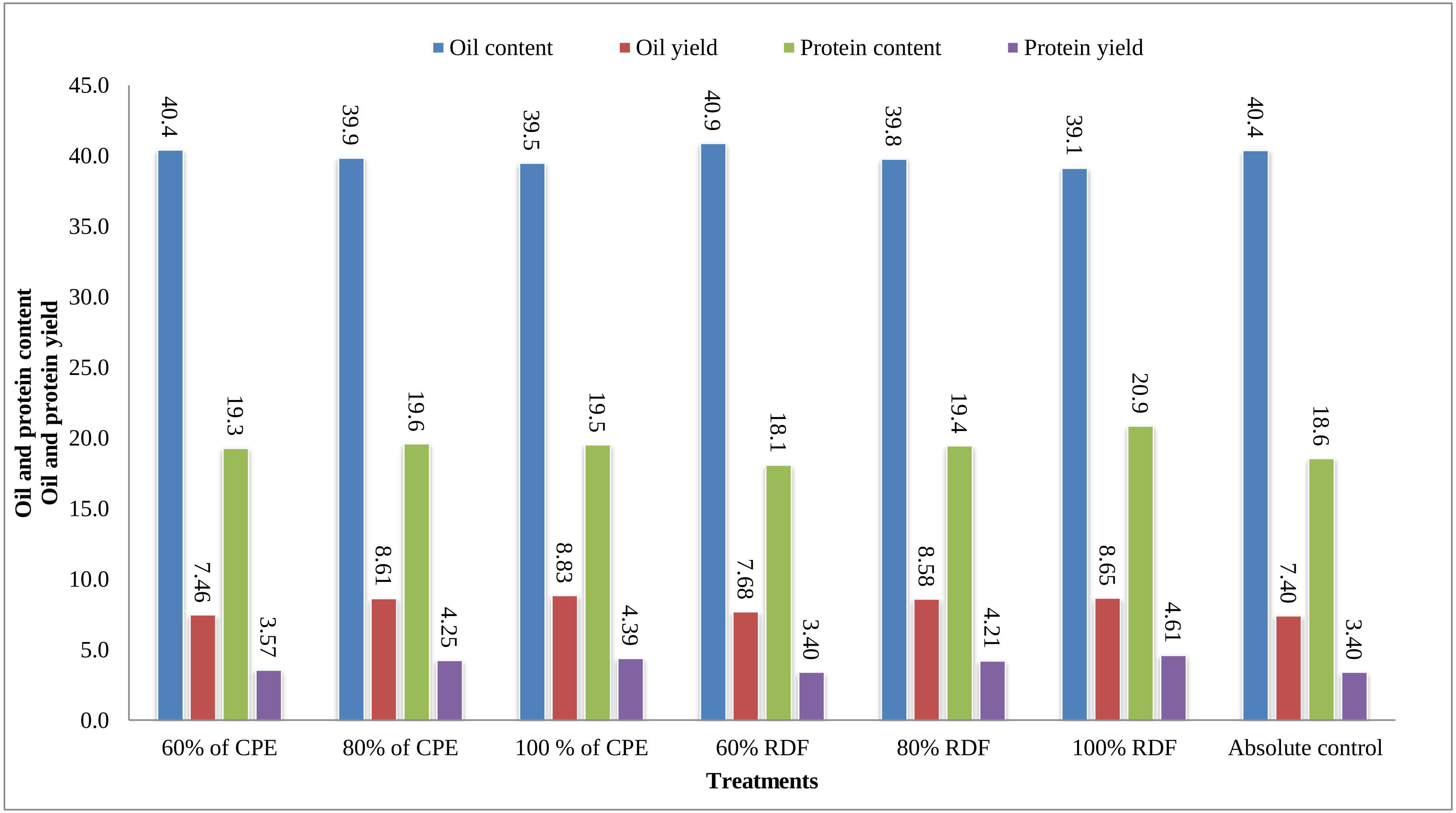


Fig 4.7: Effect of drip irrigation and fertigation schedules on oil content (%), oil yield (q ha^{-1}), protein content (%) and protein yield (q ha^{-1}) of *gobhi sarson* (pooled mean of two years)

4.3.11 Protein yield

Protein yield is obtained by multiplying the per cent protein content with the seed yield. The results regarding the protein yield of *gobhi sarson* are presented Table 4.10 and pooled data is graphically depicted in Fig 4.7.

The data indicated that the maximum protein yield was obtained by drip irrigation with 100% of CPE which was statistically at par with 80% of CPE but significantly higher than 60% of CPE. Although, protein content was non-significant for irrigation schedules, but protein yield was significant indicating that protein yield is largely dependent on seed yield.

Fertigation at 100% RDF recorded significantly higher protein yield than 80% RDF followed by 60% RDF. Fertigation at 80% RDF produced significantly higher protein yield as compare to 60% RDF. This trend was true for both the crop seasons. Higher doses of nitrogen might have increased the protein yield of the crop.

Interaction between drip irrigation and fertigation schedules was found to be non-significant, but treatment combinations resulted in significant increase in the protein yield as compared to absolute control during both the years. Drip irrigation and fertigation at 60% of CPE with 100% RDF, 80% of CPE with 80% RDF, 80% of CPE with 100% RDF, 100% of CPE with 80% RDF and 100% of CPE with 100% RDF recorded significantly higher protein yield in comparison to absolute control. Maximum protein yield was obtained in drip irrigation treatment 100% of CPE with 100% RDF and was 46.1 and 44.8 per cent higher than absolute control. Drip irrigation and fertigation treatments lead to higher protein yield which might be due to significant increase in seed yield and protein content as compared to absolute control. Another reason for higher protein yield could be decreased nutrient losses in drip irrigation as compared to flood irrigation.

4.4 Economics

4.4.1 Gross returns

Gross returns are to measure the total monetary value of the crop raised. The data pertaining to gross returns of *gobhi sarson* in crop season 2016-17 and 2017-18 are presented in Table 4.11 and pooled data is graphically depicted in Fig 4.8.

In case of drip irrigation schedules, the maximum gross returns were obtained with irrigating the crop at 100% of CPE followed by 80% of CPE which were 19.6, 15.2 and 22.7, 18.7 per cent higher than 60% of CPE during 2016-17 and 2017-18, respectively. Among fertigation schedules, maximum gross returns were obtained with 100% RDF followed by 80% RDF which were 18.0, 14.9 and 17.3, 14.8 per cent higher than 60% of CPE during 2016-17 and 2017-18, respectively.

Table 4.11: Effect of drip irrigation and fertigation schedules on gross returns (Rs ha^{-1}), net returns (Rs ha^{-1}) and B:C ratio of *gobhi sarson* during *rabi* 2016-17 and 2017-18

Year	2016-17					2017-18				
Fertigation schedules (FS)	Irrigation schedules (IS)				Absolute control	Irrigation schedules (IS)				Absolute control
	60% of CPE	80% of CPE	100% of CPE	Mean		60% of CPE	80% of CPE	100% of CPE	Mean	
Gross returns										
60% RDF	60809	65715	67756	64760	64217	70849	83457	86921	80409	77173
80% RDF	65208	77500	80528	74412		80968	96429	99457	92285	
100% RDF	67208	79377	82748	76445		82780	98599	101551	94310	
Mean	64408	74197	77011			78199	92829	95976		
Net returns										
60% RDF	27914	32440	34197	31517	34043	37973	50299	53478	47250	47207
80% RDF	30638	42550	46294	39827		46400	61580	64324	57435	
100% RDF	30964	42752	45838	39851		46521	62059	64227	57769	
Mean	29839	39247	42110			43631	57979	60843		
B:C ratio										
60% RDF	0.85	0.97	1.02	0.95	1.13	1.16	1.52	1.60	1.42	1.58
80% RDF	0.89	1.22	1.35	1.15		1.34	1.77	1.83	1.65	
100% RDF	0.85	1.17	1.24	1.09		1.28	1.70	1.76	1.58	
Mean	0.86	1.12	1.20			1.26	1.66	1.73		

Highest gross return was obtained with drip irrigation and fertigation treatment at 100% of CPE with 100% RDF which was 28.9 and 31.6 per cent higher than absolute control during 2016-17 and 2017-18, respectively. All the treatment combinations recorded higher gross returns in comparison to absolute control except in treatment 60% of CPE with 60% RDF which recorded lower gross return than absolute control. Higher gross returns are due to higher seed yield which might be due to regular supply of moisture and nutrients through drip irrigation.

4.4.2 Net returns

Net returns are the actual monetary value obtained from raising the crop. Net return is calculated after deducting the variable cost of cultivation from gross return. The data pertaining to net returns of *gobhi sarson* during crop season 2016-17 and 2017-18 are presented in Table 4.11 and pooled data is graphically depicted in Fig 4.8.

The maximum net returns in case of drip irrigation schedules were obtained at 100% of CPE followed by 80% of CPE which were 41.1, 31.5 and 39.4, 32.9 per cent higher than 60% of CPE during 2016-17 and 2017-18, respectively. Among fertigation schedules, maximum net returns were obtained at 100% RDF followed by 80% RDF which were 26.4, 26.4 and 22.3, 21.6 per cent higher than 60% of CPE during 2016-17 and 2017-18, respectively.

The maximum net return was obtained with treatment combination 100% of CPE with 80% RDF which was 36.0 and 36.3 per cent higher than absolute control during 2016-17 and 2017-18, respectively. All treatment combinations obtained higher net returns as compared to absolute control except 60% of CPE with 60% RDF, 60% of CPE with 80% RDF, 60% of CPE with 100% RDF, which achieved lower net returns than absolute control during both the crop seasons as well as in pooled data.

