Response of Fennel (*Foeniculum vulgare* Mill.) to Drip Irrigation and Fertigation

सौंफ (*फोईनीकुलम वल्गेयर* मिल.) की बूंद-बूंद सिंचाई और उर्वरीकरण के प्रति अनुक्रिया

Geeta Kumari Giana

(15-02-01-04-23)

Thesis

Doctor of Philosophy in Agriculture (Agronomy)

2020

Department of Agronomy

S.K.N. College of Agriculture, Jobner - 303329

Sri Karan Narendra Agriculture University, Jobner

Response of Fennel (Foeniculum vulgare Mill.) to Drip Irrigation and Fertigation

सौंफ (*फोईनीकुलम वल्गेयर* मिल.) की बूंद-बूंद सिंचाई और उर्वरीकरण के प्रति अनुक्रिया

Thesis

S.K.N. College of Agriculture University, Jobner

In partial fulfillment of the requirement for

the degree of

Doctor of Philosophy

in the

Faculty of Agriculture

(Agronomy)

By

Geeta Kumari Giana

(15-02-01-04-23)

2020

सौंफ (*फोईनीकुलम वल्गेयर* मिल.) की बूंद-बूंद सिंचाई और उर्वरीकरण के प्रति अनुक्रिया

’kks/k xzUFk

Jh d.kZ ujsUnz d`f"k fo’ofo|ky;] tkscusj esa mikf/k dh vkaf’kd iwfrZ dh vko’;drk esa izLrqr

fo|kokpLifr

d`f"k ladk;

¼lL; foKku½

}kjk

गीता कुमारी गैंणा

2020

Sri Karan Narendra Agriculture University, Jobner

S.K.N. College of Agriculture, Jobner

CERTIFICATE - I

Dated : 2019

This is to certify that **Ms. Geeta Kumari Giana** has successfully completed the preliminary examination held on 12th April, 2016 as required under the regulation for Ph. D. degree.

(S.S. Yadav)
Professor & Head
Department of Agronomy

Sri Karan Narendra Agriculture University, Jobner

S.K.N. College of Agriculture, Jobner

CERTIFICATE - II

Dated: 2019

This is to certify that the thesis entitled **“Response of Fennel (Foeniculum vulgare Mill.) to Drip Irrigation and Fertigation”** submitted for the degree of Doctor of Philosophy in Agriculture in the subject of Agronomy embodies bonafide research work carried out by **Ms. Geeta Kumari Giana** under my guidance and supervision and that no part of this thesis has been submitted for any other degree. The assistance and help received during the course of investigation have been fully acknowledged. The draft of the thesis was also approved by advisory committee on……………**...**

(S.S. Yadav)
Professor & Head
Department of Agronomy

(A.C. Shivran)
Major Advisor

(G.S. Bangarwa)
DEAN
S.K.N. College of Agriculture,
Jobner

Sri Karan Narendra Agriculture University, Jobner

S.K.N. College of Agriculture, Jobner

CERTIFICATE - III

Dated: .....….2019

This is to certify that the thesis entitled **"Response of Fennel (*Foeniculum vulgare* Mill.) to Drip Irrigation and Fertigation"** submitted by **Ms. Geeta Kumari Giana** to the Sri Karan Narendra Agriculture University, Jobner in fulfillment of the requirements for the degree of Doctor of Philosophy in the subject of Agronomy, after recommendation by the external examiner, was defended by the candidate before the following members of the examination committee. The performance of the candidate in the oral examination on her thesis has been found satisfactory. We therefore, recommend that the thesis be approved.

(A.C. Shivran)
Major advisor

(O.P. Sharma)
Advisor

(B.L. Kakralya)
Advisor

(K.K. Sharma)
Advisor

(B.L. Yadav)
(Director Education Nominee)

(S.S. Yadav)
Prof. & Head
Department of Agronomy

(R.K. Pannu)
External Examiner

Approved

(G.S. Bangarwa)
Dean

Director Education
SKNAU, Jobner

Sri Karan Narendra Agriculture University, Jobner

S.K.N. College of Agriculture, Jobner

CERTIFICATE - IV

Dated: …….2019

This is to certify that **Ms. Geeta Kumari Giana** of the Department of Agronomy, S.K.N. College of Agriculture, Jobner has made all corrections/ modifications in the thesis entitled **"Response of Fennel (*Foeniculum vulgare* Mill.) to Drip Irrigation and Fertigation"** which were suggested by the external examiner and the advisory committee in the oral examination held on __________. The final copies of the thesis duly bound and corrected were submitted on __________ are forwarded herewith for approval.

(A.C. Shivran)
Major Advisor

(S.S. Yadav)
Professor & Head
Department of Agronomy

(G.S. Bangrwa)
Dean

Approved
DIRECTOR EDUCATION
SKNAU, Jobner

ACKNOWLEDGEMENT

The pride of place in this galaxy belongs to esteemed chairman of my advisory committee Dr. A.C. Shivran, Professor, Department of Agronomy, S.K.N. College of Agriculture, Jobner for suggesting and planning the present investigation, engrossing guidance, constructive criticism, kind and gracious patronage throughout the course of investigation and preparation of manuscript without which this work would not have been the light of the day.

I feel prickly conscience to remain with a single world of gratitude for the pivotal role played by the amiable members of my advisory committee Dr. O.P. Sharma, Emeritus Professor (Agronomy), Dr. B.L. Yadav, Emeritus Professor (Soil Science), Dr. K.K. Sharma, Professor and Head (Soil Scienec) and Dr. B.L. Kakralya, Professor and Head (Plant Physiology) who spared no pain in bringing out the thesis in the form with their over willing and expert advice.

Sense of obligation compels me to express my cordial thanks to Dr. S.S. Yadav, Professor and Head, Department of Agronomy, S.K.N. College of Agriculture, Jobner for providing assistance and necessary facilities as and when required.

The author wishes to put on record his cordial thanks to Dr. M.L. Jakhar, Director Education, Sri Karan Narendra Agriculture University, Jobner and Dr. G.S. Bangarwa, Dean, S.K.N. College of Agriculture, Jobner for providing necessary facilities and administrative help in this venture.

I feel gratified to record my cordial thanks to Dr. D.K. Jajoriya, Assoc. Professor (Agronomy), Dr. B.L. Dudwal, Sh. B.R. Meena, Dr. Priyanka Kumawat, Asstt, Professors (Agronomy), Sh. S.L. Jakhar, Sh. U.S. Manohar, Mr. Ramnarayan and other staff members of the department including farm for their valuable co-operation in completing this investigation smoothly.

Finally, my felicitousness overwhelms to express my deepest sense of reverence and indebtedness to my father-in-law Late Sh. K.M. Karwasra and Mother-in-law Smt. Shanti Devi, sister Champa and her husband Mr. Suresh Karwasra and my beloved son lovesh and my parents Sh. Laxman Ram Giana and Smt. Patasee Devi whose blessings and inspiration always encouraged me for higher studies. I also express my deep affection to my brothers Girdhari, Madan and sister-in-laws Mamta, Suman and whole family along with other well wishers whose incessant love, affection and encouragement brought the present task to completion.

I am also greatful to Mr. Suresh Yadav, M/s. Vimal Computers, Jobner for typing the manuscript within a short period.

The most cordial appreciation goes to my husband Mr. Ashok Kumar for his moral encouragement during the course of work.

Last but not the least, a million thanks to almighty GOD, who made me to this task and made every job a success for me.

Place : Jobner

Dated : / /2019 **(Geeta Kumari Giana)**

LIST OF CONTENTS

Chapter No.	Title	Page No.
	Abstract in English	....
	Abstract in Hindi	....
1.	**Introduction**	....
2.	**Review of Literature**	....
3.	**Materials and Methods**	....
4.	**Experiment Results**	....
5.	**Discussion**	....
6.	**Summary and Conclusion**	....
	Bibliography	....
	Appendices	....

ACRONYMS

@	At the rate of
%	Per cent
A.O.A.C.	Association of official analytical chemical
CD	Critical difference
ANOVA	Analysis of variance
d.f.	Degree of freedom
DAS	Days after sowing
CV	Coefficient of variation
dS/m	Deci Siemen per metre
ECe	Electrical Conductivity of saturation extract
Fig.	Figure
G	Gram
Ha	Hectare
Cm	Centimetre
K	Potassium
Kg/ha	Kilogram per hectare
RGR	Relative growth rate
CGR	Crop growth rate
EC	Emulsifiable concentrate
m^2	Square metre
Mm	Millimetre
HW	Hand weeding
MSS	Mean sum of square
N	Nitrogen
RDF	Recommended dose of fertilizer
RDN	Recommended dose of nitrogen
No.	Number
CF	Conventional fertilization
NS	Non-Significant
P	Phosphorus
SMW No.	Standard meteorological week number
₹/ha	Rupees per hectare
SEm±	Standard Error of Mean
USDA	United States Department of Agriculture
viz.,	Vide licit
^{0}C	Degree Celsius
Ppm	Part per million
WUE	Water use efficiency
FUE	Fertilizer use efficiency

LIST OF TABLES

Table No.	Particulars	Page No.
3.1	Mean weekly weather parameters during crop growth period	………..
3.2	Cropping history of the experimental field	………..
3.3	Physico-chemical characteristics of the soil of experimental field	………..
3.4	Quality of irrigation water and method of determination	………
3.5	Treatments and their symbols	………..
3.6	Schedule of cultural operations carried out during the crop seasons of 2015-16 and 2016-17	………..
4.1	Effect of drip irrigation and fertigation on plant stand per metre row length of fennel	………..
4.2	Effect of drip irrigation and fertigation on plant height of fennel	………..
4.3	Effect of drip irrigation and fertigation on dry matter accumulation per plant of fennel	………..
4.4	Effect of drip irrigation and fertigation on number of branches per plant and chlorophyll content of fennel	………..
4.5	Effect of drip irrigation and fertigation on crop growth rate of fennel	………
4.6	Effect of drip irrigation and fertigation on relative growth rate of fennel	………..
4.7	Effect of drip irrigation and fertigation on yield attributes of fennel	………..
4.8	Effect of drip irrigation and fertigation on seed, straw, biological yields and harvest index of fennel	………..
4.9	Effect of drip irrigation and fertigation on nitrogen content in seed and straw of fennel	………..
4.10	Effect of drip irrigation and fertigation on nitrogen uptake by seed, straw and total uptake of fennel	………..

4.11	Effect of drip irrigation and fertigation on phosphorus content in seed and straw of fennel	…………
4.12	Effect of drip irrigation and fertigation on phosphorus uptake by seed, straw and total uptake of fennel	……….
4.13	Effect of drip irrigation and fertigation on potassium content in seed and straw of fennel	………
4.14	Effect of drip irrigation and fertigation on potassium uptake by seed, straw and total uptake of fennel	………
4.15	Effect of drip irrigation and fertigation on essential oil content, oil yield and protein content of fennel	……….
4.16	Effect of drip irrigation and fertigation on consumptive use of water and water use efficiency of fennel	………
4.17	Effect of drip irrigation and fertigation on water use and water saving of fennel	………
4.18	Effect of drip irrigation and fertigation on fertilizer use efficiency of fennel	………
4.19	Effect of drip irrigation and fertigation on net returns and B:C ratio of fennel	………
4.20	Correlation coefficients and linear regression equation showing relationship between growth, yield attributes and nutrient uptake and yield	………

LIST OF FIGURES

Figure No.	Particulars	Page No.
3.1a	Mean weekly weather parameters recorded during crop growth period (*Rabi,* 2015-16)	………..
3.1b	Mean weekly weather parameters recorded during crop growth period (*Rabi,* 2016-17)	………..
3.2	Layout plan of experiment	………..
4.1	Effect of drip irrigation and fertigation on plant height of fennel (pooled data)	………..
4.2	Effect of drip irrigation and fertigation on dry matter accumulation of fennel (pooled data)	………..
4.3	Effect of drip irrigation and fertigation on number of branches per plant and chlorophyll content of fennel (pooled data)	………..
4.4	Effect of drip irrigation and fertigation on yield attributes of fennel (pooled data)	………..
4.5	Effect of drip irrigation and fertigation on seed, straw and biological yields of fennel (pooled data)	………..
4.6	Effect of drip irrigation and fertigation on nitrogen uptake by seed and straw and total uptake of fennel (pooled data)	………..
4.7	Effect of drip irrigation and fertigation on phosphorus uptake by seed and straw and total uptake of fennel (pooled data)	………..
4.8	Effect of drip irrigation and fertigation on potassium uptake by seed and straw and total uptake of fennel (pooled data)	………..
4.9	Effect of drip irrigation and fertigation on essential oil content and oil yield of fennel (pooled data)	………..
4.10	Effect of drip irrigation and fertigation on net returns and B:C ratio of fennel (pooled data)	………..

LIST OF APPENDICES

Appendix No.	Particulars	Page No.
I	Analysis of variance (MSS) for plant stand /m row length	………..
II	Pooled analysis of variance (MSS) for plant stand /m row length	………..
III	Analysis of variance (MSS) for plant height (cm)	………..
IV	Pooled analysis of variance (MSS) for plant height (cm)	………..
V	Analysis of variance (MSS) for dry matter accumulation per plant (g)	………..
VI	Pooled analysis of variance (MSS) for dry matter accumulation per plant	………..
VII	Analysis of variance (MSS) for number of branches per plant and chlorophyll content	………..
VIII	Pooled analysis of variance (MSS) for number of branches per plant and total chlorophyll content	………..
IX	Analysis of variance (MSS) for crop growth rate	………..
X	Pooled analysis of variance (MSS) for crop growth rate	………..
XI	Analysis of variance (MSS) for relative growth rate	………..
XII	Pooled analysis of variance (MSS) for relative growth rate	………..
XIII	Analysis of variance (MSS) for yield attributes	………..
XIV	Pooled analysis of variance (MSS) for yield attributes	………..
XV	Analysis of variance (MSS) for seed, straw and biological yields and harvest index	………..

XVI	Pooled analysis of variance (MSS) for seed, straw and biological yields and harvest index	………..
XVII	Analysis of variance (MSS) for nitrogen content, uptake by seed and straw and total uptake	………..
XVIII	Pooled analysis of variance (MSS) for nitrogen content, uptake by seed and straw and total uptake	………..
XIX	Analysis of variance (MSS) for phosphorus content, uptake by seed and straw and total uptake	………..
XX	Pooled analysis of variance (MSS) for phosphorus content, uptake by seed and straw and total uptake	………..
XXI	Analysis of variance (MSS) for potassium content, uptake by seed and straw and total uptake	………..
XXII	Pooled analysis of variance (MSS) for potassium content, uptake by seed and straw and total uptake	………..
XXIII	Analysis of variance (MSS) for protein content, essential oil content and oil yield	………..
XXVI	Pooled analysis of variance (MSS) foe protein content, essential oil content and oil yield	………..
XXV	Analysis of variance (MSS) for consumptive use and water use efficiency	………..
XXVI	Pooled analysis of variance (MSS) for consumptive use and water use efficiency	………..
XXVII	Analysis of variance (MSS) for fertilizer use efficiency	………..
XXVIII	Pooled analysis of variance (MSS) for fertilizer use efficiency	………..
XXIX	Analysis of variance (MSS) for net returns and B:C ratio	………..
XXX	Pooled analysis of variance (MSS) for net returns and B:C ratio	………..
XXXI	Cost of cultivation of fennel	………..
XXII	Economics of treatment 2015-16	………..
XXIII	Economics of treatment 2016-17	………..

Response of Fennel (*Foeniculum vulgare* mill.) to Drip Irrigation and Fertigation

Geeta Kumari Giana* | **Dr. A. C. Shivran ****
(Scholar) | **(Major Advisor)**

ABSTRACT

A field experiment was conducted at Agronomy Farm, S.K.N. College of Agriculture, Jobner (Jaipur) at 26^{0} 05' north latitute, 75^{0} 28' east longitude and at an altitude of 427 metres above mean sea level during two consecutive *Rabi* seasons of the year 2015-16 and 2016-17 to study the response of fennel to drip irrigation and fertigation grown on irrigated loamy sand soil of semi arid eastern plain zone of Rajasthan. The experiment comprised of ten treatments *i.e* surface irrigation with CF with 100 per cent RDF, drip irrigation with CF (50, 75 and 100 per cent RDF), drip fertigation with (50, 75 and 100) per cent RDN as well as RDF were replicated three times in randomized block design.

Surface irrigation with conventional fertilization represented significantly lower magnitude of growth parameters *viz.,* plant height (at 35, 70, 105 DAS and at harvest), dry matter accumulation per plant (at 35, 70, 105 DAS and at harvest), chlorophyll content in leaves at 75 DAS, yield attributes (umbels/plant, umbellets/umbel, seeds/umbel, test weight), seed, straw and biological yields. Nitrogen, phosphorus, potassium contents, their uptake in seed and straw, essential oil content in seed, oil yield and net returns (₹ 98203/ha) were also significantly lower in surface irrigation with conventional fertilization over other drip irrigated and fertigated treatments.

Among different drip irrigation and fertigation treatments, drip fertigation at 75 per cent RDF, remained at par with drip fertigation with 100 per cent RDF as well as 100 per cent RDN, significantly increased the plant height (at 35, 70, 105 DAS and at harvest), dry matter accumulation per plant (at 35, 70, 105 DAS and at harvest), chlorophyll content in leaves at 75 DAS, umbels per plant, umbellets per umbel, seeds per umbel, seed, straw and biological yields, water use efficiency, essential oil content, potassium content and net returns over other treatments. However, nitrogen and phosphorus contents, their uptake, protein content, oil yield improved significantly with drip fertigation with 100 per cent RDF over other treatments. Drip fertigation with 75 per cent RDF fetched significantly highest seed yield (2516 kg/ha) and net returns (₹ 154162/ha) with increase of 50.0 and 52.2 per cent over surface irrigation with conventional fertilization.

Results further revealed that drip fertigation with 100 per cent RDN, being at par with fertigation of 75 per cent RDN as well as 50 per cent RDF, significantly increased the plant height, dry matter accumulation per plant (at 35, 70, 105 DAS and at harvest), chlorophyll content in leaves at 75 DAS, umbels per plant, umbellets per umbel, seeds per umbels, test weight, water use efficiency, oil yield, seed, straw and biological yields. However, nitrogen, phosphorus and potassium contents and their uptake in seed and straw, protein, essential oil content in seed were significantly increased with drip fertigation with 100 per cent RDN over drip irrigation with CF (50,75 and 100 per cent RDF) and drip fertigation with 50 per cent RDN as well 50 per cent RDF. Drip fertigation with100 per cent RDN significantly increased seed yield (2390 kg/ha) and net returns (₹ 146901/ha) with registered an increase of 42.5 and 49.6 per cent over surface irrigation with conventional fertilization.

---

* Ph. D. student, Department of Agronomy, S.K.N. College of Agriculture, Jobner, Sri Karan Narendra Agriculture University, Jobner, Jaipur.

** Thesis submitted to Sri Karan Narendra Agriculture University, Jobner, Jaipur in partial fulfilment of the requirement for the degree of Doctor of Philosophy in faculty of Agriculture in the subject of **Agronomy** under the supervision of **Dr. A.C. Shivran,** Professor (Agronomy), S.K.N. College of Agriculture, Jobner, Jaipur (Rajasthan).

