

**EFFECT OF IRRIGATION LEVELS ON
PRODUCTIVITY OF OILSEED *BRASSICA* SPECIES
UNDER NATURAL AND CONVENTIONAL FARMING**

THESIS

By

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(A-2019-30-010)**

Submitted to



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CERTIFICATE – I

This is to certify that the thesis entitled, “**Effect of irrigation levels on productivity of oilseed *Brassica* species under natural and conventional farming**” submitted in partial fulfilment of the requirements for the award of the degree of **Master of Science (Agriculture)** in the discipline of **Agronomy** of CSK Himachal Pradesh Krishi Vishvavidyalaya, Palampur is a bonafide research work carried out by **Alisha Thakur (A-2019-30-010)** daughter of **Smt. Damyanti Thakur & Sh. Satya Prakash**, under my supervision and that no part of this thesis has been submitted for any other degree or diploma.

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

Place : Palampur
Dated : ,2021

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CERTIFICATE- II

This is to certify that the thesis entitled, “**Effect of irrigation levels on productivity of oilseed *Brassica* species under natural and conventional farming**” submitted by **Alisha Thakur (A-2019-30-010)**, daughter of **Sh. Satya Prakash** to the CSK Himachal Pradesh Krishi Vishvavidyalaya, Palampur in partial fulfilment of the requirements for the degree of **Master of Science (Agriculture)** in the discipline of **Agronomy** has been approved by the Advisory Committee after an oral examination of the student in collaboration with an External Examiner.

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LIST OF ABBREVIATIONS USED

Abbreviation	Meaning
B:C	Benefit Cost Ratio
OC	Organic Carbon
MOP	Muriate of Potash
SSP	Single Super Phosphate
kg ha ⁻¹	kg per hectare
DAS	Days after sowing
HI	Harvest Index
C _u	Consumptive Use
IWUE	Irrigation water use efficiency
N	Nitrogen
P	Phosphorus
K	Potassium
t ha ⁻¹	tonne per hectare
cm	Centimetre
i.e.	<i>id est</i> (that is)
Fig.	Figure
ha	Hectare
g	Gram
<i>et al.</i>	Et alia (and others)
m ⁻²	per square metre
<i>viz.</i>	Namely
°C	degree Celsius

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Abstract

A field experiment was conducted at the Water Management Farm of CSK Himachal Pradesh Krishi Vishvavidyalaya, Palampur during *rabi* 2020-21 to study the effect of irrigation levels on the productivity of oilseed *Brassica* species under natural and conventional farming. The treatments comprised of two irrigation levels viz. I₁ (irrigation 30 DAS and at flowering) and I₂ (pre-sowing, 30 DAS and at flowering) in main plot and combination of three *Brassica* species (*Brassica oleracea* var brown sarson 'KBS 3', *Brassica juncea* 'RCC 4' and *Brassica napus* 'GSC 7' and two management system (conventional and natural farming) in sub plot laid out in split plot design with three replications. The soil of the experimental site was silty clay loam in texture having pH 5.3, medium in available nitrogen, high in phosphorus and medium in potassium. An irrigation of 5 cm depth was applied through pipes. Application of two irrigations being statistically at par with three irrigations for growth, yield attributes and being early in maturity for *Brassica oleracea* var 'KBS 3' gave higher yield among *Brassica* species evaluated and management system used. N, P, K uptake was higher when three irrigations were applied, conventional practice was adopted and *Brassica oleracea* brown sarson 'KBS 3' was grown. The water productivity and irrigation water use efficiency was higher when two irrigations were applied, *Brassica oleracea* 'KBS 3' among different *Brassica* species was raised under conventional farming system. The net returns and B:C in same variety under same management system remained statistically at par whether two irrigation or three irrigations were applied.

Thus, for higher crop and water productivity and economic returns, *Brassica oleracea* 'KBS 3' should be grown under conventional system with recommended fertilizers and irrigated at 30 days after sowing and flowering stage.

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1. INTRODUCTION

Rapeseed mustard group of crops comprises of rapeseed cultivars of *Brassica campestris* (toria, brown sarson, yellow sarson), *Brassica juncea* (Indian mustard), *Brassica nigra* (Black mustard), taramira and an exotically introduced *Brassica napus* (gobhi sarson) and *Brassica carinata* (Ethopian rai). Rapeseed mustard is third most important oilseed crop in world after soybean and palm. The mustard seeds are rich in phytonutrients, minerals, vitamins and antioxidants. It is an excellent source of vitamin B- complex, vitamin A, C and K.

In world, it occupies an area of 36.59 m ha with 72.37 million tonnes production and productivity of 1980 kg ha⁻¹ (AICRP DRMR 2019-20). India is the second largest rapeseed mustard growing country after China and accounts for 19.8 per cent and 9.8 per cent of the total acreage and production (AICRP DRMR 2019-20). Among seven edible oilseeds cultivated in India, rapeseed-mustard contributes 28.6 per cent of total oilseeds. In India, rapeseed mustard occupies an area of 6.23 million ha with 9.34 million tonne production and productivity of 1499 kg ha⁻¹ (AICRP 2019-2020). There is a significant yield gap between European countries and India. Growing long duration *Brassica* species in fertile soil under irrigated condition are major yield contributing factors in these countries. In contrast to them the rapeseed mustard crop in India is mostly a rainfed crop of marginal lands except in few states like UP, Rajasthan and MP where these crops are grown under irrigated conditions with recommended package of practices.

The domestic demand for vegetable oil is increasing at the rate of 6 per cent on account of enhanced per capita consumption (19 kg per annum) whereas the output is increasing at 2 per cent per annum only. Of the 20 million tonne consumption of edible oil, India imports 60 per cent of this demand and this is likely to increase with increasing income and population. The production and productivity of rapeseed mustard grew at 1.8 per cent and 1.84 per cent, respectively during 2008-09 to 2018-19 while the area decreased by 0.3 per cent (NMOOP 2018). India accounts for 15-20 per cent global oilseeds area, 6-7 per cent vegetable oil production and 9-10 per cent

of oil consumption (NMOOP 2018). The key factors for growth of oilseed production and yield are irrigation, quality seeds and efficient management through technological interventions. Only less than 30 per cent area under oilseed crops is irrigated and the availability of water in agriculture is decreasing because of competition from other sectors. The problem is more severe with respect to *rabi* season where the rainfall is less.

Agriculture sector which at present uses 70-80 per cent of available water is facing a challenge from sectors like domestic use and industries. With increasing population and decreasing water availability the food security initiative necessitates the improvement in crop water productivity. The sustainability in production can be achieved with better agronomic and efficient water management practices. The *rabi* crop production has various limitations regarding water availability. The low and erratic rainfall of *rabi* in state poses problem at initial stage for sowing and later at reproductive phase where lesser water coupled with high temperature reduces the productivity to a great extent. Thus, the limited water which could be available as conserved or stored water has to be used efficiently by effective irrigation scheduling or application at critical stages only.

As rapeseed mustard is primarily cultivated in temperate regions with varying climatic and edaphic conditions, a careful selection of varieties that suits the condition is vital for achieving desired productivity and enhancing resource utilization. A variety that can adapt to various weather vagaries, having efficient root system to explore soil for water and nutrient, complete the phenological stages with least stress and is disease and pest resistant need to be evaluated and adopted. In addition, a genotype with impressive vegetative structure i.e. taller in height and a higher number of primary branches associated with modest test weight, deep green leaves with high chlorophyll content and a lower range of proline content, would be ideal (Kumar and Srivastava 2003). The different species within a genus differ in their water use efficiency by virtue of different morphological and metabolic changes in response to the stress. The agronomic management practices like date of planting, varietal selection and nutrient management help in attaining the optimum productivity. A well fertilized crop by canopy expansion and root development increases the water use efficiency by reducing evaporation and expansion of water exploration zone.

Wheat is the major *rabi* crop of the state, productivity of which fluctuates with climate variables especially rainfall and temperature. Wheat crop requires 4-5 irrigation along with other management practices for giving optimum yield. However, in *rabi*, the state receives very less rainfall and generally the sowing is delayed except when it was able to utilize residual moisture of monsoon rains is practiced. In recent years the terminal heat stress has become a very big hurdle in achieving the wheat productivity target. Hence, we should look for the crop that can be profitably cultivated with the little water resources available. Compared to wheat, oilseed *Brassica* crop with its less water requirement of 240-400 mm has higher water use efficiency by virtue of well developed extensive root system (Shekhawat et al. 2012) and fits well in rainfed cropping system. However some of its phenological stages are very sensitive for water stress and may determine the crop productivity. Further, nutrient uptake is a function of water availability more specifically to critical stages where the requirement of crop is more. This can be alternative to wheat in some areas only if its productivity is increased by improved management practices.

Under limited water availability, deficit/limited irrigation has been used to improve water use efficiency without reducing the crop yield. But the application of this concept relies on sound knowledge of sensitive growth stages of water stress. Different *Brassica* species by virtue of their different morphological and phenological character may respond differently to various supplement irrigation regimes. In addition under different farming practices where nutrient and amendments use varies, the response of species under varying irrigation schedule can differ with respect to crop and water productivity. Information on response of different oilseed *Brassica* species to varying irrigation levels under different farming practices is limited. Hence this present investigation entitled “Effect of irrigation levels on productivity of oilseed *Brassica* species under natural and conventional farming” was carried out at Irrigation and Water Management Farm of CSKHPKV, Palampur with the following objectives:

- To evaluate the crop and water productivity of oilseed *Brassica* species under different irrigation levels and farming practices, and
- to workout the economic viability of the treatments.

2. REVIEW OF LITERATURE

An attempt has been made in this chapter to review the literature pertaining to the present investigation entitled 'Effect of irrigation levels on productivity of oilseed *Brassica* species under natural and conventional farming'. The relevant literature has been reviewed under the following heads:

2.1 Effect of irrigation levels on growth characters, yield attributes, yield, water use efficiency, oil content and nutrient uptake

2.1.1 Effect of irrigation level on growth characters

2.1.2 Effect of irrigation levels on yield attributes and yield

2.1.3 Effect of irrigation levels on water use efficiency

2.1.4 Effect of irrigation levels on oil content and nutrient uptake

2.1.5 Effect of irrigation levels on economics

2.2 Effect of nutrient management on growth characters, yield attributes, yield, water use efficiency, oil content, nutrient uptake and economics

2.2.1 Effect of nutrient management on growth characters

2.2.2 Effect of nutrient management on yield attributes and yield

2.2.3 Effect of nutrient management on water use efficiencies

2.2.4 Effect of nutrient management on oil content and protein content

2.2.5 Effect of nutrient management on nutrient uptake

2.2.6 Effect of nutrient management on soil studies

2.2.7 Effect of nutrient management on economics

2.3 Effect of natural farming on growth characters, yield attributes, yield, water use efficiency, oil content and nutrient uptake

2.1 Effect of irrigation levels on growth characters, yield attributes, yield, water use efficiency, oil content and nutrient uptake

2.1.1 Effect of irrigation regimes on growth characters

Raut et al. (2001) found that irrigation given at pre-flowering, 50 per cent flowering, flowering and seed filling stages resulted in higher dry matter yield at 90 DAS and harvest in mustard over no irrigation.

Singh et al. (2002) conducted a field experiment on *Brassica juncea* at Bharatpur. They reported that two irrigations at 30 DAS and 60 DAS increased growth characters and seed yield of Indian mustard significantly than one or no irrigation whereas, Rana et al. (2007) reported that irrigation given to rapeseed at 45 days after sowing resulted in an increase in plant height and dry matter accumulation.

Meena and Sumeriya (2003) in a study on *Brassica juncea*, observed highest number of secondary branches per plant (7.0) under two irrigation levels. Similarly, Nagdive et al. (2007) from Akola Maharashtra recorded an increase in plant height, number of branches, leaf area index, dry matter per plant and 1000-seed weight on applying irrigation at branching, flowering and siliquae development stages in *Brassica juncea* over no irrigation.

Sarkar and Pal (2004) recorded that increased irrigation levels resulted in superior plant height, dry matter accumulation, crop growth rate and the number of branches per plant in rapeseed.

Tahir et al. (2007) observed that under limited water situation in Pakistan the higher crop growth rate, net assimilation rate and yield can be obtained with three irrigations at early vegetative, flowering and seed formation (21, 56 and 93 DAS).

Hasanuzzan et al. (2008) observed that the irrigation levels significantly affected the number of branches per plant. Significantly higher branches (9.45) were recorded when the crop was irrigated twice at 30 and 60 DAS, while the lowest values (4.49) was recorded when no irrigation was applied.

Sultana et al. (2009) in a study conducted in Dhaka (Bangladesh) on rapeseed *Brassica campestris* reported that irrigation exerted significant influence on the number of branches per plant in rapeseed. The maximum number of branches per

plant was found when the crop was subjected to three irrigations, one at 20 DAS, one at 35 DAS and another at 50 DAS. The lowest number of branches per plant was found from the control treatment.

Piri et al. (2011) from Tehran (Iran), while working on Indian mustard (*Brassica juncea*), concluded that one and two irrigations significantly increased dry matter per plant of over no irrigation. In a field experiment conducted by Verma et al. (2014) at Faizabad, Uttar Pradesh on Indian mustard (*Brassica juncea* L.) they reported the same results where all the growth parameters increased significantly with the application of one irrigation at the branching stage over no irrigation.

2.1.2 Effect of irrigation levels on yield attributes and yield

Majid and Simpson (1998) conducted a two years research at Islamabad (Pakistan) on mustard and reported that the seed yield of mustard increased by 57 per cent and 44 per cent due to triple irrigation at each flowering, early pod development and early pod ripening during the first and second year respectively over dry condition. Triple irrigation substantially increased siliquae per plant, number of seeds per siliquae and test weight of mustard. Similarly, Singh and Dixit (1989) from Kumarganj (Faizabad) reported that two irrigations at 45 DAS and 90 DAS produced a significantly higher number of siliquae per plant over one irrigation and no irrigation in mustard crop.

Gill and Narang (1991) observed the response of gobhi sarson (*Brassica napus* species *oleifera* annua) to nitrogen and irrigation regimes and found that the highest seed yield (21.1 kg ha⁻¹) was obtained when 150 kg ha⁻¹ nitrogen was given with three irrigations. The seed yield increased with increased level of irrigation.

Padmani et al. (1992) in a field experiment reported that with the increasing irrigation levels seed yield of mustard (*Brassica juncea*) also increased progressively. The yield attributes viz., seeds siliquae⁻¹, 1000-seed weight and siliquae plant⁻¹ also showed a similar trend.

Garg et al. (2001) concluded that seed yield of Indian mustard increased significantly with increasing nitrogen levels and improvement was found to be more under higher level of irrigation. The seed yield obtained at the lowest level of

irrigation (IW/CPE=0.3) with 60 kg N ha⁻¹ was significantly higher than that at the highest level of irrigation (0.7) without nitrogen fertilization.

Singh et al. (2001) concluded that the application of two irrigations first at the initiation of branching (40 DAS) and another at flowering (60 DAS) or pod developed stage (100 DAS) gave the seed yield at par with three irrigations. Moreover, when only two irrigations were applied at flowering and pod development stage the yield decreased significantly as compared to three irrigations in Indian mustard (*Brassica juncea*).

A field study conducted by Raut et al. (2003) on mustard found that irrigation given at pre-flowering, 50 per cent flowering and seed filling stage resulted in a higher number of siliquae per plant and maximum leaf area.

Bandopadhyay and Bose (2004) recorded the highest crop growth rate and seed yield upon giving three irrigations to the mustard crop. All three irrigation levels and phosphorus @ 80 kg ha⁻¹ increased seed yield significantly over control. Likewise, Sharma et al. (2005) showed that irrigation given at 30 and 60 DAS lead to a significant increase in grain and stover yield of both mustard and linseed over control. Piri et al. (2006) also recorded the similar results where seed yield of Indian mustard increased significantly with increasing levels of irrigation.

A field experiment was conducted by Panda et al. (2004 b) to study the effect of irrigation levels (irrigation at the flowering stage or the flowering and pod development stages) and cultivars on the growth, yield attributes, productivity, consumptive water use and water use efficiency of Indian mustard (*Brassica juncea*). Results showed that growth, yield attributes, yield (seed and oil yields) increased with increasing irrigation levels.

A study conducted by Mandal et al. (2006) at Bhopal on heavy clay soil concluded that applying organic manure + 100 per cent NPK fertilizers with two irrigations first at pre-sowing and second at flowering stage gave the best result in Indian mustard. Significantly higher seed and biomass yield was obtained with two irrigations as compared to other treatments.

Hasanuzzaman and Karim (2007) carried out an experiment in Bangladesh and concluded that two irrigations first at the pre-flowering stage and second at the siliquae development stage had a significant effect on yield attributes and harvest index in Rapeseed (*Brassica campestris* L.).

Nagdive et al. (2007) carried out a field experiment in Akola to study the seed yield, oil yield, protein content and nutrient uptake by Indian mustard (*Brassica juncea*) as influenced by irrigation and nutrient management treatments. The results indicated that among irrigation treatments, application of irrigation at branching, flowering and siliquae development stages recorded maximum yield attributes, seed yield and oil yield over no irrigations. Similarly, Rana et al. (2007) in a study on rapeseed revealed that irrigation given at 45 days after sowing resulted in an increase in the number of siliquae per plant, number of seeds per siliquae, test weight and oil content over no irrigation.

Tahir et al. (2007) from a study on canola (*Brassica napus* L.) in Faisalabad concluded that seeds per siliquae, test weight and seed yield were highest under three irrigations given at early vegetative, flowering and seed formation compared to control treatment. Istanbuluoglu et al. (2010) from an experiment on *Brassica napus* in Turkey concluded that in areas with limited water availability if one irrigation has to be applied then it should be given at the flowering stage, which gives maximum grain yield.

Yadav et al. (2010) carried out the study on sandy loam soil at Morena and studied the effect of irrigation and levels of NPK nutrients (per cent of recommended dose) on growth, yield, economics and quality parameters of Indian mustard (*Brassica juncea* L.). Irrigation at flower initiation and seed development stage recorded higher values of yield attributes and resulted in 8.78 per cent and 24.18 per cent higher seed yield over one irrigation applied at flower initiation stage and siliquae development stage, respectively.

Hossain et al. (2013) carried out an experiment at the University of Rajshahi (Bangladesh) to study the effect of irrigation on yield and yield attributes of mustard. The results so obtained showed that irrigation had a significant effect on the yield and yield contributing characters i.e. number of filled siliquae per plant, number of seeds per siliquae and 1000 seeds. These increased with increasing levels of irrigation. The

same results were obtained by Sanches et al. (2014) where there was a significant increase in the oil content and 1000-grain weight of canola as a function of irrigation and nitrogen doses. The yield under irrigation (3145.65 kg ha⁻¹) was higher than under non-irrigated conditions (1354.45 kg ha⁻¹).

A field experiment was conducted by Verma et al. (2014) at Faizabad to evaluate the response of newly released Indian mustard (*Brassica juncea* L.) varieties to irrigation. They showed that all yield attributes and yield increased significantly when one irrigation was applied at the branching stage over control.

Tyagi and Upadhaya (2017) while working on Indian mustard (*Brassica juncea* L.) cultivar Pusa Tarak confirmed that two irrigations given at 40 and 75 DAS gave significantly more number of siliquae per plant, number of seeds per siliquae, seed yield, biological yield and harvest index followed by one irrigation given at 40 DAS and the lowest was found when no irrigation was given after sowing.

Ganya et al. 2018. observed that the physiological and morphological characteristics of the cultivars may determine the response to fertilizer application. In Zimbabwe although a minor difference in leaf canopy was observed but yield response recorded similar. Hence, both the tested cultivars of *Brassica napus* were recommended.

Shivran et al. (2018) conducted a field experiment on sandy loam soil in Uttar Pradesh to study the effect of various irrigation schedules on productivity and water use efficiency of Indian mustard (*Brassica juncea* L.). Significantly higher seed yield of Indian mustard was recorded when the crop was provided with three irrigations at 30-35 DAS, flowering and siliquae development over no irrigation.

Singh et al. (2020) Application of suitable irrigation scheduling technique and mulching can improve the growth, yield of field mustard. In a study conducted at Pantnagar, India, it was reported that during winter rain *Brassica rapa* should be given irrigation at 0.9 IW/CPE ratio whereas under scarcity with rainfall 1.2 IW/CPE ratio is required.

2.1.3 Effect of irrigation levels on water use efficiency

Ramamoorthy et al. (1998) from Tamil Nadu while working on direct-sown upland rice showed that the medium moisture regime IW/CPE ratio of 1.50 saved

about 13 per cent of irrigation water and gave higher water-use efficiency compared with higher moisture regime IW/CPE ratio 2.00. Li et al. (2001) showed an improvement in water use and an increase in water use efficiency on the application of pre-sowing irrigation and phosphorus on spring wheat.

Hati et al. (2001) conducted an experiment in Bhopal, Madhya Pradesh on *Brassica juncea* and reported that water use efficiency was highest (7.1 and 6.8 kg ha⁻¹ mm⁻¹) at no irrigation followed by one and two irrigation treatments.

Hu et al. (2002) while working on cotton observed that irrigation given at flowering and budding stages were suitable for a limited supply of water and significantly improving water use efficiency by 57 per cent.

Husain et al. (2008) at Kanpur carried an experiment to study the effect of irrigation schedules on yield and water use in rice. The irrigation schedule having three days drainage period yielded higher rice with maximum water use efficiency while the irrigation schedule having four or five days drainage periods was found to be detrimental.

Rezaei et al. (2009) from Iran reported the effect of different irrigation management (full irrigation, 5 and 8 days interval irrigation) and showed that increasing irrigation intervals decreased water use, but increased water productivity in 5 and 8 days interval irrigation by 40 and 60 per cent, respectively, in comparison to full irrigation, without any yield loss.

Shekara et al. (2010) carried a field trial of 2 years and reported that the irrigation scheduled at IW/CPE ratio of 1.0 recorded higher water use efficiency (52.09 kg grain ha⁻¹cm⁻¹) using total water (91.84 cm) than IW/CPE ratio of 2.5 (41.31 kg grain ha⁻¹cm⁻¹) using total water (154.8 cm).

Verma et al. (2015) reported significantly higher consumptive use of water (57.8 cm.), rate of water use (4.52 mm per day) and water use efficiency (87.3 kg ha⁻¹ mm⁻¹) with irrigation at 40 mm CPE in wheat (*Triticum aestivum*). Yan et al. (2017) from North China Plain concluded that straw mulching with pre-sowing irrigation up to 70 mm depth is the ideal water-saving in summer maize.

2.1.4 Effect of irrigation levels on oil content and nutrient uptake

Raut et al. (2000) conducted an experiment in Akola and observed maximum values of oil content on the application of irrigation at pre-flowering, 50 per cent flowering, siliquae setting and filling stages in mustard crop over two irrigations at pre-flowering and siliquae development stage.

Giri et al. (2003) in an experiment on mustard observed the significant effect of different irrigation levels on the quality parameters of mustard. They found a significant increase in oil content and oil yield of mustard on giving irrigation at pre-sowing, vegetative, 50 per cent flowering and grain filling stage over no irrigation.

Sharma et al. (2003) recorded the highest oil content on giving one irrigation over no irrigation in Indian mustard (*Brassica juncea* L.). Bandopadhyay and Bose (2004) from West Bengal revealed that four irrigation regimes increased the oil content gradually in short duration mustard.

Panda et al. (2004 a) concluded an experiment and revealed that yield in Indian mustard (*Brassica juncea*) increases on giving irrigation at flowering and pod development stages and irrigation at flowering stage over control treatment by 62.9 per cent and 41.7 per cent respectively. Application of irrigation at critical stages also leads to an increase in oil and protein content.

Khaled (2006) reported that the highest oil content of 40.4 per cent was found at 7 days interval of irrigation in canola (*Brassica napus* L.). The longer interval of irrigation reduced the oil content relative to the lower moisture content available.

Singh et al. (2004) reported that two irrigations at pre-flowering and pod development stages in chickpea + Indian mustard intercropping recorded the highest seed, straw and protein yield and nutrient uptake over no irrigation or one irrigation at the pre-flowering stage. Nutrient uptake increased with increasing levels of sulphur.

2.1.5 Effect of irrigation levels on economics

Mishra et al. (2018) concluded that benefit: cost ratio improved with increasing irrigation frequency up to three irrigations. However, the application of two irrigations to the Indian mustard remained comparable with the application of three irrigations.

2.2 Effect of nutrient management practices

2.2.1 Effect of nutrient management on growth characters

Mankotia and Sharma (1997) revealed that dry matter accumulation in gobhi sarson, toria in gobhi sarson and toria cropping system increased with increasing supply of N, P and FYM. Similarly, Akhtar and Bohra (2000) observed a significant increase in plant height and the average number of primary and secondary branches per plant in mustard crop on application of 60 kg N ha⁻¹ in rainfed conditions.

Bhari et al. (2000) studied the effect of different N levels (30, 60, 90, and 120 kg N ha⁻¹) on Indian mustard (*Brassica juncea*) Varuna and noticed that application of N up to 120 kg ha⁻¹ resulted in a significant increase in plant height, primary and secondary branches per plant.

Singh and Singh (2002) while studying the response of two Indian mustard (*Brassica juncea*) cultivars (Varuna and Vardhan) to nitrogen levels (0, 40, 80, 120 and 160 kg ha⁻¹) under varying sowing dates (14 October, 29 October, 13 November and 28 November) observed superior growth characters such as plant height, leaves per plant, leaf-area index, dry-matter accumulation per plant, primary and secondary branches per plant on the successive increase in nitrogen up to 120 kg ha⁻¹.

Tripathi and Tripathi (2003) conducted an experiment to study the effect of N levels (80, 120, 160 and 200 kg ha⁻¹) on growth, yield and quality parameters of Indian mustard (*Brassica juncea*) cultivar 'Varuna'. The result showed that dry-matter accumulation per plant, leaf-area index, plant height, primary and secondary branches per plant increased with increasing levels of N up to 160 kg ha⁻¹.

Maurya et al. (2004) from Uttar Pradesh studied the effect of N fertilizer (0, 50, 100 and 150 kg ha⁻¹) on high-yielding Indian mustard (*Brassica juncea*) cultivars. They observed that the application of 150 kg N ha⁻¹ on Pusa Bold and Vardan gave the highest germination percentage, maximum plant height and number of branches per plant.

Singh and Meena (2004) concluded that application of N at 80 kg ha⁻¹ and sulphur at 60 kg ha⁻¹ significantly increased dry-matter accumulation, plant height, primary and secondary branches of Indian mustard (*Brassica juncea*). Likewise,

Thanki et al. (2004) carried out an experiment on Indian mustard (*Brassica juncea*) cv. Gujarat Mustard-1 and revealed that plant height and the number of branches per plant increased significantly with increased rates of N supply i.e. 25, 50 and 70 kg N ha⁻¹.

Dongarkar et al. (2005) while working on (*Brassica juncea*) observed that plant height, number of branches and dry matter accumulation were significantly superior with the application of 75 kg N ha⁻¹ over 25 kg N ha⁻¹ and control but at par with 50 kg N ha⁻¹ and 40 kg S ha⁻¹ over 20 kg S ha⁻¹ and control.

Bhat et al. (2006) studied the effect of three levels of nitrogen and phosphorus i.e. 60 kg N + 30 kg P ha⁻¹, 80 kg N+ 40 kg P ha⁻¹ and 100 kg N+50 kg P ha⁻¹ on the growth, yield and quality of mustard (*Brassica juncea*) cultivars Pusa Bold and Kranti and observed that application of 100 kg N ha⁻¹ significantly increased all the growth parameters i.e. plant dry matter, leaf area, leaf number, number of primary and secondary branches and as compared to other treatments.

Bhati and Sharma (2006) carried out a study to observe the influence of K on leaf area index (LAI) and chlorophyll content of mustard and found that application of K @ 60 kg K ha⁻¹ significantly increased LAI by 23.77 and 21.78 per cent over the control at 45 DAS. K also significantly increased chlorophyll content at 45 and 90 DAS.

Sah et al. (2006) revealed that plant height and primary branches per plant increased significantly up to 80 kg N ha⁻¹, while secondary branches and dry matter accumulation per plant increased on the application of 120 kg N ha⁻¹ in Indian mustard (*Brassica juncea* (L.) Czern & Coss).

Arya et al. (2007) in his study on chickpea + mustard intercropping system found that integrated nutrient application (INA) (50 per cent (RDF) + FYM @ 5 t ha⁻¹ + biofertilizers+ Rhizobium+ PSB) significantly increased plant height, crop biomass, grain and biological yield of mustard as compared to control.