4.4.3 B:C ratio

The data pertaining to B:C ratio of *gobhi sarson* during crop season 2016-17 and 2017-18 are presented in Table 4.11 and pooled data is graphically depicted in Fig 4.8.

The highest B:C ratio was obtained with drip irrigation at 100% of CPE followed by 80% of CPE which was 39.5, 30.2 and 37.3, 31.7 per cent higher than 60% of CPE during 2016-17 and 2017-18, respectively. But in case of fertigation schedules, 80% RDF recorded the highest B:C ratio and then 100% RDF which was 21.1, 14.7 and 16.2, 11.3 per cent higher than 60% of CPE during 2016-17 and 2017-18, respectively.

The highest B:C was obtained in drip irrigation and fertigation treatment 100% CPE with 80% RDF which was 19.5 and 15.8 per cent higher than absolute control during 2016-17 and 2017-18, respectively. Drip irrigation and fertigation treatments at 80% of CPE with 80% RDF, 80% of CPE with 100% RDF, 100% of CPE with 80% RDF and 100% of CPE with 100% RDF obtained higher B:C ratio as compared to absolute control in 2016-17 and in pooled data. While in 2017-18 treatment combination 100% of CPE with 60% RDF also recorded higher B:C ratio than absolute control.

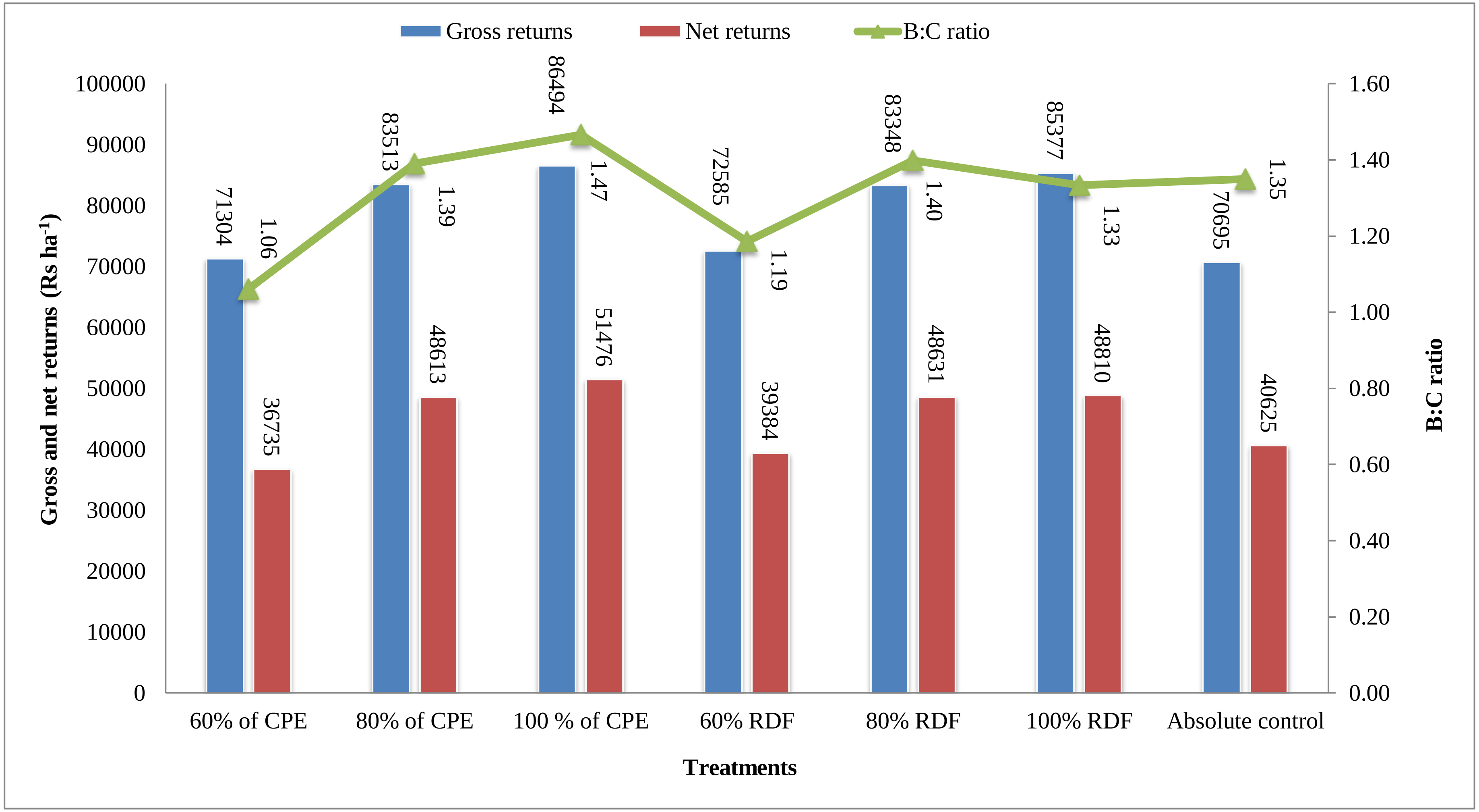


Fig 4.8: Effect of drip irrigation and fertigation schedules on gross returns (Rs ha^{-1}), net returns (Rs ha^{-1}) and B:C ratio of *gobhi sarson* (pooled mean of two year)

4.5 Energetics

4.5.1 Energy input

The data pertaining to energy input of *gobhi sarson* during crop season 2016-17 and 2017-18 are presented in table 4.12 and pooled data is graphically depicted in Fig 4.9.

The highest energy input was noticed in drip irrigation at 100% of CPE then in 80% of CPE and the lowest in 60% of CPE due to greater volume of water applied at higher levels of irrigation. Energy input was the highest in fertigation schedules of 100% RDF and then in 80% RDF and the lowest was found in 60% RDF, due to higher amount of fertilizer used in higher fertigation levels. The results were similar in both the crop seasons and in pooled data also. Maximum energy input was in absolute control as compared to all other treatments due to larger volume of water applied during both the crop seasons.

Table 4.12: Effect of drip irrigation and fertigation schedules on energy input and output (MJ ha^{-1}) of *gobhi sarson* during *rabi* 2016-17 and 2017-18

Year	2016-17					2017-18				
Fertigation schedules (FS)	Irrigation schedules (IS)				Absolute control	Irrigation schedules (IS)				Absolute control
	60% of CPE	80% of CPE	100% of CPE	Mean		60% of CPE	80% of CPE	100% of CPE	Mean	
Energy input										
60% RDF	10214	10438	10660	10437	14736	10048	10268	10489	10268	14574
80% RDF	12099	12324	12546	12323		11934	12153	12375	12154	
100% RDF	13985	14210	14432	14209		13820	14039	14260	14040	
Mean	12099	12324	12546			11934	12153	12375		
Energy output										
60% RDF	41087	44402	45781	43757	43390	44281	52161	54325	50256	48233
80% RDF	44059	52365	54411	50278		50605	60268	62161	57678	
100% RDF	45411	53633	55911	51652		51737	61625	63470	58944	
Mean	43519	50133	52034			48874	58018	59985		

4.5.2 Energy output

The data pertaining to energy output of *gobhi sarson* in crop season 2016-17 and 2017-18 are presented in Table 4.12 and pooled data is graphically depicted in Fig 4.9.

The maximum energy output was achieved in drip irrigation schedules at 100% of

CPE then in 80% of CPE and lowest in 60% of CPE. Similarly, in fertigation schedules, the maximum energy output was obtained with 100% RDF and then in 80% RDF and lowest in 60% RDF due to higher seed yield obtained with higher levels of irrigation and fertigation.

Absolute control achieved lower energy output in comparison to drip irrigation and fertigation treatments except in treatment 60% of CPE with 60% RDF which recorded lower energy output than the absolute control. The maximum energy output was achieved in treatment combination 100% of CPE with 100% RDF which was 28.9 and 31.6 per cent higher than absolute control during 2016-17 and 2017-18, respectively.

4.5.3 Energy use efficiency

The data pertaining to energy use efficiency of *gobhi sarson* under different irrigation and fertigation schedules during crop season 2016-17 and 2017-18 are presented in Table 4.13 and pooled data is graphically depicted in Fig 4.9.

Table 4.13: Effect of drip irrigation and fertigation schedules on energy use efficiency and energy productivity (g MJ^{-1}) of *gobhi sarson* during *rabi* 2016-17 and 2017-18

Year	2016-17					2017-18				
Fertigation schedules (FS)	Irrigation schedules (IS)				Absolute control	Irrigation schedules (IS)				Absolute control
	60% of CPE	80% of CPE	100% of CPE	Mean		60% of CPE	80% of CPE	100% of CPE	Mean	
Energy use efficiency										
60% RDF	4.02	4.25	4.29	4.19	2.94	4.41	5.08	5.18	4.89	3.31
80% RDF	3.64	4.25	4.24	4.04		4.24	4.96	5.02	4.74	
100% RDF	3.25	3.77	3.87	3.63		3.74	4.39	4.45	4.19	
Mean	3.64	4.09	4.17			4.13	4.81	4.88		
Energy productivity										
60% RDF	160.9	170.2	173.8	167.6	117.8	176.3	203.2	207.2	195.5	132.4
80% RDF	145.7	170.0	172.5	163.0		169.6	198.4	200.9	189.6	
100% RDF	129.9	151.0	155.0	145.3		149.7	175.6	178.0	167.8	
Mean	145.5	163.7	166.7			165.2	192.4	195.4		
LSD (p=0.05)	IS= 9.1 FS= 9.1 ISxFS=NS ISxFS v/s absolute control= 11.8					IS=11.8 FS=11.8 ISxFS=NS ISxFS v/s absolute control= 15.3				

The maximum energy use efficiency was obtained with drip irrigation at 100% of CPE followed by 80% of CPE which were 14.6, 12.4 and 18.1, 16.5 per cent higher than 60% of CPE during 2016-17 and 2017-18, respectively.