सौंफ (*फोईनीकुलम वल्गेयर* मिल.) की बूंद-बूंद सिंचाई और उर्वरीकरण के प्रति अनुक्रिया

गीता कुमारी गैणा *
(शोधकर्ता)

डॉ. ए.सी. शिवरान **
(मुख्य सलाहकार)

अनुक्षेपण

बूंद–बूंद सिंचाई और उर्वरीकरण के प्रति सौंफ की अनुक्रिया के प्रयोग का अध्ययन करने के लिए राजस्थान के अर्द्वशुष्क पूर्वी मैदानी क्षेत्र की सिंचित दोमट बलुई मृदा पर श्री कर्ण नरेन्द्र कृषि महाविद्यालय, जोबनेर (जयपुर) 26^0 05' उत्तरी अक्षांश, 75^0 28' पूर्वी देशान्तर और समुद्र तल से 427 मीटर ऊँचाई के सस्य विज्ञान प्रक्षेत्र पर रबी में दो वर्ष 2015–16 एवं 2016–17 में परीक्षण किया गया। प्रयोग में दस उपचार जिनमें सतह सिंचाई पारंपरिक उर्वरीकरण के साथ (100 प्रतिशत आर डी एफ), बूंद–बूंद सिंचाई पारंपरिक उर्वरीकरण के साथ (50, 75 और 100 प्रतिशत आर डी एफ) एवं बूंद–बूंद सिंचाई उर्वरीकरण (50, 75 और 100 प्रतिशत आर डी एन और आर डी एफ) सम्मिलित किए गये, उनका मुल्यांकन यादृद्विच्छक ब्लॉक अभिकल्पना में तीन पुनरावृतियों के साथ किया गया।

सतह सिंचाई पारंपरिक उर्वरीकरण से करने पर वृद्धि कारकों (पौधों की ऊँचाई और शूष्क पदार्थ संग्रहण बुवाई के 35, 70, 105 दिन बाद एवं कटाई पर, प्रति पौधा शाखाओं की संख्या) पर्ण हरित की मात्रा, पादप वृद्वि दर और उपज कारकों (प्रति पादप पुष्पछत्र, पुष्प छत्रिया प्रति पुष्पछत्र, बीज प्रति पुष्पछत्र, बीज एवं भूसे की उपज, गुणवता मानकों, पोषक तत्वों की मात्रा, एवं उनका उद्ग्रहण, जल उपयोग दक्षता, शुद्व आय (रूपये 98203 प्रति है.) में बूंद–बूंद सिंचाई 50 प्रतिशत पारंपरिक उर्वरीकरण को छोडकर सार्थक कमी पायी गई।

परिणामों ने दर्शाया कि बूंद–बूंद सिंचाई उर्वरीकरण 75 प्रतिशत आर डी एफ (बूंद–बूंद उर्वरीकरण 100 प्रतिशत आर डी एफ और 100 प्रतिशत आर डी एन के सिवाय) के अनुप्रयोग से पौधों की ऊँचाई (बुवाई के 35, 70, 105 दिन एवं कटाई पर), पत्तियों में सम्पूर्ण पर्णहरित की मात्रा, प्रति पादप पुष्पछत्रों की संख्या, प्रति पुष्पछत्र पुष्पछडियों की संख्या, प्रति पुष्पछत्र बीजों की संख्या, बीज, भूसा, एवं जैविक उपज, आवश्यक तेल की मात्रा, जल उपयोग दक्षता, शुद्व आय और लाभ–लागत अनुपात में और उपचारों की तुलना में सार्थकता से वृद्वि हुई। जबकि नत्रजन, फास्फोरस की मात्रा और उनका उद्धग्रहण, प्रोटीन, तेल की पैदावार 100 प्रतिशत आर डी एफ बूंद–बूंद सिंचाई उर्वरीकरण से देने पर सार्थक रूप से बढ़ें।

परिणामों से आगे ज्ञात हुआ कि बूंद–बूंद सिंचाई उर्वरीकरण 100 प्रतिशत आर डी एन के साथ करने से वृद्धि मापदण्डों (पौधों की ऊँचाई और शुष्क पदार्थ उत्पादन (बुवाई के 35, 70, 105 दिन एवं कटाई पर), शाखाओं की संख्या, सम्पूर्ण पर्णहरित की मात्रा, उपज विशेषताओं, पैदावार, जल उपयोग दक्षता, तेल पैदावार में सार्थक वृद्वि हुई। जबकि उपर्युक्त उपचार, बूंद–बूंद सिंचाई उर्वरीकरण 75 प्रतिशत आर डी एन और 50 प्रतिशत आर डी एफ के लगभग बराबर है। नत्रजन, फास्फोरस और पोटेशियम की मात्रा और उनका उदग्रहण, प्रोटीन, आवश्यक तेल की मात्रा बूंद–बूंद सिंचाई उर्वरीकरण 100 प्रतिशत आर डी एन से बूंद–बूंद सिंचाई पारंपरिक उर्वरीकरण के साथ (50, 75, 100 प्रतिशत आर डी एफ), बूंद–बूंद सिंचाई 50, 75 प्रतिशत आर डी एन और 50 प्रतिशत आर डी एफ की तुलना में अधिक सार्थकता से बढ़ें। आमदनी रूपये 48698 प्रति हैक्टेयर तथा जल व खाद उपयोगिता 43.2 प्रतिशत एवं 138.1 प्रतिशत बढें।

---

* विद्यावाचस्पति छात्र, सस्य विज्ञान विभाग, श्री कर्ण नरेन्द्र कृषि महाविद्यालय, जोबनेर

** कृषि संकाय में विद्यावाचस्पति उपाधि की आंशिक आवश्यकता की पूर्ति के लिए **डॉ. ए.सी. शिवरान,** आचार्य, सस्य विज्ञान विभाग, श्री कर्ण नरेन्द्र कृषि महाविद्यालय, जोबनेर (राजस्थान), श्री कर्ण नरेन्द्र कृषि विश्वविद्यालय, जोबनेर के निर्देशन में प्रस्तुत किया गया शौधग्रंथ

Chapter-1

INTRODUCTION

A spice is a dried seed, fruit, root, bark or vegetative substance used in flavouring, seasoning and imparting aroma in variety of food items and beverages. In India, wide varieties of spices are grown and many of them are native to the subcontinent and also known as “Home of Spices”. Besides importance in food industry, the spices have medicinal properties and thus are used in various pharmaceutical preparations and also in cosmetic industry. The usages of spices by consumers are increasing world-wide because they are completely natural, rather than artificial additives for seasoning and flavouring of foods. Thus, an increasing trend in export of spices has been observed in the last decade particularly to Asian, Latin American and Middle Eastern developing countries.

Among the spices, seed spices are the group, which denotes all those annuals whose dried fruit or seeds are used as spices. The seed spices are aromatic vegetable products of tropical origin and are commonly used in pulverized form, primarily for seasoning or garnishing the foods and beverages. They are also used in preparation of various value added products *viz*., spice oils, oleoresins and spice powders. Seed spices also have industrial importance and are used in various pharmaceutical preparations and medicines. Seed spices contribute about 50 per cent of total area and 20 per cent of production of spices in the country (Kusuma *et al*., 2019). In India, spices and seed spices occupies an area of 3.97 and 1.42 million hectare with production of 8.41 and 1.93 million tonnes, respectively (Anonymous, 2017-18). Similarly, in spices and seed spices Rajasthan occupies an area of 10.04 and 9.80 lakh hectare with production of 13.91 and 12.07 lakh tonnes, respectively (Anonymous, 2017-18).

Fennel (*Foeniculum vulgare* Mill.) plant is stout, aromatic, annual herb (with potency of regeneration) belongs to family Apiaceae. It is mainly cultivated in Gujarat, Rajasthan and Uttar Pradesh. It is used as condiment and culinary spice. The plant is pleasantly aromatic and each part of the fennel (leaves, stalks, bulbs and seeds) is edible. Fennel symbolizes longevity, courage and strength. In addition to its use a medicinal value, fennel has much health benefiting nutrient, essential compounds, anti-oxidants, dietary fiber, minerals and vitamins. The aroma is due to presence of volatile oil *viz*., anethole and fechane. The fish string like leaves are valued as source of flavour garnish and also possess diuretic properties. The root is regarded as a purgative. In India, the seeds are also used for mastication and chewing either alone or with betel leaves.

The fennel seeds are used to flavour biscuits, sausages and stuffing. Furthermore, the fruits and essential oil of fennel are used as diuretic, laxative, stomachic, stimulant, aperitif, emmenagogue, galactogoguo, expectorant to relieve spasms and flatulence and to promote secretion (Salim *et al*., 2013). The seeds contain about 9.5 per cent protein, 10.0 per cent fat, 42.3 per cent carbohydrates, 18.5 per cent fiber and 13.4 per cent minerals. Further, the seeds contain about 0.7 to 6.0 per cent volatile oil depending on the genotypes or botanical types. The volatile oil which is used in the manufacture of cordials and enters into the composition of fennel water is employed medicinally. The essential oil extracted from seeds is used for scenting soaps and as flavoring material for cakes. The active principal in the fennel are known to have anti-oxidant, digestive, carminative and anti-flatulent properties. Fennel seeds indeed contain numerous flavonoid anti-oxidants like kaempferol and quercetin.

In India, the fennel stands third in production and area among seed spices and is mainly grown in the states of Gujarat, Rajasthan and to some extent in Uttar Pradesh, Karnataka, Andhra Pradesh, Punjab and Madhya Pradesh as a cool weather crop. Total area under the crop in India is about 0.89 lakh hectare with an annual production of 1.49 lakh tonnes having the productivity of 1674 kg/ha (Anonymous, 2017-18). In Rajasthan, it occupies an area of 0.45 lakh hectare and production of 0.56 lakh tonnes with average productivity of 1244 kg/ha. In Rajasthan, it is mainly cultivated in the districts of Sirohi, Nagaur, Tonk, Dausa and Sawai Madhopur (Anonymous, 2017-18).

Fennel is cultivated mainly as transplanted crop, although it can also be raised profitably as a winter direct seeded crop. The yield potential of transplanted fennel (2500 kg/ha) is always higher than the direct seeded crop (Menaria and Maliwal, 2007). Direct seeded fennel is very popular in Rajasthan due to short duration as it requires less water than transplanted crop. Thus direct seeded fennel is profitable than other common winter crops like mustard, chickpea and wheat.

In spite of this fact, the productivity (1400 kg/ha) of fennel is low in India and Rajasthan compared to its potential productivity (2500 kg/ha). The reason for low productivity is lack of adoption of ideal agronomic practices including nutrient management for *rabi* drilled fennel (Mevada *et al*., 2018).

In recent years water resources have become scarce due to low rainfall, expansion in cultivated area and poor recharge of ground water, especially in the arid and semi-arid areas of Rajasthan. In such areas, instead of intensive irrigation over a limited area, the right approach would be to serve maximum area with reduced irrigation intensity in order to increase the overall production and irrigation water use efficiency which can be ensured by irrigating the crop at such phenological stages of growth which are very critical in their demand for water. In case of fennel crop, moisture is the most critical factor and any fluctuations in irrigations shows moisture deficit symptoms in early stage itself (Honnappa *et al*., 2017). Seed yield of fennel is mainly depends on timely irrigation and adequate nutrients supply. In arid and semi-arid regions scarcity of water and soil type necessitates frequent irrigation for success crop production. Uncertain rainfall and midseason moisture stress reduces the soil moisture in the root zone which reduces the crop yield drastically (Harisha *et al*., 2017b). Since water is a precious commodity and the studies on water use efficiency, consumptive use of water and moisture distribution pattern in the soil are of direct interest for maximizing crop yields.

Reduced agricultural productivity and water use efficiency are mainly due to conventional method of irrigation (flooding) and poor adoption of scientific water management practices. Therefore, drip method of irrigation is most suited for semi-arid and arid areas where water is scarce and where low water consuming and high value crops can be grown. Drip method of irrigation helps to reduce the over exploitation of ground water that partly occurs because of inefficient use of water under surface method of irrigation (Meena *et al*., 2017). Environmental problems associated with the surface method of irrigation like water logging and salinity are also completely absent under drip method of irrigation. It is particularly suitable for irrigation with water of poor quality (saline water) irrigating daily pushes of the salt to the periphery of the moist zone (Rathore and Gaur, 2010).

Drip method helps in achieving saving in irrigation water, increase water use efficiency, decrease tillage requirement, higher quality products, increased crop yields and higher fertilizer use efficiency. At field level, water use efficiency under conventional method of irrigation is very low (50 to 60 per cent) as against drip method (95 per cent) (Kanwar *et al*., 2018). Drip irrigation system optimize the irrigation water and put it uniformly and directly to the root zone of the plants at frequent interval based on crop water requirement through a closed net work of pressure plastic pipes. Superiority of drip system in terms of water saving and increased yield along with other benefits over surface method of irrigation is proved by many research evidences. Drip irrigation system improves the WUE because of improving the yield and quality of produce (Singh *et al.,* 2005). Pressurized irrigation system has been found to be quite effective under limited water availability not only in achieving higher productivity but also economizing other inputs such as fertilizers, pesticides, labour etc.

Drip irrigation system is a conventional and effective means of supplying water directly to soil and nearer to the roots of plant without much loss of water resulting in higher water productivity (Bandyopadhyay *et al*., 2005). Most of the Indian farmers are adopting surface irrigation practices for fennel irrigation. This leads to excess usage and wastage of water and nutrients. The drip irrigation has potential to improve productivity on sustainable basis by overcoming demerits of poor irrigation practices. Increasing popularity of drip in Rajasthan undoubtedly increases opportunities for improved fertilizer management. In recent days agriculture human availability of labour, improper application of fertilizers and effective use of applied nutrients is important concern. In arid and semi arid regions where water is limited and soils are poor sandy or sandy loam soil type makes more number of irrigation and fertilizers applications necessary in crop production. Higher soil nutrient holding ability and timely supply to crop is very important in order to achieve higher yields. But in actual condition it is not happening. Soils are depleting faster due to non judicious use of fertilizers particularly nitrogen fertilizers.

Drip irrigation and fertigation is most suited for semi-arid and arid areas. Drip irrigation system has the potential for improving two of the most common contributing factors to N leaching i.e. over fertilization and over irrigation. To overcome these difficulties adopting drip irrigation and fertigation is highly necessary among the farmers so that can save labour, water and even fertilizers also. Fertigation is one important precision farming technique which can give better nutrient use efficiency as compared to surface irrigation method. Application of nutrients untimely, following inappropriate method of application leads to severe loss of nutrients by leaching and fixation (Harisha *et al*., 2017a).

A large number of research experiments have clearly demonstrated that the average sugarcane yield increased to the tune of 40 per cent by applying drip fertigation to sugarcane as compared to traditional irrigation and soil application (Veeraputhiran *et al*., 2012). Similarly fertigation also enhances the fertilizer use efficiency, nutrient uptake, improves quality parameters and minimizes the water and nutrient losses to the extent of 25–30 per cent (Singh *et al*., 2010). Fertigation through drip irrigation can increase yield and fertilizer savings in the range of 25 to 50 per cent (Godara *et al*., 2013). It is also reported that crop growth will be optimum when crop is supplied with nutrients and irrigation in right time and in right quantity (Sonu *et al*., 2016). Optimum split applications of these fertilizer through drip improves quality and quantity of crop yield than the conventional practice (Ravikumar *et al*., 2011). The drip resulted into 24.7 per cent increase in yield with 56.9 per cent water saving, whereas drip with fertigation resulted into 31.7 to 64 per cent increase in seed cotton yield with equal amount of water saving as compared to conventional method (Pawar *et al*., 2014). Controlled watering through drip and efficient nutrient management through fertigation, not only improves the production but quality as well due to better control over soil and water borne diseases (Singh and Pandey, 2014). However, appropriate recommendations including optimal schedule of fertilizer application to exploit the potential of drip fertigation for fennel cultivation are not available.

Considering above facts a trial entitled **"Response of Fennel (*Foeniculum vulgare* Mill.) to Drip Irrigation and Fertigation"** was conducted during *Rabi* seasons 2015-16 and 2016-17 with the following objectives:

i. To find the effect of drip irrigation on growth, yield and quality of fennel,

ii. to find the effect of drip fertigation on growth, yield and quality of fennel,

iii. to assess suitable fertilizer application method for fennel,

iv to work out water and fertilizer use efficiency of fennel under drip irrigation and fertigation and

v. to assess economic viability of different treatments.

Chapter-2

REVIEW OF LITERATURE

A brief review pertaining to research problem entitled "**Response of Fennel (*Foeniculum vulgare* Mill.) to Drip Irrigation and Fertigation**" is being presented in this chapter. Since information on fennel crop is meagre, therefore, pertinent literature on other crops has also been incorporated in this text.

2.1 Growth parameters

Veeraputhiran *et al*. (2002) during their investigation at Agriculture Research Station, Trivandrum, observed that the drip fertigation with 75 per cent recommended dose of NPK (120-75-50 kg/ha) as water soluble fertilizer produced significantly more number of bolls per plant and maximum boll weight which was comparable with treatment drip fertigation with 100 per cent recommended dose of N and K as straight fertilizer (P as basal) compared to conventional surface irrigation with soil application of fertilizer in cotton.

All the growth attributes of chilli, *viz*. number of fruit per plant, weight of fruit per plant of chilli were significantly higher owing to fertigation of recommended dose of fertilizer (100-50-50 kg/ha) at every irrigation (2 days interval) up to 105 days (Tumbare and Nikam, 2004).

Hebbar *et al.* (2004) during their study at HAU, Hisar, observed that the drip fertigation with 100 per cent WSF (75-50-50 kg/ha) increased the Chlorophyll content, total dry matter and LAI of tomato significantly over furrow-irrigated control and drip irrigation.

Singandhupe *et al*. (2005) also reported that application of 150 per cent of RDF once in 12 days recorded significantly higher plant height, cob length and dry matter accumulation of maize than 100 per cent of RDF. Surface irrigation and absolute control treatments registered lower values.

Singandhupe *et al.* (2007) in their study at Jabalpur reported that the pointed gourds (*Trichosanthes dioica*) grown by using fertilizer through drip irrigation system with 100 percent recommended dose (75-50-40 kg/ha) at monthly interval gave higher dry matter accumulation.

Kavino *et al.* (2008) during their research at Dharwad, Karnataka, reported that the higher number of leaves, plant height, greater leaf area of maize can be achieved with fertigation and the significantly lower values of growth contributing characters were obtained for all the parameters in conventional method of irrigation and fertilizer application.

Rao and Subramanyam (2009) stated that when nitrogen was applied through drip irrigation the highest plant height was recorded in 50 per cent recommended dose of nitrogen at fortnight intervals followed by 50 per cent recommended dose of nitrogen at monthly intervals in maize.

A field study was conducted by Brahma *et al.* (2010a) at Nagpur, Maharastra, revealed that 100 per cent fertigation of recommended dose of nitrogen (120 kg/ha) in broccoli produced the highest plant height, leaves per plant, plant spread and head diameter over conventional method of application but statistically at par with 80 per cent fertigation level of recommended dose of N.

Baskaran and Kavimani (2010) reported that the drip fertigation of 100 per cent P & K applied as 50 per cent as basal as conventional fertilizer and balance 50 per cent as water soluble fertilizer + liquid bio fertilizer + humic acid recorded higher plant height, number of sympodial branches as compared to drip fertigation of 50, 75 per cent P & K and soil application of recommended dose of fertilizer with drip irrigation in cotton.

Brahma *et al*. (2010b) revealed that the maximum plant height and number of branches were produced by 100 per cent RD of N & K through drip followed by 75 per cent RD of N & K through drip, which were statistically at par but 100 per cent RD of N & K through drip has recorded significantly higher values for plant height than 50 per cent RD of N & K through drip and 100 per cent RD of NPK as conventional soil application in tomato.

Rajaraman *et al.* (2010) conducted an experiment at Anand, Gujarat to evaluate the effect of fertigation on growth and physiology in coriander genotypes Co CR-4 and CS 11. They found that fertigation with 125 per cent water soluble fertilizers had registered significantly increased leaf area index and higher dry matter production in both the genotypes over drip fertigation with water soluble fertilizer at 100 per cent RDF, drip fertigation with water soluble fertilizer at 75 per cent RDF and recommended normal fertilizer applied to soil with furrow irrigation.

Savitha *et al*. (2010) observed that application of 75 percent RDF recorded significantly highest plant height, number of leaves/plant and root length followed by 100 percent and 125 percent RDF through drip fertigation in onion. The lowest value was observed with soil application of RDF.

Fanish *et al*. (2011) in their study at Tamil Nadu agricultural University, Coimbatore, obtained the significantly higher plant height, dry matter accumulation, total number of tillers and LAI in drip fertigated maize with 100 per cent RDF with 50 per cent P and K as water soluble fertilizer followed by 150 per cent RDF. The lowest values are recorded in drip and surface irrigation with soil application of 100 per cent RDF.

Imamsaheb *et al.* (2011) revealed that the application of 100 per cent water soluble fertilizer through drip at 80 per cent evaporation resulted in significantly higher growth attributes *viz*., plant height (96.70 cm), number of branches (18.25), stem diameter (2.06 cm) and leaf area index (3.49) over rest of the treatments and surface irrigation with conventional method of fertilization in tomato..

Roy *et al.* (2011) showed in capsicum that the length and width of fruit and number of fruits per plant increased significantly with increasing nitrogen doses up to 100 kg N/ha through drip fertigation.

Tanaskovik *et al.* (2011) reported that in tomato drip fertigation treatments 100 per cent and 75 per cent RDF shows greater plant height, dry matter accumulation and chlorophyll content as compared to conventional fertilizer application and furrow method.

A field experiment was conducted at Agricultural College and Research Institute, Madurai by Krishnasamy *et al*. (2012) to study the effect of drip fertigation on growth, yield and quality of maize and found that 125 per cent RDF of N, P and K as water soluble fertilizers through drip fertigation registered higher plant height and dry matter production as compared to surface irrigation with soil application of fertilizer.

Nijamudeen *et al*. (2013) in their study recorded that the maximum plant height, dry matter and LAI production were observed with the treatment of 125 per cent N and 75 per cent K but it was at par with the treatment of 125 per cent N and 100 per cent K and significantly higher than the all remaining treatments under drip-fertigation for greenhouse grown sweet pepper.

Godara *et al.* (2013) in their study conducted at Swami Keshwanand Rajasthan Agricultural University, Bikaner found that the application of 100 per cent fertigation level through drip proved significantly superior to 75 per cent RDF and 50 per cent RDF with respect to plant height, number of branches per plant at 50 per cent flowering and dry matter of fennel.

Kumar *et al.* (2013) reported that the maximum growth of cauliflower head was recorded with fertigation of 125 per cent RDF over control.

Pawar *et al*. (2013) reported that the number of internodes in sugercane decreased with decreasing levels of fertilizer from 100 to 60 per cent fertigation of RDF. The higher number, length of internodes, leaves per plant and girth of internodes were noticed under 100 per cent fertigation schedule B (26 weekly splits), however it was on par with 100 per cent fertigation schedule A (12 equal split at an interval of 15 days) and 80 per cent fertigation schedule B (26 weekly splits).

Haneef *et al*. (2014) in an experiment observed that the fertigation and drip irrigation levels had significant effect on vegetative characteristics like plant height, dry matter production, leaf area index of maize. Among various fertigation levels at 125 per cent RDF showed higher plant height, dry matter production, leaf area index. However, it was at par with 100 per cent RDF for leaf area index.

Pawar *et al*. (2014) revealed that application of 125 per cent recommended dose of water soluble fertilizer applied through drip recorded maximum monopodial branches/plant and plant height as compared to 100 per cent water soluble fertilizer and nitrogen through drip fertigation and surface irrigation with conventional method of fertilizer application in cotton.

Rajendran and Arunvenkatesh (2014) during their field experiment on cotton reported that drip fertigation with 150 per cent recommended dose of NPK as water soluble fertilizer registered significantly highest monopodial branches, sympodial branches and plant height of 123.3 cm as compared to other treatments.

Kachwaya and Chandel (2015) reported that in capsicum the significant effect on plant height, head size and weight was also recorded in fertigation with full recommended dose of NPK.

Yadav and Chauhan (2016) reported that the drip fertigation of 100 per cent RD of N and K in six equal splits significantly increased plant population, plant height, number of bolls/plant of cotton in comparison to recommendation practice of surface irrigation and fertilizer application.

Bibe *et al.* (2017) while working at Parbhani (Maharastra) reported that the application of fertilizer at 100 per cent RDF through drip, recorded significantly highest growth parameters of maize like plant height, and dry matter production over the application of fertilizer with 100 per cent RDF through soil and 50 RDF through drip, respectively but it was on par with 75 per cent RDF through drip. Significantly lowest growth parameters were recorded at 50 per cent RDF through drip and were at par with 100 per cent RDF through drip.

Kanwar *et al.* (2018) observed that the application of fertilizers at 100 per cent RDF through drip was recorded highest plant height and it was at par with drip fertigation at 75 per cent RDF in fenugreek.

Jena and Aladakatti (2018) observed that the maximum growth and physiology parameters *viz*. dry matter accumulation per plant, leaf area index, leaf area duration and chlorophyll content in leaf were found at fertigation with 100 per cent RDF through conventional fertilizers applied in six equal splits than other treatments in cotton.

Padmaja and Malla Reddy (2018) conducted a field experiment during rainy season of two consecutive years (2011 and 2012), in sandy loam soils of Warangal, Telangana State to study the response of aerobic rice to drip irrigation and nitrogen fertigation under semi-arid environment and data revealed that the growth parameters *viz*. plant height, LAI, SPAD meter reading, tillers/m^2 and dry matter accumulation increased with level of N fertigation from 90 to 120 kg N/ha while root volume and dry weight were higher at 150 kg N/ha.