Kumar et al. (2007) while working on mustard (*Brassica juncea* (L.) Czern & Coss) observed the effect of plant densities (166 x 103, 222 x 103 and 333 x 103) and N levels (0, 40, 80 and 120 kg ha⁻¹) on its growth rate and yield attributes. It was

observed that the number of branches per plant, the number of leaves per plant, leaf area index, dry matter accumulation per plant and growth rate increased significantly with the increasing level of N up to 120 kg ha⁻¹.

Kumar and Kumar (2007) observed the effect of varying levels of nitrogen (0, 60, 80, 100, 120 and 140 kg ha⁻¹) on Indian mustard (*Brassica juncea*) cv. Vardan. It was observed that increasing nitrogen level significantly increased all the growth parameters (number of leaves, plant height, number of branches, leaf area and number of primary secondary and tertiary branches) over the control. Dawson et al. (2009) observed that plant height and plant dry matter accumulation was recorded maximum in mustard (*Brassica juncea*) with the application of 100 kg N ha⁻¹ over 80 kg.

Kumar et al. (2010) found that increasing levels of nitrogen up to 80 kg ha⁻¹ and sulphur up to 45 kg ha⁻¹ improved the growth characters such as plant height, primary and secondary branches and dry matter accumulation in Indian mustard (*Brassica juncea* (L.) Czern. and Coss).

Zimik et al. (2010) studied the effect of nitrogen levels (50 and 100 kg ha⁻¹) on the growth and yield of mustard. The result showed that the leaf area (LA), leaf area index (LAI), net assimilation rate (NAR), dry matter percentage improved significantly on the application of 100 kg N ha⁻¹. Mohiuddin et al. (2011) revealed that the plant height and the number of branches per plant increased significantly with an increasing rate of N up to 80 kg ha⁻¹ in oilseed mustard (*Brassica* species).

Sahu et al. (2011) in a field study on Indian mustard (*Brassica juncea*) cv Pusa Bold revealed that the plant height, primary branches per plant, leaf area index (LAI), dry matter accumulation per plant, crop growth rate (CGR) and relative growth rate (RGR) increased significantly up to 50 kg P₂O₅ ha⁻¹ over control.

Singh and Pal (2011) reported that application of (RDF) 120: 17.6 : 16.6: 40 (N : P: K: S kg ha⁻¹) + FYM 10 t ha⁻¹ +25 kg Zn SO₄ ha⁻¹ and treating seed with Azotobacter improved plant height, total dry matter accumulation, leaf area index, seed and stover yields of mustard (*B. juncea* (L.) Czernj & Cosson).

Kumar et al. (2018) observed that the application of 50 per cent RDF + FYM@ 6 t ha⁻¹ + vermicompost @ 2 t ha⁻¹ + biofertilizer resulted in an increase in

dry matter production, leaf area index, plant height and branches per plant in the mustard crop.

2.2.2 Effect of nutrient management on yield attributes and yield

Aulakh et al. (1995) observed that seed yield of transplanted gobhi sarson (*Brassica napus* species *oleifera* annua) increased linearly from 8.5 q ha⁻¹ in the control to 17.8 q ha⁻¹ on the application of 100 kg N ha⁻¹. The combined application of N and S enhanced the seed and straw yield. However, the effect was limited to the application of 50 kg S ha⁻¹ in case of seed and 75 kg S ha⁻¹ in case of straw yield. Combined application of 120 kg N ha⁻¹ along with 50 kg S ha⁻¹ gave the maximum seed yield (5.60 g pod⁻¹) in gobhi sarson. Moreover, the application of nitrogen and sulphur also increased the uptake of nitrogen and sulphur in *Brassica napus* species *oleifera* annua significantly (Biswas et al. 1995).

Akhtar and Bohra (2000) observed that number of siliquae per plant, test weight, seed yield and stover yield of mustard increased significantly with increasing levels of N up to 90 kg ha⁻¹. Application of 60 kg N ha⁻¹ under rainfed conditions also leads to an increase in siliquae per plant, test weight and seed yield.

Bhari et al. (2000) while working on Indian mustard (Varuna) found that increasing application of N up to 120 kg ha⁻¹ resulted in a significant increase in the siliquae per plant. Moreover, both the levels i.e. 90 and 120 kg N ha⁻¹ were at par in respect of seeds per siliquae and 1000-seed weight.

Jat et al. (2000) recorded that number of siliquae per plant, the number of seeds per siliquae and seed yield increased significantly with the increasing level of P (40 kg ha⁻¹) in mustard (*Brassica juncea* (L.) Czern and Coss). However, the harvest index was not affected significantly by the P application.

Sumeriya et al. (2000) from Jobner, Rajasthan observed that application of phosphorus fertilizer at 60 kg ha⁻¹ significantly improved the yield attributes and yield in mustard (*Brassica juncea* (L.) Czernj. & Cosson). The highest number of siliquae per plant, seeds per siliquae and seed yield was obtained with 60 kg P₂O₅ ha⁻¹ whereas Patel and Shelke (2000) found that test weight, seed and stover yields of mustard significantly increased with the application of P₂O₅ up to 80 kg ha⁻¹.

Chaubey et al. (2001) reported that there was a significant increase in yield attributes (siliquae per plant, length of siliquae, seeds per siliquae and 1000-seed weight) and yield of Indian mustard (*Brassica juncea*) on the increasing level of P and S up to 60 kg P₂O₅ and 30 kg S ha⁻¹, respectively. Similarly, Garg et al. (2001) showed that yield attributes i.e siliquae per plant, length of siliquae and seed yield of Indian mustard increased with increasing levels of N progressively up to 60 kg N ha⁻¹. Similarly, Meena et al. (2002) observed that application of 60 kg N ha⁻¹ resulted in significantly higher seed and stover yields of mustard (*Brassica juncea* (L.) Czernj. & Cosson) over control.

Kantwa and Meena (2002) from Jobner, Rajasthan reported that application of phosphorus up to 45 kg P₂O₅ ha⁻¹ significantly increased the yield attributes, seed and stover yield of mustard. Moreover, seed inoculation with PSB significantly increased the number of siliquae per plant, seed and stover yields over no inoculation.

Shukla et al. (2002) reported that application of 50 and 100 per cent of the recommended fertilizer rates + FYM @ 10 t ha⁻¹ + Azotobacter resulted in the highest number of siliquae per plant, siliquae length, 1000-seed weight, number of seeds per siliquae, seed yield per plant and seed yield of Indian mustard (*Brassica juncea*).

Dhaka and Kumar (2003) and Jain et al. (2009) reported that seed and stover yields improved with increasing N rates up to 80 kg N ha⁻¹, while the integration of P₂O₅ and N produced higher yield as compared to sole application of 80 kg N ha⁻¹ in Raya and *Brassica juncea*, respectively. Sumeriya (2003) showed that the application of P₂O₅ @ 60 kg ha⁻¹ significantly increased the yield attributing characters i.e. number of siliquae per plant, seeds per siliquae and 1000-seed weight, seed yield (1407 kg ha⁻¹) in mustard (*Brassica juncea* L.) over the lower P levels.

Mandal and Sinha (2004) in an experiment on Indian mustard (*Brassica juncea*) in West Bengal revealed that application of FYM and/or borax + ZnSO₄ in combination with 100 per cent and 50 per cent of NPK influenced the growth characters significantly. It was observed that yield attributes were improved on the application of FYM or borax or ZnSO₄ or borax + ZnSO₄ combined with 100 per cent NPK. Integrated application of nutrients i.e. 100 per cent NPK + FYM

increased the uptake of N, P, K and S in both seed and stover and hence increasing the total uptake (seed + stover).

Premi and Kumar (2004) reported a significant increase in the number of siliquae per plant up to 120 kg N ha⁻¹ and the number of seeds per siliquae up to 80 kg N ha⁻¹ in Indian mustard (*Brassica juncea*). Thanki et al. (2004) while working on Indian mustard cv. Gujarat Mustard-1, also observed that the number of siliquae per plant, 1000-seed weight, seed yield were highest on the application of 50 kg P₂O₅ ha⁻¹ over the 0 and 25 kg P₂O₅ ha⁻¹.

Kumar et al. (2005) in a work conducted at Kangra, Himachal Pradesh reported that application of 10 tonnes FYM along with 100 per cent NPK either to one crop or both crops increased the system productivity of Maize (*Zea mays*) and gobhi sarson (*Brassica napus* species *oleifera* annua) cropping sequence by 7.7 per cent over 100 per cent NPK application alone.

Rana et al. (2005) conducted an experiment on rainfed Indian mustard (*Brassica juncea* cv. Pusa Barani) and reported a progressive increase in yield attributes and seed yield with increased levels of P, but the significant differences in seed yield were noticed up to 25 kg P₂O₅ ha⁻¹ only.

Saxena et al. (2005) found that application of 40 kg P₂O₅ ha⁻¹ recorded a significant increase in dry matter production, siliquae per plant and seed yield per plant than the treatment without P₂O₅ application in mustard (*Brassica juncea* L.).

Yadav et al. (2005) carried out an experiment in Haryana, to determine the P requirement of Indian mustard. The highest seed yield of 2451 and 2125 kg ha⁻¹ was recorded with the basal application of 66 kg P₂O₅ ha⁻¹ through DAP.

Singh and Kaistha (2006) in an experiment on gobhi sarson (*Brassica napus* L.) at Akrot, Una reported that both seed and stover yield increased by 92 per cent and 160 per cent, respectively with the application of nitrogen and sulphur fertilizers over control.

Singh and Rana (2006) while working on Indian mustard (*Brassica juncea*) and lentil (*Lens culinaris*) intercropping system reported that the growth parameters and seed yield increased as a result of adoption of moisture conservation

practices. A significant increase in seed yield of Indian mustard and lentil was recorded with 100 per cent fertility levels however, the yield was found to be 19.9 and 25.3 per cent higher over the 50 per cent RDF & control, respectively.

Basumatary and Talukdar (2007) found that combined usage of FYM @ 1.5 or 3 t ha⁻¹ and S @ 30 kg ha⁻¹ in rapeseed (*Brassica napus*)-rice (*Oryza sativa*) sequence gave the highest seed yield, stover yield than that of a single application of S or FYM.

Dawson et al. (2009) witnessed more number of siliquae per plant, seeds per siliquae and test weight were obtained with the increased level of nitrogen, which ultimately resulted in higher seed yield in mustard (*Brassica juncea*).

Dutta et al. (2009) while working on yellow sarson (*Brassica campestris*), recorded maximum seeds per siliquae, test weight and seed yield on the application of 60 per cent N fertilizer, 75 per cent P fertilizer + 12 kg ha⁻¹ biofertilizer and organic manure @ 5 t ha⁻¹.

Fanaei et al (2009) conducted an experiment on rapeseed (*Brassica napus* L.) and Indian mustard (*Brassica juncea* L.) species. (Persian) and reported that potassium application significantly affected grain yield and water use efficiency of rapeseed and Indian mustard in severe and mild stress conditions.

Jain et al. (2009) conducted an experiment to study the influence of the basal application of N and P with/without supplemental foliar dosage of N, P and S on yield characteristics and oil contents of mustard (*Brassica juncea*) cv Pusa kranti. Data showed that foliar application of P and S @ 2 kg ha⁻¹ along with 60 kg N ha⁻¹ and 28 kg P ha⁻¹ significantly improved all yield characteristics.

Cheema et al. (2010) carried out a study on canola (*Brassica napus* L.) and found that total dry matter (TDM), seed yield, oil yield and protein content were significantly enhanced by different nitrogen levels. Nitrogen application @ 120 kg ha⁻¹ resulted in higher values of all traits as compared to control.

Gupta and Sharma (2010) in maize-gobhi sarson cropping sequence, observed that integrated use of inorganics and organics affected the nutrient uptake, grain and straw yield of both maize and gobhi sarson significantly over the use of chemical fertilizer alone.

Narits (2010) in Iran conducted an experiment on (*Brassica napus* L. *oleifera* sub-*biennis*) and reported that the application of nitrogen significantly increased its seed yield and seed protein concentration. Similarly, Tripathi et al. (2010) found that INM of 2 t FYM ha⁻¹ + 40 kg S ha⁻¹ + RDF or 75 per cent RDF resulted in 18.2 per cent and 20.3 per cent higher yield of Indian mustard (*Brassica juncea*) over RDF (1.69 t ha⁻¹) and 75 per cent RDF (1.57 t ha⁻¹) alone.

According to Saha et al. (2010) balanced use of inorganic fertilizer (100 per cent NPK) + lime + biofertilizer + FYM leads to an increase in the yield of the mustard under maize (*Zea mays*)-mustard (*Brassica campestris*) cropping sequence as compared to the control plot.

Zimik et al. (2010) conducted a study to record the effect of nitrogen, phosphorus and potassium on the growth and yield of mustard. The result revealed that the leaf area (LA), leaf area index (LAI), net assimilation rate (NAR), edible yield rate (EYR), yield efficiency rate (YER), dry matter percentage (DM per cent), NPK content and vegetable yield improved significantly by individual application and interaction as compared to control. The significantly higher vegetative yield was obtained in the treatment combination of 100 kg N ha⁻¹, 100 kg P₂O₅ ha⁻¹, and 100 kg K₂O ha⁻¹.

Mohiuddin et al. (2011) witnessed that the siliquae plant⁻¹, seed and shoot yield increased with increasing levels of N up to 80 kg N ha⁻¹. However, further increase in N level i.e. 120 kg N ha⁻¹ showed a negative effect on seed yield of oilseed mustard (*Brassica* species).

Sahu et al. (2011) observed that the application of 50 kg P₂O₅ ha⁻¹ and 40 kg S ha⁻¹ in Indian mustard (*Brassica juncea*) increased the seed yield as a result of increased plant height, primary branches per plant and more photosynthates accumulated per plant.

Parihar et al. (2012) reported that nutrients were utilized by the pearl millet-mustard cropping system in a better way if organic (FYM) and inorganic (prilled urea and single super phosphate) sources of fertilizer were used in combination. Thus, enhancing the growth, yield attributes and yield of mustard.

Mahajan et al. (2013) under rainfed conditions in Maharashtra reported that maximum yield, as well as higher returns, were obtained in Indian mustard (*Brassica juncea*) on the application of 75 per cent RDF of N (37.5 kg ha^{-1}) + 2.5 ton of Castor cake / FYM + biofertilizer/ bio inoculants.

Gupta et al. (2014) worked on maize (*Zea mays* L.) - gobhi sarson (*Brassica napus* L.) cropping system and found residual effect of FYM given in the preceding maize crop, with the highest seed yield (1081 kg ha^{-1}) and it was 81 per cent higher than the control. Seed yield of gobhi sarson is increased significantly when 50 per cent N is replaced by FYM/crop residue.

Singh et al. (2014) in an experiment on rapeseed mustard observed that superior yield was obtained on applying a higher dose of N i.e. 80 kg N ha^{-1} in combination with biofertilizers and FYM as compared to the application of N alone @ 80 kg N ha^{-1} . It was also found that application of FYM (5.0 t ha^{-1}) and seed inoculation with biofertilizers significantly increased the yield attributes, seed and stover yield of Indian mustard (*Brassica juncea*).

Kansotia et al. (2015) in a study on Indian mustard (*Brassica juncea* L.) found that on applying vermicompost @ 6 t ha^{-1} + $80 \text{ kg N} + 40 \text{ kg P}_2\text{O}_5 \text{ ha}^{-1}$ nutrient uptake, seed, stover yield, as well as net returns of Indian mustard (*Brassica juncea*), increased significantly over other treatments.

Solanki et al. (2015) showed that maximum yield was obtained in Indian mustard (*Brassica juncea* L.) on the application of both P and S @ 50 kg ha^{-1} and seed inoculation with PSB biofertilizer.

Mukherjee (2016) found that application of FYM 20 t ha^{-1} resulted in improved plant growth parameters, higher plant height and seed yield in Indian mustard (*Brassica juncea* (L.) followed by FYM @ 10 t ha^{-1} . Incorporation of FYM @ 20 t ha^{-1} was found to increase the stover yield by 74.0 per cent as compared to no FYM treatment.

A field study conducted by Kumar et al. (2017 a) showed an increase in the number of siliquae plant^{-1} , seeds siliquae^{-1} , test weight, and seed yield of mustard on the application of 50 per cent RDF along with FYM.

Kumar et al. (2017 b) from Uttarakhand observed that the highest seed yield (1.93 t ha^{-1}) and nutrient uptake (99 kg N , $42 \text{ P}_2\text{O}_5$ and $172 \text{ kg K}_2\text{O ha}^{-1}$) was obtained on the application of $100 \text{ kg N} + 40 \text{ kg P}_2\text{O}_5 + 30 \text{ kg K}_2\text{O ha}^{-1}$ followed by $100 \text{ kg N} + 40 \text{ kg P}_2\text{O}_5 + 0 \text{ kg K}_2\text{O ha}^{-1}$ and $100 \text{ kg N} + 20 \text{ kg P}_2\text{O}_5 + 30 \text{ kg K}_2\text{O ha}^{-1}$ treatments in Indian mustard (*Brassica juncea* L.).

Sharma and Das (2017) reported that two irrigations given at flowering and siliquae formation stage resulted in 6.8, 11.6 and 46.9 per cent higher yield over single irrigation at flowering, single irrigation at pod formation and rain-fed crop respectively. Among the fertilizer levels, application of N: P: K @ 90:60:60 kg ha^{-1} being at par with 75:50:50 gave the highest yield attributes, seed yield, net return and B:C ratio in yellow sarson (*Brassica rapa* (L.) trilocularis).

A field study by Singh et al. (2017) on Indian mustard (*Brassica juncea* L.) recorded higher seed yield (17.96 q ha^{-1}) and oil yield (6.72 q ha^{-1}) in a treatment containing 100 per cent RDF of NPK + FYM @ 5 t ha^{-1} + S @ 40 kg ha^{-1} .

Thaneswar et al. (2017) reported that on the combined application of RDF ($120:60:40:30 \text{ kg ha}^{-1}$ NPKS) + vermicompost @ 5.0 t ha^{-1} ; yield attributes such as the total number of siliquae⁻¹, siliquae length, the number of seeds siliquae⁻¹ and grain yield (22.75 q ha^{-1}) of Indian mustard (*Brassica juncea* L.) increased significantly.

Chandan et al. (2018) recorded maximum number of siliquae plant⁻¹, seeds siliquae⁻¹ and seed and stover yield in mustard (*Brassica juncea* L.) on integrated application of 75 per cent RDF + S @ 40 kg ha^{-1} + vermicompost @ 5 t ha^{-1} + Azotobacter + PSB.

Islam et al. (2018) concluded that application of N @ 120 kg ha^{-1} along with 45 kg S ha^{-1} resulted in the highest plant growth parameters, seed yield, stover yield, biological yield and harvest index of rapeseed.

Sahoo et al. (2018) recorded highest seed and stover yield under the treatment having 75 per cent RDF + FYM @ 5 t ha^{-1} + Zn @ 5 kg ha^{-1} + Azotobacter. Similarly, Solanki et al. (2015) showed that maximum yield in mustard was obtained by P and S application @ 50 kg ha^{-1} and seed inoculation with PSB biofertilizer. Significant increase in oil content of mustard (*B. juncea* L.) was also registered with 50 per cent RDF + FYM @ 5 t ha^{-1} + Zn @ 5 kg ha^{-1} + Azotobacter.

2.2.3 Effect of nutrient management on water use efficiency

Liu et al. (1998) from Ningxia recorded the highest yield and maximum water use efficiency under optimum fertilizer input of 90 kg N ha⁻¹ and 13 kg P ha⁻¹ in spring wheat. Similarly, He et al. (1999) reported that both N application and water supply significantly increased water use efficiency in potato.

Hati et al. (2001) while working on Indian mustard (*Brassica juncea*) revealed that seed yield increased significantly with the increase in irrigation levels on the other hand water-use efficiency was highest under no irrigation. Compared with the recommended dose of NPK and control treatments, water use efficiency was found to be highest on application of a recommended dose of NPK + FYM @10 tonnes ha⁻¹ applied.

Xu and Zhao (2001) from China reported that water use efficiency increased slowly from 0.22 to 0.90 kg m⁻³ over 10 years due to the adoption of water conservation measures, adoption of new varieties and increasing the amount of N fertilizers.

Garg et al. (2004) showed that the application of phosphorus improved growth under scarce water conditions and the positive effects of plant growth increased stomatal conductance of moth bean (Bruck et al. 2000) and hence water use efficiency (Sawwan et al. 2000).

Ma (2004) observed that K⁺ accumulation on three genotypes of *Brassica napus* oilseed leads to an increase in water use efficiency by utilizing soil moisture more efficiently than K deficient plants.

Wang et al. (2004) showed the highest water use efficiency of 4.4 kg m⁻³ for biomass and 2.2 kg m⁻³ for the grain of winter wheat was obtained on addition of N fertilizer @ 225 kg ha⁻¹ over lower level of N application.

Chongtham et al. 2015 reported that significant and the highest WUE was observed in potato cv. (*Kufri surya*) when N was applied @ 300 kg ha⁻¹. However, the application of 150- and 225 kg ha⁻¹ was at par with the application of 300 kg ha⁻¹.

Sun et al. (2015) in their study on potatoes observed that WUE was higher when phosphorus was given with partial root drying zone method of irrigation as compared to when no phosphorus was given.

Wang et al. (2018) reported from a four years research that application of nitrogen @ 180 kg ha⁻¹ significantly increased the grain (13.24 kg mm⁻¹ha⁻¹) and biomass water-use efficiency (30.44 kg mm⁻¹ ha⁻¹) in wheat crop. However, the application of 120 kg ha⁻¹ was at par with the application of 180 kg ha⁻¹ for both the parametres 12.35 kg mm⁻¹ha⁻¹ and 28.34 kg mm⁻¹ha⁻¹ respectively.

2.2.4 Effect of nutrient management on oil and protein content

Brar et al. (1998) conducted an experiment on gobhi sarson (*Brassica napus* L.) and barley (*Hordeum vulgare*) at Ludhiana and found that application of N at 100 kg ha⁻¹ increased the seed yield of gobhi sarson. Seed yield, straw yield and oil yield were also increased significantly with each increment of nitrogen. Maximum seed yield (14.3 q ha⁻¹ and 13.78 q ha⁻¹) and oil yield (5.69 q ha⁻¹ and 5.71 q ha⁻¹) were recorded when 200 kg N ha⁻¹ was applied during both years respectively.

Nanwal et al. (2000) in his study found the response of Indian mustard (*Brassica juncea*) to nitrogen and Azotobacter and observed that seed yield and oil content was improved with increasing level of N. Similarly, Dhaka and Kumar (2003) observed that protein content increased with increasing N rates in Raya. Singh et al. (2007) noticed that 80 kg N ha⁻¹ was quite advantageous for the production of oil in mustard (*Brassica juncea*).

Bhat et al. (2006) observed that the oil content of mustard decreased with increasing N and P levels. Although, the rate of decrease in seed oil content was lower than the increase in seed yield. Hence, total edible oil production was still higher with higher fertilizer rates compared to the normal recommended rates of fertilizer.

Faujdar et al. (2008) carried out an experiment on response P (0, 20, 40 and 60 kg P₂O₅ ha⁻¹) towards the yield and quality of Indian mustard (*Brassica juncea*). They concluded that application of P was beneficial in increasing yield, oil content and oil yield, protein content, chlorophyll content and S- containing amino acids in seeds.

Lone et al. (2010) showed that the oil content of mustard increased with increasing P levels (0, 30 and 60 kg ha⁻¹) however, further increase in phosphorus level showed no considerable increase in oil content.

Singh et al. (2010 a) reported that quality parametres of Indian mustard (*Brassica juncea* (L.) Czern and Coss.) such as oil and protein content in seed and

their yield were influenced significantly by various fertility levels. Oil content increased significantly with increasing fertility level up to 100 per cent RDF but decreased thereafter with an increase in fertility. However, protein content increased with an increasing level of fertility and recorded the highest value at 150 per cent RDF. Varieties also recorded noticeable changes in oil and protein content of mustard seed under late sown conditions.

De and Sinha (2012) recorded maximum oil content and protein content in seeds of rapeseed (*Brassica campestris* L.), when crop was fertilized with 50 per cent RDF (30:15:15 kg ha⁻¹ of NPK) + FYM @ 2.5 t ha⁻¹ + vermicompost @ 1.25 t ha⁻¹ + neem cake @ 1.25 t ha⁻¹ + poultry manure @ 1.25 t ha⁻¹.

Rundala et al. (2012) observed that seed inoculation of Indian mustard (*Brassica juncea* L.) with Azotobacter + PSB significantly increased protein content in seed over control.

Dubey et al. (2015) in their study on Linseed (*Linum usitatissimum*) and Indian mustard (*Brassica juncea*) from Uttar Pradesh found that superior yield, protein and oil content were obtained on the application of 75 per cent RDN + 25 per cent N through farmyard manure (FYM) + Azotobacter + phosphate solubilizing bacteria (PSB). Moreover, NPK uptake by Indian mustard as well as linseed was also enhanced on the application of 75 per cent RDN only followed by 50 per cent RDN + 50 per cent N through FYM + Azotobacter + PSB treatments.

Majumder et al. (2017) revealed that maximum seed yield (14.2 q ha⁻¹), oil content (43.2 per cent) and protein content (21.82 per cent) was obtained in rapeseed (*Brassica campestris* L. yellow sarson) which received higher doses of S, Zn along with FYM and RDF. Application of higher doses of S, Zn + FYM and RDF of N, P and K fertilizers in combination increased N, P, K, S and Zn uptake in rapeseed.

Saini et al. (2017) showed a significant increase in oil content of rapeseed (*Brassica campestris toria*) under the treatment consisting of Azotobacter + PSB + 30 kg ha⁻¹ N through inorganic fertilizer + 30 kg ha⁻¹ N through poultry manure. Combined application of 100 per cent RDF of NPK + FYM @ 5 t ha⁻¹ + S @ 40 kg ha⁻¹ recorded highest protein content (21.06 per cent) in Indian mustard (*Brassica juncea* L.) (Singh et al. 2017).

2.2.5 Effect of nutrient management on nutrient uptake

Raut et al. (2000) noticed significantly higher content of sulphur and phosphorus in straw and seed and total uptake of sulphur, nitrogen and phosphorus by mustard crop in treatment receiving 60 kg S ha⁻¹.

Singh and Nad (2000) studied that the NS interaction with respect to the direct effect of different combinations of nutrient uptake in mustard. The total N uptake values in mustard were significantly higher due to the individual application of N or FYM, whereas, the total uptake of S was increased by the inclusion of P, N and individual treatments of FYM.

Thakur et al. (2003) in a work on gobi-sarson (*Brassica napus*) crop reported that Nitrogen uptake increased significantly with an increase in N application from 60 to 100 kg ha⁻¹. Hegde and Sudhakar (2004) recorded an increase in nutrient uptake from 2-7 per cent due to usage of fertilizers singly or in combination with major, secondary and micronutrients in oilseeds.

Thakur et al. (2005) in a work at Kangra, Himachal Pradesh on gobhi sarson (*Brassica napus* L.) concluded that the application of nitrogen @ 120 kg ha⁻¹ increased the uptake of nitrogen significantly, followed by 90 kg N ha⁻¹ and 60 kg N ha⁻¹. Significantly highest values of phosphorus and potassium uptake were obtained with 120 kg N ha⁻¹ though these were at par with 90 kg N ha⁻¹.

Roul et al. (2006) in their experiment on rice (*Oryza sativa*)-Indian mustard (*Brassica juncea*) sequence observed that treatment with a 100 per cent recommended dose of N along with FYM, significantly increases the N uptake by Indian mustard.

Sah et al. (2006) reported that the uptake of N by both seed and stover increased significantly in mustard (*Brassica juncea* (L.) Czern & Coss) with the successive increase in N level up to 120 kg N ha⁻¹.

Satyajeet and Nanwal (2007) found that N, P, S uptake in mustard were highest in plots receiving a combination of 75 per cent recommended dose of NPK (45:22.5:22.5 kg NPK ha⁻¹) + FYM @ 5 t ha⁻¹ + Azotobacter + PSB in a pearl millet-mustard cropping system.

Kumar and Thakur (2009) studied the effect of in-situ green manures and fertility levels on productivity and soil N balance in maize-gobi sarson cropping systems and reported that application of recommended fertilizers in gobi-sarson after kharif crop maintained the positive N balance compared to escaping fertilizers in this crop.

Singh et al. (2010 b) showed the highest uptake of N, P, K, S and Zn by seed and stover in Indian mustard crop (*Brassica juncea* (L.) on application of a recommended dose of fertilizers (120:40:20:40 kg N: P₂O₅:K₂O: S ha⁻¹) along with FYM + ZnSO₄ + seed treatment.