But among fertigation schedules, maximum energy use efficiency was obtained at 60% RDF followed by 80% RDF which were 15.4, 11.3 and 16.7, 13.1 per cent higher than 100% RDF during 2016-17 and 2017-18, respectively, because of lower energy input in 60% RDF. Similarly, Sinha *et al* (2017) also obtained the maximum energy use efficiency in fertigation with 60% RDF.

Among drip irrigation treatment combination 100% CPE with 60% RDF achieved maximum energy use efficiency which was 45.9 and 56.5 per cent higher than absolute control during 2016-17 and 2017-18, respectively. The lowest energy use efficiency was obtained in absolute control as compared all other treatment combinations.

4.5.4 Energy productivity

The data pertaining to energy productivity of *gobhi sarson* under different irrigation and fertigation schedules during crop season 2016-17 and 2017-18 are presented in Table 4.13.

The maximum energy productivity was obtained in drip irrigation with 100% of CPE which was statistically at par with 80% of CPE and 14.6, 12.5 per cent and 18.3, 16.5 per cent higher than 60% of CPE during 2016-17 and 2017-18, respectively.

While in case of fertigation schedules, the maximum energy productivity was obtained with fertigation at 60% RDF which was statistically at par with 80% RDF but 15.3, 12.2 and 16.5, 13 per cent higher than 100% RDF during 2016-17 and 2017-18, respectively. The energy productivity successively decreased from 100% to 60% RDF and maximum value was obtained in 60% RDF due to less energy input (Sinha *et al* 2017).

The maximum energy productivity was obtained in treatment combination at 100% of CPE with 60% RDF which was 47.5 and 56.5 per cent higher than absolute control for 2016-17 and 2017-18, respectively. Absolute control recorded minimum energy productivity than all other drip irrigation and fertigation treatments due to higher energy input and lower energy output.

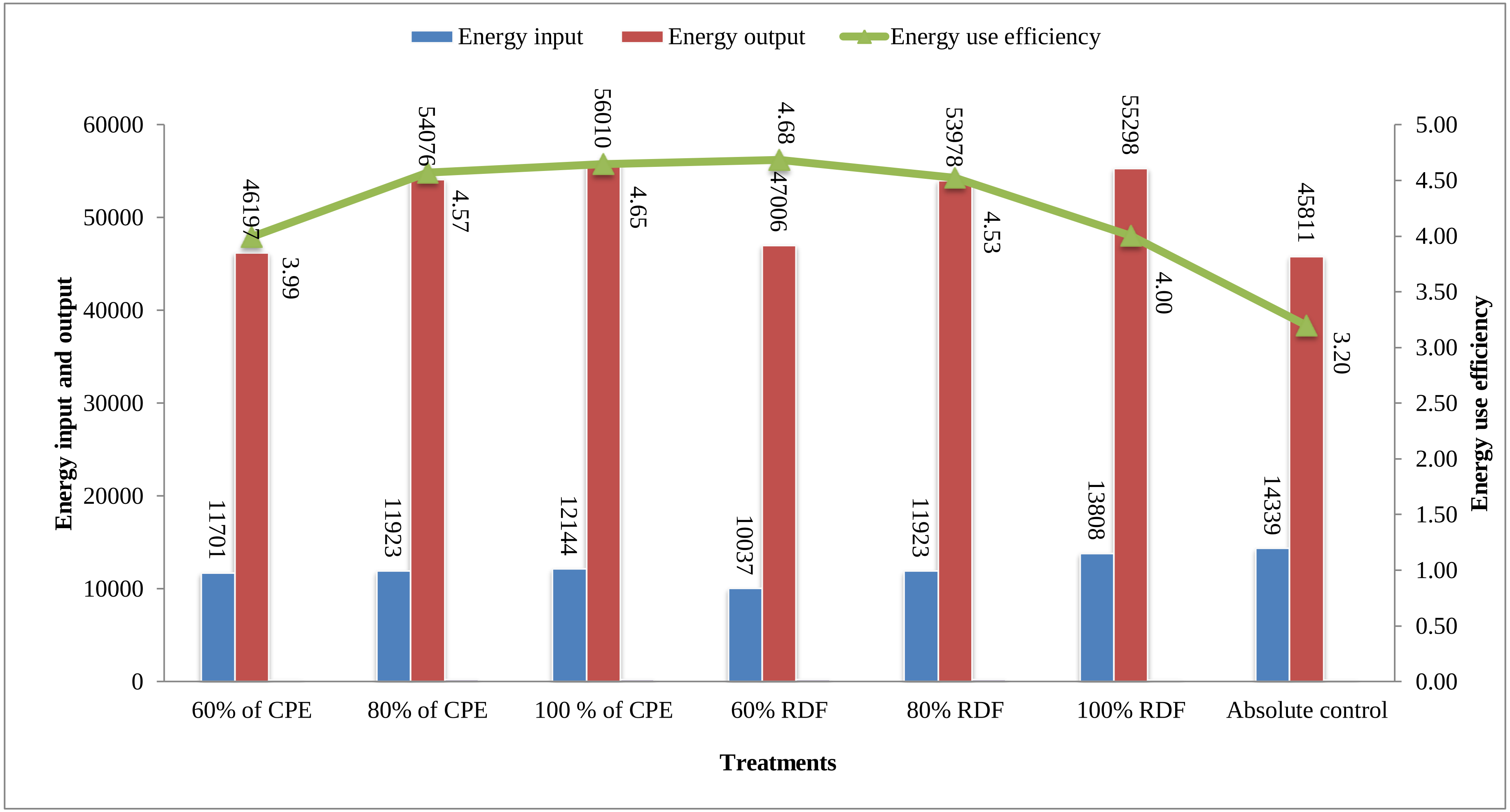


Fig 4.9: Effect of drip irrigation and fertigation schedules on energy input (MJ ha^{-1}), energy output (MJ ha^{-1}) and energy use efficiency of *gobhi sarson* (pooled mean of two year)

4.6 Water studies

4.6.1 Irrigation water input and total water input

The data pertaining to irrigation water and total water applied in different irrigation and fertigation schedules during 2016-17 and 2017-18 are presented in Table 4.14 and pooled data is graphically depicted in Fig 4.10.

Table 4.14: Effect of drip irrigation and fertigation schedules on irrigation water and total water input (mm) of *gobhi sarson* during *rabi* 2016-17 and 2017-18

Year	2016-17					2017-18				
Fertigation schedules (FS)	Irrigation schedules (IS)				Absolute control	Irrigation schedules (IS)				Absolute control
	60% of CPE	80% of CPE	100% of CPE	Mean		60% of CPE	80% of CPE	100% of CPE	Mean	
Irrigation water input										
60% RDF	205.5	240.7	275.9	240.7	325.0	204.5	239.3	274.1	239.3	325.0
80% RDF	205.5	240.7	275.9	240.7		204.5	239.3	274.1	239.3	
100% RDF	205.5	240.7	275.9	240.7		204.5	239.3	274.1	239.3	
Mean	205.5	240.7	275.9			204.5	239.3	274.1		
Total water input										
60% RDF	299.2	334.4	369.6	334.4	418.7	280.9	315.7	350.5	315.7	401.4
80% RDF	299.2	334.4	369.6	334.4		280.9	315.7	350.5	315.7	
100% RDF	299.2	334.4	369.6	334.4		280.9	315.7	350.5	315.7	
Mean	299.2	334.4	369.6			280.9	315.7	350.5		

Maximum depth of irrigation water was applied in absolute control i.e. flood irrigation method followed by drip irrigation at 100% of CPE, 80% of CPE and finally at 60% of CPE. Drip irrigation at 100% of CPE, 80% of CPE and 60% of CPE recorded irrigation water saving of 15.1, 26.1 and 36.8 per cent, respectively in 2016-17 and 15.7, 26.4 and 37.1 per cent in 2017-18, as compared to flood irrigation, respectively. Maximum water saving was observed under drip irrigation at 60 % CPE followed by 80 % of CPE and 100 % of CPE

Total water input includes irrigation water applied plus total rainfall recorded during the crop season. The data revealed that the maximum depth of total water input was in case of absolute control i.e. flood irrigation followed by drip irrigation at 100% of CPE, 80% of CPE and lowest at 60% of CPE. Drip irrigation at 100% of CPE, 80% of CPE and 60% of CPE recorded total water saving of 11.7, 20.1, 28.5 per cent and 12.7, 21.4, 30 per cent as compared to flood irrigation during 2016-17 and 2017-18, respectively.

4.6.2 Apparent water productivity

The data pertaining to apparent water productivity of *gobhi sarson* under different irrigation and fertigation schedules during crop season 2016-17 and 2017-18 are presented in Table 4.15 and pooled data is graphically depicted in Fig 4.10.

The maximum apparent water productivity (AWP) was obtained with drip irrigation at 60% of CPE which was statistically at par with 80% of CPE but 11.0 and 9.8 per cent higher than 100% of CPE during 2016-17. But during 2017-18, maximum AWP was obtained in drip irrigation at 80% of CPE which was statistically at par with 60% of CPE but was 9.8 and 8.5 per cent higher than 100% of CPE. Similar results were also observed in pooled data. This might be due to less irrigation water applied in case of 80% of CPE than 100% of CPE. Fertigation at 100% RDF was statistically at par with 80% RDF but significantly higher than 60% RDF for both the crop seasons as well as for pooled data.