Singh *et al.* (2018) noted that the drip fertigated pigeon pea at 100 per cent recommended dose of water soluble fertilizers recorded significantly higher plant height, chlorophyll content and branches per plant as compared to 80 per cent and 60 per cent recommended dose of fertilizers.

Karthika and Ramanathan (2019) conducted a field experiment at Soil and Water Management Research Institute, Kattuthottam, Thanjavur to study effect of drip fertigation on growth and physiological parameters of rice grown in sandy loam soils. The results of the study indicated that drip fertigation at 200 per cent PE + 125 per cent RDF recorded higher growth and physiological parameters *viz*., plant height, LAI, dry matter Production over surface irrigation with soil application of RDF and other drip fertigation levels.

Karangiya *et al*. (2019) found during their study that the highest plant height of wheat were observed at fertigation level 100 per cent

RDN and irrigation level 1.0 IW/ETC but, it was found that 0.8 IW/ETC statistically at par with 1.0 IW/ETC over other fertigation and irrigation levels.

2.2 Yield attributes and yield

Ajmalkhan (2000) stated that fertigation of recommended dose of nitrogen (100 kg/ha) as urea and K_2O as muriate of potash applied in 15 equal splits at eight days interval through drip system recorded higher tomato yield as compared to surface irrigation with conventional method of fertilizer application on sandy loam soil at Madurai (TNAU) in Tamil Nadu.

Veeranna (2000) compared the furrow and drip irrigations and reported that drip irrigation produced significantly higher dry chilli yield with 42 per cent higher water use efficiency over furrow method.

Sharmasarkar *et al*. (2001) during their research at Akola, Maharastra, reported that sugar beet yields and sugar contents under drip irrigation along with fertigation were higher (3-28 per cent) than those with flood irrigation.

Veeranna *et al.* (2001) reported that 80 per cent water soluble fertilizer (100 kg/ha N) was effective in producing about 31 and 24.7 per cent higher chilly fruit yield over soil application of normal fertilizers at 100 per cent recommended level in furrow and drip irrigation methods, respectively, with 20 per cent of saving in fertilizers.

Shinde *et al*. (2002) during their experiment conducted at Madurai, Tamilnadu, in brinjal by using irrigation and different levels of fertigation (50, 75, 100 and 125% recommended dose of solid soluble fertilizer) (75-40-40 kg/ha) was found that drip irrigation with 100 per cent recommended dose of solid soluble fertilizer recorded highest number of fruits per plant, weight of fruit and fruit yield over other fertigation levels.

Tumbare and Bhoite (2002) reported that the application of 100 per cent recommended dose of solid soluble fertilizer through fertigation recorded significantly higher yield of green chilli (*Capsicum annuum* L.). However, it was at par with application of 70 per cent N and 80 per cent P and K through fertigation indicating saving of N to the extent of 30 per cent, while P and K to extent of 20 per cent.

Veeraputhiran *et al.* (2002) conducted a field experiment at Madurai, Tamilnadu, observed that the application of nutrients through drip fertigation with 75 per cent RDF as water soluble fertilizer improved seed cotton yield by 33.44 per cent compared to conventional surface irrigation with soil application of fertilizer.

Ritcher (2004) observed that the drip fertigation system in onion produced higher yields compared to drip irrigation and surface irrigation with fertilizer broadcasting. Hebbar *et al*. (2004) observed that the drip fertigation with 100 per cent WSF increased the fruit yield of tomato significantly over furrow-irrigated control and drip irrigation.

Singandhupe *et al*. (2005) also reported that application of 150 per cent of RDF once in 12 days recorded significantly higher grain yield of maize than 100 per cent of RDF. Surface irrigation and absolute control treatments registered lower values.

Ananta (2006) reported that the highest fruit yield of tomato was noticed when nitrogen was supplied in10 split doses with 100 per cent RDF over 75 percent RDF in 6 split doses through drip irrigation.

Jan Rumpel *et al.* (2007) reported that onion yield were greater with 150 kg/ha N through drip fertigation (79 per cent) followed by 50 kg/ha N was applied through drip fertigation (41 per cent) over control (nitrogen without fertigation).

Ngouajio *et al.* (2007) showed that drip irrigation along with fertigation at flowering and fruit development stage increased tomato yield by 8–15 per cent, fruit number by 12–14 per cent over control treatment.

Bhanu Rekha *et al*. (2009) in their study revealed that highest pod yield was recorded through drip fertigation with 120 kg N/ha and drip irrigation at 1.00 Epan as compared to furrow irrigated crop recorded 54 and 57 per cent lower yield of bhindi.

Patel *et al.* (2009) in okra nitrogen fertigation with 100 per cent recommended dose gave higher pod yield of 16.9 tonnes per hectare as compared to other fertigation levels.

Patel *et al.* (2010) observed that application of 100 per cent RDN through fertigation recorded significantly highest seed yield as compared to 50 per cent RDN through fertigation and 100 per cent RDN through spot application in castor.

Baskaran and Kavimani (2010) found that drip fertigation of 100 per cent P & K applied as 50 per cent as basal as conventional fertilizer and balance 50 per cent as watersoluble fertilizer+ liquid bio fertilizer + humic acid recorded higher number of symbodial branches, number of squares/plant, number of bolls/plant and seed cotton yield as compared to drip fertigation of 50, 75 per cent P & K and soil application of recommended dose of fertilizer with drip irrigation in cotton.

In brinjal, highest yield was recorded in drip irrigation at 75 per cent of recommended N and K with maximum shoot length and number of branches per plant when compared to other levels of irrigation and fertigation (Vijayakumar *et al*., 2010)

Sampathkumar and Pandian (2010) an experiment conducted at at Agricultural College and Research Institute, Coimbatore observed that the fertigation of 150 per cent RDF (80-40-35 kg/ha) applied once in 6 days registered higher values of yield components of maize *viz*., cob length, girth, number of rows, number of grains per cob and cob weight whereas, Surface irrigation and absolute control treatments registered lower values.

Savitha *et al*. (2010) observed that the application of fertilizer through drip with 75 per cent recommended dose of fertilizers (45: 45: 22.5 kg of NPK/ha) registered higher bulb yield (8.34 and 11.05 t/ha) compared to soil application of fertilizer in onion.

Vijayakumar *et al.* (2010) studied at Agricultural Research Station, Bhavanisagar in chilli observed that the maximum yield was observed in drip irrigation along with fertigation of 75 per cent of recommended N and K (100-60-40 kg/ha) with maximum shoot length and more number of branches over rest of the treatments.

Sadarunnisa *et al*. (2010) reported that in tomato the maximum yield, no. of fruits/plant, fruit weight was obtained under 75 per cent drip fertigation which was on par with the yield of tomato supplied with 100 per cent RDF through drip compared to the treatments in which soil application of fertilizers was done.

Tanaskovik *et al.* (2011) reported that in tomato drip fertigation with100 per cent and 75 per cent RDF shows greater yield and increases 28 per cent of fruit yield with conventional fertilizer application and 25 per cent in case of furrow method.

Jat *et al.* (2011) reported that the drip fertigation of 100 per cent N and K, being at par with 125 per cent N and K recorded higher pod yield of chili as compared to surface irrigation at entire NPK as soil application.

Fanish *et al*. (2011) conducted a field experiment during kharif 2008 - 2009 at Tamil Nadu agricultural University, Coimbatore to study the effect of drip fertigation on growth, yield and economics of intensive maize based intercropping system and found that drip fertigated maize with 100 per cent RDF with 50 per cent P and K as water soluble fertilizer recorded significantly higher grain yield followed by 150 per cent RDF.

Dingre *et al*. (2012) during their experiment at Pantnagar, Uttarakhand, showed that drip fertigation resulted into 12 to 74 per cent increase in the productivity of onion seed as compared to conventional method.

Krishnasamy (2012) reported that the drip fertigation of 125 per cent RDF through WSF excelled other treatments by recording significantly higher cob length, cob girth, cob weight and grain yield of maize.

Kaushal *et al.* (2012), where they reported that the drip irrigation adoption increases water use efficiency (60-200 per cent), saves water (20-60 per cent), reduces fertilization requirement (20-33 per cent) through fertigation, produces better quality crop and increases yield (7-25 per cent) as compared with conventional irrigation in sugercane Ramniwas *et al.* (2012) investigation indicated that the effect of drip irrigation and fertigation levels in brinjil showed that 100 per cent RDF of water soluble fertilizers gave maximum yield as compared to soil application of solid fertilizers.

Castellanos *et al.* (2013) reported that the highest yields were obtained with a dose of about 160 kg/ha of nitrogen through fertigation and over doses causes negative effects on yield and loss of nitrate leaching.

Godara *et al.* (2013) in their experiment at Agriculture University Bikaner, reported that the application of 100 per cent fertigation level (90-40-0 kg/ha) through drip proved significantly superior to 75 per cent RDF and 50 per cent RDF with respect to number of umbelletes per umbel, number of seeds per umbellete, test weight, seed and biological yields of fennel.

Kumar *et al.* (2013) reported that the maximum yield of cauliflower were observed with fertigation of 100 per RDF as compared to rest fertigation levels.

Pawar and Dingre (2013) observed that the highest average yield of maize was recorded with 100 per cent RDF of NPK as water soluble fertilizer were applied in 18 splits as per growth stages of crop and it was at par with 100 per cent RDF as water soluble fertilizer in 16 splits at an interval of 15 days and 80 per cent RDF as water soluble fertilizer in 18 splits as per growth stages but was significantly superior over 100 per cent and 60per cent fertigation, only 'N' through drip treatments and surface method of irrigation.

Pawar *et al*. (2013)) conducted a field experiment to study effects of drip fertigation on growth, yield and economics of sugarcane (*Saccharum officinarum* L.) on clay soils in western Maharashtra and found that drip fertigation of 100 per cent RDF of NPK with schedule B (26 weekly splits) produced maximum cane and sugar yield and it was on par with 100 per cent fertigation with schedule A (12 equal fortnightly splits) and 80 per cent fertigation with schedule B. Yield increased upto 25.3 per cent by applying only 'N' through drip as against conventional method (133.4 t/ha).

Kapoor *et al.* (2013) showed that increase in NPK fertigation level from 33.3 to 100 per cent RDF significantly increased number of leaves, relative leaf water content, and marketable yield of cauliflower in comparison to flood and conventional fertilizer application method. Haneef *et al*. (2014) in an experiment observed that fertigation level of 125 per cent RDF of NPK recorded the maximum number of cobs, length of cobs and yield of maize and this level was at par with 100 per cent RDF of NPK.

Barua and Hazarika (2014) based on their study reported that fertigation with 120 per cent of RDF of N, P and K has considerable influence on fruit yield in terms of number of fruits per plant over fertigation level of 100 and 80 per cent of RDF. However, lowest yield obtained under soil application of fertilizer with 100 per cent RDF in lemon.

Jayakumar *et al*. (2014) an experiment conducted at Agronomy Regional Coffee Research Station, Chundale, Wayanad, Kerala observed that adoption of drip fertigation with 150 per cent recommended dose of NPK with biofertigation recorded highest number of fruiting points, number of bolls, boll weight and seed yield of cotton. However, it was produced comparable yield with 150 per cent recommended dose of NPK and 125 per cent NPK with bio fertigation and were superior over the rest of the treatments. Surface irrigation with soil application of 100 per cent recommended dose of NPK resulted least in the all yield components.

Kapoor *et al.* (2014) during their study on cauliflower revealed that the highest yield was recorded under 120 per cent CPE with 100 per cent RDF through drip followed by 100 per cent CPE with 66.6 per cent RDF in comparison to flood irrigation with 100 per cent RDF.

Pawar *et al*. (2014) reported that application of 125 per cent recommended dose of NPK as water soluble fertilizers through drip recorded significantly more bolls/plant and seed cotton yield as compared to 100, 75 per cent fertigation and nitrogen through drip and drip irrigation with conventional fertilizer application method.

Rajendran and Arunvenkatesh (2014) during their field experiment at Agricultural Research Station, Dharwad, Karnataka on cotton reported that application of nutrients through drip fertigation with 75 per cent RDF as water soluble fertilizer improved boll weight, No. of bolls/plant and seed cotton yield by 33.44 per cent compared to conventional surface irrigation with soil application of fertilizer.

Gupta *et al*. (2015) showed that among the various fertigation treatments, fertigation at 60 per cent recommended dose of NPK produced maximum fruit weight and fruit yield, whereas the minimum fruit weight and fruit yield was observed with 100 per cent NPK as manual.

Patil and Das (2015) concluded that the significantly highest capsicum fruit yield (87.20 q/ha) was recorded with 75 per cent RDF of N through drip irrigation over other treatments.

Sharma and Kaushal (2015) an field experiment was done at the research farm of department of Soil and Water Engineering, PAU, Ludhiana recorded that the maximum average okra yield was obtained in 80 per cent N with 0.80 IW/CPE ratio under drip fertigation followed by 100 per cent N with 0.80 IW/CPE ratio in drip fertigation, both of these are statistically at par with each other but superior to 60 per cent N with 0.80 IW/CPE ratio and 100 per cent N with 1.00 IW/CPE ratio.

Pramanik and Patra (2015) conducted an experiment on a silty clay soil in Utter Pradesh on sugarcane and found that when crop fertigated with three levels at 50, 60 and 80 per cent of recommended dose of NPK fertilizers including surface irrigation at IW/CPE 1.0, the cane yield consistently and significantly increased with increase in NPK fertigation up to 80 per cent of recommended dose of fertilizers.

Yadav and Chauhan (2016) reported that the maximum yield of brinjal was recorded with the drip fertigation of 80 per cent recommended dose of N and K in 12 equal splits at an interval of 10 days and it was at par with the same dose in 9 equal splits in 13 days interval but significantly superior than rest of the treatments (60 per cent RD in 9 splits and 60 per cent RD in 12 splits).

Shruti and Aladakatti (2017) while working at Agricultural Research Station, Dharwad reported that the significantly higher seed cotton yield was in drip irrigation at 1.0 Etc with fertigation of 100 per cent N and K in six equal splits, however it was on par with drip irrigation at 0.8 Etc and 75 per cent N and K in six equal splits as compared to other drip irrigation and fertigation levels.

A field experiment was conducted at Zonal Agricultural Research Station, Karnataka by Reddy and Krishna Murthy (2017) to study the yield attributes and yield of maize as influenced by drip fertigation and found that irrigation at 100 per cent cumulative pan evaporation + drip fertigation at 125 per cent RDF, recorded significantly higher kernel and stover yields.

Kanwar *et al*. (2018) reported that the drip fertigation at 100 per cent RDF, being at par with fertigation at 75 per cent RDF, recorded significantly higher seed yield of fenugreek as compared to lower fertigation levels.

Jena and Aladakatti (2018) an experiment conducted at College of Agriculture, University of Agricultural Sciences, Dharwad and observed that the maximum yield attributes *viz.* sympodial branches, bolls per plant and seed cotton yield per plant were found at fertigation with 100 per cent RDF applied in six equal splits than other treatments in cotton.

Magare *et al.* (2018) indicated that the seed cotton yield was recorded significantly highest under 100 per cent recommended dose + Zn (4 kg/ha) + Fe (5 kg/ha) through drip from water soluble fertilizer over 100 per cent RD + Zn (4 kg/ha) + Fe (5 kg/ha) through soil application, which was at par with 75 per cent recommended dose + Zn (3 kg/ha) + Fe (3.75 kg/ha) fertilizer through drip irrigation and 100 per cent recommended dose of fertilizer through drip from water soluble fertilizer.

Padmaja and Malla Reddy (2018) conducted a field experiment during rainy season of two consecutive years (2011 and 2012), in sandy loam soils of Warangal, Telangana State to study the response of aerobic rice to drip irrigation and nitrogen fertigation under semi-arid environment and data revealed that yield attributes (panicles/m^2 , panicle length and filled spikelets/panicle) and yield increased with level of N fertigation from 90 to 120 kg N/ha.

Singh *et al.* (2018) noted that the drip fertigated pigeon pea at 100 per cent RDF with WSF recorded significantly higher seed yield as compared to 80 per cent and 60 per cent recommended dose of fertilizers. Agrawal *et al*. (2018) investigated that the maximum yield of tomato (426.75q/ha) was observed under drip fertigation in comparison to non-fertigation condition (230.72q/ha).

Abdelraouf *et al*. (2019) carried out a field experiment at Agriculture Production and Research Station, National Research Centre, El Nubaria Province, Egypt to study the effects of fertigation levels and irrigation requirements on yield attributes and yield of wheat and the results showed that decreasing of fertigation levels from 100 to 50 per cent NPK of the RDF significantly decreased number of spikelets per spike, number of spikes per meter, grain and biological yields of wheat.

Karthika and Ramanathan (2019) conducted a field experiment at Soil and Water Management Research Institute, Kattuthottam, Thanjavur to study effect of drip fertigation on yield attributes and yield of rice grown in sandy loam soils. The results of the study indicated that drip fertigation at 200 per cent PE + 125 per cent RDF recorded yield increment as high as 46 per cent and 22 per cent over drip fertigation at 100 per cent PE + 75 per cent RDF and Surface irrigation with soil application of 100 per cent RDF.

Karangiya *et al*. (2019) found during their study that the highest yield attributes, grain and straw yields of wheat were observed at fertigation level 100 per cent RDN and irrigation level 1.0 IW/ETC but, it was found that 0.8 IW/ETC statistically at par with 1.0 IW/ETC over other fertigation and irrigation levels.

2.3 Nutrient content, uptake and quality

A study was carried out by Brahma *et al*. (2010) to find out the effect of fertigation level of N & K through drip irrigation on tomato fruit quality and achieved that fruit quality parameters were significantly influenced by fertigation treatments but 100 per cent fertigation of recommended dose of N & K recorded the highest fruit length, fruit girth, pericarp thickness, edible portion, juice percentage, total soluble solids and ascorbic acid content.

Bader *et al*. (2010) reported that the tomato accumulated more NPK with fertigation levels than drip and furrow irrigation.

Gupta *et al*. (2010) while working at Srinagar observed that the fertigation with 80 per cent of recommended dose of NPK in capsimum resulted in maximum fruit length, total soluble solids, fruit dry matter, chlorophyll content and vitamin C content. However, fruit diameter was found maximum with 60 per cent recommended dose of NPK through fertigation which was statistically at par with 80 per cent recommended NPK through fertigation but All the fertigation levels proved significantly superior and produced better quality than traditional method of fertilizer application.

Magdi *et al*. (2011) during their experiment resulted that biofertigation and humic substances jointly with 50 per cent recommended dose of NPK added through drip fertigation system recorded the highest N, P and total crude protein in both seeds and straw of cowpea compared to other treatments.

Sampathkumar and Pandian (2011) conducted a field experiment at Agricultural College and Research Institute, Coimbatore to study the effect of drip fertigation levels and frequencies on nutrient uptake rate of hybrid maize and found that supply of 150 per cent RDF of NPK once in 6 days recorded significantly higher nutrient uptake than 100 per cent RDF of NPK and surface irrigation with conventional fertilization.

A field investigation was carried at Tamil Nadu Agricultural University by Fanish (2013) to study the effect of drip fertigation on nutrient use efficiency of maize based intercropping systems and found that drip fertigation with 50 per cent RDF (50 per cent P and K as WSF) resulted in higher nutrient use efficiency and the lowest was recorded by surface irrigation with soil application of fertilizer.

Gundlur *et al*. (2013) found that the application of 100 per cent fertigation through drip in cotton was significantly superior over soil application under surface irrigation and registered the maximum N, P and K contents at 90 days gradually it was decreasing at harvest stage.

Krishnamoorthy *et al*. (2013) conducted an experiment at the Department of Spices and Plantation Crops, Horticultural College and Research Institute, Tamil Nadu Agricultural University, Coimbatore with different treatments among them application of 125 per cent RDF of NPK as water soluble fertilizer through drip fertigation registered the highest N, P and K contents in cocoa.

Haneef *et al*. (2014) in an experiment observed that fertigation level 125 per cent RDF of NPK recorded the maximum N, P & K contents in seeds and straw of maize.

Jayakumar *et al*. (2014) while working on drip fertigation in cotton obtained that drip fertigation with 150 per cent recommended dose of NPK with biofertigation was significantly superior in N, P and K uptake and statistically on par with 150 per cent recommended dose of NPK and drip fertigation with 125 per cent recommended NPK with biofertigation. Significantly lower N, P and K uptake was observed under surface irrigation with soil application of 100 per cent RDF of NPK.

Rajak *et al.* (2015) based on their study reported that the maximum uptake of nitrogen, phosphorus and potassium by cabbage head were observed with drip irrigation with 80 per cent ET and fertigation at 75 per cent of RDF over other drip irrigation and fertigation levels. Ciba and Syamala (2017) found that the application of 100 per cent drip fertigation through water soluble fertilizers along with bio stimulants significantly increased N, P and K contents in chilli over other drip fertigation levels.

Kakade *et al*. (2018) conducted a field experiment at Akola and reported that the higher uptake of N, P and K in pigeonpea were observed at 125:100:100 per cent levels of N, P and K fertigation (100-50-50 kg/ha). Progressive increase in applied level of N, P and K correspondingly increased the nutrient uptake and lower uptake was noticed in conventional method of fertilizer application in furrow irrigation.

Kanwar *et al.* (2018) while conducting a field study at Jaipur reported that the fertigation at 100 per cent RDF resulted in higher seed protein content of fenugreek as compared to lower fertigation levels. Harish *et al.* (2018) observed that the maximum N, P and K contents was observed in treatment 100 per cent fertigation through drip irrigation and was decreased with decreasing fertilizer levels. The lowest value of N, P and K contents was observed in conventional fertilizer under drip irrigation and 100 per cent conventional fertilizers under surface irrigation at all stages.

Singh *et al.* (2018) noted that the drip fertigated pigeon pea at 100 per cent RDF with WSF recorded significantly higher NPK content and uptake as compared to 80 per cent and 60 per cent recommended dose of fertilizers.

Padmaja and Malla Reddy (2018) conducted a field experiment during rainy season in sandy loam soils of Warangal, Telangana State to study the response of aerobic rice to drip irrigation and nitrogen fertigation under semi-arid environment and data revealed that the nitrogen content and uptake were higher at drip fertigation with 150 kg N/ ha compared to lower N levels.