Shekhawat et al. (2012) found that integrated nutrient management in gobhi sarson reduced the demand for inorganic fertilizers and increased the efficiency of nutrients applied. They also emphasized the use of balanced use of fertilizers.

Chouksey et al. (2016) recorded that application P₂O₅ @ 15 kg ha⁻¹ in Indian mustard *Brassica juncea* (L.) cultivars significantly increased the uptake of P by plants at all the growth stages. It also increased the protein yield of Indian mustard.

According to Kumar et al. (2016) there was significant increase in uptake of N, P, K and yield attributes of Indian mustard on combined application of N, P, K + vermicompost @ 2 t ha⁻¹ + S @ 40 kg ha⁻¹ + ZnSO₄ @ 25 kg ha⁻¹ + B @ 1 kg ha⁻¹ and seed inoculation with Azotobacter @ 10 g kg⁻¹ seed. Similarly, Bijarnia et al. (2017) also reported that N, P, K uptake in *Brassica juncea* was highest in the treatment with 5 tonne FYM + 100 per cent RDF and 5 tonne FYM + 75 per cent RDF + biofertilizer.

Gour et al. (2017) in his trial found that application of vermicompost (control, 2.5 and 5 t ha⁻¹) and different nutrients (control, S @ 40 kg ha⁻¹; S @ 40 kg ha⁻¹ + 9.5 kg Fe ha⁻¹; 40 kg S ha⁻¹ + 5 kg Zn ha⁻¹ and 40 kg S ha⁻¹ + 9.5 kg Fe ha⁻¹ + 5 kg Zn ha⁻¹) on mustard along with RDF of NPK showed an increase in uptake of N, P, K, S, Zn, and Fe and seed as well as stover yield of mustard *Brassica juncea*.

Avanesh et al. (2001) observed the highest land equivalent ratio (LER), effective yield total (YET), net returns and benefit-cost ratio were obtained at a 6:2 row ratio. Among Phosphorus levels, 60 kg P₂O₅ ha⁻¹ were found most economic. P

uptake was significantly higher at 60 kg P₂O₅ ha⁻¹ in comparison with 30 kg P₂O₅ ha⁻¹. Net returns were also highest i.e. Rs. 22,042.90 and 20,182.04 ha⁻¹ at 6:2 row ratio and 60 kg P₂O₅ ha⁻¹, respectively.

Scagel et al. (2012). A study on *Rhododendron* plants revealed that increased N application rate increased the nutrient uptake by the crop. Nitrogen availability influences growth and uptake and storage of N and other nutrients by evergreen and deciduous cultivars of *Rhododendron* species. Nitrogen uptake increased with increasing N application rate and ER (English Roseum') had the greatest N uptake.

2.2.6 Effect of nutrient management on soil studies

Choudhary et al. (2003) reported that availability of N, P and K and Zn was higher under sulphur application as compare to no sulphur application. N, P, K, S and Zn availability in the soil after harvest of the crop increased significantly with the addition of sulphur up to 60 kg ha⁻¹.

Gauri et al. (2002) carried out an experiment to study the effect of integrated nutrient management on properties of soil revealed that application of farm yard manure along with inorganic fertilizer improved the bulk density, organic carbon content, CEC and available N, P and K content in soil at harvest of the crop.

2.2.7 Effect of nutrient management on economics

Mohapatra et al. (2020) observed that the cost of cultivation was maximum in treatment combination NPK (120-40-30) i.e. Rs 26590 ha⁻¹ although the net return was maximum in treatment with nutrient doses of NPK (100-40-30) i.e. Rs 21112 ha⁻¹. The gross returns per rupee investment (1.80) were also highest in this treatment.

Jha et al. (2004) from Varanasi reported that 100 per cent N through fertilizers recorded higher net returns followed by 50 per cent RDN through fertilizers + 50 per cent through FYM and was lowest with 100 per cent RDN through FYM. The results are supported by observation of Lhungdim et al. (2014) who also reported higher returns with the application of 100per cent RDF thorough inorganic fertilizers.

2.3 Effect of mulching on growth, yield and water use efficiency

Moitra et al. (1996) worked on yellow sarson (*Brassica rapa* L. var glauca) and ensured that seed yield and water use efficiency was more in mulched plots

compared to non mulched treatment. Moreover, Feng (1999) showed that mulching with crop residue helps in increasing water retention in soil.

Katiyar (2001) found that under different mulch materials, soil moisture and water use efficiency ($10.71 \text{ kg seed ha}^{-1} \text{ mm}^{-1}$) was found higher in mustard with maize stalk mulch @ 4 t ha^{-1} as compared to the control plot ($6.33 \text{ kg seed ha}^{-1} \text{ mm}^{-1}$).

Katiyar (2002) found that application of dry maize fodder as mulch @ 4 t ha^{-1} between rows of the mustard crop after 20 days of sowing resulted in higher growth parameters; yield attributes and root development of mustard. Mukhrjee et al. (2003) observed that polythene mulch gave higher growth and yield attributes in rapeseed followed by straw mulch over control.

Singh and Agrawal (2004) recorded maximum oil content and protein content in mustard (*Brassica juncea*) on the application of paddy straw mulch which also led to moisture conservation. They also found improvement in physical, physiological or chemical properties of post harvest soil on the application of different types of mulches.

Wang et al. (2004) in their study on wheat found that biomass and grain yield in mulched treatment were 39.5 per cent and 28.9 per cent higher than in treatments without mulching.

Ghanbahadur and Lanjewar (2006) in Akola conducted a study on mustard cv. ACN-9 and observed that the sowing dates, irrigation regimes and mulching increases the uptake of N and P with irrigation regime 0.6 IW/CPE ratio. Mulching proved beneficial as its application significantly increased the nutrient content and their uptake both in stover and seed.

Awasthi et al. (2007) from Kanpur (U.P) reported that paddy straw mulch resulted in the maximum water use efficiency in Indian mustard, followed by grass mulch while the lowest water use efficiency was recorded in control treatment in Indian mustard *Brassica juncea*.

Regar et al. (2007) carried out an experiment to find out the effect of field bunding and deep tillage during preceding rainy (Kharif) season and straw mulch on Indian mustard (*Brassica juncea* (L.) Czernj. & Cosson) productivity. They concluded

that straw mulching at 5 t ha⁻¹ significantly increased mean seed yield by 17.7 per cent over no mulch, with water-use efficiency of 8.3 kg ha⁻¹mm⁻¹.

Mondal et al. (2008) observed that polythene mulch and rice straw mulch conserve more moisture than other tillage operations. It was found that mulching resulted in better growth of crops and maximum seed yield (1164 kg ha⁻¹) was obtained in mustard with polythene mulch followed by rice straw mulch (1089 kg ha⁻¹).

Youkhana and Idol (2009) and Leblance et al. (2006) showed that using cheap and locally available indigenous mulches provide a better avenue for the mustard crop. Also, indigenous mulches add organic matter and plant nutrients into the soil.

Ghosh et al. (2010) found that conjunctive use of organic and inorganic nutrients, as well as paddy straw mulch in rapeseed–green gram cropping system under rainfed conditions, resulted in a higher yield of rapeseed as well as green gram. The uptake of NPK was higher in the treatment receiving 10 t ha⁻¹ of farmyard manure (FYM) in rapeseed along with a 50 per cent recommended dose of NPK for two consecutive years. Similar results were found by Mitra and Mandal (2012) who reported superior soil physicochemical properties with mulch-treated plots compared with no mulch treatment in rapeseed (*Brassica campestris*)–green gram (*Vigna radiata*)–rice (*Oryza sativa*) cropping system.

Awal and Sultana (2011) carried out an experiment on the mustard crop at Bangladesh Agricultural University to find out the effect of indigenous mulches viz. rice straw, ash and sawdust on microclimate, growth and yield of the mustard crop. It was found that as compared to ash mulch and control, straw and sawdust mulches increased the moisture content of the soil. Moreover, sawdust mulch showed better performances for most of the parameters like shoot height, the number of primary branches per plant, dry matter accumulation and yield components and yield.

Usage of mulching material not only conserves soil moisture but also helps in reducing soil temperature, minimizing evaporation losses and enhancing root growth (Singh et al. 2011; Faget et al. 2012).

Tetarwal et al. (2013) from Jhalawar found that application of straw mulch @ 4 t ha⁻¹ done 21 days after sowing along with kaolin 6 per cent spray at 60 DAS in Indian mustard (*Brassica juncea*) significantly increased the growth, yield attributes, seed yield, oil yield, NPS uptake, and water use efficiencies as compared to other moisture conservation practices.

Su et al. (2014) from China conducted an experiment on rice-winter oilseed rape (*Brassica napus* L.) and found that there was a positive impact of the application of rice straw mulch and nitrogen fertilization on yield and nitrogen uptake of winter oilseed rape. Rice straw mulch had the potential to enhance the productivity of winter oilseed rape.

3. MATERIALS AND METHODS

A field experiment was conducted at the Water Management Farm of CSK Himachal Pradesh Krishi Vishvavidyalaya, Palampur, during *rabi* season of 2020-2021 to study ‘**Effect of irrigation levels on the productivity of oilseed *Brassica* species under natural and conventional farming**’. The details of materials used and methods employed for carrying out the experimental work have been described in this chapter.

3.1 General description of the experimental area

3.1.1 Location of the experimental site

The experiment was conducted at the Water Management Research Farm of the Department of Soil Science, CSK Himachal Pradesh Krishi Vishvavidyalaya, Palampur. The area lies in 32° 06′ 39.1″ N latitude and 76° 32′ 10.5″ E longitude and at an elevation of 1290 m above mean sea level in North-Western Himalayas.

3.1.2 Climate

The geographical area of Palampur comes under sub temperate humid zone which is characterized by mild summers and cool winters. The mean weekly meteorological data during crop season *rabi*, 2020 recorded at Meteorological Observatory of the Department of Agronomy, College of Agriculture, CSK Himachal Pradesh Krishi Vishvavidyalaya, Palampur has been appended in Appendix-I and illustrated graphically in the in Figure 3.1. A cursory glance at Figure 3.1 and Appendix- I revealed that during the life cycle of the *Brassica* crop (October 2020 to April 2021), the mean weekly minimum and maximum temperature ranged between 0.8 °C to 13.9 °C and 14.8 °C to 28.5 °C, respectively. The total rainfall during the crop season amounted to 342.6 mm while effective rainfall was 233.3 mm, which was very low in beginning and high at later stages near harvesting. The mean relative humidity ranged between 42.7 per cent to 78.8 per cent during the cropping season. During the crop season, the mean daily evaporation was about 3.06 mm day⁻¹ with a maximum evaporation of 8.24 mm and a minimum of 1.66 mm on peak sunny and rainy days. The overall weather was partially favorable for the growth and development of the crop.

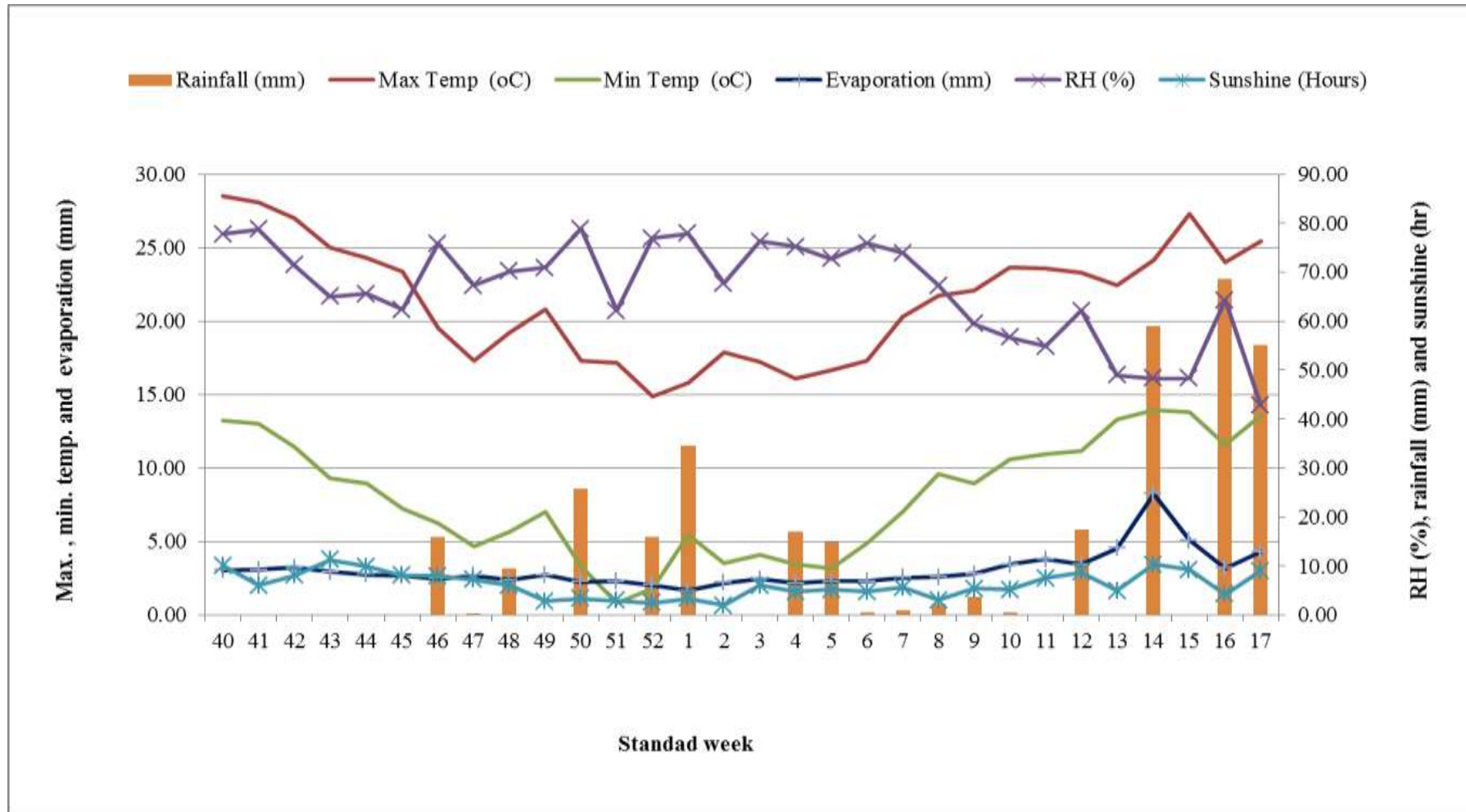
3.1.3 Soil characteristics of experimental site

Before starting the experiment, composite soil samples from 0-15 cm depth were drawn at random from the experimental site. The composite soil sample was air-dried, grounded in pestle mortar, passed through a 2 mm sieve and subjected to mechanical and chemical analysis. The results obtained after analysing the physico-chemical properties of soil have been given in Table 3.1. A perusal of data presented in Table 3.1 shows that the soil of the experimental field was acidic in reaction, medium in available nitrogen, high in available phosphorus and medium in available potassium.

Table 3.1 Physico-chemical characteristics of experimental soil (0-15 cm)

Soil properties	Value	Analytical method employed
A. Mechanical analysis (per cent)		
Sand (%)	17.5	
Silt (%)	50.0	
Clay (%)	32.5	International pipette method (Piper 1966)
Bulk density (g cm ⁻³)	1.27	
Texture	Silty clay loam	
B. Chemical properties		
pH (1:2.5, Soil: Water)	5.30	Glass electrode pH metre (Jackson 1967)
Organic carbon (g kg ⁻¹)	8.51	Wet digestion method (Walkley and Black 1934)
C. Available nutrient (kg ha⁻¹)		
Available nitrogen	263.6	Alkaline permanganate method (Subbiah and Asija 1956)
Available phosphorus	33.4	Olsen's method (Olsen et al. 1954)
Available potassium	242.6	Ammonium acetate extraction method (AOAC 1970)

Fig. 3.1 Mean weekly weather data during the crop season (14th October 2020 to 29th April 2021)



3.2 Experimental details

3.2.1 Design and layout

The experiment was laid out in split plot design with main plot consisting of irrigation levels and sub plot comprising of *Brassica* species and management practices. The treatments were replicated three times and layout plan is given in **Figure 3.2**.

3.2 Treatment details

Treatments

A. Main Plot (2)

I₁: Two irrigations at 30 DAS and flowering

I₂: Three irrigations at pre-sowing, 30 DAS and flowering

B. Sub plot: *Brassica* species (3)

B₁: *Brassica oleracea* ‘KBS 3’

B₂: *Brassica juncea* ‘RCC 4’

B₃: *Brassica napus* ‘GSC 7’

C. Sub plot: Management practices (2)

M₁: Conventional management

M₂: Natural management

Design : Split plot design

Treatment combinations: 12

Replications : 3

Total number of plots : 36

Plot size : 9 m²

Gross plot size : 1.8 m * 5.0 m = 9 m²

Net plot size : 1.2 m * 4.0 m = 4.8 m²

Fig. 3.2 Field layout of the experiment

R₁	I ₁ B ₃ M ₂	I ₁ B ₁ M ₂	I ₁ B ₂ M ₁	I ₁ B ₂ M ₂	I ₁ B ₁ M ₁	I ₁ B ₃ M ₁	I ₂ B ₁ M ₂	I ₂ B ₃ M ₂	I ₂ B ₁ M ₁	I ₂ B ₃ M ₁	I ₂ B ₂ M ₁	I ₂ B ₂ M ₂
R₂	I ₂ B ₁ M ₁	I ₂ B ₂ M ₁	I ₂ B ₂ M ₂	I ₂ B ₃ M ₂	I ₂ B ₁ M ₂	I ₂ B ₃ M ₁	I ₁ B ₂ M ₁	I ₁ B ₁ M ₂	I ₁ B ₃ M ₁	I ₁ B ₁ M ₁	I ₁ B ₃ M ₂	I ₁ B ₂ M ₂
R₃	I ₁ B ₂ M ₁	I ₁ B ₃ M ₂	I ₁ B ₂ M ₂	I ₁ B ₃ M ₁	I ₁ B ₁ M ₁	I ₁ B ₁ M ₂	I ₂ B ₂ M ₂	I ₂ B ₁ M ₂	I ₂ B ₁ M ₁	I ₂ B ₃ M ₂	I ₂ B ₂ M ₁	I ₂ B ₃ M ₁

I₁ : Two irrigations at 30 DAS and flowering

I₂ : Three irrigations at pre- sowing, 30 DAS and flowering

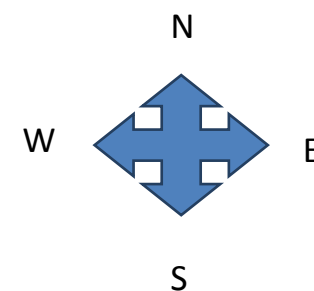
B₁ : *Brassica oleracea* ‘KBS 3’

B₂ : *Brassica juncea* ‘RCC 4’

B₃ : *Brassica napus* ‘GSC 7’

M₁ : Conventional management

M₂ : Natural management



3.3 Details of field operation

3.3.1 Preparatory cultivation

The experimental field was ploughed with the help of a power tiller. Stones, stubbles and weeds were removed from the field. Field was divided into required number of plots as per the layout plan i.e. two main plots (I₁ and I₂) followed by sub plot treatments in each main plot. The layout of experiment was carried out manually and plots were prepared and then levelled. The treatments were allocated randomly to each plot using random number table. The field arrangement of replications and plots has been shown in Fig. 3.2.

3.3.2 Irrigation method, depth and time

The irrigation method used was surface irrigation with 5 cm depth. Irrigations were given at pre-sowing, 30 DAS and flowering for I₂ and 30 DAS and flowering for I₁.

3.3.3 Soil treatment

Prior to sowing, powdered *ghanjeevamrit* @ 395 kg ha⁻¹ was applied in the soil and incorporated in the plots imposed with the natural management treatment.

3.3.4 Seed rate and sowing

In conventional management system, the seeds of mustard were soaked in water for 2 hours, dried under shade and sown in furrows while in natural treatments, seeds were treated with *beejamrit* @ 200 ml kg⁻¹ of seeds for 30 minutes, dried in shade and sown. The seeds were sown at a spacing of 30*10 cm at a depth of 2 to 2.5 cm using a seed rate of 6 kg ha⁻¹.

3.3.5 Nutrient management

The recommended dose of fertilizer was 120 kg N: 60 kg P₂O₅: 40 kg K₂O per hectare for *Brassica napus* and 60 kg N: 40 kg P₂O₅: 40 kg K₂O per hectare for *Brassica juncea* and *Brassica oleracea*. The recommended dose of phosphorus and potassium was supplied through SSP (16 % P₂O₅) and MOP (60 % K₂O), respectively, whole at the time of sowing for the conventional management system. However, nitrogen was applied through Urea (46 % N), ½ as basal application and

other ½ in two equal splits i.e. 30 DAS and at flowering. For natural management treatments, freshly prepared *Jeevamrit* diluted with water in 1:10 ratio was sprayed at 21 days intervals. The detailed composition and nutrient content of these ingredients is given in Table 3.3 and 3.4.

Table 3.3 Total nutrient applied as per the treatments

Treatment	Nutrient applied (kg ha ⁻¹)		
	N	P ₂ O ₅	K ₂ O
M ₁ (<i>Brassica napus</i>)	120	60	40
M ₁ (<i>Brassica juncea</i> , <i>Brassica oleracea</i>)	60	40	40
M ₂ (Natural farming)	9.33	3.67	3.44

M₁: 100 % NPK through inorganic sources; M₂: Natural farming (*Ghanjeevamrit* and *Beejamrit* at sowing+ *Jeevamrit* at 21 days interval)

Table 3.4 Ingredients used in natural farming and their composition

Sr. No.	Input	Ingredients	N (%)	P (%)	K (%)
1	<i>Beejamrit</i>	Cow dung – 5 kg Cow urine – 5 liter Lime – 50 g Water – 20 liter Handful of soil	2.26	0.121	0.463
2	<i>Jeevamrit</i>	Cow dung – 10 kg Cow urine – 10 liter Jaggery – 2 kg Legume flour – 2 kg Water – 200 liter Handful of soil	1.93	0.169	0.264
3	<i>Ghanjeevamrit</i>	Cow dung – 100 kg Cow urine – 10 liter Jaggery – 100g Besan – 100g	1.33	0.84	0.73

3.3.6 Weed management

In order to check the weeds, manual hand weeding was done twice (40 and 65 DAS) during the growing season. The entire soil surface was dug to shallow depth with the help of hand hoe; weeds were uprooted and then removed. In natural management, weeds were uprooted and left on surface to be used as mulch.

Table 3.5 Details of various field operations performed during *rabi* 2020-2021

Sr. No.	Activity	Date
1	Land preparation using power tiller followed by manual leveling	10 October 2020
2	Pre-sowing irrigation	10 October 2020
3	Opening of furrows, band placement of fertilizers as per treatment before sowing and treating the seeds	14 October 2020
4	Mulching (Natural)	20 October 2020
5	<i>Jeevamrit</i> application	4 November 2020
6	Irrigation applied	14 November 2020
7	Urea 1 st top dressing	16 November 2020
8	<i>Jeevamrit</i> application	24 November 2020
9	Hand weeding	25 November 2020
10	Irrigation applied	10 December 2020
11	Urea 2 nd top dressing and <i>Jeevamrit</i> application	16 December 2020
12	Hand weeding	19 December 2020
13	<i>Jeevamrit</i> application	7 January 2021
14	<i>Jeevamrit</i> application	28 January 2021
15	<i>Jeevamrit</i> application	19 February 2021
16	Insecticide spray	22 February 2021
17	<i>Jeevamrit</i> application	12 March 2021
18	1 st harvesting	17 March 2021
19	<i>Jeevamrit</i> application	3 April 2021
20	2 nd harvesting	26 April 2021
21	Threshing and winnowing	30 April 2021

3.3.7 Harvesting

When the plants turned brown (physiologically mature) harvesting was done manually with the help of sickles from net plot area. The produce of net plot was sun dried, tied in to bundles, weighed and threshed manually with wooden sticks and then cleaned before weighing.

3.3.8 Schedule of agronomic operations

The details and scheduling of various agronomic operations performed during the crop season have been tabulated in the Table 3.5.

3.4 Experimental observations

3.4.1 Growth studies

3.4.1.1 Number of plants per metre row length

The number of plants per metre was counted from the net plot using a metre scale. The recordings were taken from two places, and the average was recorded and expressed as the mean number of plants per metre row length.

3.4.1.2 Plant height

Five plants were selected at random from the net plot and tagged for taking the observation. Plant height was recorded at monthly interval starting from one month after sowing. The height of these tagged plants was recorded from ground level to the top most leaf base. The average of these plants was expressed as mean plant height in centimetres.

3.4.1.3 Dry matter accumulation

Samples for studying dry matter accumulation were taken from the second row of each plot at 30 days intervals. The plants from 50 cm row length were clipped as close to the ground as possible. The dry matter (g m^{-2}) was recorded after drying the plants in the oven to constant weight at 70°C .

3.4.2 Developmental studies

3.4.2.1 Days to 50 per cent flowering

All the plants in the plot were keenly observed for recording days to flowering. When 50 per cent plants in the plot showed anthesis, that date was noted and days were then calculated from the date of sowing.

3.4.2.2 Days to physiological maturity

Physiological maturity is reached when the seed achieves maximum dry weight which marks the end of swelling phase of the seeds (Shaw and Lumis 1950). Hence, days to physiological maturity were recorded by taking the weight of seeds from 30 siliquae from each plot after the plants have turned greenish-yellow at every 2 days interval. When the weight of seeds became constant and no increase in seed weight was observed, that was taken as its physiological maturity.

3.4.3 Yield and yield attributes

3.4.3.1 Primary branches plant⁻¹

The number of primary branches per plant was recorded from five randomly selected plants one week before the harvest from each plot. The branches that originated from the main shoot were counted as primary branches.

3.4.3.2 Secondary branches plant⁻¹

Secondary branches per plant were recorded from five randomly selected plants one week before the harvest from each plot and branches that originated from primary branches were taken as secondary branches.

3.4.3.3 Number of siliquae plant⁻¹

The number of siliquae per plant was recorded from the five randomly selected plants one week before harvest from each plot.

3.4.3.4 Number of seeds siliquae⁻¹

Fifty siliquae were taken at random from each plot and threshed manually and total seeds in these siliquae were counted.

3.4.3.5 1000 seed weight (g)

One thousand seeds were counted from the produce of each plot and weighed and expressed in gram (g).

3.4.4 Seed yield (kg ha⁻¹)

The sun-dried bundles from the net plot with a constant weight (12 per cent moisture content) were threshed. The seeds were weighed and expressed as kg ha⁻¹.

3.4.5 Stover yield (kg ha⁻¹)

After threshing, the bundles of the net plot were weighed and expressed as kg ha⁻¹ and summed up.

3.4.6 Biological yield (kg ha⁻¹)

The crop was harvested manually from each plot and tied into bundles, separating them into the gross plot and net plot bundles. The piles were left in the field for drying until constant weight has reached. The sun-dried bundles from the net plot were weighed for their biological (above-ground) yield.

3.4.7 Harvest Index (%)

Harvest index was calculated as follows:

$$HI = \frac{\text{Grain yield (kg/ha)}}{\text{Biological yield (kg/ha)}} \times 100$$

3.4.8 Soil and water studies

3.4.8.1 Soil moisture determination at 0-15 cm and 15-30 cm depth before and after irrigation and at 15 days interval

The soil water studies included changes in soil water content and soil water stock. The changes in soil water content before and after irrigation at 0-15 cm and 15-30 cm depths were determined using the gravimetric method.

3.4.8.2 Soil pH, OC and available N, P and K content in the soil before sowing and after harvest of the crop

Before starting the experiment and after completing the investigation, soil samples from surface soil (0-15 cm) were collected from each experimental plot. The samples were air-dried, ground, passed through a 2 mm sieve and were subjected to analysis of soil pH, organic carbon, available N, P and K as per methods given in Table 3.1.

3.4.9 Water use efficiency Indices

3.4.9.1 Consumptive water use (mm)

*Consumptive water use was calculated using formula given by FAO (Appendix III).