Interaction between drip irrigation and fertigation schedules was found non-significant, but interaction between treatment combinations and absolute control was significant. Drip irrigation and fertigation treatment at 80% of CPE with 100% RDF recorded the maximum AWP which was 66.9 per cent higher than absolute control during 2016-17. Whereas in 2017-18, drip irrigation and fertigation at 60% of CPE with 100% RDF recorded the maximum AWP which was 70.4 per cent higher than absolute control. Absolute control recorded the lowest apparent water productivity than all the other treatment combinations due to maximum water application during both the crop seasons.

4.6.3 Total water productivity

The data pertaining to total water productivity of *gobhi sarson* in different irrigation and fertigation schedules during crop seasons 2016-17 and 2017-18 are presented in Table 4.15 and pooled data is graphically depicted in Fig 4.10.

The maximum total water productivity (TWP) was obtained with drip irrigation at 80% of CPE which was statistically at par with 60% of CPE but 6.2 and 6.8 per cent higher than 100% of CPE for 2016-17 and 2017-18, respectively. This might be due to less water applied in case of 80% of CPE than in 100% of CPE. Fertigation at 100% RDF was statistically at par with 80% RDF but significantly higher than 60% RDF for both the crop seasons as well as for pooled data also.

Interaction between drip irrigation and fertigation schedules was found to be non-significant, but interaction between treatment combinations and absolute control was significant. Drip irrigation and fertigation at 80% of CPE with 100% RDF recorded the maximum TWP which was 54.7 and 62.4 per cent higher than absolute control during 2016-17 and 2017-18. Absolute control recorded the lowest total water productivity than all the other treatment combinations due to maximum water applied in absolute control during both the years.

Table 4.15: Effect of drip irrigation and fertigation schedules on apparent and total water productivity (kg m^{-3}), consumptive use (mm) and water use efficiency (%) of *gobhi sarson* during *rabi* 2016-17 and 2017-18.

Year	**2016-17**					**2017-18**				
Fertigation schedules (FS)	**Irrigation schedules (IS)**				**Absolute control**	**Irrigation schedules (IS)**				**Absolute control**
	60% of CPE	**80% of CPE**	**100% of CPE**	**Mean**		**60% of CPE**	**80% of CPE**	**100% of CPE**	**Mean**	
Apparent water productivity										
60% RDF	0.800	0.738	0.664	0.734	0.534	0.866	0.872	0.793	0.844	0.594
80% RDF	0.858	0.870	0.789	0.839		0.990	1.007	0.907	0.968	
100% RDF	0.884	0.891	0.811	0.862		1.012	1.030	0.926	0.989	
Mean	0.847	0.833	0.754			0.956	0.970	0.875		
LSD (p=0.05)	IS= 0.046 FS= 0.046 ISxFS=NS ISxFS v/s absolute control= 0.057					IS=0.059 FS=0.059 ISxFS=NS ISxFS v/s absolute control= 0.072				
Total water productivity										
60% RDF	0.549	0.531	0.495	0.525	0.415	0.631	0.661	0.620	0.637	0.481
80% RDF	0.589	0.626	0.589	0.601		0.721	0.764	0.709	0.731	
100% RDF	0.607	0.642	0.605	0.618		0.737	0.781	0.724	0.747	
Mean	0.582	0.600	0.563			0.696	0.735	0.685		
LSD (p=0.05)	IS=0.033 FS= 0.033 ISxFS=NS ISxFS v/s absolute control= 0.04					IS=0.045 FS=0.045 ISxFS=NS ISxFS v/s absolute control= 0.055				
Consumptive water use										
60% RDF	266.6	294.6	323.9	295.0	274.7	269.2	298.4	333.2	300.3	276.1
80% RDF	270.8	300.1	332.0	301.0		271.7	306.6	336.1	304.8	
100% RDF	278.0	307.8	340.2	308.7		278.5	310.4	342.9	310.6	
Mean	271.8	300.8	332.0			273.1	305.1	337.4		
Water use efficiency										
60% RDF	89.1	88.1	87.6	88.3	65.6	95.8	94.5	95.1	95.1	68.8
80% RDF	90.5	89.7	89.8	90.0		96.7	97.1	95.9	96.6	
100% RDF	92.9	92.0	92.0	92.3		99.1	98.3	97.8	98.4	
Mean	90.8	90.0	89.8			97.2	96.7	96.3		

4.6.4 Consumptive water use

The data pertaining to consumptive water use by the crop for 2016-17 and 2017-18 are presented in Table 4.15 and pooled data is graphically depicted in Fig 4.10.

Maximum water use by the crop was recorded in drip irrigation at 100% of CPE followed by 80% of CPE which was 22.1, 10.7 and 23.5, 11.7 per cent higher than 60% of CPE during 2016-17 and 2017-18, respectively. Higher water use by the crop at higher levels of irrigation might be due to more availability of moisture for absorption. Moreover, higher dry matter production and leaf area of the plant at 100% of CPE and 80% of CPE might have increased the demand of water for transpiration by the crops as compared to 60% of CPE. Similarly, Rushima *et al* (2014) stated that water use was higher with irrigation scheduling at 40 CPE which deceased with increase in CPE.

Fertigating the crop at 100% RDF followed by 80% RDF and 60% RDF recorded the maximum water use by the crop. Very little difference in water use by the crop was recorded between fertigation levels.

All the treatment combinations recorded greater water use by the crops as compared to absolute control except in treatment 60% of CPE with 60% RDF (266.6 mm) and 60% of CPE with 80% RDF (270.8 mm) which recorded lower water use by the crops. The highest value for water use was recorded with treatment 100% of CPE with 100% RDF which was 23.8 and 24.2 per cent higher than absolute control during 2016-17 and 2017-18, respectively. These results might be due to higher dry matter production and leaf area index of the plant in drip irrigation and fertigation treatments which increased the rate of transpiration by the crops, hence higher water use by the crop as compared to absolute control.

4.6.5 Water use efficiency

The data pertaining to water use efficiency of *gobhi sarson* during 2016-17 and 2017-18 are presented in Table 4.15 and pooled data is graphically depicted in Fig 4.10.

Water use efficiency was affected by different levels of drip irrigation and fertigation, maximum water use efficiency was obtained in drip irrigation with 60% of CPE followed by 80% of CPE and 100% of CPE for both the crop seasons. Higher water use efficiency in case of 60% CPE might be due to comparatively lessor water applied. The lower water use efficiency at 100% of CPE might be due to higher expense of water use. In case of fertigation treatments, highest water use efficiency was obtained at fertigation with 100% RDF followed by 80% RDF and 60% RDF.

Interaction between drip irrigation schedules and fertigation was found to be non-significant, but interaction between treatment combinations and absolute control was significant. Absolute control recorded the minimum water use efficiency as compared to all other treatment combinations. This result might be due to higher volumes of water applied to absolute control.

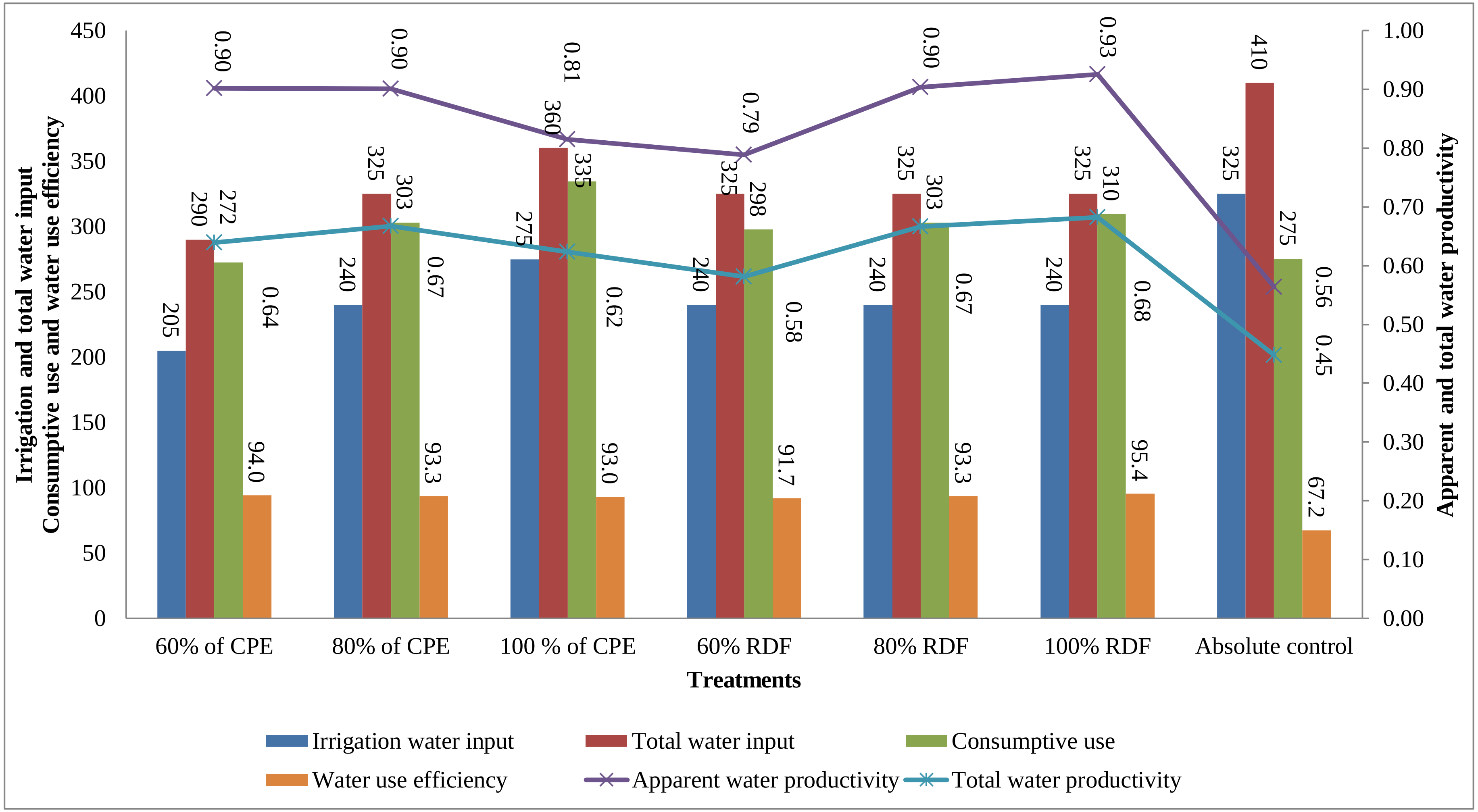


Fig 4.10 : **Effect of drip irrigation and fertigation schedules on irrigation water input (mm), total water input (mm), apparent and total water productivity (kg m⁻³), consumptive use (mm) and water use efficiency (%) of *gobhi sarson* (pooled mean of two year)**

4.7 N, P, K and S content in seed and stover

4.7.1 Nitrogen content in seed

The data pertaining to N content in seed of *gobhi sarson* under different drip irrigation and fertigation schedules during crop season 2016-17 and 2017-18 are presented in table 4.16.