Abdelraouf *et al*. (2019) carried out a field experiment at Agriculture Production and Research Station, National Research Centre, El Nubaria Province, Egypt to study the effects of fertigation levels and irrigation requirements on quality parameters of wheat and the results showed that decreasing of fertigation levels from 100 to 50 per cent NPK of the RDF significantly decreased protein and carbohydrate contents.

2.4 Soil moisture studies

Drip irrigation with fertigation in Brinjal gave superior water use efficiency and saved 37-49 per cent water when compared to surface irrigation with conventional fertilization (Goswami *et al*., 2006).

Aujla *et al*. (2007) reported that higher water use efficiency and 50 per cent water saving could be achieved through drip irrigation in brinjal while obtaining 4 per cent yield increase as compared to furrow irrigation.

Tanaskovik *et al.* (2011) reported that in tomato drip fertigation with 100 and 75 per cent RDF shows greater water use efficiency and increases 32 per cent of water use efficiency comparing with conventional fertilizer application in drip and 87 per cent in case of furrow method.

Krishnasamy *et al*. (2012) while conducting a field experiment to study the effect of drip fertigation on water use efficiency of maize indicated that 125 per cent RDF (80-40-40 kg/ha) as water soluble fertilizer through drip resulted in higher water use efficiency as compared to 100, 75 per cent RDF through drip and surface irrigation with 100 per cent RDF.

Pawar and Dingre (2013) reported that maximum water use efficiency (69.5 kg/ha-mm) in sugercane was obtained in treatment where 100 per cent water soluble fertilizers were applied through drip as per crop growth stages.

A field study was carried out by Barua and Hazarika (2014) to evaluate the water use efficiency of lemon under fertigation and reported that the highest water use efficiency of 397.74 kg /ha-mm was recorded in the treatment where 120 per cent RDF of fertilizer was given through fertigation over the other treatments.

Pawar *et al*. (2014) in their study on cotton achieved that application of 125 per cent RDF (120-90-75 kg/ha) of NPK through drip fertigation recorded maximum field water use efficiency followed by 75, 100 per cent RDF and the water use efficiency under conventional method of irrigation (3.73 kg/ha-mm) was lowest of all.

Kapoor *et al.* (2014) during their study on cauliflower revealed that the highest water use efficiency was recorded under 120 per cent CPE with 100 per cent RDF followed by 100 per cent CPE with 66.6 per cent RDF in comparison to rest of the treatments and lowest under control.

Shruti and Aladakatti (2017) found that the significantly higher water use efficiency was recorded at 100 per cent fertigation of RD N & K and it was on par with 75 per cent fertigation of RD N & K as compared to 50 per cent RDN and K fertigation in cotton.

Padmaja and Malla Reddy (2018) conducted a field experiment during rainy season in sandy loam soils of Warangal, Telangana State to study the response of aerobic rice to drip irrigation and nitrogen fertigation under semi-arid environment and data revealed that the water use efficiency increased with the increase in N level from 90 to 150 kg N/ha during both the years of study. In contrary, nitrogen use efficiency was enhanced with the increase in water input in drip irrigation and reduced with the increase in N level of application.

Kakade *et al*. (2018) during their field experiment at Akola reported that Water use efficiency was markedly improved by drip fertigation at higher level compared to conventional soil application (100-50-50 kg/ha). However, NUE showed a declining trend with increasing level of N, P and K, but higher NUE in drip fertigation was observed than conventional method of fertilizer application in pigeonpea.

Abdelraouf *et al*. (2019) carried out a field experiment at Agriculture Production and Research Station, National Research Centre, El Nubaria Province, Egypt, to study the effects of fertigation levels and irrigation requirements on soil moisture content of wheat and the results showed that decreasing of fertigation levels from 100 to 50 per cent NPK of the RDF significantly increased water use efficiency of wheat.

2.5 Economics

Veeraputhiran *et al*. (2002) observed that the highest B : C ratio recorded with drip fertigation with 100 per cent RDF as straight fertilizer and the next with 75 per cent RDF as water soluble fertilizer. Surface irrigation with soil application of 100 per cent RDF as straight fertilizer recorded the least value of net return and B : C ratio in cotton.

Khan *et al*. (2003) found that drip fertigation with 100 per cent RDF in potato has recorded higher net profit when compared to drip fertigation with 75 per cent and 50 per cent RDF and furrow irrigation with 100 per cent RDF. Similarly, drip irrigation at 100 per cent RDF registered the highest additional net income and B : C ratio in chilli which was closely followed by drip irrigation at 75 per cent RDF registering an additional net income of ₹ 1,19,488 and B : C ratio of 3.23 over surface irrigation (Selvakumar, 2006).

A field study was conducted by Brahma *et al*. (2010a) revealed that the higher gross, net seasonal income and B : C ratio were recorded by 100 per cent fertigation of recommended dose of nitrogen in broccoli which is closely followed by 80 percent fertigation level and the lowest values recorded by conventional soil application of recommended dose of nitrogen.

Brahma *et al*. (2010b) conducted a study on fertigation efficiency and economics of cultivation of tomato and revealed that the highest B : C ratio was recorded in the 100 per cent fertigation of recommended dose of N & K followed by 75 per cent fertigation level of recommended dose, whereas the lowest B : C ratio was recorded by 50 per cent fertigation level.

Gupta *et al.* (2010) concluded that by adopting drip irrigation system, the highest income could be generated in capsicum as against realized under conventional method. B : C ratio was also noticed maximum with the same treatment combination *i.e.* 80 per cent ET through drip + 80 per cent recommended NPK through fertigation.

Patel *et al*. (2010) observed that application of 100 per cent recommended dose of nitrogen through fertigation recorded significantly highest net returns as well as B : C ratio as compared to treatments 50 per cent through fertigation and 100 per cent through spot application of recommended dose of nitrogen in castor.

Fanish and Muthukrishnan (2011) while conducting their experiment at Tamil Nadu on maize + radish intercropping system and found that drip fertigation at 100 per cent RDF with 50 per cent P and K as water soluble fertilizer recorded higher gross income, whereas, higher net return and B : C ratio were recorded by drip fertigation at 150 per cent RDF with radish as intercrop system compared to soil application of fertilizer with surface irrigation.

Fanish *et al*. (2011) during their experiment at Tamil Nadu agricultural amil Nadu agricultural University, Coimbatore based on their study reported that the highest net returns and B : C ratio were obtained under drip fertigation with 150 per cent recommended dose of fertilizer (80-40-35 kg/ha) as compared to 100 per cent and soil application with RDF of NPK through surface method of irrigation in maize.

Ramah *et al*. (2011) found that the gross income of maize was higher in the treatment with 100 per cent water requirement of crop with 125 per cent RDF through drip fertigation than 80 per cent water requirement and 100 per cent RDF. Whereas, higher B : C ratio was recorded by drip irrigation at 100, 75 per cent water requirement of crop with soil application of 100 and 125 per cent RDF respectively.

Krishnasamy *et al*. (2012) based on their study concluded that the higher net income (₹.1,22,230 /ha) was observed under 125 per cent drip fertigation as against surface irrigation with soil application of 100 per cent RDF in maize.

Chandel *et al.* (2013) studied that drip fertigation with 3/4 of recommended dose of NPK fertilizers had higher fertilizer-use efficiency than the recommended dose of NPK applied both through drip and soil application, They reported the higher net returns (₹. 65520 /ha) without affecting the size, yield and quality of fruits in Kiwi..

Pawar *et al*. (2013) reported that the gross income, net income were significantly higher in 100 per cent fertigation of NPK using schedule B (26 weekly splits) over conventional method but on par with

100 per cent fertigation schedule A (12 equal splits at an interval of 15 days) and 80 per cent fertigation schedule B in sugarcane.

Barua and Hazarika (2014) conducted a field experiment on alluvial sandy loam soils of Jorhat, Assam indicated that net seasonal income from lemon was found to be highest in fertigation with 120 per cent RDF of N, P and K followed by 100 per cent RDF. However, highest B : C ratio was obtained for fertigation with 80 per cent of RDF followed by 100 per cent RDF.

Pawar *et al*. (2014) while conducting a field experiment on cotton found that maximum net seasonal income was obtained when applied100 per cent RDF of NPK as water soluble fertilizer through drip as compared to 125, 75 per cent RDF, nitrogen through drip, drip and surface irrigation with conventional fertilizer application method in cotton.

Rajendran and Arunvenkatesh (2014) during their field experiment at Cotton Breeding Station (CBS), TNAU, Coimbatore on cotton found that the highest B : C ratio recorded with drip fertigation with 100 per cent RDF (75 kg/ha) as straight fertilizer with the net return of ₹. 75605 /ha followed by drip fertigation with 75 per cent RDF as water soluble fertilizer. Surface irrigation with soil application of 100 per cent RDF as straight fertilizer recorded the least value of net return and B : C ratio.

Yadav and Chauhan (2016) during their study at Jabalpur reported that the maximum B : C ratio 6.43 was recorded with 80 per cent recommended dose of N (85 kg/ha) and K in 12 equal splits followed by 6.08 recorded at the same dose of fertilizer in 9 equal splits as against 4.71 under flood irrigation with recommended fertilizer dose in brinjal.

Agrawal *et al*. (2018b) based on their study at Raipur reported that the B : C ratio of cabbage was found to be highest under 0.8 CPE water by drip + 80 per cent WSF (80-40-40 kg/ha) and same was lowest in conventional irrigation method.

Shruthi *et al.* (2018) obtained higher net returns and B : C ratio with drip fertigation of 75 per cent of recommended nitrogen and potassium when compared to control where surface irrigation method was followed in maize.

Agrawal *et al.* (2018a) investigated that the highest net seasonal income of tomato crop was observed in drip fertigation with water soluble fertilizer (₹ 1,12,320/ha) as compared to without fertigation (₹ 74,360//ha). The B : C ratio (3.95) was also observed higher in drip irrigation with water soluble fertilizer as compared to farmer practice (1.79).

Padmaja and Malla Reddy (2018) conducted a field experiment during rainy season in sandy loam soils of Warangal, Telangana State to study the response of aerobic rice to drip irrigation and nitrogen fertigation under semi-arid environment and data revealed that the gross returns, net returns and B : C ratio were higher in drip irrigation schedule of 200 per cent PE and 150 kg N/ha closely followed by that realized at 120 kg N/ ha in the same irrigation schedule.

Chapter-3

MATERIALS AND METHODS

A field experiment entitled "**Response of Fennel (*Foeniculum vulgare* Mill.) to Drip Irrigation and Fertigation**" was conducted at Agronomy Farm, S.K.N. College of Agriculture, Jobner during *Rabi* seasons of the year 2015-16 and 2016-17. The details of the procedures adopted for raising the crop and criteria used for treatment evaluation and methods adopted during the course of investigation are presented in this chapter.

3.1 Experimental site

An experiment was conducted on plot No. B-1 at Agronomy Farm, S.K.N. College of Agriculture, Jobner, District Jaipur (Rajasthan). Geographically, Jobner is located 45 km west of Jaipur at 26^0 05' North latitute, 75^0 28' East longitude and at an altitude of 427 metres above mean sea level. The place falls in agroclimatic zone III A (Semi-arid Eastern Plain Zone) of Rajasthan.

3.2 Climate and weather conditions

The climate of this region is a typically semi-arid, characterized by extremes of temperature during both summer and winter. During summer, the temperature may go as high as 48^0C while in winter, it may fall as low as -1.0^0C. The average annual rainfall of this tract ranges between 300-400 mm, most of which is contributed by the South-west monsoon during the months of July and August. A total of 41.8 mm rainfall was received during the crop season and pan evaporation was 610.4 mm during crop season. The maximum and minimum temperatures during crop growing period ranged from $18.5^{\mathbf{0}}$ to 35.9^0C and 2.3 to 16.3^0C, respectively. The mean weekly data on weather parameters for the crop season recorded at college meteorological observatory are presented in table 3.1 and illustrated in fig. 3.1a and 3.1b.

Table:3.1 Mean weekly weather parameters recorded for crop season (*Rabi* 2015-16 and 2016-17)

SMW* No.	Period	Temperature ^0C				Relative humidity (%)		Sunshine (hrs/day)		Evaporation (mm/day)		Rainfall (mm)	
		Maximum		Minimum									
		2015-16	2016-17	2015-16	2016-17	2015-16	2016-17	2015-16	2016-17	2015-16	2016-17	2015-16	2016-17
44	Nov.01 to Nov.04	31.8	32.2	15.0	08.5	60	49	08.3	0.2	05.4	05.4	00.0	00.0
45	Nov.05 to Nov.11	31.9	32.0	15.1	08.6	61	49	08.3	0.2	05.5	05.4	00.0	00.0
46	Nov.12 to Nov.18	31.0	30.4	11.6	08.7	56	53	09.1	09.1	05.9	05.6	00.0	00.0
47	Nov.19 to Dec. 25	29.1	31.0	09.0	06.6	53	49	09.1	09.0	05.8	05.5	00.0	00.0
48	Dec. 26 to Dec. 02	27.2	30.5	09.3	08.6	61	53	06.2	09.0	03.4	04.0	00.0	00.0
49	Dec. 03 to Dec. 09	28.4	29.4	06.9	06.2	60	59	08.6	09.0	02.3	02.9	00.0	00.0
50	Dec. 10 to Dec. 16	23.5	28.1	03.2	09.4	63	59	07.1	07.2	02.3	02.8	00.0	00.0
51	Dec. 17 to Dec. 23	23.0	27.2	02.1	04.4	57	54	08.7	08.5	01.9	02.5	00.0	00.0
52	Dec. 24 to Dec. 31	27.7	27.3	04.0	06.1	57	61	08.5	07.6	02.1	02.9	00.0	00.0
1	Jan. 01 to Jan. 07	27.2	24.4	08.1	07.2	63	71	07.7	08.2	02.9	03.1	00.0	00.0
2	Jan. 08 to Jan. 14	26.1	20.4	05.5	02.8	59	63	09.0	08.6	02.4	02.7	00.0	00.0
3	Jan. 15 to Jan. 21	21.7	21.1	03.3	04.9	67	63	08.5	08.4	02.2	03.2	00.0	00.0
4	Jan. 22 to Jan. 28	24.1	23.2	03.5	10.5	62	72	09.6	05.0	02.8	03.1	00.0	21.8
5	Jan. 29 to Feb. 04	25.7	24.7	07.7	09.9	64	65	09.1	07.4	02.8	03.5	00.0	00.0
6	Feb. 05 to Feb. 11	25.2	24.4	05.2	07.8	51	55	09.4	07.3	03.5	03.9	00.0	00.0
7	Feb. 12 to Feb. 18	25.0	27.9	09.3	08.9	48	49	07.5	07.5	03.2	03.6	03.6	00.0
8	Feb. 19 to Mar. 25	27.6	29.9	09.6	09.1	55	45	05.3	08.9	03.2	05.7	00.0	00.0
9	Feb. 26 to Mar. 04	33.2	30.8	12.1	11.1	49	49	09.2	07.5	04.1	05.4	00.0	00.4
10	Mar. 05 to Mar. 11	33.5	29.3	13.9	10.9	55	53	09.4	04.8	04.8	04.6	00.0	02.6
11	Mar. 12 to Mar. 18	31.8	28.6	16.0	10.5	57	47	05.5	08.0	05.6	04.9	01.4	00.0
12	Mar. 19 to Mar. 25	34.9	34.8	14.3	15.1	49	47	08.1	07.2	07.2	06.4	00.0	00.0
13	Mar. 26 to April 01	35.0	39.9	16.0	16.1	47	37	06.1	10.5	06.8	07.5	00.6	00.0
14	April 02 to April 08	37.7	38.3	19.7	18.2	40	41	07.0	10.0	07.4	07.7	00.0	00.0
15	April 09 to April 15	36.7	38.1	17.9	14.9	39	40	09.5	10.9	07.9	08.6	00.0	00.0
16	April 16 to April 22	39.5	42.8	21.2	23.0	39	35	08.8	11.5	09.0	11.4	00.0	00.0
17	April 23 to April 29	39.7	39.1	19.3	20.9	20	47	08.8	09.3	10.1	10.5	00.0	00.0
18	April 30 to May 06	41.5	40.1	22.2	22.9	19	46	09.2	09.8	11.2	10.5	15.2	00.0

SMW = Standard meteorological weeks

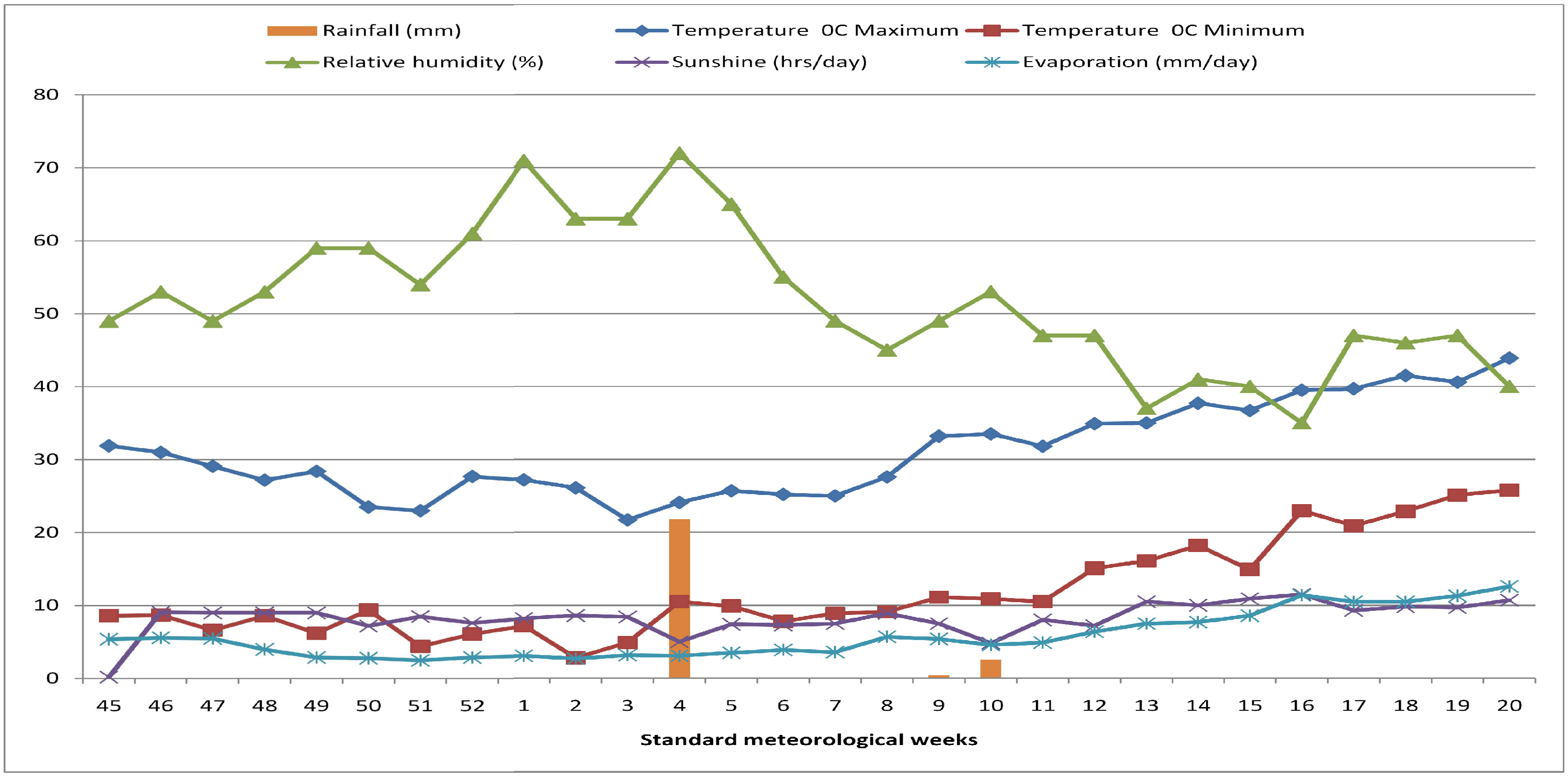


Fig. 3.1a Mean weekly weather parameters recorded for crop season (*Rabi*-2015-16)

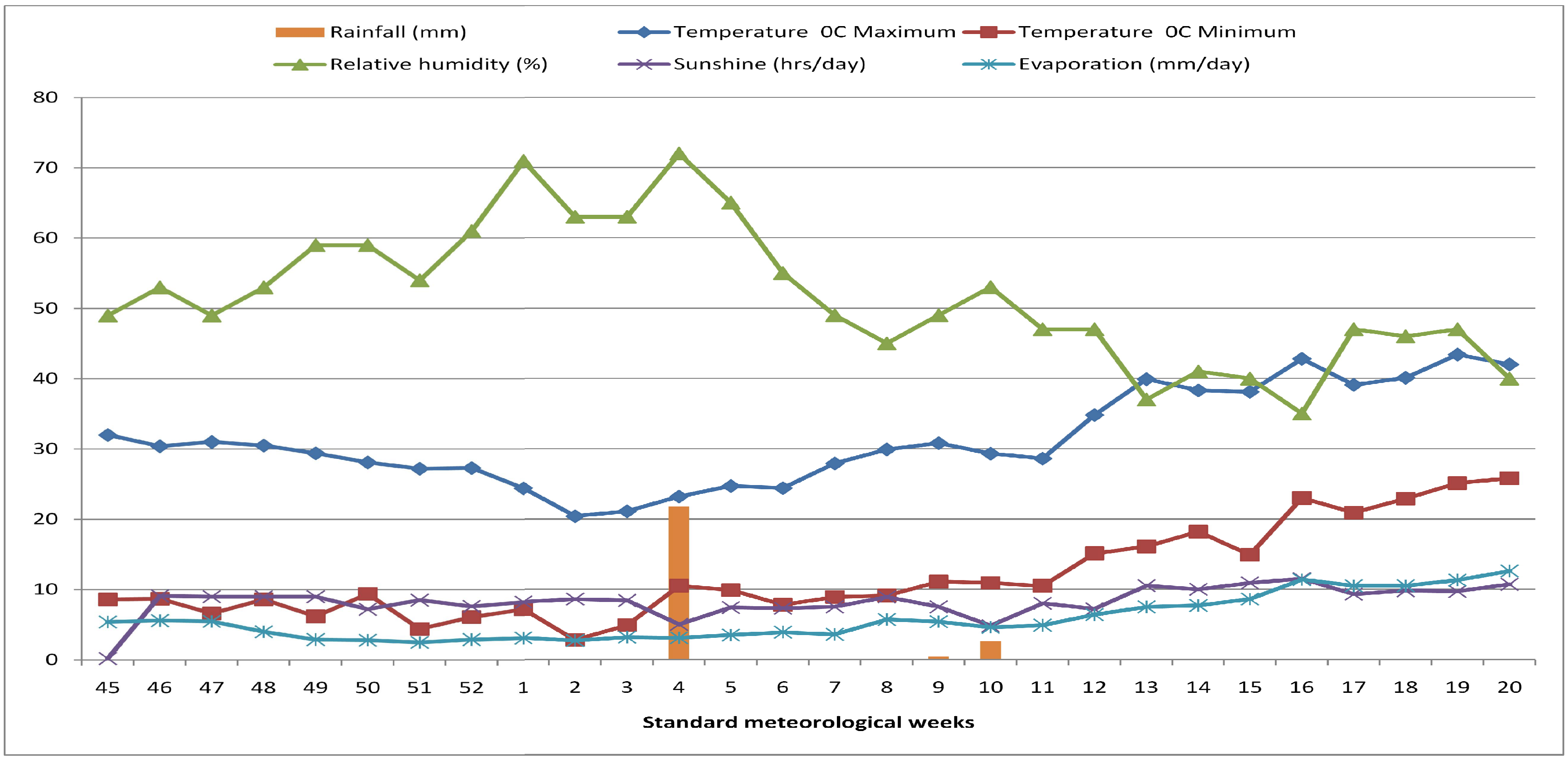


Fig. 3.1b **Mean weekly weather parameters recorded for crop season (*Rabi*-2016-17)**

3.3 Cropping history of the experimental field

The cropping history of the experimental field is given in table 3.2.