Total water use = Effective rainfall + Total water applied through irrigation + ΔS

3.4.9.2 Water productivity (kg m^{-3})

Water productivity (WP) was computed as follows:

$$\text{WP (kg m}^{-3}\text{)} = \frac{\text{Seed Yield (kg ha}^{-1}\text{)}}{\text{Total water use (mm)}}$$

3.4.9.3 Biomass water use efficiency ($\text{kg ha}^{-1} \text{mm}^{-1}$)

$$\text{Biomass water use efficiency} = \frac{\text{Biological yield (kg ha}^{-1}\text{)}}{\text{Total water use (mm)}}$$

3.4.9.4 Irrigation water use efficiency ($\text{kg ha}^{-1} \text{mm}^{-1}$)

Irrigation water use efficiency was worked out as:

$$\text{IWUE} = \frac{\text{Yield (kg ha}^{-1}\text{)}}{\text{Irrigation water use (mm)}}$$

3.4.10 Plant and quality analysis

3.4.10.1 NPK uptake at harvest

The samples of seeds and stover from each plot were collected and subjected to chemical analysis after drying and processing by adopting the following methods of plant analysis.

Table 3.6 Analytical methods used for plant analysis

Nutrient	Method
Nitrogen	Modified micro-Kjeldahl's method (Jackson 1973)
Phosphorous	Vanado-molybdate-phosphoric acid method (Jackson 1973)
Potassium	Flame photometre technique (Jackson 1967)

Total uptake of N, P and K by crop was calculated by multiplying the percentage of each nutrient in seed with seed yield (kg ha^{-1}) and percentage of each nutrient in stover with stover yield (kg ha^{-1}) and summing up both.

3.4.10.2 Oil content and oil yield

Oil was extracted from the seed samples by the Soxhlet apparatus for determining oil percentage. For estimating oil content, the seeds from each sample were dried at 105 ± 2 °C in a hot air oven for 16 hours and cooled in a desiccator for half an hour. From this, 2 g of seeds were ground in a porcelain mortar and packed

adequately in Whatman No.1 filter. After weighing round bottom flask (A), this was transferred to an extraction thimble. The thimble was then placed inside the Soxhlet extractor to a sufficient quantity (100 ml) of petroleum ether solvent with a boiling point of 40-60°C was added and heated for six hours until 6-8 siphoning were completed. Then the filter paper packet was taken out and the extractant and oil mixture was collected in a round bottom flask which was then dried in a hot air oven maintained at $105 \pm 2^\circ\text{C}$ for 6 hours, cooled in a desiccator for half an hour and weighed (B). The oil content was calculated using the following formula and expressed as a percentage. The total yield of oil was computed by multiplying seed yield and oil percentage.

$$\text{Oil content} = \frac{B-A}{2} \times 100$$

$$\text{Oil yield (kg ha}^{-1}\text{)} = \text{Seed yield} \times \text{Oil content}$$

3.4.11 Economic studies

3.4.11.1 Cost of cultivation (₹ ha⁻¹)

The cost of cultivation was calculated by adding all costs involved in each operation and input. The details of prevailing market prices and components of economics have been given in appendix VI.

3.4.11.2 Gross returns (₹ ha⁻¹)

The treatment-wise seed and stover yields were multiplied with their respective market prices. The gross returns were calculated by adding returns received from seed and stover yields.

3.4.11.3 Net returns (₹ ha⁻¹)

The treatment-wise net returns were obtained by subtracting the cost of cultivation from the gross returns of the respective treatments.

3.4.11.4 Benefit Cost ratio (B:C ratio)

The benefit to cost ratio was obtained by dividing net returns by the cost of cultivation.

3.4.12 Statistical analysis

The data were analyzed using standard statistical techniques as suggested by Gomez and Gomez (1984). Wherever the effects were significant at a 5 per cent level of probability, the CD was calculated.

4. RESULTS AND DISCUSSION

The results obtained from the present investigation entitled ‘**Effect of irrigation levels on productivity of oilseed *Brassica* species under natural and conventional farming**’ conducted during *rabi* 2020-2021 at Water Management Farm, CSK Himachal Pradesh Krishi Vishvavidyalaya, Palampur have been presented in this chapter. The interaction effect of treatments, wherever found significant, is described after the main effects. An attempt has been made to explain the crucial findings by establishing a cause and effect relationship based on available data and literature evidence.

4.1 Effect of treatments on growth and developmental studies

4.1.1 Growth studies

4.1.1.1 Plant population at harvest

The data on plant population per metre row length at harvest as influenced by different irrigation levels and management practices given in Table 4.1 revealed that the plant population in different *Brassica* species did not differ significantly at varying irrigation levels as well as with different management practices.

4.1.1.2 Plant height

The data on the effect of irrigation levels and management practices on plant height of different *Brassica* species recorded has been presented in Table 4.1. A critical examination of data showed that irrigation levels significantly influenced the plant height of *Brassica* species at all the stages of observation. At all the growth stages except at 30 DAS, significantly taller plants were recorded when three irrigations were given to the crop viz. pre-sowing, 30 DAS and flowering (I_2) over two irrigations (I_1) i.e. 30 DAS and flowering. However, at 30 DAS, plant height was not found significant. The taller plants in I_2 level of irrigation might be due to pre-sowing irrigation, helping in better root establishment leading to good crop establishment right from the beginning, hence resulting in taller plants (Chen et al. 2019). The results are in proximity with those of Sarkar and Pal (2004) and Verma et al. (2014).

Table 4.1 Effect of irrigation levels, *Brassica* species and management practices on plant population (per metre row length) and plant height (cm)

Treatment	Plant population		Plant height (cm)		
	At harvest	30 DAS	60 DAS	90 DAS	At harvest
Irrigation levels					
I ₁	14.2	9.2	22.3	68.8	107.6
I ₂	15.0	9.6	24.8	74.1	114.3
SEm±	0.2	0.1	0.4	0.8	1.1
CD (p=0.05)	NS	NS	2.4	4.9	6.4
<i>Brassica</i> species					
B ₁ - <i>Brassica oleracea</i> ‘KBS 3’	15.2	10.5	26.4	80.5	119.1
B ₂ - <i>Brassica juncea</i> ‘RCC 4’	14.4	9.4	23.2	70.7	109.8
B ₃ - <i>Brassica napus</i> ‘GSC 7’	14.3	8.3	21.1	63.2	103.9
SEm±	0.3	0.2	0.5	0.8	0.7
CD (p=0.05)	NS	0.6	1.4	2.4	2.0
Management practices					
M ₁ -Conventional management	14.9	10.9	27.8	89.6	134.2
M ₂ - Natural management	14.3	7.9	19.3	53.3	87.6
SEm±	0.2	0.2	0.4	0.7	0.6
CD (p=0.05)	NS	0.5	1.2	1.9	1.7

I₁: Irrigation at 30 DAS and flowering; I₂: Irrigation at pre-sowing, 30 DAS and flowering

Different *Brassica* species differed significantly in plant height at all the stages of observation. Significantly taller plants were recorded in *Brassica oleracea* ‘KBS 3’ followed by *Brassica juncea* ‘RCC 4’ and *Brassica napus* ‘GSC 7’. The taller plants in ‘KBS 3’ might be due to its inherent genetic character, which has higher adaptability and suitability for this region.

Plant height was also significantly influenced by different management practices and significantly taller plants were recorded with conventional management system compared to natural system at all the stages of observation. The plants require N and P for robust root and shoot growth; however, the supply of these vital nutrients in natural management system is not adequate. The plant height in conventional system was significantly higher due to easy and adequate availability of the vital plant

nutrients, which plants readily absorb during their vegetative phase. Similar results were reported by Thanki et al. (2004); Kumar and Kumar (2007) and Adhikari (2009).

A significant interaction effect between irrigation levels and *Brassica* species on plant height was found at harvest stage (Table 4.2). At both the irrigation levels, significantly taller plants were recorded in *Brassica oleracea* ‘KBS 3’ (B₁) followed by *Brassica juncea* ‘RCC 4’ (B₂) and *Brassica napus* ‘GSC 7’ (B₃).

Further perusal of data revealed that *Brassica oleracea* ‘KBS 3’ with three irrigation regimes (I₂) being statistically at par with *Brassica oleracea* ‘KBS 3’ with two irrigation regimes (I₁) resulted in significantly taller plants over all other treatments. The latter treatment was in turn found statistically at par with *Brassica juncea* ‘RCC 4’ under three irrigation levels. Significantly shorter plants were recorded in *Brassica napus* ‘GSC 7’ with two irrigations.

Table 4.2 Interaction effect of irrigation levels and *Brassica* species on plant height (at harvest)

<i>Brassica</i> species	Irrigation levels	
	I ₁	I ₂
B ₁ - <i>Brassica oleracea</i> ‘KBS 3’	117.3	120.8
B ₂ - <i>Brassica juncea</i> ‘RCC 4’	105.5	114.2
B ₃ - <i>Brassica napus</i> ‘GSC 7’	100.0	107.8
	S $E_{m\pm}$	CD (p=0.05)
<i>Brassica</i> species at same irrigation levels	1.0	2.9
Irrigation levels at same or different <i>Brassica</i> species	1.3	5.4

The interaction between *Brassica* species and management practices was found significant for plant height at 90 DAS (Table 4.3). Under both the management system significantly taller plants were obtained from *Brassica oleracea* ‘KBS 3’ followed by *Brassica juncea* ‘RCC 4’ and *Brassica napus* ‘GSC 7’. Further, the tallest plants were observed in *Brassica oleracea* ‘KBS 3’ under conventional management system whereas the shortest plants (46.3 cm) were noticed in *Brassica napus* ‘GSC 7’ when grown under natural management system.

Table 4.3 Interaction effect of management practices and *Brassica* species on plant height at 90 DAS

<i>Brassica</i> species	Management practices	
	Conventional management	Natural management
B ₁ - <i>Brassica oleracea</i> ‘KBS 3’	97.9	63.1
B ₂ - <i>Brassica juncea</i> ‘RCC 4’	90.9	50.5
B ₃ - <i>Brassica napus</i> ‘GSC 7’	80.1	46.3
SEm±	1.1	
CD (p=0.05)	3.4	

4.1.1.3 Dry matter accumulation

Data pertaining to dry matter accumulation in different *Brassica* species as influenced by different irrigation levels and management practices have been presented in Table 4.4.

Different irrigation regimes significantly influenced the dry matter accumulation with significantly higher dry matter accumulation recorded when the crop was irrigated thrice (I₂) over two irrigations (I₁) at all stages of observation. Significantly higher dry matter accumulation in (I₂) may be attributed to pre-sowing irrigation, which significantly increased root distribution and physiological activity in the surface or deep soil profile (Chen et al. 2019). This improvement in root traits contributed to greater shoot biomass and higher reproductive organ biomass accumulation. Many studies indicated that larger root biomass could absorb more nitrogen and water from the soil and support a greater rate of aboveground biomass production (Yang et al. 2004; Zhang et al. 2009 and Wasson et al. 2012). The results are also supported by studies of Rana et al. (2007) and Piri et al. (2011) in Indian mustard.

Dry matter accumulation in all the *Brassica* species differed significantly at all stages of observation. *Brassica oleracea* ‘KBS 3’ recorded significantly higher dry matter accumulation followed by *Brassica juncea* ‘RCC 4’ and *Brassica napus* ‘GSC 7’. Each species differed significantly from one another. Dry matter is also positively

correlated with plant height; hence significantly higher dry matter accumulation was recorded in *Brassica oleracea* ‘KBS 3’, where the tallest plants were also observed.

Table 4.4 Effect of irrigation levels, *Brassica* species and management practices on dry matter accumulation (g m^{-2})

Treatment	Dry matter accumulation (g m^{-2})			
	30 DAS	60 DAS	90 DAS	At harvest
Irrigation levels				
I ₁	14.4	129.9	265.5	400.1
I ₂	16.4	138.9	285.9	435.2
SEm±	0.3	1.5	2.0	5.7
CD (p=0.05)	1.9	8.9	12.2	34.6
<i>Brassica</i> species				
B ₁ - <i>Brassica oleracea</i> ‘KBS 3’	18.7	162.3	332.0	461.1
B ₂ - <i>Brassica juncea</i> ‘RCC 4’	16.1	127.8	270.2	420.5
B ₃ - <i>Brassica napus</i> ‘GSC 7’	11.3	113.1	224.8	371.3
SEm±	0.3	1.3	2.2	3.3
CD (p=0.05)	1.0	3.9	6.5	9.8
Management practices				
M ₁ -Conventional management	20.2	178.9	342.8	472.8
M ₂ - Natural management	10.6	90.0	208.6	362.5
SEm±	0.3	1.1	1.8	2.7
CD (p=0.05)	0.8	3.2	5.3	8.0

I₁: Irrigation at 30 DAS and flowering; I₂: Irrigation at pre-sowing, 30 DAS and flowering

Among management practices, the conventional management system resulted in significantly higher dry matter accumulation at all the growth stages over natural management system. In conventional management system, adequate amount and readily available forms of nutrients from chemical fertilizers might have increased the growth of plants, thereby increasing their height resulting in higher dry matter accumulation. Moreover, an elevated supply of nitrogen boosted dry matter accumulation through the production of photo assimilates via leaves which is the centre of plant growth during the vegetative stage and later distribution of assimilates to the reproductive organ of the plants (Dordas and Sioulas 2008; Azarpour et al.

2014). The results are in conformity with those of Sahu et al. (2011); Singh and Pal (2011) and Kumar et al. (2018).

Interaction effect of different management practices and *Brassica* species on dry matter accumulation was found significant at 30 DAS and 90 DAS (Table 4.5). At both 30 and 90 DAS, significantly higher dry matter accumulation was recorded in *Brassica oleracea* ‘KBS 3’ when grown under conventional management system followed by *Brassica juncea* ‘RCC 4’ and *Brassica napus* ‘GSC 7’ grown under same management system. The lowest dry matter accumulation was recorded in *Brassica napus* ‘GSC 7’ when raised under natural management system.

Table 4.5 Interaction effect of management practices and *Brassica* species on dry matter accumulation (g m^{-3}) at 30 DAS and 90 DAS

<i>Brassica</i> species	Management practices		Dry matter accumulation	
			(30 DAS)	(90 DAS)
	Conventional management	Natural management	Conventional management	Natural management
B ₁ - <i>Brassica oleracea</i> ‘KBS 3’	24.2	13.2	435.1	228.9
B ₂ - <i>Brassica juncea</i> ‘RCC 4’	20.3	12.0	333.0	207.5
B ₃ - <i>Brassica napus</i> ‘GSC 7’	16.0	6.7	260.3	189.3
SEm±		0.5		3.1
CD (p=0.05)		1.4		9.3

Interaction effect among irrigation levels, *Brassica* species and management practices was found significant at harvest and is presented in Table 4.6. At harvest, significantly higher dry matter accumulation was recorded in *Brassica oleracea* ‘KBS 3’ raised under conventional management system with three irrigation regimes although it was statistically at par with *Brassica oleracea* ‘KBS 3’ under conventional management system with two irrigation regime. The lowest dry matter accumulation was recorded in *Brassica napus* ‘GSC 7’ under natural management system with two irrigation regime (I₁).

Table 4.6 Interaction effect of irrigation levels, *Brassica* species and management practices on dry matter accumulation at harvest (g m⁻³)

Treatments	Dry matter accumulation (At harvest)
I ₁ B ₁ C ₁	508.9
I ₁ B ₁ C ₂	382.2
I ₁ B ₂ C ₁	457.3
I ₁ B ₂ C ₂	358.4
I ₁ B ₃ C ₁	403.3
I ₁ B ₃ C ₂	290.4
I ₂ B ₁ C ₁	533.2
I ₂ B ₁ C ₂	420.0
I ₂ B ₂ C ₁	495.7
I ₂ B ₂ C ₂	370.6
I ₂ B ₃ C ₁	438.3
I ₂ B ₃ C ₂	353.3
SEm±	8.3
CD	36.7

I₁: Irrigation at 30 DAS and flowering; I₂: Irrigation at pre-sowing, 30 DAS and flowering, B₁- *Brassica oleracea* ‘KBS 3’, B₂- *Brassica juncea* ‘RCC 4’, B₃- *Brassica napus* ‘GSC 7’; M₁- Conventional management, M₂- Natural management

4.1.2 Developmental and root studies

4.1.2.1 Days to 50 per cent flowering

The data on days to 50 per cent flowering as influenced by different irrigation levels and management practices have been presented in Table 4.7. Data revealed that days to 50 per cent flowering were not influenced significantly by different irrigation levels. However, various *Brassica* species differed significantly for number of days taken to 50 per cent flowering. Significantly minimum number of days (62.8 days) for 50 per cent flowering was taken by *Brassica oleracea* ‘KBS 3’ followed by *Brassica juncea* ‘RCC 4’ while *Brassica napus* ‘GSC 7’ took maximum number of days to reach 50 per cent flowering. Days taken to 50 per cent flowering is a genetic attribute with little influence of agronomic practices. Growth phase of brown sarson showed

synchronization with optimum environment for better expression of growth and yield. *Brassica oleracea* ‘KBS 3’ being early in flowering and maturity faced less abiotic stress of temperature and moisture compared to other species which were late (Rathore et al. 2012 and Akhtar et al. 2015).

Among different management practices, natural management system took significantly longer days (69.1 days) for 50 per cent flowering over conventional system. Plants experiencing transient N deficiency had slower leaf emergence than plants with a continuous supply of nitrogen. The effect of N deficiency on flowering time was primarily a result of slower leaf emergence (Ma et al. 1997). Low N and P availability in natural system during the early stages of growth might have interfered with the initiation and development of leaves and flowers and the overall maturity of the plant.

The interaction between irrigation levels and management practices with respect to days to 50 per cent flowering was not significant.

4.1.2.2 Days to physiological maturity

The data on the effect of different irrigation levels and management practices on the number of days taken for physiological maturity by different *Brassica* species is presented in Table 4.7. Data showed that irrigation levels had no significant influence on the days taken to physiological maturity.

A further perusal of data revealed that the number of days taken to physiological maturity differed significantly among various *Brassica* species, *Brassica napus* ‘GSC 7’ took the maximum number of days for physiological maturity followed by *Brassica juncea* ‘RCC 4’ and *Brassica oleracea* ‘KBS 3’. The difference is due to their genetic build up.

Among different management practices natural management system took significantly longer days for physiological maturity than under conventional system. Slower growth during different phenological phases, starting from germination, might have contributed to delayed physiological maturity in natural management systems. Since sulphur plays an essential role in oilseed crops for its proper growth and development (Raza et al. 2018) stunting of plants and delayed maturity in natural

management system may be due to inadequate supply of sulphur and other nutrients. However, in conventional system, sulphur alongwith other nutrients were supplied in adequate amount through chemical which resulted in the normal functioning of the plants.

Table 4.7 Effect of irrigation levels, *Brassica* species and management practices on days taken for different phenophases and root biomass (g m⁻²)

Treatment	Days to 50 % flowering	Days to physiological maturity	Root biomass (g m ⁻²)
Irrigation levels			
I ₁	68.2	153.8	1.77
I ₂	68.1	152.8	1.98
SEm±	0.6	0.3	0.02
CD (p=0.05)	NS	NS	0.14
<i>Brassica</i> species			
B ₁ - <i>Brassica oleracea</i> ‘KBS 3’	62.8	142.3	2.27
B ₂ - <i>Brassica juncea</i> ‘RCC 4’	68.0	155.3	1.93
B ₃ - <i>Brassica napus</i> ‘GSC 7’	73.6	162.3	1.42
SEm±	0.6	0.4	0.05
CD (p=0.05)	1.7	1.3	0.15
Management practices			
M ₁ - Conventional management	67.1	151.8	2.45
M ₂ - Natural management	69.1	154.8	1.30
SEm±	0.5	0.4	0.04
CD (p=0.05)	1.4	1.0	0.12

I₁: Irrigation at 30 DAS and flowering; I₂: Irrigation at pre-sowing, 30 DAS and flowering

The interaction effect of different irrigation levels and management practices on days taken to physiological maturity by different *Brassica* species was not significant.

4.1.2.3 Root biomass

Table 4.7 presents the data regarding root biomass. Different irrigation levels and management practices had a significant influence on root biomass of different

Brassica species. A significantly higher root biomass was recorded with three irrigation regimes (I_2) compared to two irrigations (I_1). The better root biomass in I_2 can be attributed to pre-sown irrigation which helped in better germination and early establishment of viable root system right from the beginning (Mandal et al. 2009).

Among different *Brassica* species significantly higher root biomass was observed in *Brassica oleracea* ‘KBS 3’ followed by *Brassica juncea* ‘RCC 4’ and *Brassica napus* ‘GSC 7’. Different management practices also differ with respect to root biomass and significantly higher root biomass was recorded under conventional management system over natural system. The higher total root biomass has been reported with N fertilization and irrigation by Mandal et al. (2009).

The interaction effect of different irrigation levels and management practices on days to physiological maturity by different *Brassica* species was not significant.

4.1.3 Yield attributes

The data on the number of primary branches per plant, secondary branches per plant, siliquae per plant and seeds per siliquae in different *Brassica* species as influenced by different irrigation levels and management practices have been presented in Table 4.8.

4.1.3.1 Number of primary branches per plant

A keen examination of data given in Table 4.8 revealed that irrigation levels significantly influenced the number of primary branches per plant in different *Brassica* species. The *Brassica* crop provided with three irrigations (I_2) at pre-sowing, 30 DAS and flowering stage recorded a significantly higher number of primary branches per plant over two irrigations (I_1). Hasanuzzaman et al. (2008) and Sultana et al. (2009) also reported an increase in number of branches with increasing irrigation levels.

A further perusal of data showed that significant variations were observed among all *Brassica* species for number of primary branches per plant. *Brassica oleracea* ‘KBS 3’ gave significantly higher number of primary branches per plant followed by *Brassica juncea* ‘RCC 4’ and *Brassica napus* ‘GSC 7’. In that order, each species differed significantly from one another.

Table 4.8 Effect of irrigation levels, *Brassica* species and management practices on yield attributes

Treatment	Primary branches	Secondary branches	Siliquae per plant	Seeds per siliquae	1000-seed weight
Irrigation levels					
I ₁	4.08	5.17	98.92	11.22	3.13
I ₂	4.52	5.80	109.14	12.75	3.15
SEm±	0.05	0.10	0.74	0.12	0.02
CD (p=0.05)	0.30	0.61	4.49	0.76	NS
<i>Brassica</i> species					
B ₁ - <i>Brassica oleracea</i> ‘KBS 3’	5.51	5.91	110.52	12.63	3.21
B ₂ - <i>Brassica juncea</i> ‘RCC 4’	3.98	5.84	104.48	12.00	3.00
B ₃ - <i>Brassica napus</i> ‘GSC 7’	3.40	4.71	97.10	11.33	3.19
SEm±	0.06	0.09	0.91	0.13	0.03
CD (p=0.05)	0.18	0.28	2.70	0.37	0.10
Management practices					
M ₁ - Conventional management	5.09	6.48	119.31	12.98	3.15
M ₂ - Natural management	3.50	4.50	88.75	11.00	3.12
SEm±	0.05	0.08	0.75	0.10	0.03
CD (P=0.05)	0.15	0.22	2.20	0.30	NS

I₁: Irrigation at 30 DAS and flowering; I₂: Irrigation at pre-sowing, 30 DAS and flowering

Among different management practices, a significantly higher number of primary branches per plant were observed when the crop was raised with conventional management system over natural management. The results are in conformity with those of Mohiuddin et al. (2011) and Sahu et al. (2011) who have also observed more branching with addition of nutrients.

Table 4.9 Interaction effect of irrigation levels and *Brassica* species on primary branches plant⁻¹

<i>Brassica</i> species	Irrigation levels	
	Primary branches plant ⁻¹	
	I ₁	I ₂
B ₁ - <i>Brassica oleracea</i> ‘KBS 3’	5.11	5.92
B ₂ - <i>Brassica juncea</i> ‘RCC 4’	3.85	4.10
B ₃ - <i>Brassica napus</i> ‘GSC 7’	3.27	3.53
	SEm±	CD (p=0.05)
<i>Brassica</i> species at same irrigation levels	0.09	0.26
Irrigation at same or different <i>Brassica</i> species	0.09	0.45

Table 4.9 shows that the interaction between irrigation levels and *Brassica* species was found significant for number of primary branches per plant. Data showed that at both the irrigation regimes viz. I₁ and I₂, the number of primary branches per plant in *Brassica oleracea* ‘KBS 3’ was significantly higher followed by *Brassica juncea* ‘RCC 4’ and *Brassica napus* ‘GSC 7’.

A further perusal of data revealed that *Brassica oleracea* ‘KBS 3’ provided with three irrigations resulted in the highest number of primary branches per plant. However, the lowest number of primary branches was recorded in *Brassica napus* ‘GSC 7’ when raised with two irrigations. The primary branches per plant in *Brassica juncea* and *Brassica napus* were at par at both the levels of irrigation.

Table 4.10 Interaction effect of management practices and *Brassica* species on primary branches plant⁻¹

<i>Brassica</i> species	Management practices	
	Primary branches plant ⁻¹	
	Conventional management	Natural management
B ₁ - <i>Brassica oleracea</i> ‘KBS 3’	6.59	4.43
B ₂ - <i>Brassica juncea</i> ‘RCC 4’	4.71	3.25
B ₃ - <i>Brassica napus</i> ‘GSC 7’	3.97	2.83
SEm±	0.09	
CD (p=0.05)	0.26	

The data on the interaction effect of management system and *Brassica* species on the number of primary branches per plant is presented in Table 4.10. A perusal of data showed that significantly higher number of primary branches per plant was recorded by *Brassica oleracea* ‘KBS 3’ when raised with conventional management system followed by *Brassica juncea* ‘RCC 4’ under same management system and *Brassica napus* ‘GSC 7’ grown under natural management system. The lowest number of primary branches was recorded in *Brassica napus* ‘GSC 7’ when raised with natural management system.

4.1.3.2. Number of secondary branches per plant

A perusal of data in Table 4.8 revealed that significant variations were noticed among irrigation levels for numbers of secondary branches per plant. Irrigation given at three stages viz. pre-sowing, 30 DAS and flowering recorded a significantly higher number of secondary branches per plant over irrigations at two stages viz. 30 DAS and flowering. Similar results were shown by Nagdive et al. (2007) and Sultana et al. (2009) where higher number of irrigations increased the branching.

Among *Brassica* species, a statistically similar number of secondary branches per plant were observed by *Brassica oleracea* ‘KBS 3’ and *Brassica juncea* ‘RCC 4’ and this was significantly higher than *Brassica napus* ‘GSC 7’.

Table 4.11 Interaction effect of irrigation levels and management practices on secondary branches plant⁻¹

Management practices	Irrigation levels	
	I ₁	I ₂
M ₁ - Conventional management	6.04	6.91
M ₂ - Natural management	4.30	4.70
	SEm±	CD (p=0.05)
Management practices at same irrigation levels	0.11	0.32
Irrigation levels at same or different management practices	0.13	0.52

Number of secondary branches differed with different management practices. Conventional management system recorded a significantly higher number of

secondary branches per plant over natural management system. The results were in conformity with Kumar and Kumar (2007) and Kumar et al. (2010) who also observed more number of branches with increased fertility levels over low nutrient application.

Data presented in Table 4.11 shows that the interaction effect of irrigation level and management practices on the number of secondary branches of *Brassica* species. A critical analysis of data revealed that at both the irrigation levels, significantly higher number of secondary branches was obtained when the crop was raised with conventional management system over natural management.

A further perusal of data revealed that the highest number of secondary branches was observed when three irrigations (I_2) were given to the crop raised with conventional management system. The least number of secondary branches per plant were recorded in natural management system with the application of two irrigations though it was at par with crop raised under natural system with three irrigations.

4.1.3.3. Number of siliquae per plant

The data on the number of siliquae per plant in different *Brassica* species as influenced by different irrigation levels and management practices is given in Table 4.8. Data revealed that three irrigations given to crop at pre-sowing, 30 DAS and flowering resulted in a significantly higher number of siliquae per plant over two irrigations. A well-developed root system attributed to pre-sowing irrigation which enhanced the moisture and nutrient uptake during the different plant phenological stages might have contributed to better growth leading to an increase in the number of siliquae per plant. This result is in conformity with Padmani et al. (1992) and Hasanuzzaman and Karim (2007) who have also reported higher number of siliquae per plant with higher irrigation levels.

All the *Brassica* species differed significantly for the number of siliquae per plant. *Brassica oleracea* 'KBS 3' recorded significantly higher number of siliquae followed by *Brassica juncea* 'RCC 4' and *Brassica napus* 'GSC 7'. This might be attributed to the inherent genetic make up of the different species.