Drip irrigation scheduling did not have any significant effect on N content for both the crop seasons. Fertigation at 100% RDF recorded maximum N content which was 7.7, 16.1 and 6.7, 14.8 per cent higher than both 80% RDF as well as 60% RDF during 2016-17 and 2017-18, respectively. Higher doses of nitrogen application may have resulted in more absorption and accumulation of N in the seed.

Interaction between drip irrigation and fertigation schedules was found to be non-significant, but interaction between treatment combinations and absolute control was significant. Drip irrigation and fertigation at 60% of CPE with 100% RDF, 80% of CPE with 80% RDF, 80% of CPE with 100% RDF, 100% of CPE with 80% RDF and 100% of CPE with 100% RDF were found to have significantly higher N content as compared to absolute control for both the crop seasons. Drip irrigation along with fertigation provided water soluble nutrients to the crop up to flowering stage, which might have resulted in greater nutrient uptake and their accumulation in the seeds as compare to absolute control in which N was applied once at the time sowing and the next with first irrigation.

4.7.2 Phosphorous content in seed

The data pertaining to the P content in seed of *gobhi sarson* under different drip irrigation and fertigation schedules during crop season 2016-17 and 2017-18 are presented in Table 4.16.

Drip irrigation scheduling did not have any significant effect on P content during both the crop seasons. Fertigation at 100% RDF was found to be statistically at par with 80% RDF but 7.9, 5.3 and 10.8, 5.4 per cent higher P content than 60% RDF during 2016-17 and 2017-18, respectively. These results might be due to the fact that nutrients at higher doses led to their greater accumulation in the seeds as compared to their lower doses.

Interaction between drip irrigation and fertigation schedules was found to be non-significant, but interaction between treatment combinations was found to be significantly higher than absolute control. For crop season 2016-17 treatment combinations at 80% of CPE with 80% RDF, 80% of CPE with 100% RDF, 100% of CPE with 80% RDF and 100% of CPE with 100% RDF recorded higher P content as compared to absolute control whereas, for crop season 2017-18 treatment combinations at 60% of CPE with 100% RDF, 80% of CPE with 80% RDF, 80% of CPE with 100% RDF, 100% of CPE with 80% RDF and 100% of

Table 4.16: Effect of drip irrigation and fertigation schedules on N, P, K and S content (%) in the seeds of *gobhi sarson* during *rabi* 2016-17 and 2017-18

Year	2016-17					2017-18				
Fertigation schedules (FS)	Irrigation schedules (IS)				Absolute control	Irrigation schedules (IS)				Absolute control
	60% of CPE	80% of CPE	100% of CPE	Mean		60% of CPE	80% of CPE	100% of CPE	Mean	
N content										
60% RDF	2.87	2.91	2.87	2.89	2.98	2.87	2.93	2.89	2.90	2.96
80% RDF	3.05	3.13	3.14	3.11		3.02	3.14	3.19	3.12	
100% RDF	3.32	3.34	3.38	3.35		3.38	3.35	3.26	3.33	
Mean	3.08	3.13	3.13			3.09	3.14	3.11		
LSD (p=0.05)	IS=NS FS= 0.06 ISxFS=NS ISxFS v/s absolute control= 0.08					IS=NS FS=0.10 ISxFS=NS ISxFS v/s absolute control= 0.12				
P content										
60% RDF	0.38	0.38	0.37	0.38	0.37	0.37	0.37	0.36	0.37	0.373
80% RDF	0.39	0.40	0.41	0.40		0.39	0.40	0.41	0.39	
100% RDF	0.39	0.43	0.41	0.41		0.40	0.41	0.41	0.41	
Mean	0.39	0.401	0.40			0.39	0.39	0.39		
LSD (p=0.05)	IS=NS FS= 0.02 ISxFS=NS ISxFS v/s absolute control= 0.02					IS=NS FS=0.02 ISxFS=NS ISxFS v/s absolute control= 0.02				
K content										
60% RDF	0.16	0.15	0.17	0.16	0.16	0.16	0.15	0.16	0.16	0.15
80% RDF	0.15	0.17	0.17	0.16		0.14	0.17	0.16	0.16	
100% RDF	0.15	0.16	0.17	0.16		0.16	0.16	0.17	0.16	
Mean	0.15	0.16	0.17			0.15	0.16	0.16		
LSD (p=0.05)	IS=NS FS= NS ISxFS=NS ISxFS v/s absolute control= NS					IS=NS FS=NS ISxFS=NS ISxFS v/s absolute control= NS				
S content										
60% RDF	0.45	0.46	0.46	0.46	0.43	0.46	0.46	0.46	0.46	0.44
80% RDF	0.46	0.47	0.46	0.46		0.47	0.46	0.46	0.46	
100% RDF	0.50	0.49	0.51	0.50		0.49	0.50	0.50	0.50	
Mean	0.47	0.47	0.47			0.47	0.47	0.47		
LSD (p=0.05)	IS=NS FS=0.01 ISxFS=NS ISxFS v/s absolute control= 0.01					IS=NS FS=0.01 ISxFS=NS ISxFS v/s absolute control= 0.01				

CPE with 100% RDF were found to have higher P content as compared to absolute control. Drip irrigation and fertigation provided nutrients up to later growth stages which could have resulted in their more absorption and accumulation in the seeds as compared to absolute control where P was applied only once at the time of sowing.

4.7.3 Potassium content in seed

The data pertaining to the K content in the seed of *gobhi sarson* under different drip irrigation and fertigation schedules for crop season 2016-17 and 2017-18 are presented in Table 4.16.

K content was found to be non-significant for both drip irrigation and fertigation schedules as well as in interaction between drip irrigation and fertigation schedules. Interaction between treatment combinations and absolute control were also non-significant because no K fertilizer was added to the soil.

4.7.4 Sulphur content in seed

The data pertaining to the S content in the seed of *gobhi sarson* in different drip irrigation and fertigation schedules during crop season 2016-17 and 2017-18 are presented in Table 4.16.

S content was found non-significant for irrigation schedules. Whereas, fertigation at 100% RDF was found significantly 8.7 per cent higher than both 80% RDF and 60% RDF during 2016-17 and 2017-18, respectively. Sulphur being required by the crop for oil production was found to be higher in seeds with higher doses of S application as compared to lower doses.

Interaction between drip irrigation and fertigation schedules was found to be non-significant, but interaction between treatment combinations and absolute control was significant. Absolute control recorded the minimum S content as compared to drip irrigation and fertigation treatments, this might be due to the fact that through fertigation S was made available to the crop up to flowering stage which might have resulted in its greater accumulation and utilization in the seeds as compared to absolute control in which S was applied in the form of SSP during sowing time.

4.7.5 Nitrogen content in stover

The data pertaining to N content in the stover of *gobhi sarson* during different drip irrigation and fertigation schedules for crop season 2016-17 and 2017-18 are presented in Table 4.17.

Nitrogen content was found to be non-significant for irrigation schedules. Fertigation at 100% RDF obtained maximum N content which was found to be 17.8, 70.8 and 31.2, 71.2 per cent higher than 80% RDF and 60% RDF during 2016-17 and 2017-18, respectively. Higher doses of N at higher fertigation levels might have resulted in its greater accumulation in the stover as compared to lower doses.