Table 3.2 Cropping history of the experimental field

Years	Crop season			
	Field of experiment 2015-16		**Field of experiment 2016-17**	
	Kharif	***Rabi***	***Kharif***	***Rabi***
2012-13	Guar	Coriander	Fallow	Fenugreek
2013-14	Fallow	Fenugreek	Fallow	Coriander
2014-15	Fallow	Fennel	Fallow	Fenugreek
2015-16	Fallow	Fennel*	Fallow	Fallow
2016-17	Fallow	Fallow	Fallow	Fennel *

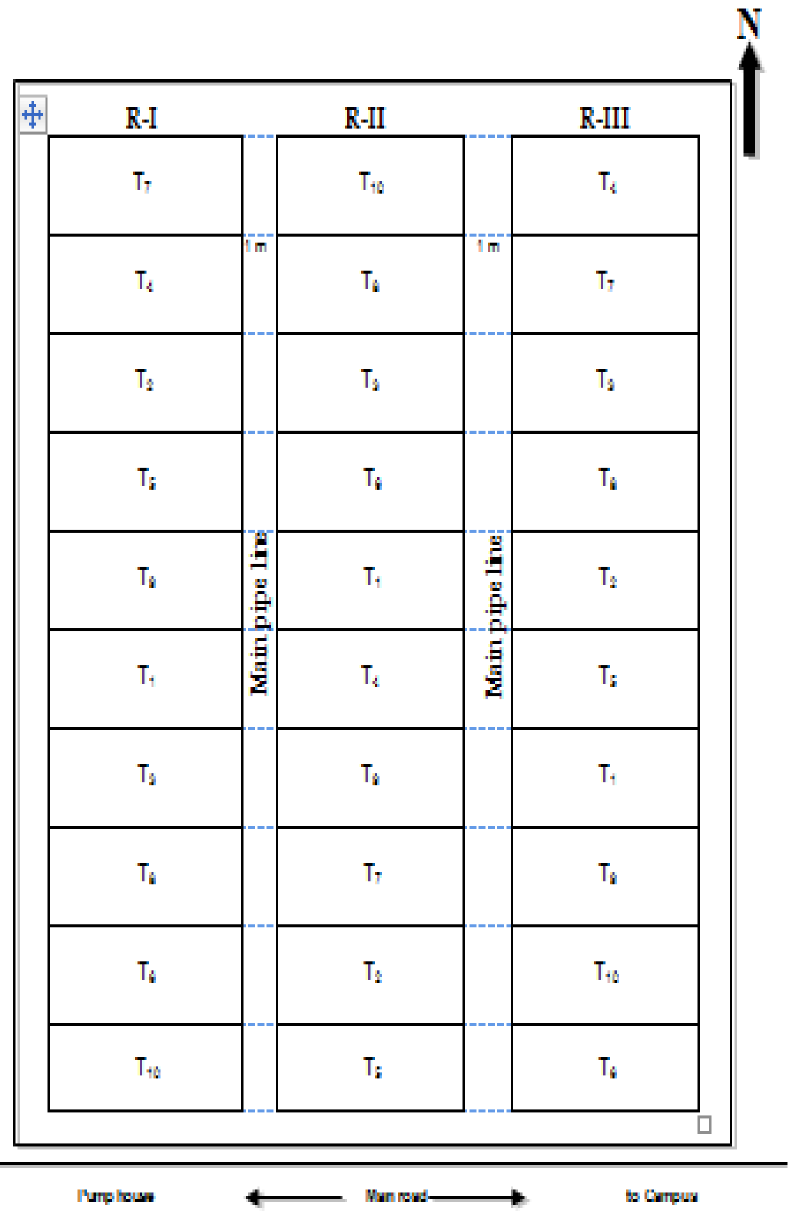
* Experimental crop

3.4 Soil of the experimental field

In order to evaluate the physico-chemical properties, soil samples from 0-30 cm depth were taken from five random spots of the experimental field prior to layout and representative composite sample was prepared by mixing and processing of all soil samples together. The homogeneous composite soil sample was subjected to mechanical, physical and chemical analysis. The results of these analysis along with methods used for determination are presented in table 3.3. It is apparent from data that the soil of the experimental field was loamy sand in texture, alkaline in reaction, poor in organic carbon with low available nitrogen and phosphorus and medium in potassium content, field capacity of soil is 10.85 per cent and PWP is 4.32 per cent.

Table 3.3 Physico-chemical characteristics of the soil of experimental field

	Parameters	Value		Method adopted
		2015-16	2016-17	
A.	**Mechanical**			
	(i) Coarse sand (%)	22.47	22.30	International Pipette Method (Piper, 1950)
	(ii) Fine sand (%)	58.90	58.78	"
	(iii) Silt (%)	10.73	10.95	"
	(iv) Clay (%)	7.90	8.03	"
	(v) Textural class	Loamy sand	Loamy sand	Using USDA triangle (Soil Survey Staff, 1975)
B.	**Physical**			
	(i) Bulk density (Mg/m^3)	1.60	1.58	Method No. 38, USDA Hand Book No. 60 (Richards, 1968)
	(ii)Particle density (Mg/m^3)	2.61	2.63	Method No. 39, USDA Hand Book No. 60 (Richards, 1968)
	(iii) Porosity (%)	39.43	42.35	Method No. 40, USDA Hand Book No. 60 (Richards, 1968)
	(iv) Field capacity (%)	11.04	11.95	Method No. 33, USDA Hand Book No. 60 (Richards, 1968)
C.	**Chemical**			
	(i) Organic carbon (%)	0.17	0.18	Walkely and Black rapid titration method (Jackson, 1973)
	(ii) Available N (kg/ha)	127.5	128.4	Alkaline permanganate method (Subbiah and Asija, 1956)
	(iii) Available P_2O_5 (kg/ha)	17.10	17.18	Olsen's method (Olsen *et al.*, 1954)
	(iv) Available K_2O (kg/ha)	171.94	173.40	Flame photometer method (Metson, 1956)
	(v) Available SO_4^{-2} (ppm)	8.35	8.50	Turbidimetric method (Chesnin and Yien, 1950)
	(vi) Available Zn (ppm)	0.45	0.43	Atomic absorption spectrophotometer (Varion Techtron AAS-120) (Lindsay and Norvell, 1978)
	(vii) ECe of saturated extract at 25 ^0C (dS/m)	1.48	1.47	Method No. 4, USDA Hand Book No. 60 (Richards, 1968)
	(viiii) pH (1:2) soil water suspension	8.40	8.30	Method No. 21 (b), USDA Hand Book No. 60 (Richards, 1968)



Gross Plot Size	-	6 x 3 m^2	Path	-	1 m
Design	-	R.B.D.	Replication	-	3
Treatments	-	10	Total plots	-	30

Fig. 3.2 : Layout plan of experiment

3.5 Quality of irrigation water

The crop was irrigated with the water from tube well of Kuchchyawas near Jobner. A representative water sample was taken and analysed for quality parameters. The results so obtained are presented in table 3.4. The data revealed that water used for irrigation was little alkaline but can safely be used in light textured soil for irrigating fennel crop.

Table 3.4 Quality of irrigation water and method of determination

Particular	Value	Method	Reference
EC(dS/m at 25 ^{0}C)	1.56	Method No.4 USDA Hand Book No. 60	Richards (1954)
pH	8.15	Method No. 2 (1) USDA Hand Book No. 60	Richards (1954)
Na^+(m mol/l)	26.4	With the help of flame photometer as per method (10_a) USDA, Hand Book No. 60	Richards (1954)
CO_3^{2-}(m mol/l)	1.0	Titration was carried out with standard H_2SO_4 as per method 12 USDA, Hand Book No. 60	Reitemier (1943)
Ca and Mg (m mol/l)	2.2	Versenate titration	Richards (1954)
HCO_3 (m mol/l)	6.5	Titration was carried out with standard H_2SO_4 as per method 12 USDA, Hand Book No. 60	Reitemier (1943)
RSC (meq/l)	2.5	RSC = CO_3^2 + HCO_3^-) - Ca^{++} + Mg^{++}	-
SAR	8.61	Relationship given in USDA Hand Book No. 60	Richards (1954)
Class (USSL)*	C_3S_1	Relationship given in USDA Hand Book No. 60	Richards (1954)

*United States Salinity Laboratory, California (USSL)

3.6 Experimental details

3.6.1 Treatments

The experiment consisted of ten treatments (Surface irrigation with CF (100 per cent RDF), drip irrigation with CF (50, 75 and 100 percent RDF), drip fertigation with (50, 75 and 100 percent RDN and RDF). The experiment was laid out in Randomized Block Design with three replications. The treatments with their symbols are given in table 3.5.

Table 3.5 Treatments with their symbols

Treatment	Symbols
1. Surface irrigation with CF (100%RDF)	T_1
2. Drip irrigation with CF (50% RDF)	T_2
3. Drip irrigation with CF (75% RDF)	T_3
4. Drip irrigation with CF (100%RDF)	T_4
5. Drip fertigation with 50% RDN	T_5
6. Drip fertigation with 75% RDN	T_6
7. Drip fertigation with 100% RDN	T_7
8. Drip fertigation with 50% RDF (N-P)	T_8
9. Drip fertigation with 75% RDF	T_9
10. Drip fertigation with 100% RDF	T_{10}

CF = Conventional fertilizer

RDF = Recommended dose of fertilizer (90-40-0)

RDN = Recommended dose of nitrogen

Other details

(i) Season	:	*Rabi,* 2015-16 and 2016-17
(ii) Total treatment	:	10
(iii) Replications	:	3
(iv)Total number of plots	:	10x3 = 30
(v) Experimental design	:	RBD
(vi) Plot size	:	6 m X 3 m = 18.0 m^2
(vii) Row spacing	:	50 cm X 20 cm
(viii) Variety	:	RF-125
(ix) Seed rate	:	10 kg/ha

3.6.2 Design and layout of the experiment

The experiment was laid out in Randomized Block Design and treatments were replicated three times. The treatment allocation to different experimental units was done with the help of random number table as advocated by Fisher and Yates (1963). The layout plan of experiment with allocation of treatments and other details are shown in fig. 3.2.

3.7 Varietal characteristics

Variety RF-125 was developed at S.K.N. College of Agriculture, Jobner (Jaipur) in the year 2004. Plants are erect with 102-120 cm height, compact umbels and long bold seed. It matures in 120-130 days.

3.8 Details of crop raising

The schedule of different pre and post sowing operations carried out in the experimental field is given in table 3.6.

Table 3.6 Schedule of cultural operations carried out during the crop season of 2015-16 and 2016-17

S.No.	*Particulars*	Date of operation	
		2015-16	**2016-17**
1.	Disc ploughing	25.10.15	20.10.16
2.	Disc harrowing by planking	05.11.15	29.10.16
3.	Layout of the experimental field	06.11.15	31.10.16
4.	Pre sowing irrigation	21.10.15	17.10.16
5.	Fertilizers application as basal	07.11.15	01.11.16
6.	Sowing	07.11.15	01.11.16
7.	Top dressing of N fertilizer in CF		
	I	08.12.15	03.12.16
	Ii	10.01.16	05.01.17
	Iii	15.02.16	10.02.17
8.	Fertigation in drip irrigation		
	I	29.11.15	28.11.16
	Ii	21.12.15	20.12.16
	Iii	12.01.16	11.01.17
	Iv	03.02.16	03.02.17
	V	26.03.16	25.03.17
9.	Spray of insecticides	08.02.16	02.02.17
10.	Thinning	12.12.15	17.12.16
11.	Weeding and hoeing		
	I	07.12.15	12.12.16
	Ii	27.12.15	02.01.17
12.	Harvesting	02.05.16	01.05.17
13.	Threshing and winnowing	12.05.16	13.05.17

3.8.1 Field preparation

The field was ploughed after pre sowing irrigation by tractor drawn disc plough and disc harrow followed by planking. The seed beds of 6 m x 3 m size were prepared as per layout plan.

3.8.2 Treatment application

3.8.2.1 Fertilizers : The recommended dose of fertilizer for fennel in the semi-arid eastern plain zone is 90:40:0 kg/ha. In conventional method of fertilizer application (T_1 to T_4) the entire quantity of phosphorus was applied as basal through single super phosphate and nitrogen through urea in three equal splits as top dressing. In treatment of RDN (T_5, T_6 and T_7) the phosphorus through single super phosphate was applied as basal and nitrogen through urea as drip fertigation. In drip fertigation treatments of RDF (T_8, T_9 and T_{10}) the nitrogen and phosphorus were applied through urea and urea phosphate as drip fertigation in five splits at an interval of 20 days. The sulphur supplied with single super phosphate in some treatments was adjusted with the application of elemental sulphur in rest of the treatments so that sulphur applied will remain same in all the treatments.

3.8.2.2 Irrigation : The measured quantity of irrigation water was supplied by drip irrigation in drip irrigation treatments and by check basin in surface irrigation at 0.8 IW/CPE ratio determined by cumulative pan evaporation. The required pressure and discharge in drip system was maintained with overflow valve with the supply source. The irrigation was given on alternate day in drip irrigation and at an interval of 10-20 days in surface irrigation.

3.8.3 Planting method: The crop was planted at a row spacing of 50 cm. The plant space mainted at 20 cm within the row.

3.8.4 Seed and sowing

The crop was sown on 07.11.2015 and 01.11.2016. Sowing was done by *kera* method in rows using a seed rate of 10 kg/ha at a depth of 3-5 cm.

3.8.5 Plant protection measures

Before sowing, the seeds were treated with bavistin @ 3 g/kg seeds to protect the crop from seed borne diseases. During growth stage spray with chloropyriphos @ 4.0 l/ha, imidacloprid @ 0.5 l/ha and karathene @ 0.5 l/ha were done at 90 DAS to protect the crop from insect pests attack.

3.8.6 Thinning and weeding

In order to minimize weed competition, two weeding and hoeing was done manually at 25 and 45 days after sowing. The weeds were pulled out manually in all plots. To maintain uniform plant stand at an intra row spacing of 20 cm, extra plants were thinned out.

3.8.7 Harvesting, threshing and winnowing

The crop from net area was harvested on 02.05.2016 and 01.05.2017. Plots were harvested separately and tied in bundles and tagged. These bundles were left on the threshing floor for sun drying. After complete drying, bundles were weighed to record biological yield. Thereafter, threshing was done by beating the plants with sticks. Seed and straw were separated by manual winnowing and their yield per plot was recorded.

3.9. Observations for treatment evaluation

In order to evaluate the effect of different treatments on growth, yield and quality of crop, necessary periodical observations were recorded, particulars of which are given as under :

3.9.1 Growth parameters

3.9.1.1 Plant stand

Plant stand per metre row length was counted at 35 DAS and at harvest from 5 randomly selected spots (1 m row length) in each plot and the average was worked out.

3.9.1.2 Plant height

Five plants were selected randomly from each plot, tagged permanently and used for measurement of plant height. Height of each tagged plant was measured periodically at 35, 70, 105 DAS and at harvest from base of the plant to the tip of the main shoot by metre scale and average of five plants was computed as mean plant height.

3.9.1.3 Number of branches per plant

The five plants randomly selected and tagged permanently in each plot for height measurement were used to record the number of branches per plant at harvest and their average was worked out.

3.9.1.4 Dry matter accumulation per metre row length

Dry matter production was recorded at 35, 70, 105 DAS and at harvest. For this, plants from one metre row length were uprooted randomly from sample rows of each plot. After removal of root portion, the samples were first air dried for some days and finally dried in an electric oven at 70 ^{0}C till constant weight. The weight was recorded and expressed as average dry matter per metre row length.

3.9.1.5 Crop growth rate (CGR)

The CGR of a plant for a time 't' is defined as the increase in dry weight of plant material from a unit area per unit of time. It was calculated by following formula (Radford, 1967) from the periodic dry matter record at different stages.

$$\text{CGR (g/m}^2\text{/day)} = \frac{W_2 - W_1}{(t_2 - t_1)\, S}$$

Where,

W_1 = Dry matter of crop at time t_1

W_2 = Dry matter of crop at time t_2

t_1 = Time of first observation.

t_2 = Time of subsequent observation.

S = Spacing

3.9.1.6 Relative growth rate (RGR)

The RGR of a plant at an instant in time (t) is defined as the increase in dry weight of plant material per unit of material already present per unit of time.

The RGR of the crop was calculated by the following formula (Radford, 1967).

$$\text{RGR (mg/g/day)} = \frac{(\text{Log}_e\, W_2 - \text{Log}_e\, W_1)}{(t_2 - t_1)\, W_1}$$

Where,

W_1 = Total dry matter of crop at time t_1

W_2 = Total dry matter of crop at time t_2

t_1 = Time at first observation.

t_2 = Time at second observation.

3.9.1.7 Chlorophyll content

The chlorophyll content of fennel at 75 DAS was estimated by the method advocated by Arnon (1949). The leaf sample was ground in 80 per cent acetone, centrifuged for 10 minutes at 2000 rpm and made final volume to 10 ml. The resultant absorbance of clear supernatant was measured by spectronic 20 at 652 nm and presented in terms of mg/g fresh weight of leaves.

$$\text{Total chlorophyll (mg/g)} = \frac{A_{(652)} \times 29 \times \text{Total volume (ml)}}{\alpha \times 1000 \times \text{Weight of sample (gm)}}$$

Where, α is the path length = 1 cm

3.9.2 Yield attributes and yield

3.9.2.1 Number of umbels per plant

The randomly selected plants used for recording the height and branches were used for counting the number of umbels per plant at harvest and their average was worked out to record umbels per plant.

3.9.2.2 Number of umbellets per umbel

Total numbers of umbellets of 10 main umbels of five tagged plants were counted from each plot and average umbellets per umbel were computed.

3.9.2.3 Number of seeds per umbel

At the time of threshing, 10 umbels were randomly selected from five tagged plants in each plot and their total seeds were counted to record the average number of seeds per umbel.

3.9.2.4 Test weight

One thousand seeds were counted from the sample drawn randomly from the finally winnowed and cleaned produce of each plot and their weight was recorded as test weight (g).

3.9.2.5 Biological yield

The weight of the thoroughly sun dried harvested produce of each plot was recorded separately before threshing and expressed as biological yield in kg/ha.

3.9.2.6 Seed yield

After threshing, winnowing and cleaning, the produce of each plot was weighed separately in kg per plot and then converted to seed yield in kg/ha.

3.9.2.7 Straw yield

Straw yield (kg/ha) was obtained by subtracting the seed yield (kg/ha) from biological yield (kg/ha).

3.9.2.8 Harvest index

Harvest index was computed by using the formula outlined by Singh and Stoskopf (1971).

$$\text{Harvest index (\%)} = \frac{\text{Economic yield (kg/ha)}}{\text{Biological yield (kg/ha)}} \times 100$$

3.10 Nutrient content, uptake and quality parameters

3.10.1 Nitrogen content in seed and straw

Representative samples of fennel seed and straw taken at harvest were oven dried, ground in Willey mill and analysed for their nitrogen content. Nitrogen was estimated by colorimetric method (Snell and Snell, 1949). Plant samples were digested with sulphuric acid and treated with hydrogen peroxide to remove black colour. Nesseler’s reagent was used to develop the colour. The results so obtained were expressed as per cent nitrogen content.

3.10.2 Phosphorus content in seed and straw

The samples of fennel seed and straw were also subjected to chemical analysis for their phosphorus content. These samples after grinding were digested in triacid mixture and P was estimated by ‘vanadomolybdophosphate’ yellow colour method in nitric acid system (Jackson, 1958)

3.10.3 Potassium content in seed and straw

The samples of crop seed and straw were also analysed for their potassium content. These samples after grinding were digested in tri acid mixture and potassium content in plant extract was determined by flame photometric method *i.e.* when atoms of potassium are excited in flame, emit a flame of specific wave length, the intensity of emission is proportional to the content of K which is determined in flame photometer using K filter.

3.10.4 Nutrient uptake

The uptake of nitrogen, phosphorus and potassium by fennel crop at harvest was computed using the following formula:

$$\text{Total uptake (kg/ha)} = \frac{\text{Nutrient content in seed (\%)} \times \text{seed yield (kg/ha)} + \text{Nutrient content in straw (\%)} \times \text{Straw yield (kg/ha)}}{100}$$

3.10.5 Crude protein content in seed

Protein content in seed was calculated from the per cent nitrogen in the seed multiplied by the factor of 6.25 (A.O.A.C., 1990).