Among different management practices, the highest number of siliquae per plant was recorded in conventional management system over natural management. Crop plants are sensitive to nutrient deficiency during their vegetative and reproductive phase, primarily to macronutrients, as available nitrogen in vegetative organs is a decisive factor in determining the length of the seed filling period, this has a close relationship with yield performance (Munier-Jolain et al. 1996). Further, nitrogen assimilation or redistribution during the reproductive period is a limiting factor for yield attributes and seed yield. In natural management systems, this nutrient demand cannot be met in adequate amounts matching the demand in various stages. However, nitrogen topdressing in conventional management satisfied the rapid nitrogen demand during the reproductive phase resulting in a higher number of siliquae per plant (Wood et al. 1993). Similar results were reported by Premi and Kumar (2004) and Thanki et al. (2004).

Table 4.12 Interaction effect of irrigation levels, *Brassica* species and management practices on siliquae plant⁻¹

Treatments	Siliquae plant⁻¹
I ₁ B ₁ C ₁	121.33
I ₁ B ₁ C ₂	84.33
I ₁ B ₂ C ₁	115.44
I ₁ B ₂ C ₂	86.34
I ₁ B ₃ C ₁	109.16
I ₁ B ₃ C ₂	76.92
I ₂ B ₁ C ₁	130.00
I ₂ B ₁ C ₂	106.40
I ₂ B ₂ C ₁	122.91
I ₂ B ₂ C ₂	93.21
I ₂ B ₃ C ₁	117.00
I ₂ B ₃ C ₂	85.30
SEm±	1.82
CD	6.31

I₁: Irrigation at 30 DAS and flowering; I₂: Irrigation at pre-sowing, 30 DAS and flowering, B₁- *Brassica oleracea* 'KBS 3', B₂- *Brassica juncea* 'RCC 4', B₃- *Brassica napus* 'GSC 7'; M₁- Conventional management, M₂- Natural management

Data given in Table 4.12 showed a significant interaction between irrigation levels, *Brassica* species and management practices. Significantly higher number of siliquae per plant was recorded in *Brassica oleracea* ‘KBS 3’ when raised under conventional management system with three irrigation regimes. However, statistically similar number of siliquae per plant were recorded by *Brassica oleracea* ‘KBS 3’ grown under conventional system with two irrigations, *Brassica juncea* ‘RCC 4’ raised under conventional system with three irrigations and *Brassica napus* ‘GSC 7’ raised under conventional system with three irrigations. The lowest number of siliquae per plant was recorded in *Brassica napus* ‘GSC 7’ when raised under natural management system with two irrigations.

Table 4.13 Interaction effect of irrigation levels and *Brassica* species on siliquae plant⁻¹

<i>Brassica</i> species	Irrigation levels	
	I ₁	I ₂
B ₁ - <i>Brassica oleracea</i> ‘KBS 3’	102.83	118.20
B ₂ - <i>Brassica juncea</i> ‘RCC 4’	100.89	108.06
B ₃ - <i>Brassica napus</i> ‘GSC 7’	93.04	101.15
	SEm±	CD (p=0.05)
<i>Brassica</i> species at same irrigation levels	1.29	3.81
Irrigation at same or different <i>Brassica</i> species	1.29	6.51

Table 4.13 showed the interaction effect of irrigation levels and *Brassica* species on the number of siliquae per plant. When irrigation was provided to the *Brassica* species twice, a statistically similar number of siliquae were recorded by *Brassica oleracea* ‘KBS 3’ and *Brassica juncea* ‘RCC 4’. However, the application of three irrigations recorded a significantly higher number of siliquae per plant in *Brassica oleracea* ‘KBS 3’ followed by *Brassica juncea* ‘RCC 4’ and *Brassica napus* ‘GSC 7’.

A further perusal of data revealed that the highest number of siliquae per plant was recorded by *Brassica oleracea* ‘KBS 3’ when it was irrigated thrice and a significantly lower number of siliquae per plant were observed in *Brassica napus* ‘GSC 7’ when irrigated twice.

The interaction effect of irrigation levels and management practices on siliquae per plant was found significant and is presented in Table 4.14. At both the irrigation regimes viz. I₁ and I₂, significantly higher number of siliquae were recorded when the crop was raised with conventional management system over natural system. Overall, conventional system with three irrigations provided the highest number of siliquae per plant and the lowest number of siliquae were recorded under natural management system along with two irrigations. The reason might be that under conventional system the direct application of inorganic nutrients to soil are easily mobilized by water applied resulting in better uptake and distribution (Alizadeh and Nadian 2010), whereas under natural management system the basics was we add microbes which are assumed to mobilize the nutrients in soil but the release under natural system may be slow hence poor growth leading to lower yield attributes compared to conventional system where nutrients are applied directly.

Table 4.14 Interaction effect of irrigation levels and management practices on siliquae plant⁻¹ and seeds siliquae⁻¹

Management practices	Irrigation levels		Seeds siliquae ⁻¹	
	I ₁	I ₂	I ₁	I ₂
M ₁ - Conventional management	115.31	123.30	12.43	13.52
M ₂ - Natural management	82.53	94.97	10.02	11.98
	SEm±	CD (p=0.05)	SEm±	CD (p=0.05)
Management practices at same irrigation levels	1.06	3.11	0.14	0.43
Irrigation levels at same or different management practices	1.05	4.76	0.16	0.68

4.1.3.4. Number of seeds per siliquae

A perusal of data in Table 4.8 revealed that significant variations were noticed among irrigation levels for seeds per siliquae. Significantly higher number of seeds per siliquae was recorded when three irrigations (I₂) were provided to the crop. Since the root system in crop provided with three irrigations was properly developed

as a result of pre-sowing irrigation, hence the uptake and translocation of nutrients were also higher, which resulted in a higher number of seeds per siliquae. Similar findings showing more seeds with higher levels of irrigations have been reported by Tahir et al. (2007) and Hossain et al. (2013).

Different *Brassica* species also differed significantly in the number of seeds per siliquae, where a significantly higher number of seeds per siliquae were recorded by *Brassica oleracea* 'KBS 3' followed by *Brassica juncea* 'RCC 4' and *Brassica napus* 'GSC 7', each species differing significantly. The better growth attributes i.e. higher dry matter accumulation and branches may have contributed to better source and sink relationship leading to higher number of seeds per siliquae.

Among different management practices, the conventional management system produced significantly higher number of seeds per siliquae than the natural management system. Inadequate K during the reproductive phase may have an adverse effect on this mechanism and reduce the transport of assimilates, especially to the formation of seeds. Inorganic fertilizers provide plant nutrients in readily available forms; nutrient demand can be easily met through this management system. Similar results were observed by Kumar et al. (2017 a) and Thaneswar et al. (2017).

Data pertaining to the interaction effect of irrigation levels and management practices on number of seeds per siliquae have been presented in Table 4.14. At both irrigation regimes, a significantly higher number of seeds per siliquae were recorded under conventional management system compared to natural management system.

On further critical examination, it revealed that the highest number of seeds per siliquae was observed in conventional management system with three irrigation regimes and significantly lower number of seeds was recorded under natural management system when provided with two irrigations only. The mutual beneficial influence of irrigation and nutrient supply under conventional system resulted in better photosynthate formation and translocation to sink. Mandal et al. (2009) also reported better yield attributes with nutrient application under irrigated conditions.

4.1.3.5. 1000-seed weight

Data in Table 4.8 showed the effect of different irrigation levels and management practices on the test weight of *Brassica* species. Data showed that irrigation levels and management systems had no significant effect on the 1000-seed weight recorded in different *Brassica* species.

However, among *Brassica* species statistically similar test weight was recorded by *Brassica oleracea* ‘KBS 3’ and *Brassica napus* ‘GSC 7’, and this was significantly higher than *Brassica juncea* ‘RCC 4’. This might be ascribed to the inherent genetic potential of different *Brassica* species.

4.1.4 Yield

4.1.4.1 Seed yield

Data pertaining to seed yield is presented in Table 4.15. Data revealed that irrigation levels had a significant influence on the seed yield of different *Brassica* species with highest seed yield (991.8 kg ha⁻¹) recorded when three irrigations (I₂) were applied. The increase in seed yield with three irrigations over two irrigations (I₁) was 16.1 per cent. Irrigation is very important for getting the optimum productivity potential of mustard and higher irrigation regimes show a positive effect on yield attributes and yield (Kapila et al. 2012). Increase in the amount of water increased leaf water potential, stomatal conductance, light absorption, leaf area index, and evapotranspiration and decreased canopy temperature which might have contributed to higher seed yield (Yadav et al. 1994). Moreover, pre-sowing irrigation had a beneficial role in the root system’s growth and development which is the main source of nutrient absorption. Higher root biomass as a result of pre-sowing irrigation which increased the above ground biomass production (Yang 2012) and improved water and nitrogen utilization efficiency might have contributed to greater shoot biomass production and higher grain yield. The results are in conformity with Tyagi and Upadhaya (2017) and Shivran et al. (2018).

Different *Brassica* species showed a significant difference in seed yield of crop. Significantly higher seed yield (1079.0 kg ha⁻¹) was recorded in *Brassica*

oleracea 'KBS 3' followed by *Brassica juncea* 'RCC 4' and *Brassica napus* 'GSC 7'. Among *Brassica* species evaluated under sub humid conditions *Brassica campestris* brown sarson was found to be high yielder by the virtue of its higher number of siliquae compared to gobhi sarson (Shikari et al. 2015). Seed yield is a function of growth and yield attributes viz. branches, siliquae and these were significantly higher in *Brassica oleracea* 'KBS 3' hence higher yield was recorded.

Among management practices, significantly higher seed yield (1125.9 kg ha⁻¹) was observed under conventional management system compared to natural management. The increase in seed yield under conventional management over natural system was 56.3 per cent. This might be due to the reason that rapeseed-mustard has the highest requirement of sulphur (Tandon 1986) since it is an important constituent of seed protein, amino acid, enzymes, glucosinolate and is needed for chlorophyll formation. It increases the seed yield of mustard by 12 to 124 per cent (Aulakh et al. 1988) and in terms of agronomic efficiency, each kilogram of sulphur increases the yield of mustard by 7.7 kg (Katyal et al. 1997). In conventional system where sulphur is provided through fertilizer SSP and other major nutrients as per recommended dose are given might have increased the seed yield. The higher seed yield in conventional system might also be ascribed mainly due to the combined effect of higher number of siliquae per plant, more number of seeds per siliquae and higher 1000-seed weight, which was as a result of better translocation of photosynthates from source to sink (Premi and Kumar 2004). Rana et al. (2005) and Dongarkar et al. (2005) also reported similar results. Further, nitrogen top dressing in conventional management at flowering time which is the peak period for nutrient requirement might have increased the seed yield (Nishioka and Okumura 2008). However, in natural management system where nutrients requirement were partially available through *jeevamrit* and *ghanjeevamrit*, low in content could not supply nutrients in adequate amount for the optimum seed yield throughout the growth stages.

Table 4.15 Effect of irrigation levels, *Brassica* species and management practices on yield (kg ha⁻¹) and harvest index (%)

Treatment	Seed yield (kg ha ⁻¹)	Stover yield (kg ha ⁻¹)	Biological yield (kg ha ⁻¹)	Harvest Index (%)
Irrigation levels				
I ₁	854.0	2792.3	3646.3	23.5
I ₂	991.8	3080.2	4072.0	24.4
SEm±	15.1	24.1	18.7	0.4
CD (p=0.05)	91.8	146.8	113.8	NS
<i>Brassica</i> species				
B ₁ - <i>Brassica oleracea</i> ‘KBS 3’	1079.0	3446.1	4525.1	23.8
B ₂ - <i>Brassica juncea</i> ‘RCC 4’	911.8	2917.3	3829.2	23.7
B ₃ - <i>Brassica napus</i> ‘GSC 7’	777.9	2445.2	3223.1	24.3
SEm±	11.8	28.6	35.6	0.2
CD (p=0.05)	34.9	84.7	105.1	NS
Management practices				
M ₁ - Conventional management	1125.9	3540.4	4666.4	24.1
M ₂ - Natural management	719.9	2332.0	3051.9	23.7
SEm±	9.7	23.4	29.1	0.2
CD (p=0.05)	28.5	69.1	85.8	NS

I₁: Irrigation at 30 DAS and flowering; I₂: Irrigation at pre-sowing, 30 DAS and flowering

Interaction effect between irrigation levels and *Brassica* species on seed yield was found significant and is shown in Table 4.16. Data revealed that at both the irrigation levels, significantly higher seed yield was recorded in *Brassica oleracea* ‘KBS 3’ followed by *Brassica juncea* ‘RCC’ and *Brassica napus* ‘GSC 7’.

A comprehensive perusal of data showed that the higher seed yield was recorded in *Brassica oleracea* ‘KBS 3’ when raised with three irrigations levels, although it was statistically at par with same variety but with two irrigations. The lowest seed yield (668.2 kg ha⁻¹) was observed in *Brassica napus* ‘GSC 7’ when given with two irrigations.

Table 4.16 Interaction effect of irrigation levels and *Brassica* species on seed yield and biological yield

<i>Brassica</i> species	Irrigation levels		Biological yield	
	Seed yield (kg ha ⁻¹)		(kg ha ⁻¹)	
	I ₁	I ₂	I ₁	I ₂
B ₁ - <i>Brassica oleracea</i> ‘KBS3’	1047.3	1110.7	4380.0	4670.3
B ₂ - <i>Brassica juncea</i> ‘RCC4’	846.5	977.2	3689.7	3968.6
B ₃ - <i>Brassica napus</i> ‘GSC 7’	668.2	887.7	2869.1	3577.1
	SE m±	CD (p=0.05)	SE m±	CD (p=0.05)
<i>Brassica</i> species at same irrigation levels	16.7	49.4	50.4	148.7
Irrigation at same or different <i>Brassica</i> species	20.4	88.9	45.2	250.8

The interaction among irrigation levels, *Brassica* species at different management systems was found significant for seed yield (Table 4.17). The higher seed yield was obtained from *Brassica oleracea* ‘KBS 3’ under conventional management system and given three irrigations at pre-sowing, 30 DAS and at flowering stage. However the yield obtained in same species under same management system but given irrigation at 30 DAS and at flowering also remained statistically at par with above combination. The lowest yield (473.3 kg ha⁻¹) was obtained from *Brassica napus* ‘GSC 7’ under natural management system and given two irrigations only.

4.1.4.2 Stover yield

Data in Table 4.15 shows the effect of different irrigation levels and management practices on stover yield of different *Brassica* species. Irrigation levels had a significant influence on stover yield. Significantly higher stover yield (3080.2 kg ha⁻¹) was recorded when three irrigations (I₂) were provided to the crop over two irrigations (I₁) and it was 10.3 per cent higher over I₁. Pre-sowing irrigation significantly increases root growth by better establishment and a strong relationship exists between root and shoot; shoots supply sufficient carbohydrates to roots which can develop and maintain root functioning which in turn can improve shoot growth by supplying a sufficient amount of nutrients, water and phytohormone (Osaki et

al.1997; Zhang et al. 2009). This increase in shoot growth and dry matter might be the reason for higher stover yield in (I₂). Similar results were recorded Sharma et al. (2005) and Mandal et al. (2006).

Different *Brassica* species differed significantly with respect to stover yield. *Brassica oleracea* ‘KBS 3’ recorded significantly higher stover yield (3446.1 kg ha⁻¹) followed by *Brassica juncea* ‘RCC 4’ and *Brassica napus* ‘GSC 7’. The stover yield followed the dry matter accumulation pattern which was in order of ‘KBS 3’, ‘RCC 4’ and ‘GSC 7’.

Among different management practices, the highest stover yield (3540.4 kg ha⁻¹) was recorded under conventional management system over natural management system. The increase in stover yield under conventional management system was about 51.8 per cent. Adequate supply of nutrients specially N and P from inorganic sources contributed to robust shoot and root growth (Elser et al. 2007) in conventional system compared to natural management system where nutrient supply was fulfilled only by *Jeevamrit* and *Ghanjeevamrit* which are low in nutrient content, resulting in significantly lower shoot growth and ultimately lower stover yield. N fertilizer increases leaf area during vegetative growth and it is also a component of the chlorophyll molecule, which enables the plants to capture sunlight energy by photosynthesis, driving higher plant growth and hence higher stover yield (Mou et al. 2012) in conventional management system was recorded. Similar results were recorded by Singh et al. (2008) and Kansotia et al. (2015). However, the natural management practice theory is based on the fact that *ghanjeevamrit* and *jeevamrit* are applied to activate microbes which provide mineral nutrients and the release is not that fast to meet the crop demand.

Table 4.17 showed that the interaction effect between irrigation levels, *Brassica* species and management practice was significant on stover yield. Significantly higher stover yield was recorded in *Brassica oleracea* ‘KBS 3’ when grown under conventional management system with three irrigations followed by *Brassica oleracea* ‘KBS 3’ raised under conventional management system with two

irrigation regimes and *Brassica juncea* ‘RCC 4’ under conventional management system with three irrigation regimes which were found to be statistically at par with each other. The lowest stover yield was recorded in *Brassica napus* ‘GSC 7’ when raised with natural management system with the application of two irrigations.

Table 4.17 Interaction effect of irrigation levels, *Brassica* species and management practices on yield

Treatments	Seed yield (kg ha ⁻¹)	Stover yield (kg ha ⁻¹)	Biological yield (kg ha ⁻¹)
I ₁ B ₁ C ₁	1231.7	3814.8	5046.4
I ₁ B ₁ C ₂	863.0	2850.5	3713.5
I ₁ B ₂ C ₁	1071.0	3369.1	4440.1
I ₁ B ₂ C ₂	622.0	2317.4	2939.4
I ₁ B ₃ C ₁	863.0	3014.2	3877.2
I ₁ B ₃ C ₂	473.3	1387.6	1860.9
I ₂ B ₁ C ₁	1335.7	4173.3	5509.0
I ₂ B ₁ C ₂	885.7	2945.9	3831.6
I ₂ B ₂ C ₁	1153.7	3637.9	4791.5
I ₂ B ₂ C ₂	800.7	2345.0	3145.7
I ₂ B ₃ C ₁	1100.7	3233.2	4333.9
I ₂ B ₃ C ₂	674.7	2145.6	2820.3
SEm±	26.4	57.7	67.7
CD	104.8	201.8	215.9

I₁: Irrigation at 30 DAS and flowering; I₂: Irrigation at pre-sowing, 30 DAS and flowering, B₁- *Brassica oleracea* ‘KBS 3’, B₂- *Brassica juncea* ‘RCC 4’, B₃- *Brassica napus* ‘GSC 7’; M₁- Conventional management, M₂- Natural management

Table 4.18 presents the data pertaining to interaction effect between irrigation levels and *Brassica* species with respect to stover yield. At both the irrigation regimes, significantly higher stover yield was recorded by *Brassica oleracea* ‘KBS 3’ followed by *Brassica juncea* ‘RCC 4’ and *Brassica napus* ‘GSC 7’. On further evaluation, the highest stover yield (3559.6 kg ha⁻¹) was recorded by *Brassica oleracea* ‘KBS 3’ when irrigated three times whereas the lowest stover yield (2200.9 kg ha⁻¹) was observed in *Brassica napus* ‘GSC 7’ when irrigated only twice.

Table 4.18 Interaction effect of irrigation levels and *Brassica* species on stover yield

<i>Brassica</i> species	Irrigation levels	
	Stover yield (kg ha ⁻¹)	
	I ₁	I ₂
B ₁ - <i>Brassica oleracea</i> ‘KBS3’	3332.7	3559.6
B ₂ - <i>Brassica juncea</i> ‘RCC4’	2843.2	2991.5
B ₃ - <i>Brassica napus</i> ‘GSC 7’	2200.9	2689.4
	SEm±	CD (p=0.05)
<i>Brassica</i> species at same irrigation levels	40.6	119.7
Irrigation at same or different <i>Brassica</i> species	41.0	204.9

The interaction effect between management practices and *Brassica* species on stover yield was found significant and presented in Table 4.19. A significantly higher stover yield was recorded by *Brassica oleracea* ‘KBS’ when raised under conventional system followed by *Brassica juncea* ‘RCC 4’ and *Brassica napus* ‘GSC 7’ under same management system. The lowest stover yield was observed in *Brassica napus* ‘GSC 7’ when raised with natural management system.

Table 4.19 Interaction effect of management practices and *Brassica* species stover yield

<i>Brassica</i> species	Management practices	
	Stover yield (kg ha ⁻¹)	
	Conventional management	Natural management
B ₁ - <i>Brassica oleracea</i> ‘KBS 3’	3994.0	2898.2
B ₂ - <i>Brassica juncea</i> ‘RCC 4’	3503.5	2331.2
B ₃ - <i>Brassica napus</i> ‘GSC 7’	3123.7	1766.6
SEm±	40.6	
CD (p=0.05)	119.7	

4.1.4.3 Biological yield

The data pertaining to biological yield of *Brassica* species as affected by varying irrigation levels and different management practices is presented in Table

4.15. A perusal of the data revealed that varying irrigation levels and management practices significantly influenced the biological yield of all *Brassica* species.

Among irrigation levels, significantly higher biological yield ($4072.0 \text{ kg ha}^{-1}$) was recorded when three irrigations (I_2) were given to the crop over two irrigations (I_1). The increase in biological yield was 11.67 per cent over two irrigations (I_1). Significantly higher biological yield under three irrigation regimes (I_2) can be partly attributed to pre-sowing irrigation, which increased root biomass required to support the large aboveground biomass production (Garnett et al. 2009). Further, the better growth attributes, yield attributes like branches and siliquae obtained with three irrigations resulted in higher biomass yield. The improvements in root growth contributed to greater shoot biomass production, thus, increasing the biological yield of the crop. The results were in conformity to Mandal et al. (2006).

Different *Brassica* species showed a significant difference for the biological yield recorded. Significantly higher biological yield ($4525.1 \text{ kg ha}^{-1}$) was recorded in *Brassica oleracea* 'KBS 3' followed by *Brassica juncea* 'RCC 4' and *Brassica napus* 'GSC 7'. This may be attributed to higher seed yield and stover yield in *Brassica oleracea* 'KBS 3' compared to other species.

Among varying management practices, conventional system resulted in significantly higher biological yield ($4666.4 \text{ kg ha}^{-1}$) over natural management system. The increase was 52.90 per cent over natural management system. Significantly lower dry matter accumulation in natural management system due to inadequate supply of nutrients and nutritional deficiencies might have limited plant's growth by causing imbalances and reduced biomass production (Teixeira et al. 2021). Results were also in conformation with Hati et al. (2001) and Islam et al. (2018).

Data on the interaction effect of irrigation levels and *Brassica* species on biological yield was found significant and is presented in Table 4.16. At both the irrigation regimes, significantly higher biological yield were recorded in *Brassica oleracea* 'KBS 3' followed by *Brassica juncea* 'RCC 4' and *Brassica napus* 'GSC 7'.

The highest biological yield (4670.3 kg ha⁻¹) was recorded in *Brassica oleracea* ‘KBS 3’ when provided with three irrigations (I₂). The lowest biological yield was recorded in *Brassica napus* ‘GSC 7’ when two irrigations were given.

A significant interaction between irrigation levels, *Brassica* species and management practices observed on the biological yield is presented in Table 4.17. Significantly higher biological yield (5509.0 kg ha⁻¹) was recorded in *Brassica oleracea* ‘KBS 3’ when grown under conventional management system with three irrigations. The next higher biological yield was obtained from *Brassica oleracea* ‘KBS 3’ raised under conventional management system with two irrigations and *Brassica juncea* ‘RCC 4’ under conventional management system with three irrigation regimes. The lowest biological yield (1860.9 kg ha⁻¹) was recorded in *Brassica napus* ‘GSC 7’ when raised with natural management system with the application of two irrigations. The better growth maintained by fertilizer under conventional system and mobilization of nutrients by irrigation and better response of *Brassica oleracea* ‘KBS 3’ evident for yield attributed can be ascribed to higher yield. Mandal et al. (2009) also reported higher yield when 100 per cent NPK along with manure was applied to *Brassica* crop and is irrigated thrice.

4.1.4.4 Harvest Index

Table 4.15 shows that harvest index of different *Brassica* species was not influenced by different irrigation levels and management practices.

4.2 Chemical studies

4.2.1 Soil and water studies

4.2.1.1 Soil pH

The data on soil pH at harvest as influenced by irrigation levels and different management practices under different *Brassica* species is given in Table 4.20. Data revealed that the soil pH was not significantly influenced by any of the factors studied.

Table 4.20 Effect of irrigation levels and management practices on soil pH, organic carbon (g kg⁻¹) and available N, P and K (kg ha⁻¹)

Treatment	pH	Organic carbon (g kg⁻¹)	Available N (kg ha⁻¹)	Available P (kg ha⁻¹)	Available K (kg ha⁻¹)
Irrigation levels					
I ₁	5.25	8.52	264.4	33.5	242.8
I ₂	5.19	8.72	262.9	32.0	239.4
SEm±	0.05	0.11	0.5	0.3	0.9
CD (p=0.05)	NS	NS	NS	NS	NS
Brassica species					
B ₁ - <i>Brassica oleracea</i> ‘KBS 3’	5.19	8.54	262.1	31.4	240.9
B ₂ - <i>Brassica juncea</i> ‘RCC 4’	5.22	8.82	263.7	33.0	240.3
B ₃ - <i>Brassica napus</i> ‘GSC 7’	5.25	8.51	265.1	33.9	242.2
SEm±	0.05	0.11	0.8	0.5	0.8
CD (p=0.05)	NS	NS	2.3	1.3	NS
Management practices					
M ₁ - Conventional management	5.20	8.46	268.3	35.1	245.2
M ₂ - Natural management	5.23	8.79	259.0	30.5	237.0
SEm±	0.04	0.09	0.6	0.4	0.7
CD (p=0.05)	NS	0.26	1.9	1.1	2.0
Initial	5.3	8.51	263.5	32.5	242.6

I₁: Irrigation at 30 DAS and flowering; I₂: Irrigation at pre-sowing, 30 DAS and flowering

4.2.1.2 Organic carbon

The data pertaining to the organic carbon content of the soil as influenced by irrigation levels, *Brassica* species and management practices is given in Table 4.20. Irrigation levels and soil under different *Brassica* species had no significant influence on the organic carbon content in soil after harvest of the crop.

However, management practices significantly influenced the organic carbon content of the soil, where significantly higher organic carbon was recorded under natural management system over conventional management. The higher organic carbon content in natural management treatments might be due to the congenial environment brought by mulch, which helps to increase the microbial community, further enhancing the decomposition of organic mulch, which eventually contributes to higher organic carbon content. In natural management practices, the application of straw mulch encourages fungal population (Jabran 2019) with mycorrhiza which increases the accumulation of carbon by depositing glomalin, which in turn improves soil structure by binding organic matter to mineral particles in the soil (Kumar and Gopal 2015).

4.2.1.3 Available N at harvest

Data pertaining to available soil nitrogen at harvest is presented in Table 4.20. A perusal of data revealed that irrigation levels had no significant influence on the available soil nitrogen content recorded at harvest.

However, the soil under different *Brassica* species differed significantly for available nitrogen observed at harvest. Statistically similar available nitrogen at harvest was recorded under *Brassica napus* 'GSC 7' and *Brassica juncea* 'RCC 4'. Nitrogen recorded under *Brassica oleracea* 'KBS 3' was found to be at par with the nitrogen recorded under *Brassica juncea* 'RCC 4'. The difference in available nitrogen under different *Brassica* species can be attributed particularly to the yield levels as the lowest N recorded coincided with the highest yield obtained from *Brassica oleracea* 'KBS 3' which has resulted in more uptake, hence lower balance.

Among different management practices, the conventional management system resulted in significantly higher available nitrogen (268.3 kg ha^{-1}) over the natural management system. This might be due to the fact that N requirement in natural management was fulfilled by *jeevamrit* and *ghanjeevamrit* which are low in nutrient content. As a result, N was extracted from the soil leading to less availability of N in the soil. However, a slight buildup of nitrogen recorded under conventional system might be due to the addition of N through inorganic fertilizers, and mineralization process showed by other nutrients.

4.2.1.4 Available P at harvest

A perusal of data in Table 4.20 shows the effect of irrigation levels and management practices on available P at harvest. Irrigation levels had no significant influence on available P at harvest. However, it differed significantly for different *Brassica* species and management systems. Among *Brassica* species significantly higher available phosphorus content at harvest was recorded in soil with *Brassica napus* 'GSC 7' which was at par with *Brassica juncea* 'RCC 4'. The lowest available P was observed in soil with *Brassica oleracea* 'KBS 3'. It may be attributed to the low uptake of P by *Brassica napus* 'GSC 7' because of lower yield observed hence higher availability of P in soil at harvest and vice versa.