Table 4.17: Effect of drip irrigation and fertigation schedules on N, P, K and S content (%) in the stover of *gobhi sarson* during *rabi* 2016-17 and 2017-18

Year	**2016-17**					**2017-18**				
Fertigation schedules (FS)	**Irrigation schedules (IS)**				**Absolute control**	**Irrigation schedules (IS)**				**Absolute control**
	60% of CPE	**80% of CPE**	**100% of CPE**	**Mean**		**60% of CPE**	**80% of CPE**	**100% of CPE**	**Mean**	
N content										
60% RDF	0.57	0.65	0.65	0.62	0.66	0.58	0.60	0.60	0.59	0.61
80% RDF	0.86	0.88	0.96	0.90		0.73	0.74	0.88	0.77	
100% RDF	1.04	1.06	1.08	1.06		0.99	1.01	1.01	1.01	
Mean	0.82	0.86	0.90			0.77	0.78	0.83		
LSD (p=0.05)	IS=NS FS=0.1 ISxFS=NS ISxFS v/s absolute control= 0.12					IS=NS FS=0.08 ISxFS=NS ISxFS v/s absolute control= 0.10				
P content										
60% RDF	0.12	0.12	0.12	0.12	0.12	0.11	0.13	0.12	0.12	0.12
80% RDF	0.12	0.13	0.13	0.13		0.13	0.13	0.13	0.13	
100% RDF	0.13	0.14	0.14	0.13		0.13	0.13	0.13	0.13	
Mean	0.12	0.13	0.13			0.12	0.13	0.13		
LSD (p=0.05)	IS=NS FS= NS ISxFS=NS ISxFS v/s absolute control= NS					IS=NS FS=NS ISxFS=NS ISxFS v/s absolute control= NS				
K content										
60% RDF	1.86	1.90	1.85	1.87	1.60	1.83	1.83	1.81	1.82	1.88
80% RDF	1.86	1.91	1.92	1.90		1.88	1.91	1.93	1.91	
100% RDF	1.84	1.90	1.94	1.90		1.89	1.95	1.94	1.92	
Mean	1.85	1.90	1.90			1.87	1.90	1.89		
LSD (p=0.05)	IS=NS FS=NS ISxFS=NS ISxFS v/s absolute control= NS					IS=NS FS=NS ISxFS=NS ISxFS v/s absolute control= NS				
S content										
60% RDF	0.18	0.18	0.18	0.18	0.17	0.18	0.18	0.18	0.18	0.17
80% RDF	0.18	0.19	0.18	0.18		0.18	0.18	0.18	0.18	
100% RDF	0.18	0.19	0.19	0.19		0.18	0.18	0.19	0.19	
Mean	0.18	0.19	0.19			0.18	0.18	0.19		
LSD (p=0.05)	IS=NS FS=NS ISxFS=NS ISxFS v/s absolute control= NS					IS=NS FS= NS ISxFS=NS ISxFS v/s absolute control= NS				

Interaction between treatment combinations and absolute control was also found to be significant for N content for all the treatments except for 60% RDF with 60%, 80% and 100% of CPE for both the crop seasons. But interaction between drip irrigation and fertigation schedules were non-significant.

4.7.6 Phosphorous content in stover

The data pertaining to P content in the stover of *gobhi sarson* under different drip irrigation and fertigation schedules for crop season 2016-17 and 2017-18 are presented in Table 4.17.

P content was found to be non-significant for both drip irrigation and fertigation schedules as well as for interaction between drip irrigation and fertigation schedules and between treatment combinations and absolute control also, during both the crop seasons.

4.7.7 Potassium content in stover

The data pertaining to K content in the stover of *gobhi sarson* under different drip irrigation and fertigation schedules for crop season 2016-17 and 2017-18 are presented in Table 4.17.

K content was found to be non-significant for both drip irrigation and fertigation schedules as well as for interaction between drip irrigation and fertigation schedules and between treatment combinations and absolute control also, during both the crop seasons.

4.7.8 Sulphur content in stover

The data pertaining to S content in the stover of *gobhi sarson* under different drip irrigation and fertigation schedules for crop season 2016-17 and 2017-18 are presented in Table 4.17.

S content was found to be non-significant for both drip irrigation and fertigation schedules as well as for interaction between drip irrigation and fertigation schedules and between treatment combinations and absolute control also, during both the crop seasons.

4.8 Soil chemical properties

4.8.1 Soil pH

Pooled data of 2016-17 and 2017-18 pertaining to the pH of the experimental soil from 0-15 and 15-30 cm soil depth are presented in table 4.18.

The pH of the soil was found non-significant for both drip irrigation and fertigation schedules as well as for interaction between treatment combinations and absolute control. The pH of the soil was lower in 0-15 cm than in 15-30 cm. Interaction between drip irrigation and fertigation schedules were also found to be non-significant.

4.8.2 Electric Conductivity (EC)

Pooled data of 2016-17 and 2017-18 pertaining to the electric conductivity (dSm^{-1}) of the experimental soil from 0-15 and 15-30 cm soil depth presented in Table 4.18.

Table 4.18: Effect of drip irrigation and fertigation schedules on pooled pH, electric conductivity (dSm^{-1}) and organic carbon (%) of soil at harvest from 0-15 cm and 15-30 cm depth during crop season 2016-17 and 2017-18

Fertigation schedules (FS)	0-15 cm					15-30 cm				
	Irrigation schedules (IS)				Absolute control	Irrigation schedules (IS)				Absolute control
	60% of CPE	80% of CPE	100% of CPE	Mean		60% of CPE	80% of CPE	100% of CPE	Mean	
pH										
60% RDF	7.4	7.4	7.2	7.3	7.1	7.3	7.5	7.3	7.4	7.0
80% RDF	7.1	7.3	7.1	7.1		7.1	7.3	7.1	7.2	
100% RDF	7.2	7.2	7.4	7.2		7.4	7.4	7.3	7.4	
Mean	7.2	7.2	7.2			7.3	7.4	7.2		
Initial	7.3					7.4				
LSD (p=0.05)	IS=NS FS=NS ISxFS=NS ISxFS v/s absolute control= NS					IS=NS FS= NS ISxFS=NS ISxFS v/s absolute control= NS				
Electric conductivity										
60% RDF	0.42	0.45	0.45	0.44	0.41	0.24	0.23	0.25	0.24	0.23
80% RDF	0.44	0.43	0.45	0.44		0.25	0.24	0.23	0.24	
100% RDF	0.44	0.42	0.44	0.43		0.25	0.26	0.24	0.25	
Mean	0.43	0.43	0.45			0.25	0.24	0.24		
Initial	0.45					0.25				
LSD (p=0.05)	IS=NS FS=NS ISxFS=NS ISxFS v/s absolute control= NS					IS=NS FS= NS ISxFS=NS ISxFS v/s absolute control= NS				
Organic carbon										
60% RDF	0.34	0.35	0.33	0.34	0.34	0.22	0.25	0.24	0.24	0.23
80% RDF	0.32	0.34	0.33	0.33		0.22	0.25	0.22	0.23	
100% RDF	0.36	0.34	0.36	0.35		0.24	0.22	0.24	0.24	
Mean	0.34	0.34	0.34			0.23	0.24	0.23		
Initial	0.34					0.24				
LSD (p=0.05)	IS=NS FS=NS ISxFS=NS ISxFS v/s absolute control= NS					IS=NS FS= NS ISxFS=NS ISxFS v/s absolute control= NS				

EC of the soil was found non-significant for both drip irrigation and fertigation schedules as well as in interaction between treatment combinations and absolute control during both the crop seasons. However, EC of soil depth 0-15 was noticed more than 15-30 cm larger and there was decrease in the EC of the soil at harvest from 0-15 cm depth as compared to the initial EC. Interaction between drip irrigation and fertigation schedules was also found non-significant.

4.8.3 Organic Carbon (OC)

Pooled data of 2016-17 and 2017-18 pertaining to the organic carbon content (%) of the experimental soil from 0-15 and 15-30 cm soil depth are presented in Table 4.18.

There was no effect of drip irrigation and fertigation scheduling on the OC content of the soil. Interaction between treatment combinations and absolute control was also found non-significant. Similarly, interaction between drip irrigation and fertigation schedules was also non-significant. However, there was not much difference in the initial and final OC content from both the soil depths but OC from 0-15 cm was higher than 15-30 cm soil layer.

4.8.4 Available nitrogen

The pooled data of 2016-17 and 2017-18 pertaining to available N in the soil from 0-15 and 15-30 cm soil depth are presented in Table 4.19.

The data was pooled as not much difference was observed in the values of available N during both the years. N content of the soil was non-significant for both drip irrigation and fertigation schedules. Interaction between drip irrigation and fertigation schedules was non-significant. Similarly, interaction between treatment combinations and absolute control was also found to be non-significant. However, there was decrease in N content from initial to final due to crop uptake. 0-15 cm soil depth recorded more available N content than 15-30cm.

4.8.5 Available phosphorus

The pooled data of 2016-17 and 2017-18 pertaining to available P in the soil from 0-15 and 15-30 cm soil depth are presented in Table 4.19.

The data was pooled as not much difference was observed in the values of available P during both the years. P content of the soil was non-significant for both drip irrigation and fertigation schedules. Interaction between drip irrigation and fertigation schedules was non-significant. Similarly, interaction between treatment combinations and absolute control was also found to be non-significant. However, there was decrease in P content from initial to final due to crop uptake.

4.8.6 Available potassium

The pooled data of 2016-17 and 2017-18 pertaining to available potassium in the soil from 0-15 and 15-30 cm soil depth are presented in Table 4.19.