3.10.6 Volatile oil content in seed and oil yield

Volatile oil content in bulk seed of tagged plant was estimated by volatile oil distillation assembly *i.e.* Clevenger apparatus (A.O.A.C., 1990), as described below:

One hundred gram seed sample was weighed and ground finely with electric grinder. The seed powder was transferred in assembly flask (1 lit.). 540 ml water was added to fill the flask to half of its capacity and placed on heating mantle. Heating was done for 5-6 hrs continuously. The volatile oil is collected in the graduated side arm of the assembly. Two consecutive readings were taken at 30 minutes interval until there was no change in oil content. The volume of volatile oil obtained in terms of millilitre per 100 grams seed sample directly reveals per cent oil content in the seeds. Oil yield was calculated by using following formula:

$$\text{Oil yield (kg/ha)} = \frac{\text{Percent oil content in seed} \times \text{Seed yield (kg/ha)}}{100}$$

3.11 Soil moisture studies

3.11.1 Per cent soil moisture

For determination of soil moisture, soil samples were collected from central area of each plot from three successive layers *viz*. 0-15 cm, 15-30 cm, 30-45 cm at sowing, before and 24 hours after each irrigation and at harvest with the help of soil auger in aluminum boxes. After recording initial weights, boxes were kept in hot air oven at 105 ^{0}C for 24 hours till constant weight. Per cent soil moisture on oven dry weight basis was calculated as under:

$$\text{Per cent soil moisture} = \frac{\text{Weight of wet soil} - \text{weight of oven dry soil}}{\text{Weight of oven dry soil}} \times 100$$

3.11.2 Consumptive use

Consumptive use of water was computed as per following procedure suggested by Dastane (1972).

$$Cu = \Sigma u$$

$$u = (E_0 \times 0.8) \sum_{t-i}^{n} \frac{M_1i - M_2i \quad (AiDi)}{100} + ER + GWC$$

Where,

Cu = Seasonal consumptive use of water in mm

u = Consumptive use during a given irrigation interval

E_0 = Evaporation from USWB class I open pan evaporimeter during interval from the day of irrigation to the day when sampling in wet soil is possible

0.8 = A constant to be used with the USWB class I open pan evaporimeter

n = Number of soil layers sampled in the root zone depth D

M_1i = Soil moisture per cent in the i^{th} layer on the day when sampling in irrigated soil was possible

M_2i = Soil moisture percent in the i^{th} layer on the day just before the next irrigation

Ai = Apparent specific gravity of the i^{th} layer

Di = Soil depth of the i^{th} layer (cm)

ER = Effective rainfall during the interval (mm)

GWC = Ground water contribution (the contribution from ground water was considered to be zero as water table was below (30 m depth)

3.11.3 Water use efficiency

The ratio of crop yield (Y) to the amount of water depleted by the crop in the process of evapo-transpiration (ET) was computed according to the formula suggested by Viets (1961).

$$\text{WUE (kg/ha-mm)} = \frac{\text{Seed yield (kg/ha)}}{\text{Seasonal consumptive use of water (mm)}} \times 100$$

3.11.4 Fertilizer Use Efficiency (FUE)

The fertilizer use efficiency was computed as described by Veeranna (2000).

$$\text{FUE (kg/ha)} = \frac{\text{Seed yield (kg/ha)}}{\text{Total fertilizers applied (kg/ha) (N+P)}}$$

3.12 Statistical analysis

The experimental data recorded for growth, yield and other characters were statistically analysed by Fisher’s analysis of variance technique (Fisher, 1950). Appropriate standard error for each of the factor was worked out. Significance of differences among treatment effects was tested by “F” test. Critical difference (CD) was worked out wherever the difference was found to be significant at 5 per cent level of significance. The analysis of variance of different components for all parameters is given in the appendices.

3.13 Correlation and regression studies

To assess the relationship, correlation and regression coefficients between seed yield of fennel (Y) and the independent variables (X) such as yield attributes and nutrient uptake were computed using the method given by Snedecor and Cochran (1968). The regression equations were also fitted and tested for significance.

3.14 Economics

The economics of treatments is the prime consideration before making any recommendation for its adoption. Hence, to evaluate the effectiveness and profitability of the treatments, economics in terms of net returns (`/ha) was calculated. The details of calculation with prevailing market rates of the inputs and produce are given in appendices (XXXI – XXXIII).

Chapter-4

EXPERIMENT RESULTS

Results of the field experiment entitled **"Response of Fennel (*Foeniculum vulgare* Mill.) to Drip Irrigation and Fertigation"** conducted during *Rabi* seasons of the year 2015-16 and 2016-17 at Agronomy farm, S.K.N. College of Agriculture, Jobner are presented in this chapter. The observations pertaining to growth, yield and quality of fennel recorded during the courses of investigation were statistically analysed and significance of results verified. The analysis of variance for all the data have been presented in the annexures at the end. The results of all the effects are being presented in succeeding paragraphs.

4.1 Growth parameters

4.1.1 Plant stand

Data presented in table 4.1 reveals that plant stands per metre row length of fennel at 35 DAS and at harvest was not affected significantly due to drip irrigation and fertigation at different fertilizer levels during both the years of experimentation as well as on pooled basis.

4.1.2 Plant height

The critical examination of data (Table 4.2 and Fig. 4.1) indicates that the drip irrigation and fertigation at different fertilizer levels increased plant height at different stages over surface irrigation with conventional fertilization. Surface irrigation with conventional fertilization, being at par with drip irrigation at 50 per cent RDF with conventional fertilization, recorded significantly inferior plant height at 35, 70, 105 DAS and at harvest over other drip irrigated and fertigated treatments during both the years and in pooled data over two years.

Table 4.1 Effect of drip irrigation and fertigation on plant stand/metre row length of fennel

Treatments	35 DAS			At harvest		
	2015-16	**2016-17**	**Pooled**	**2015-16**	**2016-17**	**Pooled**
Surface irrigation with CF (100% RDF)	5.2	5.1	5.2	5.1	5.0	5.0
Drip irrigation with CF (50%RDF)	5.7	5.6	5.6	5.6	5.5	5.6
Drip irrigation with CF (75% RDF)	5.7	5.6	5.6	5.7	5.6	5.6
Drip irrigation with CF (100% RDF)	5.7	5.7	5.7	5.7	5.6	5.7
Drip fertigation with 50% RDN	5.7	5.6	5.6	5.6	5.6	5.6
Drip fertigation with 75% RDN	5.8	5.7	5.7	5.7	5.6	5.7
Drip fertigation with 100% RDN	5.8	5.7	5.7	5.7	5.6	5.6
Drip fertigation with 50% RDF	5.7	5.6	5.7	5.7	5.6	5.6
Drip fertigation with 75% RDF	5.8	5.7	5.8	5.7	5.7	5.7
Drip fertigation with 100% RDF	5.8	5.8	5.8	5.8	5.8	5.8
SEm±	0.2	0.2	0.2	0.2	0.2	0.1
CD (P=0.05)	NS	NS	NS	NS	NS	NS

Table 4.2 Effect of drip irrigation and fertigation on plant height of fennel

Treatments	Plant height (cm)											
	35 DAS			70 DAS			105 DAS			At harvest		
	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled
Surface irrigation with CF (100% RDF)	8.7	8.8	8.7	25.1	26.8	26.0	55.2	59.1	57.2	77.2	80.4	78.8
Drip irrigation with CF (50%RDF)	8.9	9.5	9.2	27.1	28.9	28.0	59.6	63.8	61.7	86.1	85.6	85.9
Drip irrigation with CF (75% RDF)	11.2	11.9	11.5	30.9	32.9	31.9	67.9	72.7	70.3	97.5	100.4	98.9
Drip irrigation with CF (100% RDF)	11.5	12.2	11.9	30.2	32.0	31.1	70.7	75.6	73.2	101.4	104.3	102.8
Drip fertigation with 50% RDN	10.8	11.4	11.1	29.9	31.8	30.9	65.7	70.3	68.0	94.5	97.2	95.9
Drip fertigation with 75% RDN	12.1	12.8	12.5	33.5	35.7	34.6	75.9	81.2	78.6	107.4	111.5	109.5
Drip fertigation with 100% RDN	13.3	14.2	13.8	37.7	39.6	38.7	81.1	86.8	83.9	115.5	119.0	117.2
Drip fertigation with 50% RDF	12.1	12.8	12.4	33.2	35.3	34.3	72.8	78.0	75.4	104.4	107.4	105.9
Drip fertigation with 75% RDF	14.1	15.0	14.5	38.7	41.2	40.0	85.0	90.0	87.5	121.2	124.7	122.9
Drip fertigation with 100% RDF	14.7	16.1	15.4	42.2	45.2	43.7	92.6	98.5	95.6	129.5	131.3	130.4
SEm±	0.4	0.5	0.3	1.1	1.3	0.9	2.5	2.8	1.9	3.5	3.8	2.6
CD (P=0.05)	1.2	1.4	0.9	3.4	3.8	2.4	7.5	8.4	5.4	10.5	11.5	7.8

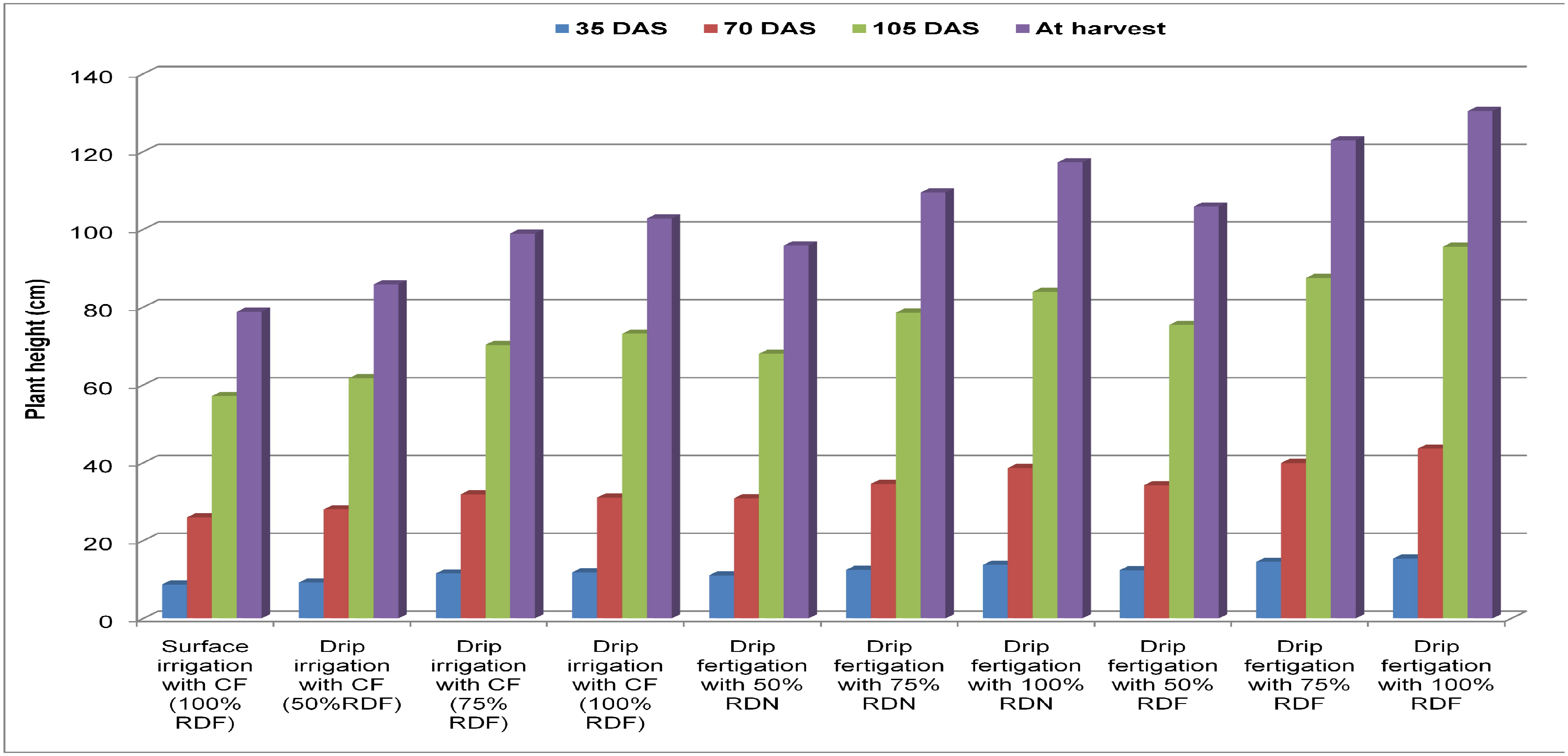


Fig. 4.1 Effect of drip irrigation and fertigation on plant height of fennel

Among different drip irrigation and fertigation treatments, drip fertigation with 75 per cent RDF, observed statistically higher plant height at 35 DAS and at harvest, which was at par with drip fertigation with 100 per cent RDF and 100 per cent RDN. At 70 and 105 DAS, 100 per cent RDF through drip fertigation, registered higher plant height, which was significantly superior over other treatments during the individual year and in pooled data analysis. The per cent increase in plant height due to drip fertigation at 75 per cent RDF was to the extent of 66.7 and 56.0 at 35 DAS and at harvest and due to 100 per cent RDF was 68.3 and 67.2 per cent at 70 and 105 DAS over surface irrigation with conventional fertilization.

Further data indicates that the drip fertigation with 100 per cent RDN, being at par with drip fertigation at 75 per cent RDN, also recorded significantly higher plant height over drip irrigation with conventional fertilization, drip fertigation with 50 per cent RDN and 50 per cent RDF at 105 DAS and at harvest, while, at 35 and 70 DAS drip fertigation with 75 per cent RDN was significant with 100 per cent RDN. The drip fertigation with 100 per cent RDN was also at par with 75 per cent RDF at 70 and 105 DAS. The per cent increase due to 75 per cent RDN was 57.7, 48.9, 46.9 and 48.8 per cent at 35, 70, 105 DAS and at harvest over surface irrigation with conventional fertilization on pooled mean basis.

4.1.3 Dry matter accumulation (DMA)

A critical examination of data in table 4.3 and fig.4.2 reveals that the dry matter accumulation per meter row length in fennel was influenced by drip irrigation as well as fertigation at different fertilizer levels at all stages over surface irrigation with conventional fertilization. Significantly minimum dry matter accumulation was observed in surface irrigation with conventional fertilization, except drip irrigation with conventional fertilization (50 per cent RDF) at 35, 70, 105 DAS and at harvest over other drip irrigated and fertigated treatments during the two year of experimentation and in pooled data analysis.

It is revealed that among different drip irrigation and fertigation treatments, drip fertigation at 75 per cent RDF, found at par with drip fertigation at 100 per cent RDF and 100 per cent RDN, significantly higher dry matter accumulation at 35, 70, 105 DAS and at harvest over other treatments. However, above mentioned treatment was also at par with 75 per cent RDN at 35 DAS during both the years and on pooled mean basis. On the basis of pooled mean, drip fertigation at 75 per cent RDF indicated an increase of 28.5, 37.8, 37.8 and 37.8 per cent dry matter accumulation at 35, 70, 105 DAS and at harvest over surface irrigation with conventional fertilization (Table 4.3 and fig.4.2).

The drip fertigation with 100 per cent RDN registered significantly higher dry matter accumulation as compared to drip irrigation with conventional fertilization and fertigation at 50 per cent RDN during Rabi 2015, 2016 and pooled analysis of two years. However, it was at par with fertigation of 75 per cent RDN as well as 50 per cent RDF. The dry matter accumulation increase observed under 100 per cent RDN over surface irrigation with conventional fertilization was 30.4, 30.4, 30.4 and 30.4 per cent at 35, 70, 105 DAS and at harvest, respectively.

Table 4.3 Effect of drip irrigation and fertigation on dry matter accumulation /metre row length of fennel

Treatments	Dry matter accumulation /metre row length (g)											
	35 DAS			70 DAS			105 DAS			At harvest		
	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled
Surface irrigation with CF (100% RDF)	11.5	10.7	11.1	45.4	42.5	44.0	88.5	83.0	85.7	237.2	222.3	229.7
Drip irrigation with CF (50%RDF)	11.9	11.1	11.5	47.7	44.6	46.1	92.9	87.0	90.0	249.0	233.2	241.1
Drip irrigation with CF (75% RDF)	12.9	12.0	12.4	52.5	49.1	50.8	102.4	95.8	99.1	274.4	256.6	265.5
Drip irrigation with CF (100% RDF)	13.2	12.3	12.7	54.1	50.6	52.4	105.5	98.7	102.1	282.8	264.4	273.6
Drip fertigation with 50% RDN	12.6	11.7	12.2	51.2	47.9	49.6	99.8	93.4	96.6	267.6	250.3	259.0
Drip fertigation with 75% RDN	13.8	13.0	13.4	56.7	53.0	54.8	110.6	103.3	106.9	296.4	276.8	286.6
Drip fertigation with 100% RDN	14.2	13.2	13.7	59.3	55.4	57.3	115.6	107.9	111.8	309.9	289.3	299.6
Drip fertigation with 50% RDF	13.5	12.5	13.0	55.4	51.8	53.6	108.1	101.0	104.5	289.6	270.6	280.1
Drip fertigation with 75% RDF	14.8	13.7	14.3	62.7	58.4	60.6	122.3	113.9	118.1	327.9	305.4	316.6
Drip fertigation with 100% RDF	15.1	14.1	14.6	65.2	61.8	63.5	127.2	120.6	123.9	340.9	323.1	332.0
SEm±	0.4	0.5	0.3	1.8	1.9	1.3	3.5	3.7	2.5	9.4	9.8	6.8
CD (P=0.05)	1.3	1.4	0.9	5.4	5.6	3.8	10.5	11.0	7.3	28.2	29.4	19.5

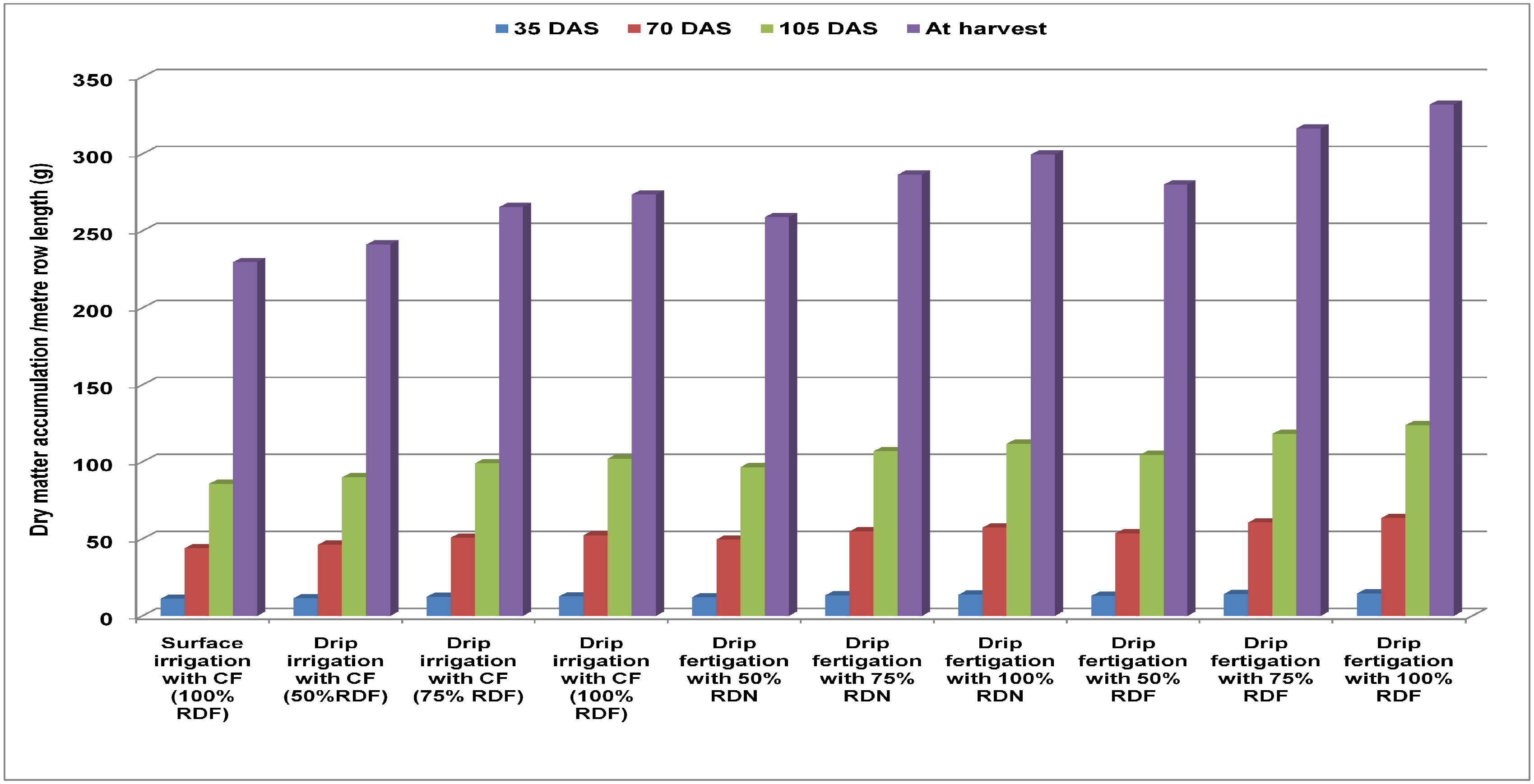


Fig. 4.2 Effect of drip irrigation and fertigation on dry matter accumulation /metre row length of fennel

4.1.4 Branches per plant

Data given in table 4.4 and depicted in fig. 4.3 indicates that surface irrigation with conventional fertilization significantly reduced branches per plant compared to that of other drip irrigated and fertigated treatments but comparable with drip irrigation with conventional fertilization at 50 per cent RDF during the two years of experimentation and in pooled data.

The pooled data of two years and during both years revealed that the drip fertigation at 75 per cent RDF, being at par with drip fertigation at 100 per cent RDF and 100 per cent RDN, produced significantly higher number of branches per plant over other treatments registering an increase of 55.8 per cent by drip fertigation at 75 per cent RDF over surface irrigation with conventional fertilization on the basis of pooled mean over two years.

The drip fertigation at 100 per cent RDN noticed significantly higher number of branches per plant over drip irrigation with conventional fertilization and drip fertigation with 50 per cent RDN and this treatment was on par with drip fertigation at 75 per cent RDN and 50 per cent RDF. The increase in branches per plant due to drip fertigation at 100 per cent RDN was to the tune of 46.1 per cent over surface irrigation with conventional fertilization on the basis of pooled mean.

4.1.5 Total chlorophyll content

Data presented in table 4.4 and fig. 4.3 indicates that drip irrigation with conventional fertilization and fertigation, except of drip irrigation with 50 per cent RDF as conventional fertilization, recorded significantly higher chlorophyll content in fennel over surface irrigation with conventional fertilization during both years and in pooled data.