The availability of P in the soil system is a complex phenomenon which is dependent on various environmental factors and soil dynamics. The data showed that the conventional management system resulted in significantly higher available P (35.1 kg ha⁻¹) at harvest compared to natural management treatments. Significantly higher availability of P in conventional system may be due to the addition of phosphorus in the soil through inorganic fertilizer resulting in residual effect in already high phosphorus soils. However, in natural management system where input of P from *ghanjevamrit* and *jeevamrit* could not meet the crop demands, it relied on the inherent soil P supply resulting in lower availability in the soil. Compared to initial P status there was decrease in P under natural management system whereas a slight increase in P was observed under conventional system.

4.2.1.5 Available K at harvest

A perusal of data shown in Table 4.20 revealed that available K at harvest did not differ significantly at different irrigation levels and under different *Brassica* species cultivation. However, different management practices differ for available K recorded at harvest. Significantly higher available K was recorded under conventional management system over natural management system. Higher available potassium (245.2 kg ha⁻¹) under conventional system may be attributed to the application of potassic fertilizer whereas under natural management system no external K input was seen and almost all crop uptake was from soil hence depletion was observed.

Further, depletion in available K content was observed compared to initial status because of uptake from the soil not supported by external supply directly.

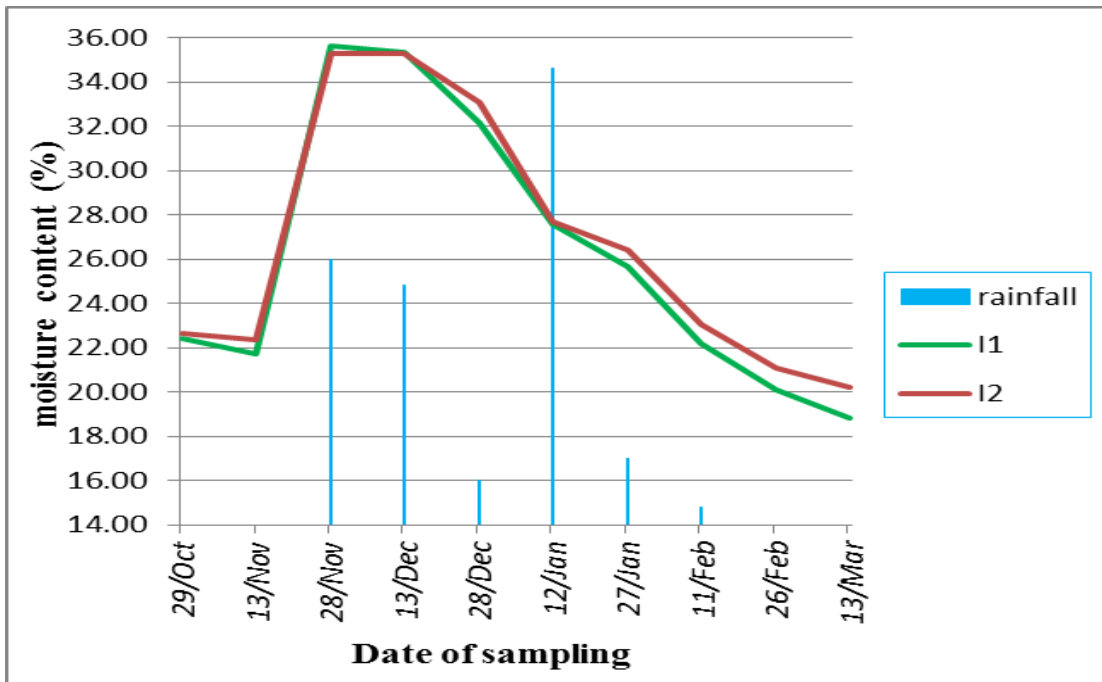
4.2.1.6 Soil moisture estimation at every 15 days interval at 0-15 cm and 15-30 cm depth (per cent by weight)

The data on available soil moisture content at 15 days interval at 0-15 cm. as influenced by different irrigation levels and management practices have been given in Appendix IV.

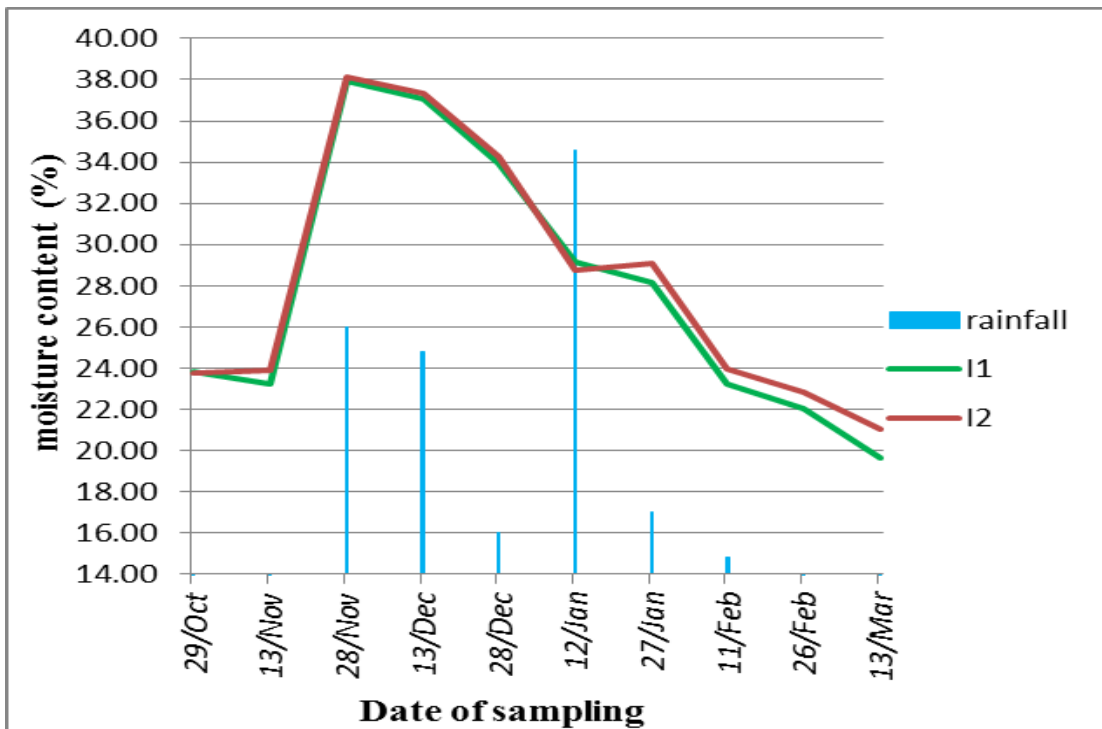
A general trend for soil moisture content was recorded at 0-15 cm. where irrigation levels and *Brassica* species showed no significant difference for soil moisture content irrespective of the date of sampling.

However, different management practices significantly affected the soil moisture content at every sampling except on 13 November where it was found non-significant. Significantly higher moisture content at every sampling was recorded under the natural management system as compared to conventional system. It might be attributed to the use of mulch under the natural management system which has a greater role in soil moisture conservation through modification of microclimatic soil conditions which helps to prevent weed growth, reduce evaporation, and increase infiltration of rainwater during the growing season (Yang et al. 2003). Mulching conserves soil water by reducing soil evaporation, regulating soil temperature & decreasing irrigation demand during crop cultivation (Kader et al. 2017). A similar trend for soil moisture content was recorded at 15-30 cm depth (Appendix V); however, a little higher moisture was recorded in 15-30 cm. which might be due to more water conservation in deeper layers of soil whereas in upper layer the extraction by roots is more.

Fig. 4.1 Effect of irrigation levels on soil moisture content (per cent)

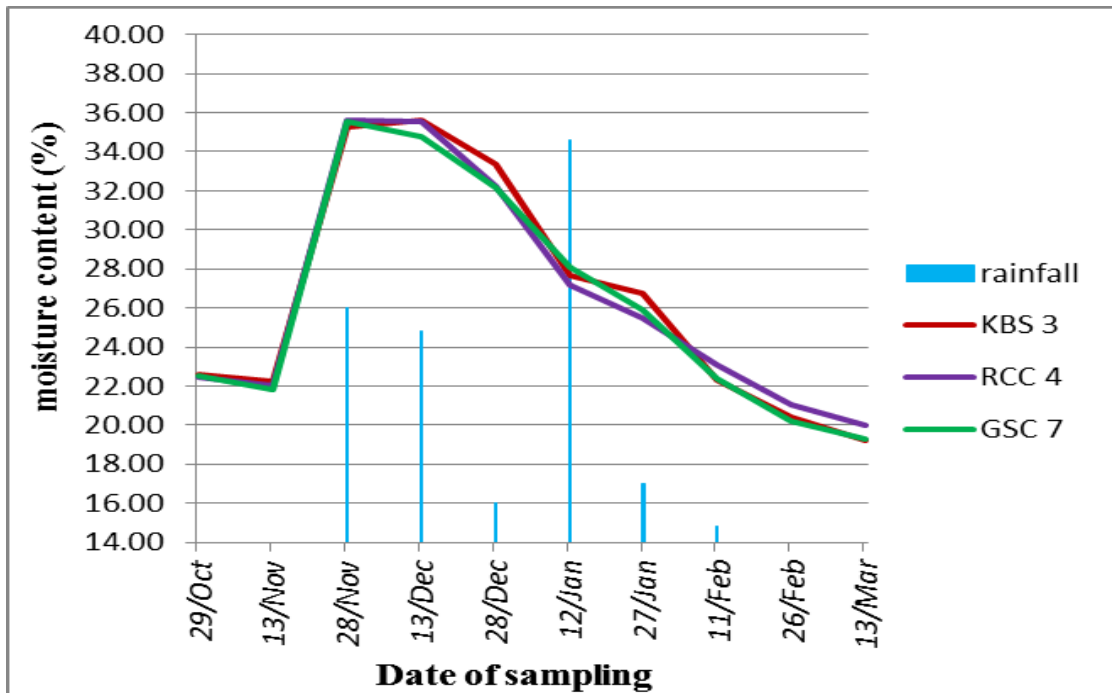


(A) Soil moisture at 0-15 cm

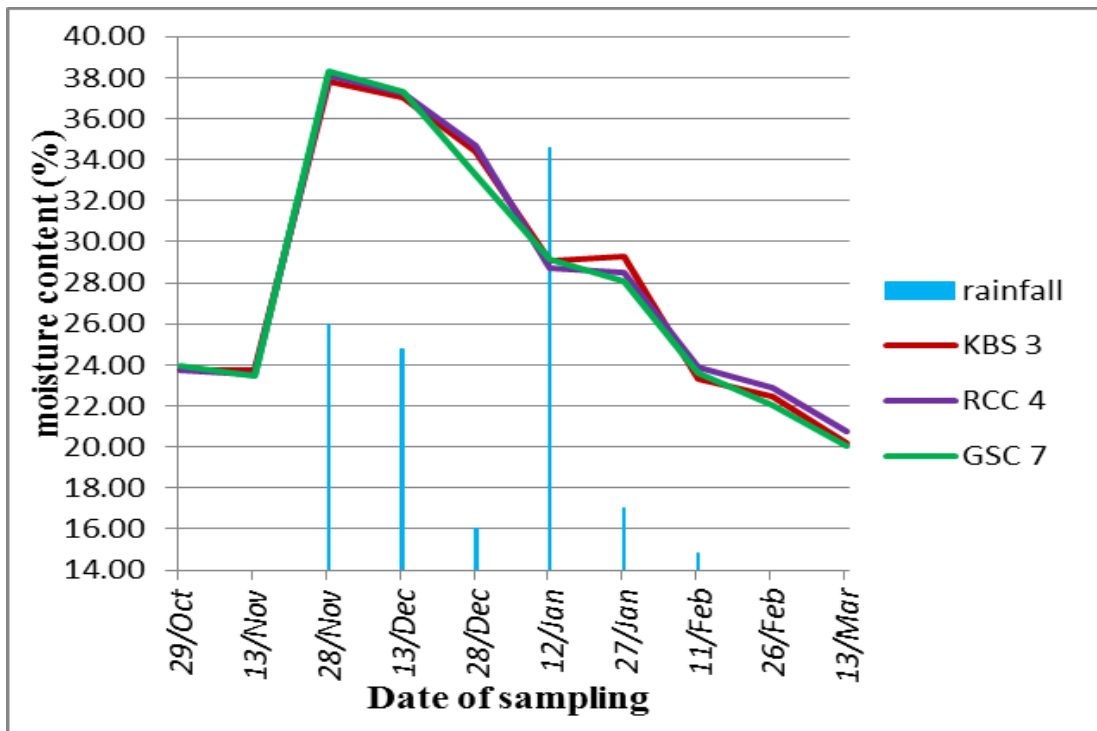


(B) Soil moisture at 15-30 cm

Fig. 4.2 Effect of *Brassica* species on soil moisture content (per cent)

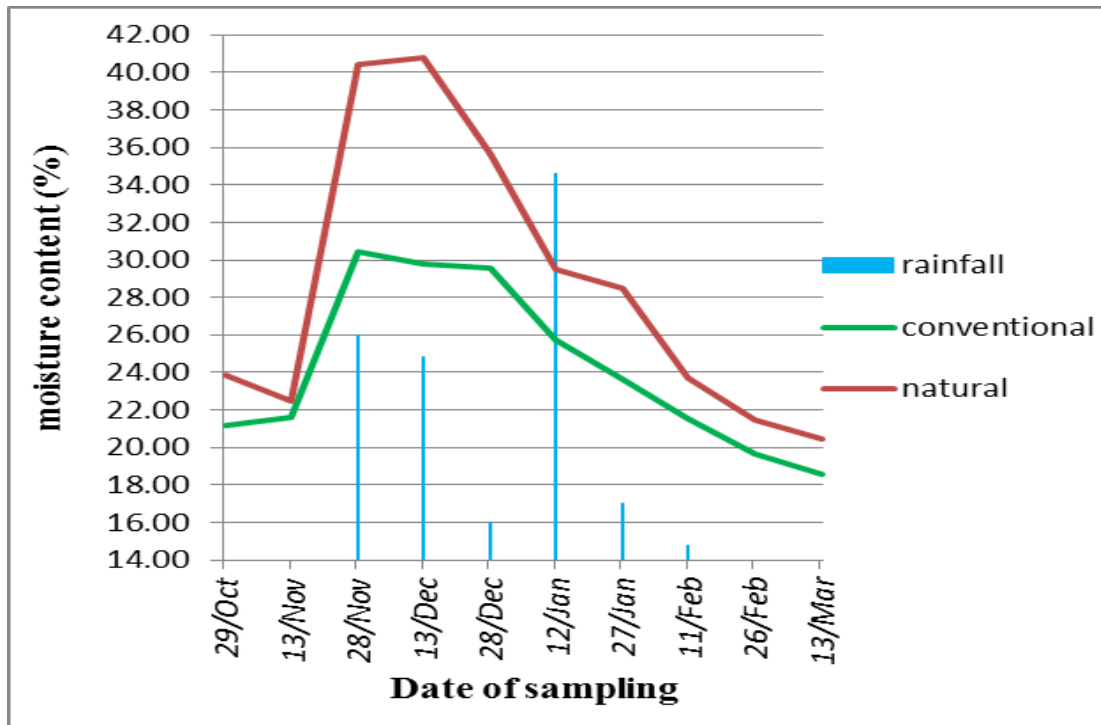


A) Soil moisture at 0-15 cm

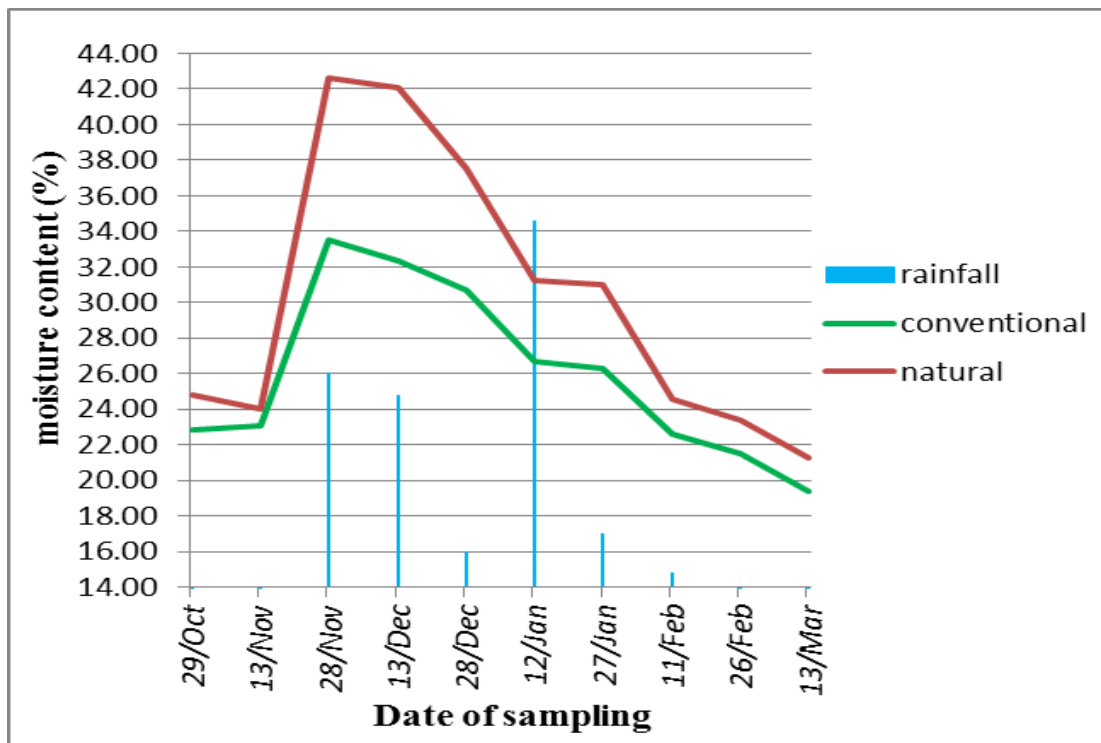


B) Soil moisture at 15-30 cm

Fig. 4.3 Effect of management practices on soil moisture content (per cent)



A) Soil moisture at 0-15 cm



B) Soil moisture at 15-30 cm

4.2.1.7 Soil moisture estimation before and after every irrigation at 0-15 cm and 15-30 cm depth

The data pertaining to available soil moisture content before and after irrigation at 0-15 cm and 15-30 cm depth as influenced by different irrigation levels and management practices is given in Table 4.21 and 4.22, respectively.

At both the depths, irrigation levels significantly influenced the soil moisture content after first irrigation where significantly higher moisture was recorded in I₂ which may be attributed to pre-sowing irrigation which increased the moisture content in I₂. However, moisture content at other irrigation stages was not found significant.

Table 4.21 Effect of irrigation levels, *Brassica* species and management practices on moisture content (per cent) before and after irrigation at 0-15 cm

Irrigation No. Treatment	Pre-sowing		30 DAS		Flowering	
	Before	After	Before	After	Before	After
Irrigation levels						
I ₁	21.0	24.4	20.6	26.4	18.4	27.9
I ₂	21.4	27.5	21.7	30.1	19.8	29.5
SEm±	0.3	0.2	0.3	0.6	0.3	0.4
CD (p=0.05)	NS	1.3	NS	NS	NS	NS
<i>Brassica</i> species						
B ₁ - <i>Brassica oleracea</i> ‘KBS 3’	21.0	26.1	20.8	28.0	19.7	28.9
B ₂ - <i>Brassica juncea</i> ‘RCC 4’	21.9	26.3	21.4	28.3	18.4	28.0
B ₃ - <i>Brassica napus</i> ‘GSC 7’	20.7	25.5	21.3	28.5	19.1	29.3
SEm±	0.4	0.4	0.3	0.5	0.4	0.4
CD (p=0.05)	NS	NS	NS	NS	NS	NS
Management practices						
M ₁ -Conventional management	20.7	25.5	20.0	26.8	18.4	27.8
M ₂ -Natural management	21.6	26.4	22.3	29.7	19.7	29.7
SEm±	0.3	0.3	0.2	0.4	0.3	0.3
CD (p=0.05)	NS	NS	0.7	1.3	0.9	0.9

I₁: Irrigation at 30 DAS and flowering; I₂: Irrigation at pre-sowing, 30 DAS and flowering

Table 4.22 Effect of irrigation levels, *Brassica* species and management practices on moisture content (per cent) before and after irrigation at 15-30 cm

Irrigation No.	Pre-sowing		30 DAS		Flowering	
Treatment	Before	After	Before	After	Before	After
Irrigation levels						
I ₁	23.3	26.4	22.5	28.6	20.0	30.2
I ₂	24.3	30.3	24.0	31.5	21.8	33.0
SEm±	0.5	0.3	0.3	0.6	0.3	0.5
CD (p=0.05)	NS	2.0	NS	NS	NS	NS
<i>Brassica</i> species						
B ₁ - <i>Brassica oleracea</i> ‘KBS 3’	24.0	28.3	23.3	29.7	21.0	32.2
B ₂ - <i>Brassica juncea</i> ‘RCC 4’	24.5	28.3	23.5	30.1	20.1	30.9
B ₃ - <i>Brassica napus</i> ‘GSC 7’	22.8	28.5	23.0	30.4	21.5	31.8
SEm±	0.5	0.4	0.3	0.5	0.5	0.4
CD (p=0.05)	NS	NS	NS	NS	NS	NS
Management practices						
M ₁ -Conventional management	23.6	28.0	22.3	28.9	20.6	31.1
M ₂ -Natural management	24.0	28.7	24.2	31.2	21.2	32.2
SEm±	0.4	0.4	0.2	0.4	0.4	0.3
CD (p=0.05)	NS	NS	0.6	1.1	NS	1.0

I₁: Irrigation at 30 DAS and flowering; I₂: Irrigation at pre-sowing, 30 DAS and flowering

Different *Brassica* species showed no significant difference for soil moisture content before and after every irrigation at both 0-15 cm and 15-30 cm depth.

With respect to different management practices, soil moisture content at 0-15 cm depth showed a significant difference at second and third irrigations viz. 30 DAS and flowering, however it was not found significant at first irrigation i.e. pre-sowing. At second and third irrigations significantly higher moisture content was observed in natural management system over conventional management that may be due to the use of mulch in natural management systems at later stages which reduces evaporation, and increases infiltration of irrigation water (Yang et al. 2003). Similar trend for soil moisture was observed at 15-30 cm depth except before third irrigation where it was not found significant.

4.2.2 Plant and quality analysis

4.2.2.1 N uptake at harvest

Data pertaining to N uptake by crop at harvest is given in Table 4.23. Data revealed that different irrigation levels and management practices significantly influenced the total uptake of N by the *Brassica* species.

Table 4.23 Effect of irrigation levels, *Brassica* species and management practices on N uptake by seed, stover and total uptake by crop (kg ha⁻¹)

Treatment	N uptake (kg ha ⁻¹)		
	Seed	Stover	Total uptake
Irrigation levels			
I ₁	16.70	7.60	24.30
I ₂	19.22	8.27	27.50
SEm±	0.29	0.02	0.28
CD (p=0.05)	1.76	0.10	1.69
<i>Brassica</i> species			
B ₁ - <i>Brassica oleracea</i> ‘KBS 3’	21.33	9.72	31.06
B ₂ - <i>Brassica juncea</i> ‘RCC 4’	17.61	7.80	25.41
B ₃ - <i>Brassica napus</i> ‘GSC 7’	14.94	6.30	21.23
SEm±	0.24	0.14	0.32
CD (p=0.05)	0.70	0.42	0.94
Management practices			
M ₁ - Conventional management	22.50	10.02	32.52
M ₂ - Natural management	13.42	5.86	19.28
SEm±	0.19	0.12	0.26
CD (p=0.05)	0.57	0.34	0.77

I₁: Irrigation at 30 DAS and flowering; I₂: Irrigation at pre-sowing, 30 DAS and flowering

Three irrigations given at pre-sowing, 30 DAS and flowering (I₂), respectively recorded significantly higher N uptake by seed and stover, hence total uptake by crop over application of two irrigations (I₁). Water availability is a potent regulator for plant development and it induces root branching through hydro patterning, which enables roots to position lateral branches toward regions of high water availability (Robbins and Dinneney 2017). The pre-sowing irrigation in I₂ might have provided

ample water for improved root growth and development (Garnett et al. 2009; Yang 2012), resulting in higher uptake of nutrients at different stages of crop growth.

Brassica species also differed significantly for N uptake by seed, stover and total uptake by crop. *Brassica oleracea* 'KBS 3' resulted in a significantly higher uptake of N followed by *Brassica juncea* 'RCC 4' and *Brassica napus* 'GSC 7' in that order each species differing significantly from one another. The biomass production is a function of uptake and vice versa. The difference in biomass production and yield results in differential agronomic efficiency and nutrient use efficiency with one having more potential, also having more uptake. Similar results showing more uptake by *Brassica carinata* than *Brassica napus* due to biomass have been reported by (Seepaul et al. 2019).

Among management practices, conventional system recorded significantly higher N uptake by seed and stover, hence total uptake by the crop over natural system. N fertilization has been regarded as the key factor in root system development (Luo et al. 2014 and Pu et al. 2016). As the root system is vital for the growth and development of plants and root growth is closely related to shoot growth, both are affected by N availability in the soil. (Fan et al. 2010) showed that increased N application increased root length and root biomass, which may be the reason for higher uptake of N in conventional management, compared to natural management systems that produced significantly lower root system. Moreover, the robust plants increased synthesis and accumulation of carbohydrates, thus higher dry matter accumulation required higher uptake of nutrients in conventional system (Chen et al. 2020). In natural management system, the availability of N in soil was significantly lower due to low nutrient content of the sources used for fertilization such as *jeevamrit* and *ghanjeevamrit* which added 9.33 kg ha⁻¹. It supplies only a fraction of the plants nutrient required and hence the lower uptake in the aforementioned system was observed. Low growth and yield under lower N application in rapeseed has been observed (Kant et al. 2011).

Table 4.24 shows that the interaction effect between irrigation levels and *Brassica* species on total N uptake was significant. At both the irrigation regimes,

significantly higher total uptake of N was recorded in *Brassica oleracea* ‘KBS 3’ followed by *Brassica juncea* ‘RCC 4’ and *Brassica napus* ‘GSC 7’.

Critical examination of data showed that *Brassica oleracea* ‘KBS 3’ with three irrigations and *Brassica oleracea* ‘KBS 3’ with two irrigations recorded statistically similar total N uptake by the crop. The lowest uptake (18.91 kg ha⁻¹) was observed in *Brassica napus* ‘GSC 7’ when supplied with two irrigations.

Table 4.24 Interaction effect of irrigation levels and *Brassica* species on total N uptake

<i>Brassica</i> species	Irrigation levels	Total N uptake (kg ha ⁻¹)	
		I ₁	I ₂
B ₁ - <i>Brassica oleracea</i> ‘KBS 3’		30.28	31.83
B ₂ - <i>Brassica juncea</i> ‘RCC 4’		23.72	27.10
B ₃ - <i>Brassica napus</i> ‘GSC 7’		18.91	23.56
		SE m±	CD (p=0.05)
Management practices at same irrigation levels		0.45	1.33
Irrigation levels at same or different management practices		0.46	2.28

4.2.2.2 P uptake at harvest

The effect of different irrigation levels and management practices on P uptake by seed, stover and total uptake by crop is presented in Table 4.25. Irrigation levels and management practices significantly affected the P uptake by the crop.

Significantly higher P uptake by seed, stover and hence total uptake by the crop was recorded when three irrigations (I₂) were given to the crop over two irrigations (I₁). Drought or low water conditions could enhance phosphorus deficiency, as it is excessively immobile in soil (Sardans and Penuelas 2007). With pre-sowing irrigation, phosphate part (H₂PO₄) of water-soluble phosphatic fertilizer SSP (Single Super Phosphate) applied gets dissolved in the soil water and the roots of

growing plants easily take up this form of phosphorus. Superphosphate applied just before sowing with adequate moisture ensures a sufficient phosphorus supply in the early stages of plant growth when its requirement is the highest (Kumar 2013).