Table 4.19: Effect of drip irrigation and fertigation schedules on pooled available soil N, P, K and S (kg ha^{-1}) at harvest from 0-15 and 15-30 cm soil depth during crop season 2016-17 and 2017-18

Year	0-15					15-30				
Fertigation schedules (FS)	Irrigation schedules (IS)				Absolute control	Irrigation schedules (IS)				Absolute control
	60% of CPE	80% of CPE	100% of CPE	Mean		60% of CPE	80% of CPE	100% of CPE	Mean	
Available N										
60% RDF	162.0	168.7	167.0	165.9	161.3	158.5	160.4	161.6	160.2	159
80% RDF	166.0	171.2	172.8	170.0		160.3	162.8	163.5	162.2	
100% RDF	167.7	174.0	173.5	171.7		162.4	161.2	163.7	162.4	
Mean	165.2	171.3	171.1			160.4	161.5	162.9		
Initial	182.5					164				
LSD (p=0.05)	IS=NS FS=NS ISxFS=NS ISxFS v/s absolute control= NS					IS=NS FS= NS ISxFS=NS ISxFS v/s absolute control= NS				
Available P										
60% RDF	19.2	19.3	19.2	19.3	19.3	17.6	16.5	17.0	17.0	17.0
80% RDF	19.3	20.3	20.4	20.0		17.2	16.6	16.5	16.8	
100% RDF	19.9	20.3	20.8	20.4		16.3	18.6	17.2	17.4	
Mean	19.5	20.0	20.1			17.0	17.2	16.9		
Initial	21.6					18.4				
LSD (p=0.05)	IS=NS FS=NS ISxFS=NS ISxFS v/s absolute control= NS					IS=NS FS= NS ISxFS=NS ISxFS v/s absolute control= NS				
Available K										
60% RDF	297.3	294.0	295.5	295.6	292.7	315.4	320.4	313.4	316.4	310.1
80% RDF	295.0	294.7	294.8	294.8		310.9	308.9	321.3	313.6	
100% RDF	295.3	292.5	295.8	294.6		315.9	312	315.8	314.6	
Mean	295.9	293.7	295.4			314.1	313.8	316.8		
Initial	330.5					320.2				
LSD (p=0.05)	IS=NS FS=NS ISxFS=NS ISxFS v/s absolute control= NS					IS=NS FS= NS ISxFS=NS ISxFS v/s absolute control= NS				
Available S										
60% RDF	19.9	20.3	20.7	20.3	19.7	18.7	18.4	18.8	18.6	18.5
80% RDF	20.2	21.0	21.1	20.8		18.5	19.0	18.4	18.6	
100% RDF	20.8	21.1	21.0	21.0		18.2	19.0	18.0	18.4	
Mean	20.3	20.8	20.9			18.5	18.8	18.4		
Initial	21.3					19.1				
LSD (p=0.05)	IS=NS FS=NS ISxFS=NS ISxFS v/s absolute control= NS					IS=NS FS= NS ISxFS=NS ISxFS v/s absolute control= NS				

The data was pooled as not much difference was observed in the values of available K during both years. The available K content in the soil recorded no significant effect for both drip irrigation and fertigation schedules. Interaction between drip irrigation and fertigation schedules was non-significant. Similarly, interaction between treatment combinations and absolute control was also found to be non-significant. However, there was decrease in K content from initial to final stage due to crop uptake.

4.8.7 Available sulphur

The pooled data of 2016-17 and 2017-18 pertaining to available potassium in the soil from 0-15 and 15-30 cm soil depth are presented in table 4.19.

The data was pooled as not much difference was observed in values of available S during both years. The available Sulphur content in the soil recorded no significant effect for both drip irrigation and fertigation schedules. Interaction between drip irrigation and fertigation schedules was also non-significant. Similarly, interaction between treatment combinations and absolute control was also found to be non-significant. However, there was decrease in Sulphur content from initial to final due to crop uptake.

CHAPTER –V

SUMMARY

In India, rapeseed and mustard oil is one of the major source of vegetable oil and the third major source after soybean and oil palm among different oilseed crops in the world (FAOSTAT 2017). It constitutes a group of crops comprising of Indian mustard (*Brassica juncea*), Ethiopian mustard (*Brassica carinata*), Indian rape (*Brassica rapa* var. *toria*), oilseed rape (*Brassica napus*), yellow sarson (*Brassica rapa* var. *yellow sarson*), brown sarson (*Brassica rapa* var. *brown sarson*), black mustard (*Brassica nigra*) and taramira (*Eruca sativa*).

Among these crops, oilseed rape (*Brassica napus* L.) also referred as *gobhi sarson*, has become popular oilseed crop in Punjab and other northern states of India mainly due to its higher yield potential and compatibility with the growing conditions. Although rice-wheat cropping system is predominant in these regions, but due to immense use of inputs in the form of irrigation water, fertilizers and agro-chemicals resulted in increased cost of cultivation, degradation of natural resources and monoculture limitations, *gobhi sarson* offers a promising alternate for diversification of cereal based cropping system. Newly released *gobhi sarson* varieties viz GSC 6, GSC 7 and Hyola PAC 401 come under high yielding canola type. Canola is an improved version of rapeseed and mustard with enhancement in the fatty acid composition especially and most importantly reduction in the erucic acid content in the oil and marked reduction in glucosinolate level in the cake meal. Erucic acid is the same chemical responsible for pungency in rapeseed oil and higher content of glucosinolate in cake meal can cause health hazards in animals. The oil (42%) and protein (21%) content of these canola varieties are also high (DeClereq and Daun 1999). Moreover, canola has the lowest saturated fat content of any vegetable oil (Ahmad *et al* 2006).

Canola *gobhi sarson* responds greatly to management practices, especially irrigation and fertilizer application. Efficient irrigation method for *gobhi sarson* not only results in higher yield but also saves considerable amount of irrigation water. Drip irrigation is one of the most important and efficient irrigation method. Irrigation water and fertilizers applied through drip system provides precise and site-specific moisture and nutrients to the root zone of the crop. Moreover, irrigation through drip system eliminates run off, deep percolation, evaporation and minimize weed growth apart from providing nutrients at the same time. Water saving upto 12-84 per cent for different crops has been achieved under drip irrigation system (Ramah 2008). Moreover, up to 50 per cent irrigation water can be saved through micro-irrigation system (Rathod *et al* 2014b). Also, by use of this system there was significant increase in productivity of 20–30 per cent as well as reduction.in water consumption by 30–70 per cent than surface method for different crops (Thind *et al* 2008).

Therefore, the present study titled **"Water productivity, economics and energetics of *gobhi sarson* (*Brassica napus* L.) as influenced by drip irrigation and fertigation schedules"** was conducted with the objectives of

(1) To study the effect of drip irrigation and fertigation schedules on growth and productivity of *gobhi sarson* (*Brassica napus* L.).

(2) To compute water productivity, economics and energetics of *gobhi sarson* (*Brassica napus* L.) under different drip irrigation and fertigation schedules.

At Student's Research Farm, Department of Agronomy, PAU, Ludhiana, a field experiment was conducted for the crop season 2016-17 and 2017-18. The experimental design used was randomized complete block design (RCBD) comprising of 9 combinations of drip irrigation (60 % of CPE, 80 % of CPE and 100 % of CPE) and fertigation schedules (60% RDF, 80% RDF and 100% RDF) along with one absolute control (flood irrigation and recommended dose of nutrients was applied manually). Total eleven irrigations were applied at a fixed interval of 6 days starting from a month after sowing and volume of irrigation water applied was kept equal to the cumulative pan evaporation (CPE) depending upon the treatment levels. A total of three irrigations excluding one pre-sowing irrigation was applied to absolute control plots keeping depth at 75 mm for each irrigation. Basal dose of fertilizers for absolute control constituted phosphorous and sulphur in the form of SSP (16% P_2O_5 and 12% S) and half dose of nitrogen was applied as urea (46% N) at sowing time. The remaining dose of nitrogen was top dressed with first irrigation. For drip irrigated plots, fertilizer was applied in water soluble form in ten splits through urea, mono-ammonium phosphate (12-61-0) and elemental sulphur. The fertigation schedules were started from 15 days after sowing and applied at a fixed interval of 6 days and completed in 60 days.

Irrigation scheduling significantly affected the growth parameters, yield attributing characters, oil and seed yield of the crop. For all the growth parameters such as dry matter accumulation, plant height and leaf area index, drip irrigation at 100% of CPE was statistically at par with 80% of CPE but significantly higher than 60% of CPE. Similar trend was also observed for yield attributing characters such as number of secondary branches per plant, number of siliquae per plant, seeds per siliqua and also for oil and seed yield during both the crop seasons. Irrigation scheduling at 80% of CPE recorded the maximum total water productivity (TWP) and apparent water productivity (AWP) which was statistically at par with 60% of CPE but significantly higher than 100% of CPE. However, water use efficiency (WUE) observed was highest at 60% of CPE followed by 80% of CPE and 100% of CPE. Energy use efficiency (EUE) obtained was maximum at 100% of CPE followed by 80% of CPE and 60% of CPE. But energy productivity at 100% of CPE and 80% of CPE was observed to be statistically at par with each other. The highest B:C ratio and net returns were obtained with irrigation scheduling at 100% of CPE and minimum with 60% of CPE during both the crop seasons.

Fertigation scheduling at 100% RDF and 80% RDF was at par with each other but the former was significantly higher than 60% RDF for all the growth parameters as well as yield and yield attributes. Fertigation at 100% RDF recorded maximum AWP and TWP which was statistically at par with 80% RDF. Maximum EUE was obtained at 60% RDF followed by 80% RDF and 100% RDF. Energy productivity with 60% RDF and 80% RDF were statistically at par but 60% RDF was significantly higher than 100% RDF. Highest B:C ratio was recorded at 80 % RDF and lowest at 60% RDF.

Non-significant interaction was found among drip irrigation and fertigation schedules. Whereas, interaction between treatment combinations and absolute control was significant. Seed yield and oil yield of treatment combination 80% of CPE with 80% RDF, 100% of CPE with 80% RDF, 80% of CPE with 100% RDF and 100% of CPE with 100% RDF were significantly higher than absolute control. Minimum AWP, TWP, WUE, EUE and energy productivity were obtained in absolute control as compared to all the treatment combinations.