Table 4.4 Effect of drip irrigation and fertigation on branches per plant and chlorophyll content of fennel

Treatments	Branches per plant			Chlorophyll content (mg/g)		
	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled
Surface irrigation with CF (100% RDF)	4.5	4.4	4.4	1.3	1.1	1.2
Drip irrigation with CF (50%RDF)	4.9	4.7	4.8	1.3	1.1	1.2
Drip irrigation with CF (75% RDF)	5.6	5.4	5.5	1.5	1.4	1.4
Drip irrigation with CF (100% RDF)	5.8	5.7	5.7	1.6	1.4	1.5
Drip fertigation with 50% RDN	5.4	5.3	5.3	1.4	1.3	1.4
Drip fertigation with 75% RDN	6.1	6.1	6.1	1.7	1.6	1.6
Drip fertigation with 100% RDN	6.5	6.4	6.5	1.9	1.8	1.8
Drip fertigation with 50% RDF	6.0	5.8	5.9	1.7	1.5	1.6
Drip fertigation with 75% RDF	7.0	6.8	6.9	2.0	1.8	1.9
Drip fertigation with 100% RDF	7.3	7.2	7.2	2.0	1.8	1.9
SEm±	0.2	0.2	0.2	0.0	0.0	0.0
CD (P=0.05)	0.7	0.6	0.4	0.1	0.1	0.1

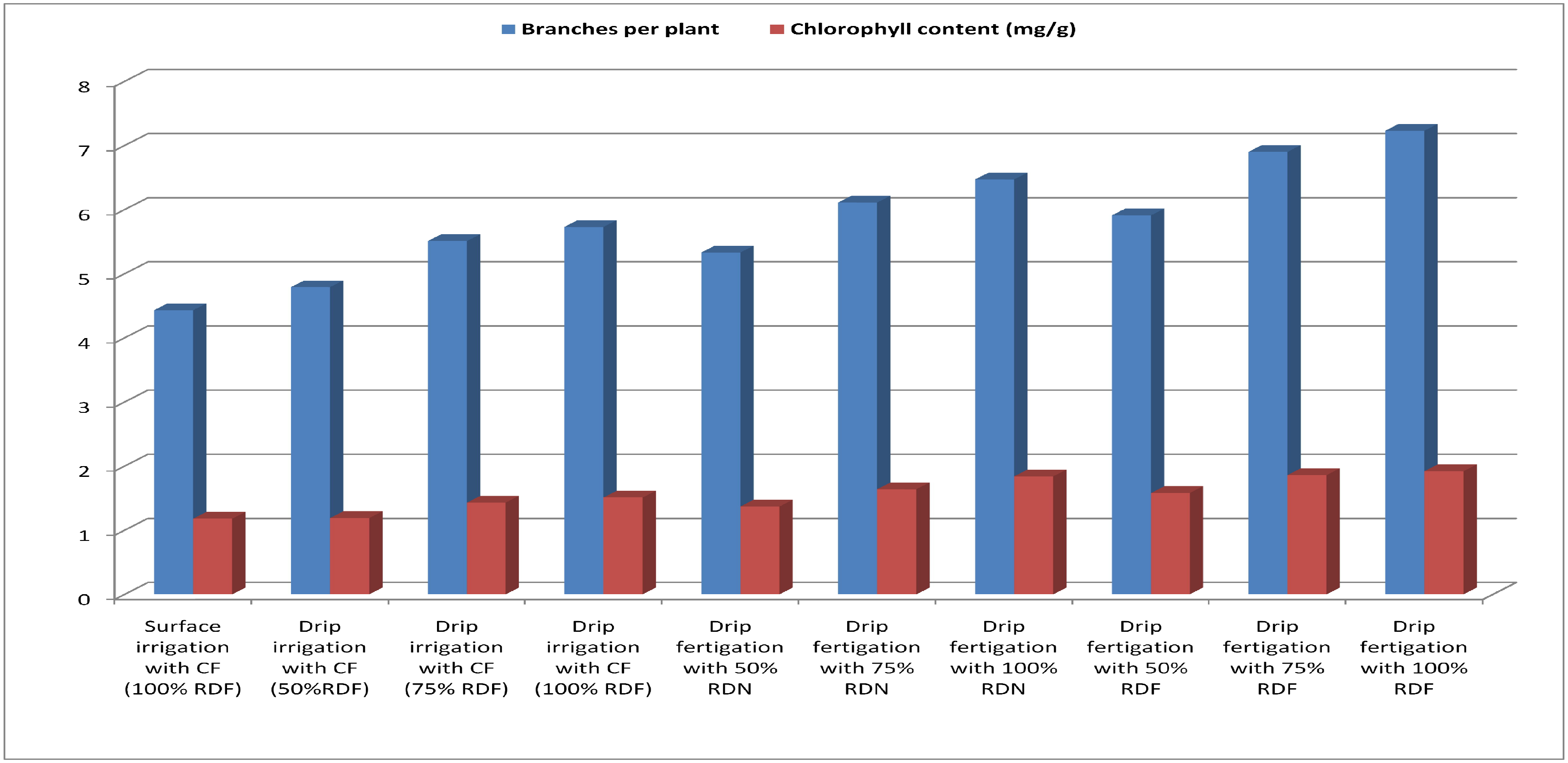


Fig. 4.3 Effect of drip irrigation and fertigation on branches per plant and chlorophyll content of fennel

The drip fertigation with 75 per cent RDF, being at par with drip fertigation with 100 per cent RDF and 100 per cent RDN, observed significantly maximum total chlorophyll content over rest of the treatments during both the years. Whereas, on pooled basis drip fertigation at 100 RDF registered significantly highest chlorophyll content representing an increase of 62.7 per cent over surface irrigation with conventional fertilization.

It was further noted that drip fertigation with 100 per cent RDN also gave significantly higher chlorophyll content during the individual year as well as pooled data of the two years as compared to drip irrigation with conventional fertilization, drip fertigation at 50 per cent and 75 per cent RDN as well as 50 per cent RDF with corresponding increase of 55.9 per cent over surface irrigation with conventional fertilization.

4.1.6 Crop growth rate of fennel

Data presented in table 4.5 reveals that surface irrigation with conventional fertilization, recorded significantly lowest crop growth rate from drip irrigation with conventional fertilization as well as fertigation. However, it remained at par with drip irrigation at 50 per cent RDF during both the years as well as in pooled data during the period of 35-70 DAS, 70-105 DAS and 105 DAS - at harvest.

The critical examination of data indicates that the drip fertigation at 75 per cent RDF found at par with drip fertigation at 100 per cent RDF and 100 per cent RDN obtained higher crop growth rate which was significantly superior over rest of the treatments during both the years of investigation and pooled mean basis. An increase of 28.5, 41.0, 37.8 and 37.8 per cent over surface irrigation with conventional fertilization during the period of 0-35 DAS, 35-70 DAS, 70-105 DAS and 105 DAS-at harvest.

Table 4.5 Effect of drip irrigation and fertigation on crop growth rate (CGR) of fennel

Treatments	Crop growth rate (g/m^2/day)											
	0-35 DAS			35-70 DAS			70-105 DAS			105-At harvest		
	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled
Surface irrigation with CF (100% RDF)	0.66	0.61	0.63	1.94	1.82	1.88	2.46	2.31	2.39	3.44	3.22	3.33
Drip irrigation with CF (50%RDF)	0.68	0.63	0.66	2.04	1.92	1.98	2.59	2.42	2.51	3.61	3.38	3.50
Drip irrigation with CF (75% RDF)	0.74	0.68	0.71	2.27	2.12	2.19	2.85	2.67	2.76	3.98	3.72	3.85
Drip irrigation with CF (100% RDF)	0.75	0.70	0.73	2.34	2.19	2.27	2.94	2.75	2.84	4.10	3.83	3.97
Drip fertigation with 50% RDN	0.72	0.67	0.70	2.21	2.07	2.14	2.78	2.60	2.69	3.88	3.63	3.75
Drip fertigation with 75% RDN	0.79	0.74	0.77	2.45	2.29	2.37	3.08	2.88	2.98	4.30	4.01	4.16
Drip fertigation with 100% RDN	0.81	0.76	0.79	2.58	2.41	2.49	3.22	3.01	3.11	4.49	4.19	4.34
Drip fertigation with 50% RDF	0.77	0.71	0.74	2.40	2.24	2.32	3.01	2.81	2.91	4.20	3.92	4.06
Drip fertigation with 75% RDF	0.85	0.79	0.82	2.74	2.55	2.65	3.41	3.17	3.29	4.75	4.43	4.59
Drip fertigation with 100% RDF	0.87	0.81	0.84	2.86	2.73	2.80	3.54	3.36	3.45	4.94	4.69	4.81
SEm±	0.03	0.03	0.02	0.09	0.08	0.06	0.12	0.10	0.08	0.17	0.14	0.11
CD (P=0.05)	0.09	0.08	0.06	0.28	0.24	0.18	0.35	0.29	0.22	0.49	0.41	0.31

Drip fertigation with 100 per cent RDN also recorded the higher crop growth rate and proved significantly superior to drip irrigation with conventional fertilization as well as fertigation at 50 per cent RDN. However, the above treatment remained at par with drip fertigation at 75 per cent RDN and 50 per cent RDF but as per pooled analysis 100 per cent RDN was also significant with 50 per cent RDF during the period of 0-35 DAS, 35-70 DAS, 70-105 DAS and 105 DAS-at harvest.

4.1.7 Relative growth rate

Data presented in table 4.6 reveals that drip irrigation and fertigation at different fertilizer levels could not bring significant improvement in relative growth rate during the period of 35-70 DAS, 70-105 DAS and 105 DAS-at harvest of fennel over surface irrigation with conventional fertilization during both the years as well as in pooled data analysis.

4.2 Yield attributes and yield

4.2.1 Umbels per plant

An examination of data (Table 4.7 and Fig. 4.4) reveals that drip irrigation with conventional fertilization and fertigation at different fertilizer levels numerically increased umbels per plant over surface irrigation. Surface irrigation with conventional fertilization, being statistically at par with drip irrigation with conventional fertilization at 50 per cent RDF and significantly reduced umbels per plant in comparison of other drip irrigated and fertigated treatments during both the years and in pooled data analysis.

Table 4.6 Effect of drip irrigation and fertigation on relative growth rate (RGR) of fennel

Treatments	Relative growth rate (mg/g/day)								
	35-70 DAS			70-105 DAS			105–at harvest		
	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled
Surface irrigation with CF (100% RDF)	16.1	16.7	16.4	7.8	8.1	7.9	6.1	6.3	6.2
Drip irrigation with CF (50%RDF)	16.0	16.6	16.3	7.7	7.9	7.8	6.0	6.2	6.1
Drip irrigation with CF (75% RDF)	15.7	16.3	16.0	7.5	7.7	7.6	5.8	6.0	5.9
Drip irrigation with CF (100% RDF)	15.6	16.2	15.9	7.4	7.6	7.5	5.8	5.9	5.8
Drip fertigation with 50% RDN	15.8	16.4	16.1	7.5	7.8	7.6	5.9	6.0	5.9
Drip fertigation with 75% RDN	15.4	15.7	15.5	7.3	7.5	7.4	5.7	5.8	5.7
Drip fertigation with 100% RDN	15.4	15.8	15.6	7.2	7.4	7.3	5.6	5.7	5.7
Drip fertigation with 50% RDF	15.6	16.1	15.8	7.3	7.6	7.5	5.7	5.9	5.8
Drip fertigation with 75% RDF	15.3	15.8	15.6	7.1	7.3	7.2	5.5	5.7	5.6
Drip fertigation with 100% RDF	15.4	16.0	15.7	7.0	7.2	7.1	5.5	5.6	5.5
SEm±	0.6	0.6	0.4	0.3	0.3	0.2	0.2	0.2	0.2
CD (P=0.05)	1.9	1.8	1.3	0.9	0.9	0.6	0.7	0.7	0.5

In reference to data given in table 4.7 that among different drip irrigation and fertigation treatments, drip fertigation at 75 per cent RDF, being at par with drip fertigation at 100 per cent RDF and 100 per cent RDN, produced significantly higher number of umbels per plant over other treatments during both the years of study and in pooled analysis representing an increase of 51.9 per cent over surface irrigation with conventional fertilization on pooled mean basis.

Drip fertigation with 100 per cent RDN, remained at par with drip fertigation with 75 per cent RDN as well as 50 per cent RDF, also recorded the significantly higher number of umbels per plant over drip irrigation with conventional fertilization and drip fertigation with 50 per cent RDN during both the years. While, in case of pooled analysis above mentioned treatment also brought about significant improvement in umbels per plant over drip fertigation at 75 per cent RDN and 50 per cent RDF registering an increase of 44.4 per cent over surface irrigation with conventional fertilization.

4.2.2 Umbellets per umbel

Data presented in table 4.7 and fig. 4.4 shows that drip irrigation with conventional fertilization as well as fertigation, except drip irrigation with conventional fertilization (50 per cent RDF), recorded significantly higher number of umbellets per umbel over surface irrigation with conventional fertilization on the basis of pooled data of two years as well as during both years.

Among different drip irrigation and fertigation treatments, drip fertigation at 75 per cent RDF, being at par with drip fertigation at 100 per cent RDF as well as 100 per cent RDN, registered significant increase in umbellets per umbel over other treatments during the year 2015-16. Whereas, on the basis of pooled data for two years and in the year of 2016-17, drip fertigation at 100 per cent RDF, observed higher umbellets per umbel. The increase in umbellets per umbel caused by 100 per cent fertigation was 67.9 per cent over surface irrigation with conventional fertilization on pooled mean basis.

Table 4.7 Effect of drip irrigation and fertigation on yield attributes of fennel

Treatments	Umbels/plant			Umbellets per umbel			Seeds per umbel			Test weight (g)		
	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled
Surface irrigation with CF (100% RDF)	20.2	19.0	19.6	16.2	15.5	15.8	260.2	232.2	246.2	4.5	4.4	4.5
Drip irrigation with CF (50%RDF)	21.1	19.8	20.4	17.6	16.8	17.2	291.5	273.9	282.7	4.4	4.3	4.4
Drip irrigation with CF (75% RDF)	24.4	22.9	23.7	20.1	19.5	19.8	330.5	318.2	324.4	5.0	5.0	5.0
Drip irrigation with CF (100% RDF)	25.4	23.9	24.6	20.9	19.9	20.4	343.5	326.3	334.9	5.3	5.1	5.2
Drip fertigation with 50% RDN	23.6	22.4	23.0	19.4	18.5	19.0	320.1	304.1	312.1	4.9	4.8	4.8
Drip fertigation with 75% RDN	27.0	25.4	26.2	22.2	21.2	21.7	364.3	346.1	355.2	5.6	5.5	5.5
Drip fertigation with 100% RDN	29.2	27.3	28.3	23.9	23.7	23.8	384.6	366.1	375.3	5.8	5.8	5.8
Drip fertigation with 50% RDF	26.2	24.6	25.4	21.5	20.6	21.0	358.9	340.2	349.6	5.5	5.4	5.4
Drip fertigation with 75% RDF	30.6	28.8	29.7	25.1	24.0	24.5	411.2	391.6	401.4	6.1	6.2	6.1
Drip fertigation with 100% RDF	32.7	30.7	31.7	26.7	26.4	26.6	437.8	414.9	426.3	6.3	6.3	6.2
SEm±	1.0	1.0	0.7	0.7	0.8	0.6	12.5	13.1	9.0	0.2	0.2	0.1
CD (P=0.05)	3.1	2.9	2.0	2.2	2.4	1.6	37.4	39.1	26.1	0.5	0.6	0.4

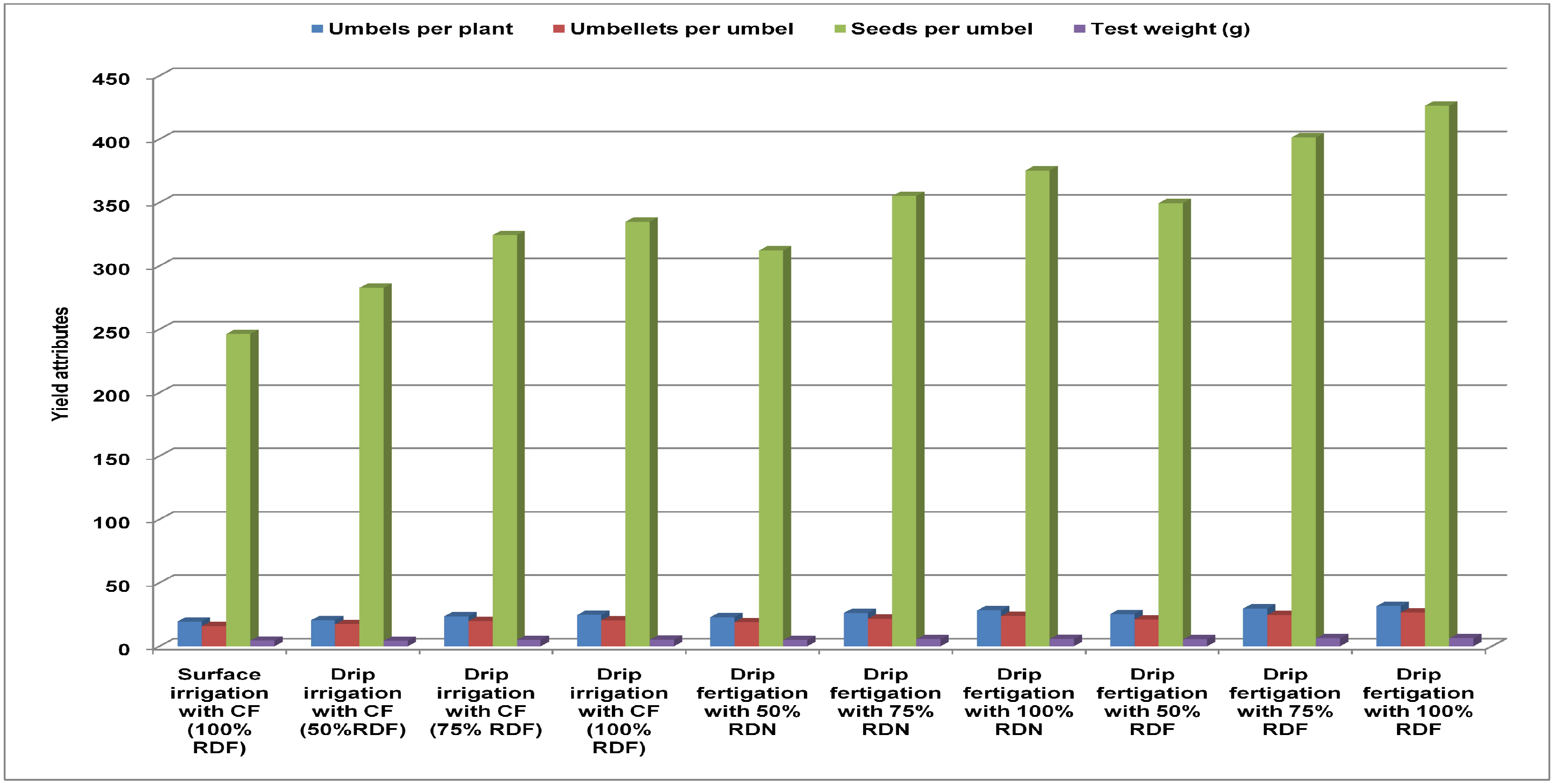


Fig. 4.4 Effect of drip irrigation and fertigation on yield attributes of fennel

In reference to data in table 4.7 indicates that drip fertigation at 100 per cent RDN significantly enhanced umbellets per umbel as compared to drip irrigation with conventional fertilization, drip fertigation at 75 per cent and 50 per cent RDN as well as 50 per cent RDF during Rabi 2016-17 and in pooled mean. However, it was comparable with treatment drip fertigation at 75 per cent RDN during Rabi 2015-16. The magnitude of increase in umbellets per umbel due to drip fertigation at 100 per cent RDN was 50.6 per cent over surface irrigation with conventional fertilization.

4.2.3 Seeds per umbel

Data (Table 4.7 and Fig. 4.4) reveals that drip irrigation with conventional fertilization as well as fertigation, improved seeds per umbel of fennel significantly when compared to surface irrigation with conventional fertilization. However, surface irrigation remained at par with drip irrigation at 50 per cent RDF with conventional fertilization during both the years of investigation as well as in pooled mean.

The examination of data indicates that the drip fertigation at 75 per cent RDF, being statistically at par with drip fertigation at 100 per cent RDF and 100 per cent RDN, significantly increased seeds per umbel among drip irrigation and fertigation treatments on the basis of pooled data of two years as well as during both years with corresponding increase of 63.01 per cent over surface irrigation with conventional fertilization.

Drip fertigation at 100 per cent RDN significantly improved seeds per umbel over drip irrigation with conventional fertilization and drip fertigation at 50 per cent RDN but the same was at par with drip fertigation at 75 per cent RDN and 50 per cent RDF on the basis of pooled mean of two years and during both the years. In terms of percentage, drip fertigation with 100 per cent RDN improved the seeds per umbel by 52.43 per cent over surface irrigation with conventional fertilization on the basis of pooled mean.

4.2.4 Test weight

Data (Table 4.7 and Fig. 4.4) reveals that drip irrigation with conventional fertilization as well as fertigation registered statistically higher values for test weight of fennel when compared to surface irrigation with conventional fertilization except drip irrigation with conventional fertilization at 50 per cent RDF during both the years as well as in pooled mean.

Drip fertigation at 75 per cent RDF, being at par with drip fertigation at 100 per cent RDF and 100 per cent RDN, gave significantly higher test weight over other treatments during both the years and in pooled mean analysis. Whereas, the drip fertigation with 75 per cent RDF was also at par with 75 per cent RDN during the year of 2015. The drip fertigation of 75 per cent RDF increased the test weight by 37.4 per cent compared to surface irrigation with conventional fertilization on the basis of pooled mean over two years.

The examination of data indicates that significantly higher test weight was attained with drip fertigation at 100 per cent RDN over drip irrigation with conventional fertilization as well as fertigation with 50 per cent RDN. However, the difference was non significant when compared with drip fertigation at 75 per cent RDN as well as 50 per cent RDF representing an increase of 29.8 per cent over surface irrigation with conventional fertilization on pooled mean basis.