Table 4.25 Effect of irrigation levels, *Brassica* species and management practices on P uptake by seed, stover and total uptake (kg ha⁻¹) by the crop

Treatment	P uptake (kg ha ⁻¹)		
	Seed	Stover	Total uptake
Irrigation levels			
I ₁	1.60	3.51	5.11
I ₂	1.90	3.87	5.77
SEm±	0.01	0.03	0.03
CD (p=0.05)	0.09	0.19	0.19
<i>Brassica</i> species			
B ₁ - <i>Brassica oleracea</i> ‘KBS 3’	2.11	4.46	6.57
B ₂ - <i>Brassica juncea</i> ‘RCC 4’	1.72	3.67	5.39
B ₃ - <i>Brassica napus</i> ‘GSC 7’	1.43	2.93	4.35
SEm±	0.04	0.06	0.09
CD (p=0.05)	0.11	0.18	0.27
Management practices			
M ₁ -Conventional management	2.21	4.58	6.78
M ₂ -Natural management	1.29	2.80	4.09
SEm±	0.03	0.05	0.07
CD (p=0.05)	0.09	0.15	0.22

I₁: Irrigation at 30 DAS and flowering; I₂: Irrigation at pre-sowing, 30 DAS and flowering

Different *Brassica* species showed a significant difference with respect to uptake of P by the crop. *Brassica oleracea* ‘KBS 3’ recorded a significantly higher uptake of P by seed, stover and total uptake by crop was followed by *Brassica juncea* ‘RCC 4’ and *Brassica napus* ‘GSC 7’. In that order each species differing significantly from one another. Total uptake being a function of total biomass, the species with high biomass also recorded high uptake.

With respect to different management practices, conventional management system recorded significantly higher uptake of P in seed and stover, hence total uptake by crop. Morphological and physiological characteristics of roots are vital for nutrient uptake (Hajabbasi and Schumacher 1994) and P affects the root branching, hence more P uptake is possible with the phosphorus application under conventional system. Also P is highly immobile in soil and improved root growth leads to its larger scavenging area due to the proliferation of roots to nutrient-rich patches, this profoundly affects the ability of the plants to acquire essential nutrients from more extensive areas resulting in higher uptake.

However, in natural management system, nutrition relies on the transformation of nutrients in the soil by microbes which may require a certain time period and the external addition through various sources such as *jeevamrit* and *ghanjeevamrit* which added only 3.53 kg ha⁻¹ of phosphorus. This amount of nutrients could not supply the amounts required by the crop for its maximum potential growth and yield, hence the lower uptake observed in natural management systems.

4.2.2.3 K uptake at harvest

The data on total K uptake as influenced by different irrigation levels and management practices is presented in Table 4.26. A perusal of data revealed that irrigation regimes and management practices significantly affected the K uptake by the crop.

Data showed that crop supplied with three irrigations (I₂) viz. at pre-sowing, 30 DAS and flowering resulted in significantly higher uptake of K by seed, stover and total uptake by crop over application of two irrigations (I₁). Water affects nutrient availability in soil by transforming unavailable nutrients to available forms and consequently affecting the absorption, total uptake and composition in plants. Soil solution potassium is readily taken up by the plant's root system and then replaced by the potassium on the exchange sites. Due to pre-sowing irrigation, potassium gets dissolved in soil water (water-soluble) at the initial crop growth stage and gets held on the exchange sites on clay particles (exchangeable K). It becomes readily available for plant growth (Prajapati 2012) resulting in higher uptake of K by the crop.

A significant variation was recorded among *Brassica* species for K uptake by the crop where a significantly higher uptake of K by seed, stover, hence total uptake by the crop was recorded by *Brassica oleracea* ‘KBS 3’ followed by *Brassica juncea* ‘RCC 4’ and *Brassica napus* ‘GSC 7’. The total uptake is a function of biomass so total uptake followed the respective species biomass production.

Different management practices differed in the uptake of K by the crop. Conventional system recorded the highest uptake of K by the crop at harvest over natural system. This may be ascribed to the application of potassic fertilizers in the conventional management system, which promoted the plant's root growth and overall growth by increasing contact between the ions and roots with increasing K availability in the soil (Chen 1997), contributing to a higher K uptake (Guimaraes et al. 2012 and Filho et al. 2017).

Table 4.26 Effect of irrigation levels, *Brassica* species and management practices on K uptake by seed, stover and total uptake (kg ha⁻¹) by crop

Treatment	K uptake (kg ha ⁻¹)		
	Seed	Stover	Total uptake
Irrigation levels			
I ₁	10.11	8.46	18.57
I ₂	11.93	9.53	21.47
SEm±	0.23	0.10	0.19
CD (p=0.05)	1.37	0.59	1.17
<i>Brassica</i> species			
B ₁ - <i>Brassica oleracea</i> ‘KBS 3’	13.01	10.71	23.72
B ₂ - <i>Brassica juncea</i> ‘RCC 4’	10.88	8.91	19.79
B ₃ - <i>Brassica napus</i> ‘GSC 7’	9.18	7.37	16.55
SEm±	0.15	0.12	0.21
CD (p=0.05)	0.43	0.35	0.63
Management practices			
M ₁ -Conventional management	13.55	11.08	24.63
M ₂ -Natural management	8.50	6.92	15.41
SEm±	0.12	0.10	0.17
CD (p=0.05)	0.35	0.29	0.51

I₁: Irrigation at 30 DAS and flowering; I₂: Irrigation at pre-sowing, 30 DAS and flowering

Interaction effect between irrigation levels and *Brassica* species on total K uptake was found significant (Table 4.27). At both the irrigation regimes, significantly higher uptake of K was recorded by *Brassica oleracea* ‘KBS 3’ followed by *Brassica juncea* ‘RCC 4’ and *Brassica napus* ‘GSC 7’.

On critical examination, the highest K uptake (24.81 kg ha⁻¹) was recorded by *Brassica oleracea* ‘KBS 3’ when three irrigations were given to it and the lowest uptake (14.43 kg ha⁻¹) was observed in *Brassica napus* ‘GSC 7’ when supplied with two irrigations.

Table 4.27 Interaction effect of irrigation levels and *Brassica* species on total K uptake

<i>Brassica</i> species	Irrigation levels	
	Total K uptake (kg ha ⁻¹)	
	I ₁	I ₂
B ₁ - <i>Brassica oleracea</i> ‘KBS 3’	22.62	24.81
B ₂ - <i>Brassica juncea</i> ‘RCC 4’	18.66	20.92
B ₃ - <i>Brassica napus</i> ‘GSC 7’	14.43	18.67
	SE m±	CD (p=0.05)
Management practices at same irrigation levels	0.30	0.89
Irrigation levels at same or different management practices	0.31	1.53

4.2.2.4 Oil content and oil yield

Data pertaining to oil content and oil yield as influenced by different irrigation levels and management practice is presented in Table 4.28. Data showed that irrigation levels had no significant influence on the oil content of the crop.

However, *Brassica* species differed significantly for oil content and significantly higher (45.51 %) oil content was recorded in *Brassica oleracea* ‘KBS 3’. The lowest oil content was recorded in *Brassica napus* ‘GSC 7’ which was at par with *Brassica juncea* ‘RCC 4’. High oil content in *Brassica rapa* yellow and brown sarson

compared to others has been represented in an analysis of their natural traits (Chauhan and Kumar 2011 and Cartea et al. 2019).

Different management practices also showed a significant difference for oil content. Significantly higher oil content (42.14 %) was observed in conventional management system as compared to natural management system. Hegde and Babu (2009) concluded that among all the oilseed crops, rapeseed and mustard have the highest requirement of sulphur which is associated with the increase in acetyl-CoA carboxylase activity and is a precursor for oil synthesis. Hence, the application of sulphur based fertilizers in rapeseed and mustard (*Brassica* species) crop might be the reason for increased oil content in conventional management system (Pandey et al. 2012 and Kumar and Trivedi 2012).

Table 4.28 Effect of irrigation levels, *Brassica* species and management practices on oil content (%), protein content (%) and oil yield (kg ha⁻¹)

Treatment	Oil content (%)	Protein content (%)	Oil yield (kg ha ⁻¹)
Irrigation levels			
I ₁	41.15	12.11	356.12
I ₂	42.22	12.00	421.86
SEm±	0.21	0.02	5.31
CD (p=0.05)	NS	NS	32.29
<i>Brassica</i> species			
B ₁ - <i>Brassica oleracea</i> 'KBS 3'	45.51	12.27	492.22
B ₂ - <i>Brassica juncea</i> 'RCC 4'	39.62	11.99	362.79
B ₃ - <i>Brassica napus</i> 'GSC 7'	39.93	11.91	311.97
SEm±	0.16	0.04	5.52
CD (p=0.05)	0.47	0.12	16.27
Management practices			
M ₁ -Conventional management	42.14	12.48	477.87
M ₂ -Natural management	41.23	11.64	300.12
SEm±	0.13	0.03	4.50
CD (p=0.05)	0.38	0.10	13.29

I₁: Irrigation at 30 DAS and flowering; I₂: Irrigation at pre-sowing, 30 DAS and flowering

Irrigation levels and management practices have a significant influence on the oil yield of the crop. Oil yield is positively correlated with the seeds yield of crop, and significantly higher oil yield (421.86 kg ha⁻¹) was recorded with the application of three irrigations (I₂) over two irrigations (I₁).

All the *Brassica* species differed significantly for oil yield where significantly higher oil yield (492.22 kg ha⁻¹) was recorded in *Brassica oleracea* ‘KBS 3’ followed by *Brassica napus* ‘GSC 7’ and *Brassica juncea* ‘RCC 4’. *Brassica* species of yellow and brown sarson has been reported for higher oil content (Chauhan and Kumar 2011) and as the *Brassica* species brown sarson ‘KBS 3’ was also having more seed yield hence, more oil yield was obtained.

Among management practices, significantly higher oil yield (477.87 kg ha⁻¹) was recorded in conventional management system over natural management practice. The oil yield is a function of oil content and seed yield. As under conventional system, higher oil content and seed yield was recorded hence the oil yield was also high compared to natural management system.

4.2.2.5 Protein content

A perusal of data given in Table 4.28 showed the influence of different irrigation levels and management practices on the protein content of *Brassica* species. Irrigation had no significant influence on protein content of different *Brassica* species however, significantly higher protein content was recorded in *Brassica oleracea* ‘KBS 3’ followed by *Brassica juncea* ‘RCC 4’ and *Brassica napus* ‘GSC 7’ which were at par with one another. Protein content is a function of nitrogen content and uptake of crops. As *Brassica campestris* ‘KBS 3’ had more nitrogen content hence, the higher protein content was also expected.

Among different management practices, significantly higher protein content was recorded under conventional management system over natural management. This can be attributed to more availability of nitrogen under conventional system compared to natural system resulting in more uptake and protein synthesis by the crops.

4.3 Water studies

4.3.1 Water productivity (kg m^{-3})

A perusal of data in Table 4.29 revealed that although higher water productivity was recorded with two irrigations in a crop but the value was not significantly higher than water productivity obtained with three irrigations.

Table 4.29 Effect of irrigation levels, *Brassica* species and management practices on water productivity (kg m^{-3}), biomass water use efficiency, irrigation water use efficiency ($\text{kg ha}^{-1}\text{mm}^{-1}$) and returns per unit water use (₹ m^{-3})

Treatment	Water productivity (kg m^{-3})	Biomass water use efficiency ($\text{kg ha}^{-1}\text{mm}^{-1}$)	IWUE ($\text{kg ha}^{-1}\text{mm}^{-1}$)	Returns per unit irrigated water use (₹ m^{-3})
Irrigation levels				
I ₁	0.200	8.544	8.540	7.915
I ₂	0.198	8.135	6.610	8.524
SEm±	0.003	0.043	0.100	0.394
CD (p=0.05)	NS	0.264	0.600	NS
<i>Brassica</i> species				
B ₁ - <i>Brassica oleracea</i> ‘KBS 3’	0.233	9.762	8.940	13.934
B ₂ - <i>Brassica juncea</i> ‘RCC 4’	0.198	8.352	7.490	8.138
B ₃ - <i>Brassica napus</i> ‘GSC 7’	0.166	6.906	6.300	2.586
SEm±	0.003	0.078	0.090	0.372
CD (P=0.05)	0.007	0.230	0.270	1.097
Management practices				
M ₁ -Conventional management	0.243	10.105	9.270	15.140
M ₂ -Natural management	0.155	6.574	5.890	1.299
SEm±	0.002	0.064	0.080	0.304
CD (P=0.05)	0.006	0.188	0.220	0.896

I₁: Irrigation at 30 DAS and flowering; I₂: Irrigation at pre-sowing, 30 DAS and flowering

The water productivity varied between the different *Brassica* species. Significantly higher water productivity (0.233 kg m^{-3}) was observed from *Brassica oleracea* ‘KBS 3’ followed by *Brassica juncea* ‘RCC 4’ and *Brassica napus* ‘GSC 7’. The lower water productivity in *Brassica napus* is ascribed to more water response of

the species and long duration of crop. Tesfamariam et al. (2010) also reported that for high yield in *Brassica napus*, it should be irrigated throughout season in comparison to *Brassica campestris* being short duration responded to the water application scheduled and completed the cycle before deficit occurs.

Among different management practices significantly higher water productivity was observed under conventional management system (0.243 kg m^{-3}) over natural system. Water productivity is a function of yield and water use. With same amount of water use in both systems, the difference in water productivity could be partly ascribed to the influence of the management system on yield and as under conventional system easily available recommended dose of nutrient was applied hence with water its utilization and uptake was facilitated hence more productivity was observed. Similar results for high water productivity with higher fertilizer application have been observed by Yadav et al. (1999).

Table 4.30 Interaction effect of irrigation levels and *Brassica* species on water productivity, IWUE (irrigation water use efficiency) and Returns per unit water use

<i>Brassica</i> species \ Irrigation levels	Water productivity (kg m^{-3})		IWUE ($\text{kg ha}^{-1}\text{mm}^{-1}$)		Returns per unit water use (₹ m^{-3})	
	I ₁	I ₂	I ₁	I ₂	I ₁	I ₂
B₁-<i>Brassica oleracea</i> ‘KBS 3’	0.242	0.223	10.47	7.40	15.928	11.941
B₂-<i>Brassica juncea</i> ‘RCC 4’	0.204	0.192	8.47	6.51	7.895	8.381
B₃-<i>Brassica napus</i> ‘GSC 7’	0.154	0.179	6.68	5.92	-0.079	5.251
	SEm±	CD (p=0.05)	SEm±	CD (p=0.05)	SEm±	CD (p=0.05)
<i>Brassica</i> species at same irrigation levels	0.004	0.010	0.13	0.39	0.526	1.552
Irrigation levels at same or different <i>Brassica</i> species	0.004	0.019	0.15	0.68	0.583	2.712

Table 4.30 shows that the interaction effect of different irrigation levels and *Brassica* species was significant for water productivity. Data revealed that at both the irrigation levels significantly higher water productivity was recorded in *Brassica oleracea* ‘KBS 3’ followed by *Brassica juncea* ‘RCC 4’ and *Brassica napus* ‘GSC 7’.

Overall, the highest water productivity (0.242 kg m^{-3}) was recorded from *Brassica oleracea* ‘KBS 3’ given two irrigations though it was at par with same variety given three irrigations. The lowest water productivity was observed in *Brassica napus* ‘GSC 7’ given two irrigations. The higher water productivity under lower irrigation level can partly be attributed to fact that as the irrigation levels are increased, the consumptive water use increases and water use efficiency decreases (Singh et al. 2001).

A significant interaction was observed between irrigation levels, *Brassica* species and management system on water productivity (Table 4.31). *Brassica oleracea* ‘KBS 3’ grown under conventional system provided with two irrigations recorded higher water productivity though the productivity recorded in *Brassica oleracea* under same management system but with three irrigations and *Brassica juncea* ‘RCC 4’ grown under conventional system given two irrigations were at par with it. The lowest water productivity was noticed in *Brassica napus* ‘GSC 7’ when raised under natural management system with only two irrigations. Similar results were observed by Kingra and Kaur (2012).

4.3.2 Biomass water use efficiency ($\text{kg ha}^{-1}\text{mm}^{-1}$)

A perusal of data in Table 4.29 revealed that although the biomass water use efficiency was significantly higher with two irrigations ($8.544 \text{ kg ha}^{-1}\text{mm}^{-1}$) over three irrigations.

The biomass water use efficiency varied significantly among different *Brassica* species. Significantly higher value ($9.762 \text{ kg ha}^{-1}\text{mm}^{-1}$) for biomass water use efficiency was obtained in *Brassica oleracea* ‘KBS 3’ followed by *Brassica juncea* ‘RCC 4’ and *Brassica napus* ‘GSC 7’. The lowest biomass efficiency in *Brassica napus* could be ascribed to the longer duration of this species which might have required water application in later stages also. Tesfamariam et al. (2010) has also reported continued application of water for higher productivity in *Brassica napus*.

Among different management practices, significantly higher biomass water use efficiency was observed under conventional management system ($10.105 \text{ kg ha}^{-1}\text{mm}^{-1}$) over natural management system. This could be ascribed to higher biomass

production facilitated by direct application of recommended nutrients compared to natural system where a negligible amount of nutrient was available.

4.3.3 Irrigation water use efficiency ($\text{kg ha}^{-1}\text{mm}^{-1}$)

Data regarding irrigation water use efficiency is presented in Table 4.29. Data showed that irrigation water use efficiency was significantly influenced by different irrigation levels. Significantly higher irrigation water use efficiency ($8.54 \text{ kg ha}^{-1}\text{mm}^{-1}$) was recorded when two irrigations were given to the crop (I_1) over three irrigations (I_2). Higher irrigation water use efficiency in I_1 may be due to less consumptive use of water. In contrast, yield increased subsequently with three irrigations, but the water used was also higher, which brought down the efficiency. Similar results were reported by Kingra and Kaur (2012).

Different *Brassica* species also showed variations with respect to irrigation water use efficiency, where significantly higher irrigation water use efficiency ($8.94 \text{ kg ha}^{-1}\text{mm}^{-1}$) was observed in *Brassica oleracea* ‘KBS 3’ followed by *Brassica juncea* ‘RCC 4’ and *Brassica napus* ‘GSC 7’. The *Brassica oleracea* ‘KBS 3’ is short duration variety and the response without deficit in later stages resulted in high yield compared to *Brassica juncea* and *Brassica napus* where after flowering also the days taken to maturity were more hence a probable deficit decreased the yield.

Among different management practices, significantly higher irrigation water use efficiency ($9.27 \text{ kg ha}^{-1}\text{mm}^{-1}$) was observed in conventional management system over natural management. The nutrient availability is known to increase the yield in *Brassica* species (Premi and Kumar 2004) under conventional system and accordingly the water use efficiency.

Interaction effect of different irrigation levels and *Brassica* species was found significant for irrigation water use efficiency and is shown in Table 4.30. Data revealed that both the irrigation levels recorded significantly higher irrigation water use efficiency in *Brassica oleracea* ‘KBS 3’ followed by *Brassica juncea* ‘RCC 4’ and *Brassica napus* ‘GSC 7’.

Overall, the highest irrigation water use efficiency ($10.47 \text{ kg ha}^{-1}\text{mm}^{-1}$) was recorded when two irrigations were provided to *Brassica oleracea* ‘KBS 3’. The

lowest irrigation water use efficiency ($5.92 \text{ kg ha}^{-1}\text{mm}^{-1}$) was recorded in *Brassica napus* ‘GSC 7’ with the application of three irrigations. The increasing irrigation levels decreased the water use efficiency in *Brassica* species (Singh et al. 2001).

Table 4.31 Interaction effect of irrigation levels, *Brassica* species and management practices on water productivity and irrigation water use efficiency

Treatments	Water productivity (kg m^{-3})	Irrigation water use efficiency ($\text{kg ha}^{-1}\text{mm}^{-1}$)
I ₁ B ₁ C ₁	0.283	12.32
I ₁ B ₁ C ₂	0.201	8.63
I ₁ B ₂ C ₁	0.258	10.71
I ₁ B ₂ C ₂	0.150	6.22
I ₁ B ₃ C ₁	0.203	8.63
I ₁ B ₃ C ₂	0.104	4.73
I ₂ B ₁ C ₁	0.269	8.90
I ₂ B ₁ C ₂	0.178	5.90
I ₂ B ₂ C ₁	0.225	7.69
I ₂ B ₂ C ₂	0.159	5.34
I ₂ B ₃ C ₁	0.223	7.34
I ₂ B ₃ C ₂	0.135	4.50
SEm±	0.005	0.20
CD	0.028	0.73

I₁: Irrigation at 30 DAS and flowering; I₂: Irrigation at pre-sowing, 30 DAS and flowering, B₁- *Brassica oleracea* ‘KBS 3’, B₂- *Brassica juncea* ‘RCC 4’, B₃- *Brassica napus* ‘GSC 7’; M₁- Conventional management, M₂- Natural management

The interaction between irrigation levels, *Brassica* species and management practice on irrigation water use efficiency was found significant and is shown in Table 4.31. Significantly higher irrigation water use efficiency ($12.32 \text{ kg ha}^{-1} \text{ mm}^{-1}$) was recorded in *Brassica oleracea* ‘KBS 3’ grown under conventional system with two

irrigation levels. The lowest irrigation water use efficiency ($4.50 \text{ kg ha}^{-1} \text{ mm}^{-1}$) was noticed in *Brassica napus* ‘GSC 7’ when raised under natural management system with only three irrigations.

4.3.4 Returns per unit water use (₹ m^{-3})

The data on returns per unit water use as influenced by different irrigation levels and management practices have been given in Table 4.29. Irrigation levels had no significant influence on returns per unit water use. Although, among various *Brassica* species significantly higher returns per unit water use ($\text{₹}13.934 \text{ m}^{-3}$) was obtained from *Brassica oleracea* ‘KBS 3’ followed by the returns of obtained from *Brassica juncea* ‘RCC 4’ and *Brassica napus* ‘GSC 7’ respectively. The return is affected by the crop yield and the return is in line with yield obtained in the species in order of *Brassica oleracea*, *Brassica juncea* and *Brassica napus*, respectively.

Among different management practices, conventional management system gave significantly higher returns per unit water use ($\text{₹}15.140 \text{ m}^{-3}$) compared to natural management, giving returns of $\text{₹} 1.299 \text{ m}^{-3}$. The lowest returns under natural management system can be attributed to the lower yield obtained in this system.

The interaction effect recorded between irrigation levels and *Brassica* species was found significant on returns per unit water use (Table 4.30). Both the irrigation levels showed the same trend where significantly higher returns were obtained in *Brassica oleracea* ‘KBS 3’ followed by *Brassica juncea* ‘RCC 4’ and *Brassica napus* ‘GSC 7’.

On critical examination, the highest returns ($\text{₹}15.928 \text{ m}^{-3}$) were obtained when two irrigations were given to *Brassica oleracea* ‘KBS 3’ followed by same species but given three irrigations. The lowest returns ($\text{₹} -0.079 \text{ m}^{-3}$) were observed when two irrigations were provided to *Brassica napus* ‘GSC 7’.

4.4 Economics studies

4.4.1 Cost of Cultivation (₹ ha^{-1})

The Table 4.32 presents the data regarding economics. Data revealed that the highest cost of cultivation ($26,887 \text{ ₹ ha}^{-1}$) was involved when three irrigations (I_2) were provided to the crop over two irrigations (I_1).

Among different *Brassica* species the highest cost of cultivation (27,218 ₹ ha⁻¹) was observed in *Brassica napus* ‘GSC 7’ followed by *Brassica oleracea* ‘KBS 3’ and *Brassica juncea* ‘RCC 4’ where the same cost of cultivation was involved. The difference in cost of production is because of different recommended dose of fertilizers and partly is due to variable cost.

With respect to different management practices, natural management system recorded the highest cost of cultivation (26,773 ₹ ha⁻¹) over conventional management system. The difference is due to different cost of inputs which is more under natural management system as was purchased from outside.

4.4.2 Gross returns (₹ ha⁻¹)

The data on gross returns as influenced by different irrigation levels and management practices have been presented in Table 4.32.

Table 4.32 Effect of irrigation levels and management practices on economics (₹ ha⁻¹)

Treatment				
Irrigation levels	Cost of cultivation (₹ ha⁻¹)	Gross returns (₹ ha⁻¹)	Net returns (₹ ha⁻¹)	B:C
I ₁	26245	34,160	7915	0.31
I ₂	26887	39,673	12,786	0.48
SEm±	-	603	603	0.02
CD (p=0.05)	-	3672	3672	0.13
Brassica species				
B ₁ - <i>Brassica oleracea</i> ‘KBS 3’	26240	43,160	16,920	0.65
B ₂ - <i>Brassica juncea</i> ‘RCC 4’	26240	36,473	10,233	0.40
B ₃ - <i>Brassica napus</i> ‘GSC 7’	27218	31,117	3899	0.13
SEm±	-	474	474	0.02
CD (p=0.05)	-	1398	1398	0.05
Management practices				
M ₁ - Conventional management	26359	45,038	18,679	0.72
M ₂ - Natural management	26773	28,796	2022	0.07
SEm±	-	387	387	0.01
CD (p=0.05)	-	1141	1141	0.04

I₁: Irrigation at 30 DAS and flowering; I₂: Irrigation at pre-sowing, 30 DAS and flowering

A perusal of data revealed that three irrigation regimes viz. pre-sowing, 30 DAS and flowering (I_2) recorded significantly higher gross returns (39,673 ₹ ha⁻¹) over two irrigation regimes, i.e. 30 DAS and flowering (I_1). As sufficient water was available in I_2 due to pre-sowing irrigation, which led to better growth and yield attributes resulting in higher yield hence higher returns. Whereas, further down the rate of irrigation level, the growth and yield attributes decreased, and that reflected lower yield hence less return. These results are in agreement with those of Singh et al. (2010 a).

Among *Brassica* species significantly higher gross returns (43,160 ₹ ha⁻¹) were observed in *Brassica oleracea* ‘KBS 3’ followed by *Brassica juncea* ‘RCC 4’ and *Brassica napus* ‘GSC 7’. The returns followed the yield trend in respective species with highest in *Brassica oleracea* ‘KBS 3’.

Different management systems showed significant difference with respect to gross returns. Significantly higher gross returns (45,038 ₹ ha⁻¹) were recorded under conventional management system over natural management. Conventional management system resulted in increased nutrient availability and better nutrient uptake thus, leading to better yield attributes, increased yield thus favoring higher returns.

Table 4.33 Interaction effect of irrigation levels and *Brassica* species on gross returns, net return and benefit cost ratio

<i>Brassica</i> species	Irrigation levels		Gross returns		Net return		B:C	
	I_1	I_2	(₹ ha ⁻¹)	(₹ ha ⁻¹)	I_1	I_2	I_1	I_2
B₁-<i>Brassica oleracea</i> ‘KBS 3’	41,893	44,427	15,928	17,911	0.62	0.68		
B₂-<i>Brassica juncea</i> ‘RCC 4’	33,860	39,087	7895	12,571	0.31	0.48		
B₃-<i>Brassica napus</i> ‘GSC 7’	26,727	35,507	-79	7876	-0.01	0.28		
	SEm±	CD	SEm±	CD	SEm±	CD		
		(p=0.05)		(p=0.05)		(p=0.05)		
<i>Brassica</i> species at same irrigation levels	670	1977	670	1977	0.02	0.07		
Irrigation levels at same or different <i>Brassica</i> species	814	3555	814	3555	0.03	0.13		

Interaction effect of irrigation levels and *Brassica* species on gross returns was found significant and is shown in Table 4.33. Data revealed that under both the irrigation regimes, significantly higher gross returns were recorded in *Brassica oleracea* ‘KBS 3’ followed by *Brassica juncea* ‘RCC 4’ and *Brassica napus* ‘GSC 7’.

On critical examination, it was observed that the highest gross returns (44,427 ₹ ha⁻¹) were observed when three irrigations were given to *Brassica oleracea* ‘KBS 3’, although it was found to be statistically at par with *Brassica oleracea* ‘KBS 3’ with two irrigation regimes. The lowest gross returns (26,727 ₹ ha⁻¹) were obtained when two irrigations were given to *Brassica napus* ‘GSC 7’.

4.4.3 Net return (₹ ha⁻¹)

The data regarding the effect of different irrigation levels and management practices on net returns are shown in Table 4.32.

The data revealed that irrigation levels had a significant influence on net returns and significantly higher net return (12,786 ₹ ha⁻¹) was recorded with three irrigation regimes over two irrigations.

Different *Brassica* species and management practices showed a significant difference with respect to net returns. Significantly higher net return (16,920 ₹ ha⁻¹) was recorded by *Brassica oleracea* ‘KBS 3’ followed by *Brassica juncea* ‘RCC 4’ and *Brassica napus* ‘GSC 7’. Among management practices, significantly higher net return (18,679 ₹ ha⁻¹) was obtained in conventional management system over natural management. The higher return in *Brassica oleracea* ‘KBS 3’ and under conventional system is attributed to better performance of this species and positive response of nutrient application by *Brassica* species under conventional management.