Conclusions

- Seed yield of *gobhi sarson* increased by 15.5 and 19.0 per cent when irrigation schedule was increased from 60% of CPE to 80% of CPE but marginal increase of 3.5 and 3.4 per cent was observed with further increasing the irrigation schedule to 100% of CPE during 2016-17 and 2017-18, respectively.
- Increase in irrigation schedule from 60% of CPE to 80% of CPE increased the oil yield by 13.0 and 17.5 per cent, whereas further increase to 100% of CPE marginally increased the oil yield by 2.7 and 2.4 per during 2016-17 and 2017-18, respectively.
- Among fertigation schedules, increasing the dose from 60% RDF to 80% RDF increased the seed yield up to 24.6 and 14.9 per cent but further increase from 80% RDF to 100% RDF increased seed yield marginally to 3.0 and 2.1 per cent during 2016-17 and 2017-18, respectively.
- Oil yield recorded at 100% RDF and 80% RDF were statistically at par with each other but significantly higher than 60% RDF.
- Drip irrigation at 100% of CPE recorded higher net returns followed by 80% of CPE. Maximum energy productivity was obtained at 100% of CPE which was statistically at par with 80% of CPE, while 80% of CPE resulted in highest water productivity
- Fertigation at 80% RDF recorded higher B:C followed by 100% of RDF. Whereas, 60% RDF resulted in maximum energy productivity which was statistically at par with 80% RDF.

- Drip irrigating at 100% of CPE or 80% of CPE with 100% RDF or 80% RDF recorded significant higher seed and oil yield, energy productivity, apparent water productivity and net returns as compared to absolute control.
- *Gobhi sarson* should be irrigated through drip irrigation at 80% of CPE and fertigation at 80% RDF to obtain high yield, water and energy productivity with saving 13.6 per cent irrigation water and 20 per cent fertilizer as compared to 100% of CPE and 100% RDF respectively.

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APPENDIX I

Weekly mean meteorological data recorded during the crop season (2016-17) at Meteorological Observatory, Department of Climate Change and Agricultural Meteorology, PAU Ludhiana

Standard Meteorological Week (SMW)		Temperature (°C)			Relative Humidity (%)			Rainfall (mm) per week	No. of Rainy Days	Total Evapo-ration (mm) per week	Sun-shine (hrs)
No.	Dates	Maximum	Minimum	Mean	Morning	Evening	Mean				
45	Nov 5-11	28.7	12.3	20.5	92	29	61	0	0	16.6	4.3
46	Nov 12-18	26.7	11.9	19.3	92	29	61	2	0	19	7.3
47	Nov 19-25	27.6	11.6	19.6	87	31	59	0	0	16.9	6.8
48	Nov 26-Dec2	26.5	10.1	18.3	88	35	61	0	0	15.9	6
49	Dec 3-9	24.5	9.5	17	95	48	71	0	0	6.6	4.2
50	Dec 10-16	20	10.1	15	97	63	80	0	0	7.9	2.8
51	Dec 17-23	22.5	6.6	14.6	95	41	68	0	0	9.5	7.1
52	Dec 24-31	21.1	7.9	14.5	93	48	71	0	0	11.9	5.1
1	Jan 1-7	20.9	9.7	15.2	95	57	76	4	1	9.2	3.3
2	Jan 8-14	16.3	3.5	9.9	95	43	69	0	0	10.2	6.5
3	Jan 15-21	16	6.2	11.1	94	64	79	1.6	0	8.2	4.5
4	Jan 22-28	19.5	10.3	14.9	93	64	78	40.1	2	10.1	3.6
5	Jan 29-Feb 4	19.8	8.7	14.3	96	64	80	5.2	1	8.2	4.5
6	Feb 5-11	20.7	8.2	14.4	92	53	73	0	0	13	6
7	Feb 12-18	24.3	9.7	17	90	44	67	0	0	19.4	8.1
8	Feb 19-25	24.8	10.6	17.7	89	39	64	0	0	18.8	8.8
9	Feb 26- March 4	25.5	9.5	17.5	90	34	63	0	0	22.2	9.6
10	March 5-11	20.9	10.5	15.7	86	46	66	40.8	2	13.8	7.3
11	March12-18	23.2	8.9	16	88	42	65	0	0	20.8	8.3
12	March 19-25	30.4	14.8	22.6	84	33	59	0	0	31	9.8
13	March 26- April 1	34.9	18.5	26.7	85	31	58	0	0	41.5	10.9
14	April 2-8	32.9	19.3	26.1	66	29	47	6.2	1	46.7	7.1

APPENDIX II

Weekly mean meteorological data recorded during the crop season (2017-18) at Meteorological Observatory, Department of Climate Change and Agricultural Meteorology, PAU Ludhiana

Standard Meteorological Week (SMW)		Temperature (^oC)			Relative Humidity (%)			Rainfall (mm) per week	No. of Rainy Days	Total Evapo-ration (mm) per week	Sun-shine (hrs)
No.	**Dates**	**Maximum**	**Minimum**	**Mean**	**Morning**	**Evening**	**mean**				
43	Oct 22-28	31.3	16.2	23.8	87	36	61	0	0	20.6	4.8
44	Oct29-Nov 4	28	15.3	21.7	91	53	72	0	0	13	0
45	Nov 5-11	26.1	14.1	20.1	96	57	77	0	0	7.6	1.7
46	Nov12-18	22.3	12.9	17.6	90	60	75	7	1	7.6	1.3
47	Nov 19-25	23.9	7.4	15.6	94	29	61	0	0	16.2	7.9
48	Nov 26-Dec2	25.4	7.9	16.6	94	31	62	0	0	14	7.4
49	Dec 3-9	22.7	7.3	15	87	30	58	0	0	14	6.2
50	Dec 10-16	17.1	9.3	13.2	90	70	80	24	1	10.2	3.4
51	Dec 17-23	21.9	7.4	14.6	91	47	69	0	0	9	7.9
52	Dec 24-31	20.7	6.3	13.5	96	49	73	0	0	13.8	4.9
1	Jan 1-7	15.9	5.4	10.6	96	66	81	0	0	6.2	2.6
2	Jan 8-14	20.8	5.3	13	94.4	42.7	68.6	0	0	11.6	7.6
3	Jan 15-21	22	6.1	14.1	92	40.1	66.1	0	0	14	7.7
4	Jan 22-28	15.5	7.6	11.5	93.4	75.6	84.5	18.4	1	9.6	3.6
5	Jan 29-Feb 4	21.2	7.6	14.4	91.4	45.6	68.5	0	0	13.6	8.1
6	Feb 5-11	21.1	5.6	13.4	89	37.6	63.3	2.4	0	15	8
7	Feb 12-18	21.1	9.3	15.2	89	53	71	21.4	1	15.8	7.4
8	Feb 19-25	25.5	11.7	18.6	87.6	48	67.8	3.2	0	17.4	7.5
9	Feb 26- March 4	25.8	13.1	19.4	88.7	50.9	69.8	0	0	17.9	6.5
10	March 5-11	27.3	12.2	19.7	87.9	41.7	64.8	0	0	24.4	10.4
11	March12-18	29.9	14.1	22	85	29.6	57.3	0	0	29.8	10
12	March 19-25	29.2	14.2	21.7	85.9	43.9	64.9	0	0	27.8	7.8

APPENDIX III

Energy equivalents of different inputs and agronomic practices

Energy source	Energy units	Energy equivalent MJ)
Human	Hrs	1.96
Machinery	Hrs	
a. Tractor	Hrs	64.80
b. Farm machinery	Hrs	62.70
Diesel (including cost of lubrication)	L	56.31
Petrol (including cost of lubrication)	L	48.23
Fertilizers	kg	
a. N	kg	60.6
b. P_2O_5	kg	11.1
c. K_2O	kg	6.7
Herbicides	kg	238
Insecticides	kg	199.0
Fungicides	kg	92.0
Oil seeds	kg	25.0
Irrigation water	m^3	0.63

Source: Brar *et al* (2015)

APPENDIX IV

Volume of irrigation applied per plot and per hectare (litres) to *gobhi sarson* under different drip and flood irrigation schedules during *rabi* 2016-17 and 2017-18

Number of irrigations	2016-17								2017-18							
	Drip irrigation (liters)						Flood irrigation (liters)		Drip irrigation (liters)						Flood irrigation (liters)	
	Per 12.09 m^2*			Per ha (x 10^3)			Per 12.09 m^2*	Per ha (x10^3)	Per Per 12.09 m^2*			Per ha (x 10^3)			Per Per 12.09 m^2*	Per ha (x 10^3)
	100% of CPE	80% of CPE	60% of CPE	100% of CPE	80% of CPE	60% of CPE			100% of CPE	80% of CPE	60% of CPE	100% of CPE	80% of CPE	60% of CPE		
1	800	640	480	658	526.4	394.8	907	750	634	507	380	524	419.2	314.4	907	750
2	73	59	44	60	48	36	907	750	170	136	102	140	112	84	907	750
3	102	82	61	84	67.2	50.4	907	750	170	136	102	140	112	84	907	750
4	140	112	84	116	92.8	69.6			120	96	72	100	80	60		
5	70	56	42	57	45.6	34.2			75	60	45	62	49.6	37.2		
6	110	88	66	92	73.6	55.2			150	120	90	126	100.8	75.6		
7	78	62	49	64	51.2	38.4			170	136	102	140	112	84		
8	100	80	60	82	65.6	49.2			45	36	27	38	30.4	22.8		
9	100	80	60	83	66.4	49.8			85	68	51	70	56	42		
10	245	196	147	202	161.6	121.2			175	140	105	144	115.2	86.4		
11	304	243	182	251	200.8	150.6			205	164	123	169	135.2	101.4		
Total	2122	1698	1273	1749	1399.2	1049.4	2721	2250	1999	1599	1199	1653	1322.4	991.8	2721	2250

***wettable area per plot**

VITA

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Year of award	**:**	2019
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Title of Master's Thesis	**:**	Water productivity, economics and energetics of *gobhi sarson* (*Brassica napus* L.) as influenced by drip irrigation and fertigation schedules.
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