The interaction effect of irrigation levels and *Brassica* species on net return was found significant and presented in Table 4.33. At both the irrigation regimes, significantly higher net returns were recorded in *Brassica oleracea* ‘KBS 3’ followed by *Brassica juncea* ‘RCC 4’ and *Brassica napus* ‘GSC 7’. Overall, the highest net return (17,911 ₹ ha⁻¹) was observed when three irrigations were provided to *Brassica oleracea* ‘KBS 3’ which was at par with two irrigations given to *Brassica*

oleracea 'KBS 3'. The lowest net return (-79 ₹ ha^{-1}) was recorded when two irrigations were given to *Brassica napus* 'GSC 7'.

4.4.4 Benefit Cost ratio

The data on benefit-cost ratio as influenced by different irrigation levels and management practices have been given in Table 4.32. Data showed that the application of three irrigations gave significantly higher benefit cost ratio (0.48) compared to two irrigation regimes.

Similarly different *Brassica* species and management practices also showed a significant difference with respect to benefit cost ratio. Significantly higher benefit cost ratio was obtained in *Brassica oleracea* 'KBS 3' followed by *Brassica juncea* 'RCC 4' and *Brassica napus* 'GSC 7'. Among management practices, a significantly higher benefit cost ratio (0.72) was obtained in conventional management system over natural management.

Interaction effect of irrigation levels and *Brassica* species on benefit cost ratio was found significant and is presented in Table 4.33. At both the irrigation regimes, significantly higher benefit cost ratio was recorded in *Brassica oleracea* 'KBS 3' followed by *Brassica juncea* 'RCC 4' and *Brassica napus* 'GSC 7'. Overall, the higher benefit cost ratio (0.68) was observed when three irrigations were provided to *Brassica oleracea* 'KBS 3' although it was at par with two irrigations given to *Brassica oleracea* 'KBS 3'. The lowest benefit cost ratio (-0.01) was recorded when two irrigations were given to *Brassica napus* 'GSC 7'.

5. SUMMARY AND CONCLUSIONS

The present study entitled ‘**Effect of irrigation levels on productivity of oilseed *Brassica* species under natural and conventional farming**’ was conducted during *rabi* season of 2020-2021 at Water Management Farm, CSK Himachal Pradesh Krishi Vishvavidyalaya, Palampur. The study aimed to fulfill the following objectives:

- 1) To evaluate the crop and water productivity of oilseed *Brassica* species under different irrigation levels and farming practices, and
- 2) to work out the economic viability of the treatments

The treatments comprised of two irrigation levels (I_2 viz. pre-sowing, 30 DAS and flowering and I_1 viz. 30 DAS and flowering) in main plot, three *Brassica* species (*Brassica oleracea* ‘KBS 3’, *Brassica juncea* ‘RCC 4’ and *Brassica napus* ‘GSC 7’) and two management practices (M_1 : Conventional management and M_2 : Natural management) in sub plot. These twelve treatment combinations ($2 \times 3 \times 2 = 12$) were replicated thrice in a split plot design. The sowing was done on 14th October, 2020. The soil of the experimental site was silty clay loam with pH 5.3 and organic carbon content of 8.51 g kg⁻¹. The soil was medium in available nitrogen (263.6 kg ha⁻¹), high in available phosphorus (33.4 kg ha⁻¹) and medium in available potassium (242.6 kg ha⁻¹). An irrigation of 5 cm depth was applied through flood irrigation at pre-sowing, 30 DAS and flowering as per the treatments.

A recommended dose of 60:40:40 kg N:P₂O₅:K₂O ha⁻¹ was applied in *Brassica oleracea* ‘KBS 3’ and *Brassica juncea* ‘RCC 4’ while 120:60:40 kg ha⁻¹ was used in *Brassica napus* ‘GSC 7’. In conventional management system P₂O₅ and K₂O were supplied through SSP (16 % P₂O₅) and MOP (60 % K₂O), whole at the time of sowing, whereas nitrogen was supplied through urea (46 % N) in three splits viz. ½ as basal dose and other half in two equal splits at 30 DAS and at flowering. In the natural management treatments, *Ghanjeevamrit* was applied at the rate of 395 kg ha⁻¹ at the time of sowing whereas *Beejamrit* and *Jeevamrit* was applied as freshly prepared

concoction diluted 10 times. The *Beejamrit* was used as a seed treatment and *Jeevamrit* was applied at 21 days interval as foliar spray directed to soil and plant. The detail of natural farming ingredients, their composition and total nutrient content is given in Table 3.4. The details of cultural operations performed are provided in the Table 3.5.

The observations were recorded on crop growth, development, yield attributes, yield, quality parameters, nutrient uptake, available nutrient content in soil, moisture estimation, water productivity and economics. The water use efficiency indices were calculated using the standard formulas and the economics of the crop was also worked out.

The salient findings that emerged out of the present investigation are summarized as follows:

5.1 Growth and developmental studies

- Significantly taller plants were recorded when three irrigations were given to the crop viz. pre-sowing, 30 DAS and flowering (I_2) over two irrigations (I_1) i.e. 30 DAS and flowering. Different *Brassica* species differed significantly for plant height and significantly taller plants were recorded in *Brassica oleracea* ‘KBS 3’. Among management practices, significantly taller plants were obtained under conventional management system compared to natural management system at all the stages of observation.
- Higher dry matter accumulation among different *Brassica* species was recorded in *Brassica oleracea* ‘KBS 3’ when raised under conventional management system with three irrigation regimes although it was at par with *Brassica oleracea* ‘KBS 3’ under conventional management system with two irrigations only.
- Irrigation levels had no significant influence on the number of days taken to 50 per cent flowering and days for physiological maturity. However, the minimum number of days for 50 per cent flowering (62.8 days) and physiological maturity (142.3 days) was recorded in *Brassica oleracea* ‘KBS 3’. Among different management practices, natural

management system took significantly longer days for 50 per cent flowering as well as for physiological maturity.

- Root biomass was found significantly higher when irrigated thrice (I₂). Significantly higher root biomass was recorded in *Brassica oleracea* ‘KBS 3’ and among management practices it was significantly higher under conventional management system.

5.2 Yield attributes and yield

- All the yield attributes viz. primary branches, secondary branches, siliquae per plant and seeds per siliquae increased with increase in irrigation regimes and significantly higher yield attributes were recorded under three irrigation regimes (I₂) over two irrigations (I₁).
- With respect to different *Brassica* species, significantly higher number of primary branches, siliquae per plant and seeds per siliquae were recorded by *Brassica oleracea* ‘KBS 3’. Among management practices, conventional management system recorded superior yield attributes over natural management system.
- Interaction effect of different treatments was found significant for number of siliquae per plant where significantly higher number of siliquae per plant was recorded in *Brassica oleracea* ‘KBS 3’ when raised under conventional management system with three irrigation regimes.
- Test weight of different *Brassica* species was not influenced by varying irrigation levels, however, it differed significantly for different *Brassica* species where, a statistically similar test weight was recorded for *Brassica oleracea* ‘KBS 3’ and *Brassica napus* ‘GSC 7’ with lowest in *Brassica juncea* ‘RCC 4’. No significant effect of management practices was found on test weight of different *Brassica* species.
- Significantly higher seed, stover and biological yield was recorded when the crop was irrigated thrice and among different *Brassica* species, *Brassica oleracea* ‘KBS 3’ resulted in significantly higher yield followed by *Brassica juncea* ‘RCC 4’ and *Brassica napus* ‘GSC 7’. With respect to different

management practices, conventional management system recorded significantly higher seed, stover and biological yield over natural management system.

- The interaction effect of irrigation levels, *Brassica* species under different management practices was found significant for seed, stover and biological yield. Significantly higher stover yield (4173.3 kg ha⁻¹) and biological yield (5509.0 kg ha⁻¹) was recorded when *Brassica oleracea* ‘KBS 3’ was grown under conventional management system and given three irrigations viz. pre-sowing, 30 DAS and flowering. This was followed by yield in same species and same management system but given two irrigations viz. 30 DAS and flowering. However, the seed yield in *Brassica oleracea* ‘KBS 3’ grown under conventional management system given three irrigations and two irrigations remained statistically at par.

5.3 Soil studies

- Organic carbon content was also not influenced significantly by different irrigation levels; however, among management practices significantly higher organic carbon content was recorded under natural management system.
- Available nitrogen, phosphorus and potassium were not influenced significantly by different irrigation levels. However, the soil under *Brassica* species differed significantly for available nitrogen and phosphorus observed at harvest. Statistically similar available nitrogen at harvest was recorded under *Brassica napus* ‘GSC 7’ and *Brassica juncea* ‘RCC 4’. However, potassium content did not differ significantly in soil under different *Brassica* species. Among different management practices, significantly higher N, P and K content was recorded under conventional management system.
- Soil moisture content at 0-15 cm and 15-30 cm depth at every 15 days interval showed a general trend for soil moisture content where irrigation levels and *Brassica* species had no significant influence on soil moisture content irrespective of the date of sampling. However, different management practices significantly affected the soil moisture content at every sampling except on 13 November where it was not significant. Significantly higher moisture content

at every sampling was recorded under the natural management system as compared to conventional system.

- Available soil moisture content before and after irrigation at 0-15 cm and 15-30 cm depth was found to be significantly influenced by different irrigation regimes, where the soil moisture content after first irrigation was recorded significantly higher when three irrigations were given (I₂). However, the moisture content at other irrigation stages was not found significant.
- With respect to different management practices, a significant difference was observed at second and third irrigations viz. 30 DAS and flowering, however it was not found significant at first irrigation i.e. pre-sowing. At second and third irrigations significantly higher moisture content was observed under natural management system over conventional management.

5.4 Plant analysis

- Significantly higher N, P and K uptake by seed and stover was recorded with the application of three irrigations over two irrigations and hence the total uptake by the crop. Among different *Brassica* species, significantly higher uptake of N, P and K by seed and stover was observed in *Brassica oleracea* 'KBS 3' and similar trend was followed for the total uptake by the crop.
- Under varying management practices, significantly higher uptake of N, P and K by seed and stover was recorded under conventional management system over natural management and hence the total uptake by the crop.

5.5 Quality analysis

- Oil content (%) and protein content (%) was not influenced significantly by different irrigation levels. However, among different *Brassica* species, significantly higher oil and protein content was recorded in *Brassica oleracea* 'KBS 3' followed by *Brassica napus* 'GSC 7' and *Brassica juncea* 'RCC 4' and the latter two were statistically at par with one another. Under varying management practices, significantly higher oil and

protein content was recorded under conventional management system over natural management.

5.6 Water studies

- Irrigation levels did not significantly influence water productivity and returns per unit irrigated water use. However, biomass water use efficiency and irrigation water use efficiency recorded was significantly higher when two irrigations were given ($8.544 \text{ kg ha}^{-1} \text{ mm}^{-1}$ and $8.54 \text{ kg ha}^{-1} \text{ mm}^{-1}$, respectively) to the crop over three irrigations.
- Among various *Brassica* species significantly higher water productivity (0.233 kg m^{-3}), biomass water use efficiency ($9.762 \text{ kg ha}^{-1} \text{ mm}^{-1}$), irrigation water use efficiency ($8.94 \text{ kg ha}^{-1} \text{ mm}^{-1}$) and returns per unit irrigated water use (13.934 ₹ m^{-3}) was recorded in *Brassica oleracea* 'KBS 3'. Among different management practices, significantly higher values of all the aforementioned parameters (0.242 kg m^{-3} , $10.105 \text{ kg ha}^{-1} \text{ mm}^{-1}$, $9.27 \text{ kg ha}^{-1} \text{ mm}^{-1}$ and 15.140 ₹ m^{-3}) were observed under conventional management system over natural system.
- A significant interaction between irrigation levels and management practices was observed on water productivity and irrigation water use efficiency by different *Brassica* species. Statistically similar water productivity was recorded in *Brassica oleracea* 'KBS 3' grown under conventional system with two irrigation levels (0.283 kg m^{-3}), *Brassica oleracea* 'KBS 3' under conventional system with three irrigation regimes (0.269 kg m^{-3}) and *Brassica juncea* 'RCC 4' grown under conventional system given two irrigations. In case of irrigation water use efficiency significantly higher efficiency ($12.32 \text{ kg ha}^{-1} \text{ mm}^{-1}$) was recorded in *Brassica oleracea* 'KBS 3' grown under conventional system with two irrigation levels followed by *Brassica juncea* 'RCC 4' under conventional system with two irrigations ($10.71 \text{ kg ha}^{-1} \text{ mm}^{-1}$).

5.7 Economics

- Significantly higher gross returns (₹39,673 ha⁻¹), net returns (₹12,786 ha⁻¹) and benefit cost ratio (0.48) was recorded with the application of three irrigations (I₂) over two irrigations (I₁).
- With respect to different *Brassica* species, significantly higher gross returns, net returns and benefit cost ratio was recorded in *Brassica oleracea* 'KBS 3' followed by *Brassica juncea* 'RCC 4' and *Brassica napus* 'GSC 7'.
- Among different management practices, significantly higher gross returns, net returns and benefit cost ratio was observed under conventional management system over natural system.
- The interaction effect of irrigation levels and *Brassica* species on gross returns, net returns and benefit cost ratio was found significant and the higher values of these parameters were recorded when three irrigations were given to *Brassica oleracea* 'KBS 3' although it was found to be at par with two irrigations in same species.

5.8 Conclusion

For obtaining higher crop and water productivity with better economic returns from oilseed *Brassica* species under different management system and irrigation levels; the *Brassica oleracea* 'KBS 3' should be grown under conventional farming and be given two irrigations at 30 DAS and flowering stage.

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APPENDICES

Appendix –I

**Mean weekly rainfall, air temperature and relative humidity for the crop period
(14 October 2020 to 29 April 2021)**

Standard week	Temperature (⁰ C)		Rainfall (mm)	Relative Humidity (per cent)
	Max.	Min.		
2020				
40	28.50	13.24	0.00	77.71
41	28.07	13.00	0.00	78.71
42	27.00	11.44	0.00	71.43
43	25.00	9.29	0.00	65.00
44	24.29	8.93	0.00	65.57
45	23.34	7.21	0.00	62.29
46	19.50	6.21	16.00	75.86
47	17.29	4.67	0.40	67.29
48	19.24	5.67	9.60	70.14
49	20.77	7.06	0.00	70.86
50	17.31	3.31	25.80	78.86
51	17.14	0.83	0.00	62.14
52	14.86	1.79	16.00	76.86
2021				
1	15.79	5.46	34.60	77.86
2	17.89	3.50	0.00	67.71
3	17.24	4.10	0.00	76.29
4	16.07	3.46	17.00	75.14
5	16.64	3.17	14.80	72.71
6	17.29	4.86	0.60	75.86
7	20.31	7.06	1.00	73.86
8	21.70	9.60	2.20	67.29
9	22.07	8.93	3.80	59.43
10	23.64	10.63	0.60	56.71
11	23.57	10.94	0.00	54.86
12	23.29	11.20	17.40	62.14
13	22.43	13.33	0.00	49.00
14	24.14	13.96	59.00	48.36
15	27.29	13.79	0.00	48.36
16	24.00	11.60	68.60	64.29
17	25.43	13.57	55.20	42.71

Appendix –II

Treatment	Nutrient content (%)					
	N (%)		P (%)		K (%)	
Irrigation levels	Seed	Stover	Seed	Stover	Seed	Stover
I ₁	1.938	0.269	0.186	0.123	1.180	0.301
I ₂	1.920	0.264	0.189	0.124	1.199	0.307
SEm±	0.004	0.002	0.002	0.001	0.004	0.002
CD (P=0.05)	NS	NS	NS	NS	NS	NS
Brassica species						
B ₁ - <i>Brassica oleracea</i> ‘KBS 3’	1.963	0.280	0.193	0.129	1.203	0.309
B ₂ - <i>Brassica juncea</i> ‘RCC 4’	1.918	0.263	0.187	0.125	1.189	0.304
B ₃ - <i>Brassica napus</i> ‘GSC 7’	1.906	0.255	0.182	0.118	1.177	0.299
SEm±	0.007	0.004	0.003	0.002	0.005	0.003
CD (P=0.05)	0.020	0.012	NS	0.005	0.016	0.007
Management practices						
M ₁ -Conventional management	1.996	0.282	0.195	0.129	1.202	0.312
M ₂ - Natural management	1.862	0.250	0.180	0.119	1.178	0.296
SEm±	0.005	0.003	0.003	0.001	0.004	0.002
CD (P=0.05)	0.016	0.010	0.008	0.004	0.013	0.006

Appendix –III

Calculation of effective rainfall using CROPWAT 8.0 software given by FAO

Month	Monthly Rainfall (mm)	Effective rainfall (mm)
October	0	0
November	26.0	24.9
December	41.8	39.0
January	51.6	47.3
February	22.4	21.6
March	18.0	17.5
April	98.6	83.0
TOTAL	258.4	233.3

Treatments	Number of irrigations	Irrigation water applied (mm)	Effective rainfall (mm)	ΔS	Total water Use (mm)
I ₁ B ₁ M ₁	2	50	233.3	101.83	435.13
I ₁ B ₁ M ₂	2	50	233.3	95.40	428.70
I ₁ B ₂ M ₁	2	50	233.3	81.86	415.16
I ₁ B ₂ M ₂	2	50	233.3	80.60	413.90
I ₁ B ₃ M ₁	2	50	233.3	91.94	425.24
I ₁ B ₃ M ₂	2	50	233.3	121.54	454.84
I ₂ B ₁ M ₁	3	50	233.3	112.93	496.23
I ₂ B ₁ M ₂	3	50	233.3	115.30	498.60
I ₂ B ₂ M ₁	3	50	233.3	129.06	512.36
I ₂ B ₂ M ₂	3	50	233.3	119.32	502.62
I ₂ B ₃ M ₁	3	50	233.3	111.09	494.39
I ₂ B ₃ M ₂	3	50	233.3	116.14	499.44

Appendix-IV: Effect of irrigation levels and nutrient management practices on soil moisture content (per cent by weight) at 15 days interval at 0-15 cm

Soil moisture content (per cent by weight) at 0-15 cm										
Treatments	29 Oct	13 Nov	28 Nov	13 Dec	28 Dec	12 Jan	27 Jan	11 Feb	26 Feb	13 Mar
Irrigation levels										
I ₁	22.4	21.7	35.6	35.4	32.1	27.6	25.7	22.2	20.1	18.8
I ₂	22.6	22.4	35.3	35.3	33.1	27.7	26.4	23.0	21.1	20.2
SEm±	0.4	0.2	0.3	0.7	0.6	0.5	0.4	0.3	0.3	0.3
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Brassica species										
B₁- Brassica oleracea 'KBS 3'	22.6	22.3	35.2	35.6	33.4	27.7	26.8	22.3	20.4	19.2
B₂- Brassica juncea 'RCC 4'	22.5	22.0	35.6	35.5	32.3	27.2	25.5	23.1	21.1	20.0
B₃- Brassica napus 'GSC 7'	22.6	21.8	35.5	34.8	32.2	28.1	25.9	22.4	20.2	19.3
SEm±	0.6	0.4	0.7	0.8	0.7	0.9	0.9	0.7	0.6	0.6
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Management practices										
M₁-Conventional management	21.2	21.6	30.5	29.8	29.6	25.7	23.6	21.5	19.7	18.6
M₂-Natural management	23.9	22.5	40.5	40.8	35.6	29.5	28.5	23.7	21.5	20.4
SEm±	0.5	0.3	0.6	0.7	0.6	0.7	0.7	0.6	0.5	0.5
CD (P=0.05)	1.4	NS	1.8	2.0	1.7	2.2	2.2	1.8	1.5	1.5

Appendix-V: Effect of irrigation levels and nutrient management practices on soil moisture content (per cent by weight) at 15 days interval at 15-30 cm

Soil moisture content (per cent by weight) at 15-30 cm										
Treatments	29 Oct	13 Nov	28 Nov	13 Dec	28 Dec	12 Jan	27 Jan	11 Feb	26 Feb	13 Mar
Irrigation levels										
I ₁	23.8	23.2	38.0	37.1	33.9	29.2	28.2	23.2	22.0	19.6
I ₂	23.8	23.9	38.2	37.4	34.3	28.8	29.1	24.0	22.9	21.0
SEm±	0.1	0.2	0.2	0.2	0.3	0.4	0.5	0.2	0.2	0.3
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
<i>Brassica species</i>										
B₁- Brassica oleracea 'KBS 3'	23.7	23.7	37.8	37.0	34.4	29.1	29.3	23.3	22.4	20.2
B₂- Brassica juncea 'RCC 4'	23.7	23.5	38.1	37.3	34.7	28.8	28.5	23.9	22.9	20.8
B₃- Brassica napus 'GSC 7'	24.0	23.4	38.3	37.3	33.3	29.1	28.1	23.6	22.0	20.0
SEm±	0.5	0.4	1.0	0.6	0.7	0.8	0.6	0.5	0.7	0.6
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Management practices										
M₁-Conventional management	22.8	23.1	33.5	32.4	30.7	26.7	26.3	22.6	21.5	19.4
M₂-Natural management	24.8	24.0	42.6	42.0	37.5	31.3	31.0	24.6	23.4	21.2
SEm±	0.4	0.4	0.8	0.5	0.6	0.7	0.5	0.4	0.6	0.5
CD (P=0.05)	1.2	NS	2.4	1.5	1.7	2.0	1.4	1.2	1.7	1.4

Appendix –VI

a) Cost of cultivation for constant inputs (Rs. ha⁻¹)

Particulars	Quantity	Unit	Rate (Rs.)	Amount (Rs.)
A. Land preparation				
1. Ploughing and harrowing	6	tractor hours	800	4800
2. Leveling and bunding	6	man days	275	1650
B. Seed	6	kg ha ⁻¹	70	420
C. Sowing	6	man days	275	1650
D. Weeding (2 times)	8	man days	275	2200
E. Thinning	6	man days	275	1650
Total				12,370

b) Cost of cultivation for variable inputs under (Rs. ha⁻¹)

Particulars	Quantity	Unit	Rate (Rs.)	Amount (Rs.)
I: Irrigation levels				
I ₁ : Irrigation at 30 DAS and flowering	4	man days	275	1100
I ₂ : Irrigation at pre sowing, 30 DAS and flowering	6	man days	275	1650
Total				2750
B₁M₁: Brassica oleracea KBS 3 - Conventional management				
A. SSP	250	kg ha ⁻¹	11.66	2915
B. MOP	66.66	kg ha ⁻¹	19	1266.54
C. Urea	130.43	kg ha ⁻¹	5.92	772.15
Application cost	1	man days	275	275
1st top dressing	1	man days	275	275
2nd top dressing	1	man days	275	275
D. Plant protection (Cypermethrin)	1234	ml ha ⁻¹	0.48	592.32
Spray cost (times)	2	man days	275	550
Total				6921.01
B₁M₂: Brassica oleracea KBS 3 - Natural management				
A. Ghanjeevamrit	395.20	kg ha ⁻¹	7	2766.40
Application cost	2	man days	275	550
B. Beejamrit	1.20	lt ha ⁻¹	7	8.4
C. Jeevamrit (7 times)	210	lt ha ⁻¹	7	1470
Spray cost	7	man days	275	1925
D. Neemastra (2 times)	50	lt ha ⁻¹	7	350

Plant protection (<i>Neemastra</i> - 2 spray)	2	man days	275	550
E. Mulching	4	man days	275	1100
Total				8719.80
B₂M₁: <i>Brassica juncea</i> RCC 4 - Conventional management				
A. SSP	250	kg ha ⁻¹	11.66	2915
B. MOP	66.66	kg ha ⁻¹	19	1266.54
C. Urea	130.43	kg ha ⁻¹	5.92	772.15
Application cost	1	man days	275	275
1st top dressing	1	man days	275	275
2nd top dressing	1	man days	275	275
D. Plant protection (Cypermethrin)	1234	ml ha ⁻¹	0.48	592.32
Spray cost (times)	2	man days	275	550
TOTAL				6921.01
B₂M₂: <i>Brassica juncea</i> RCC 4 - Natural management				
A. Ghanjeevamrit	395.20	kg ha ⁻¹	7	2766.40
Application cost	2	man days	275	550
B. Beejamrit	1.20	lt ha ⁻¹	7	8.40
C. Jeevamrit (7 times)	210	lt ha ⁻¹	7	1470
Spray cost	7	man days	275	1925
D. Neemastra (2 times)	50	lt ha ⁻¹	7	350
Plant protection (<i>Neemastra</i> - 2 spray)	2	man days	275	550
E. Mulching	4	man days	275	1100
Total				8719.80
B₃M₁: <i>Brassica napus</i> GSC 7 - Conventional management				
A. SSP	375	kg ha ⁻¹	11.66	4372.50
B. MOP	66.66	kg ha ⁻¹	19	1266.54
C. Urea	260.86	kg ha ⁻¹	5.92	1544.29
Application cost	1	man days	275	275.00
1st top dressing	1	man days	275	275.00
2nd top dressing	1	man days	275	275.00
D. Plant protection (Cypermethrin)	1234	ml ha ⁻¹	0.48	592.32
Spray cost (times)	2	man days	275	550
TOTAL				9150.65
B₃M₂: <i>Brassica napus</i> GSC 7 - Natural management				
A. Ghanjeevamrit	395.20	kg ha ⁻¹	7	2766.4
Application cost	2	man days	275	550
B. Beejamrit	1.20	lt ha ⁻¹	7	8.4
C. Jeevamrit (7 times)	210	lt ha ⁻¹	7	1470
Spray cost	7	man days	275	1925
D. Neemastra (2 times)	50	lt ha ⁻¹	7	350
Plant protection (<i>Neemastra</i> - 2 spray)	2	man days	275	550
E. Mulching	4	man days	275	1100
TOTAL				8719.80

Harvesting Cost				
I ₁ B ₁ M ₁	9	man days	275	2475
I ₁ B ₂ M ₂	8	man days	275	2200
I ₁ B ₂ M ₁	9	man days	275	2475
I ₁ B ₂ M ₂	8	man days	275	2200
I ₁ B ₃ M ₁	9	man days	275	2475
I ₁ B ₃ M ₂	7	man days	275	1925
I ₂ B ₁ M ₁	9	man days	275	2475
I ₂ B ₂ M ₂	8	man days	275	2200
I ₂ B ₂ M ₁	9	man days	275	2475
I ₂ B ₂ M ₂	8	man days	275	2200
I ₂ B ₃ M ₁	9	man days	275	2475
I ₂ B ₃ M ₂	8	man days	275	2200
Threshing and winnowing				
I ₁ B ₁ M ₁	9	man days	275	2475
I ₁ B ₂ M ₂	8	man days	275	2200
I ₁ B ₂ M ₁	9	man days	275	2475
I ₁ B ₂ M ₂	8	man days	275	2200
I ₁ B ₃ M ₁	9	man days	275	2475
I ₁ B ₃ M ₂	7	man days	275	1925
I ₂ B ₁ M ₁	9	man days	275	2475
I ₂ B ₂ M ₂	8	man days	275	2200
I ₂ B ₂ M ₁	9	man days	275	2475
I ₂ B ₂ M ₂	8	man days	275	2200
I ₂ B ₃ M ₁	9	man days	275	2475
I ₂ B ₃ M ₂	8	man days	275	2200
Total Cost				
I ₁ B ₁ M ₁	-	-	-	25341.01
I ₁ B ₂ M ₂	-	-	-	26589.80
I ₁ B ₂ M ₁	-	-	-	25341.01
I ₁ B ₂ M ₂	-	-	-	26589.80
I ₁ B ₃ M ₁	-	-	-	27570.65
I ₁ B ₃ M ₂	-	-	-	26039.80
I ₂ B ₁ M ₁	-	-	-	25891.01
I ₂ B ₂ M ₂	-	-	-	27139.80
I ₂ B ₂ M ₁	-	-	-	25891.01
I ₂ B ₂ M ₂	-	-	-	27139.80
I ₂ B ₃ M ₁	-	-	-	28120.65
I ₂ B ₃ M ₂	-	-	-	27139.80

Appendix- VII**Plate 1. Germination test of different *Brassica* species****Plate 2. Sowing**



Plate 3. *Jeevamrit* Spray



Plate 4. Measuring plant height



Plate 5 General view of the field



Plate 6. Counting of seeds per siliquae



Plate 7. Lab work

Brief Biodata of student

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Qualification	Year	School/Board/University	Marks (%)	Division
10 th	2012	Central Board of Secondary Education	96.0	First
12 th	2014	Central Board of Secondary Education	83.2	First
B.Sc. (Agriculture)	2019	CSK HPKV, Palampur (HP)	75.0	First
M.Sc. (Agronomy)	2021	CSK HPKV, Palampur (HP)	83.1	First