4.2.5 Seed yield

A reference to data (Table 4.8 and Fig. 4.5) reveals that drip irrigation with conventional fertilization as well as fertigation except drip irrigation with conventional fertilization (50 per cent RDF), recorded significantly higher seed yield of fennel over surface irrigation with conventional fertilization on the basis of pooled data of two years as well as during both years.

Among different drip irrigation and fertigation treatments, drip fertigation with 75 per cent RDF, registered significantly higher seed yield (2516 kg/ha). However, it remained statistically at par with drip fertigation of 100 per cent RDF as well as 100 per cent RDN during both the years of experimentation as well as on the basis of pooled data. The drip fertigation with 75 per cent RDF recorded 50.0 per cent improvement in seed yield over surface irrigation with conventional fertilization.

Data further shows that drip fertigation with 100 per cent RDN, being at par with drip fertigation with 75 per cent RDN and 50 per cent RDF, also recorded significantly higher seed yield over drip irrigation with conventional fertilization and drip fertigation with 50 per cent RDN registering an increase of 42.5 per cent over surface irrigation with conventional fertilization.

Generally seed yield increased significantly with increase in level of fertilizer from 50 per cent to 75 per cent. Further increase in level of fertilizer to 100 per cent could not bring significant increase over 75 per cent of fertilizer. At the same level of fertilizer, better seed yield was obtained under drip fertigation with RDF followed by drip fertigation with RDN and drip irrigation with conventional fertilization.

4.2.6 Straw yield

It is evident from data (Table 4.8 and Fig. 4.5) that drip irrigation with conventional fertilization or drip fertigation, remains at par with drip irrigation with conventional at 50 per cent RDF, had a significant effect on the straw yield of fennel over surface irrigation with conventional fertilization during both the years and pooled basis.

The pooled data of two years as well as during both the years reveals that application of 75 per cent RDF through drip had maximum straw yield which was significantly superior over other treatments. However, the difference was non significant between drip fertigation at 100 per cent RDF as well as 100 per cent RDN during both the years and in pooled analysis and showed an increase of 68.8 per cent by drip fertigation at 75 per cent RDF over surface irrigation with conventional fertilization on the basis of pooled mean data.

Drip fertigation at 100 per cent RDN, the straw yield of fennel (6607 kg/ha) was not significantly induced as compared to drip fertigation at 75 per cent RDN as well as 50 per cent RDF, whereas, drip irrigation with conventional fertilization and fertigation with 50 per cent RDN exhibited significant reduction in straw yield as compared to above mentioned treatment on the basis of pooled mean of data over two years and during both the years. The enhancement in straw yield of fennel by 2401 kg/ha corresponding to 57.1 per cent over surface irrigation with conventional fertilization.

4.2.7 Biological yield

A reference to data in table 4.8 and depicted in fig. 4.5 reveals that surface irrigation with conventional fertilization, being at par with drip irrigation at 50 per cent RDF, recorded significantly reduced biological yield over other drip irrigated and fertigated treatments during the individual year of investigation as well as in pooled data analysis.

Table 4.8 Effect of drip irrigation and fertigation on seed, straw, biological yields and harvest index of fennel

Treatments	Seed yield (kg/ha)			Straw yield (kg/ha)			Biological yield (kg/ha)			Harvest index (%)		
	2015-16	**2016-17**	**Pooled**	**2015-16**	**2016-17**	**Pooled**	**2015-16**	**2016-17**	**Pooled**	**2015-16**	**2016-17**	**Pooled**
Surface irrigation with CF (100% RDF)	1720	1634	1677	4391	4021	4206	6111	5655	5883	28.2	28.9	28.5
Drip irrigation with CF (50%RDF)	1858	1765	1811	4873	4503	4688	6731	6268	6499	27.6	28.2	27.9
Drip irrigation with CF (75% RDF)	2116	2015	2065	5666	5296	5481	7782	7311	7546	27.2	27.6	27.4
Drip irrigation with CF (100% RDF)	2202	2073	2137	5931	5561	5746	8133	7634	7883	27.1	27.2	27.1
Drip fertigation with 50% RDN	2050	1945	1997	5455	5081	5268	7505	7026	7265	27.3	27.7	27.5
Drip fertigation with 75% RDN	2327	2222	2275	6354	5984	6169	8681	8206	8444	26.8	27.1	26.9
Drip fertigation with 100% RDN	2460	2320	2390	6877	6337	6607	9337	8657	8997	26.7	27.3	27.0
Drip fertigation with 50% RDF	2274	2162	2218	6242	5932	6087	8516	8094	8305	27.0	27.2	27.1
Drip fertigation with 75% RDF	2580	2451	2516	7306	6889	7098	9886	9340	9613	26.1	26.1	26.1
Drip fertigation with 100% RDF	2700	2512	2606	7736	7266	7501	10436	9778	10107	25.6	25.2	25.4
SEm±	88	83	60	239	255	175	326	306	231	1.1	1.1	0.8
CD (P=0.05)	263	249	173	715	765	521	978	916	693	NS	NS	NS

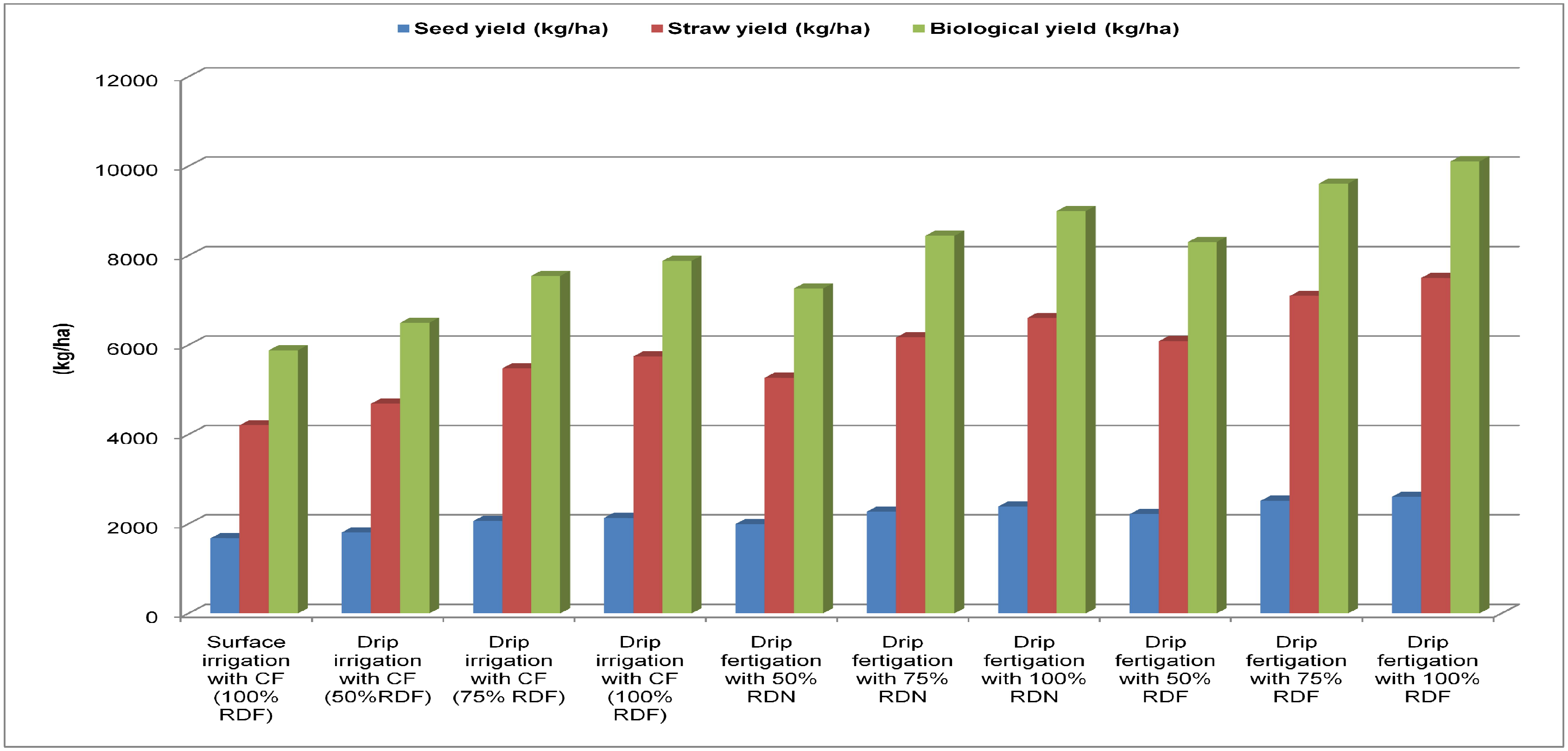


Fig. 4.5 Effect of drip irrigation and fertigation on seed, straw and biological yields of fennel

Further, it shows that the drip fertigation at 75 per cent RDF fetched significantly higher biological yield of fennel over other treatments. But the same was at par with drip fertigation at 100 per cent RDF and 100 per cent RDN during the year of 2015 and 2016 and in pooled mean analysis which was 63.4 per cent higher over surface irrigation with conventional fertilization.

A critical examination of data shows that drip fertigation at 100 per cent RDN, remaining at par with drip fertigation at 75 per cent RDN and 50 per cent RDF, also recorded the significantly higher biological yield as compared to drip irrigation with conventional fertilization and drip fertigation at 50 per cent RDN on the basis of pooled data of two years and during both the years. Increase in biological yield due to 100 per cent RDN over that of surface irrigation with conventional fertilization was 52.9 per cent on pooled mean basis.

4.2.8 Harvest index

Data presented in table 4.8 reveals that drip irrigation and fertigation at different fertilizer levels could not bring significant improvement in harvest index of fennel over surface irrigation during both the years and pooled analysis.

4.3 Nutrient content, uptake and Quality

4.3.1 Nitrogen content in seed and straw

It is evident from data (Table 4.9) that surface irrigation with conventional fertilization, remaining at par with drip irrigation at 50 per cent RDF with conventional fertilization, observed significantly lower nitrogen content in seed and straw over other drip irrigated and fertigated treatments during both the years of experimentation as well as in pooled data analysis.

Table 4.9 Effect of drip irrigation and fertigation on nitrogen content in seed and straw of fennel

Treatments	Nitrogen content (%)					
	Seed			Straw		
	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled
Surface irrigation with CF (100% RDF)	1.2	1.0	1.1	0.5	0.5	0.5
Drip irrigation with CF (50%RDF)	1.3	1.0	1.2	0.5	0.5	0.5
Drip irrigation with CF (75% RDF)	1.6	1.2	1.4	0.6	0.6	0.6
Drip irrigation with CF (100% RDF)	1.8	1.5	1.6	0.7	0.7	0.7
Drip fertigation with 50% RDN	1.5	1.3	1.4	0.6	0.5	0.5
Drip fertigation with 75% RDN	1.7	1.6	1.7	0.6	0.6	0.6
Drip fertigation with 100% RDN	2.1	1.9	2.0	0.9	0.8	0.8
Drip fertigation with 50% RDF	1.6	1.4	1.5	0.7	0.6	0.6
Drip fertigation with 75% RDF	1.8	1.8	1.8	0.8	0.7	0.8
Drip fertigation with 100% RDF	2.2	2.0	2.1	0.9	0.8	0.9
SEm±	0.1	0.1	0.0	0.0	0.0	0.0
CD (P=0.05)	0.2	0.2	0.1	0.1	0.1	0.1

The critical examination of data indicates that the drip fertigation with 100 per cent RDF recorded the significantly maximum nitrogen content in seed and straw over rest of the treatments. However, it was at par with drip fertigation at 100 per cent RDN during individual year as well as in pooled analysis. The nitrogen content in seed and straw increased with drip fertigation at 100 per cent RDF was 84.7 and 73.5 per cent, respectively over surface irrigation with conventional fertilization on pooled mean basis.

Data indicates that drip fertigation with 100 per cent RDN, registered significantly higher nitrogen content in seed and straw as compared to drip irrigation with conventional fertilization, drip fertigation with 75 per cent and 50 per cent RDN as well as 50 per cent RDF during 2015-16 and 2016-17 as well as on basis of pooled mean of observed data over two years. While, it was comparable with drip fertigation at 75 per cent RDF in straw during the year of 2015 and 2016. Enhancement in nitrogen content due to 100 per cent RDN over surface irrigation with conventional fertilization was 78.4 and 67.3 per cent in seed and straw of fennel, respectively on pooled basis.

4.3.2 Nitrogen uptake by seed and straw

Data presented in table 4.10 and fig. 4.6 reveals that the drip irrigation with conventional fertilization as well as fertigation, except drip irrigation with conventional fertilization (50 per cent RDF), recorded statistically higher values for nitrogen uptake in seed and straw over surface irrigation with conventional fertilization during both the years and pooled analysis.

The drip fertigation at 100 per cent RDF recorded the maximum nitrogen uptake by seed and straw and remained significantly superior to other treatments during both the years of study and in pooled data enhancing the nitrogen content by 188.1 and 213.6 per cent over surface irrigation with conventional fertilization.

The examination of data indicates that the drip fertigation with 100 per cent RDN, also significantly improved higher nitrogen uptake by seed and straw over drip irrigation with conventional fertilization, drip fertigation (50 per cent and 75 per cent RDN as well as 50 per cent RDF). The drip fertigation with 100 per cent RDN registered an increase of 154.4 and 163.8 per cent nitrogen uptake by seed and straw, respectively over surface irrigation with conventional fertilization on pooled basis.

4.3.3 Total Nitrogen uptake

It is evident from the data (Table 4.10 and Fig.4.6) that surface irrigation at 100 per cent RDF with conventional fertilization, being at par with drip irrigation at 50 per cent RDF with conventional fertilization, recorded significantly lower total nitrogen uptake over other drip irrigated and fertigated treatments during both the years and in pooled data analysis.

The critical examination of data indicates that among drip irrigation as well as fertigation treatments, drip fertigation at 100 per cent RDF recorded significantly highest total nitrogen uptake over other treatments during individual year and in pooled analysis. The total nitrogen uptake increased with drip fertigation at 100 per cent RDF was 201.5 per cent over surface irrigation with conventional fertilization on pooled mean analysis basis.

Drip fertigation with 100 per cent RDN registered significantly higher total nitrogen uptake by fennel as compared to drip fertigation with conventional fertilization, drip fertigation 50 per cent RDN as well as 50 per cent RDF. However, it was remained at par with drip fertigation with 75 per cent RDF. The increase in total nitrogen uptake caused by drip fertigation at 100 per cent RDN was 159.3 per cent over surface irrigation with conventional fertilization on pooled mean basis.

Table 4.10 Effect of drip irrigation and fertigation on nitrogen uptake by seed, straw and total uptake of fennel

Treatments	Nitrogen Uptake (kg/ha)						Total nitrogen Uptake (kg/ha)		
	Seed			Straw			2015-16	2016-17	Pooled
	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled			
Surface irrigation with CF (100% RDF)	20.8	16.3	18.6	22.0	18.9	20.5	42.8	35.3	39.0
Drip irrigation with CF (50%RDF)	24.2	18.0	21.1	26.4	23.0	24.7	50.5	41.0	45.8
Drip irrigation with CF (75% RDF)	33.9	23.8	28.8	34.9	31.0	32.9	68.8	54.8	61.8
Drip irrigation with CF (100% RDF)	39.9	30.5	35.2	42.7	36.7	39.7	82.6	67.2	74.9
Drip fertigation with 50% RDN	31.0	25.7	28.3	29.8	24.9	27.3	60.7	50.5	55.6
Drip fertigation with 75% RDN	39.8	35.8	37.8	40.7	36.9	38.8	80.5	72.6	76.6
Drip fertigation with 100% RDN	50.4	44.1	47.3	59.8	48.2	54.0	110.3	92.2	101.3
Drip fertigation with 50% RDF	37.1	30.3	33.7	40.6	37.1	38.9	77.7	67.4	72.5
Drip fertigation with 75% RDF	46.7	42.9	44.8	60.0	49.6	54.8	106.7	92.5	99.6
Drip fertigation with 100% RDF	58.1	49.0	53.5	70.4	58.0	64.2	128.5	107.0	117.7
SEm±	1.5	1.3	1.0	1.7	1.4	1.1	3.2	2.2	1.9
CD (P=0.05)	4.5	3.8	2.8	5.0	4.2	3.1	9.5	6.7	5.5

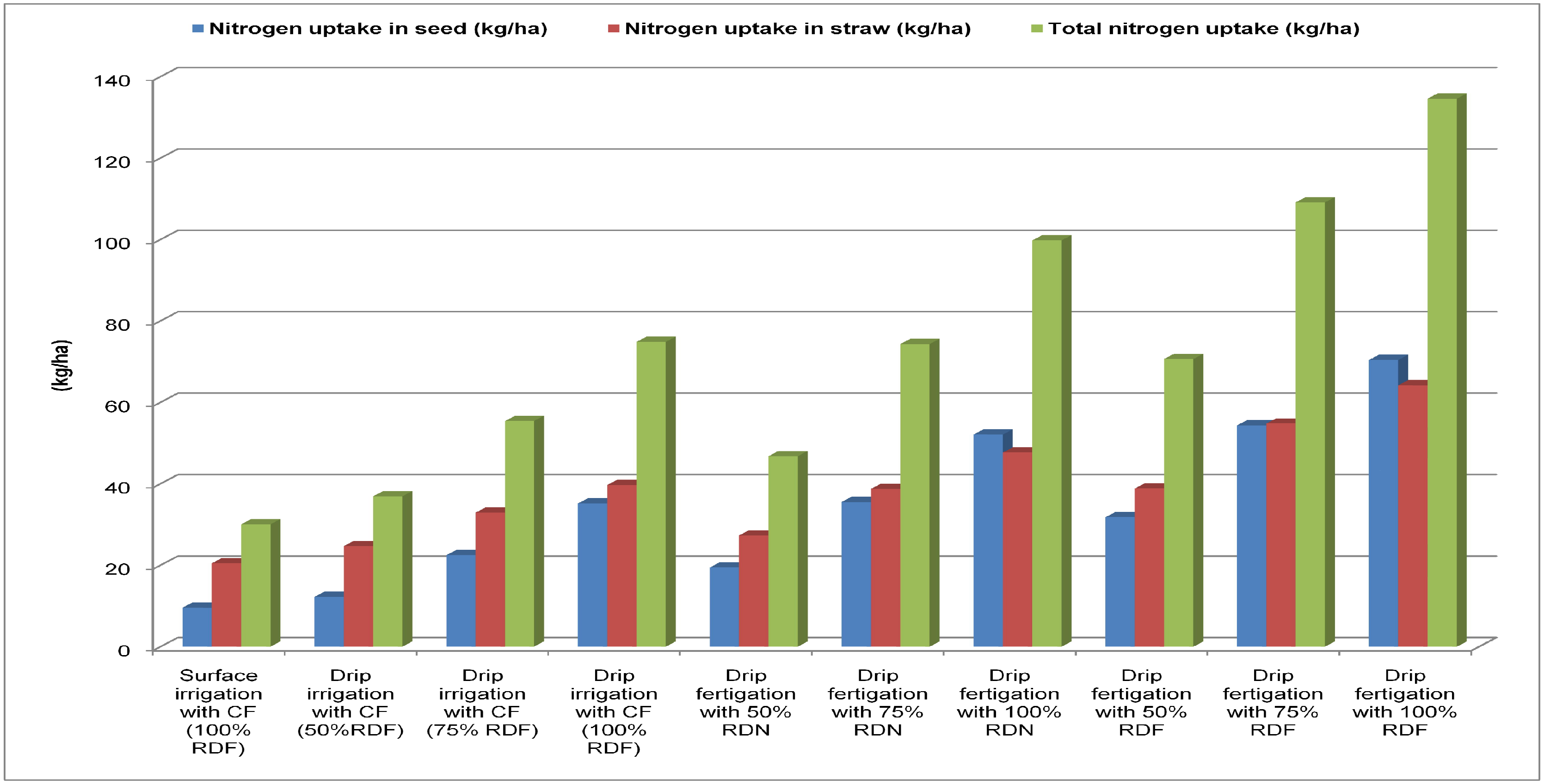


Fig. 4.6 **Effect of drip irrigation and fertigation on nitrogen uptake by seed, straw and total nitrogen uptake of fennel**

4.3.4 Phosphorus content in seed and straw

It is evident from data (Table 4.11) that surface irrigation with conventional fertilization accumulated significantly less content of phosphorus in seed and straw as compared to that when it was grown with drip irrigation with conventional fertilization as well as fertigation, remaining at par with drip irrigation with conventional fertilization at 50 per cent RDF during both the years of experimentation and in pooled data analysis.

The critical examination of data indicates that among the various drip irrigation and fertigation levels, drip fertigation at 100 per cent RDF, showed significantly maximum phosphorus content in seed and straw over other treatments during 2015-16 and 2016-17 as well as on basis of pooled mean of observed data over two years. The per cent increase in phosphorus content on pooled data basis with drip fertigation at 100 per cent RDF was 72.1 and 70.8 over surface irrigation with conventional fertilization.

Further data indicates that drip fertigation with 100 per cent RDN, also registered significantly higher phosphorus content in seed and straw as compared to drip irrigation with conventional fertilization, drip fertigation (50 per cent and 75 per cent RDN as well as 50 per cent RDF), while, the same was at par with drip fertigation with 75 per cent RDF during both the years of field experimentation and in analysis of pooled mean of the data of two years. The respective increases on pooled basis in seed and straw due to drip fertigation at 100 per cent RDN was 55.7 and 50.8 per cent over surface irrigation with conventional fertilization.

Table 4.11 Effect of drip irrigation and fertigation on phosphorus content in seed and straw of fennel

Treatments	Phosphorus content (%)					
	Seed			Straw		
	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled
Surface irrigation with CF (100% RDF)	0.34	0.31	0.32	0.14	0.12	0.13
Drip irrigation with CF (50%RDF)	0.36	0.33	0.34	0.14	0.12	0.13
Drip irrigation with CF (75% RDF)	0.41	0.38	0.40	0.17	0.14	0.16
Drip irrigation with CF (100% RDF)	0.47	0.43	0.45	0.19	0.16	0.18
Drip fertigation with 50% RDN	0.40	0.37	0.38	0.16	0.14	0.15
Drip fertigation with 75% RDN	0.45	0.42	0.44	0.19	0.16	0.17
Drip fertigation with 100% RDN	0.52	0.48	0.50	0.21	0.18	0.20
Drip fertigation with 50% RDF	0.44	0.41	0.42	0.18	0.16	0.17
Drip fertigation with 75% RDF	0.51	0.46	0.49	0.21	0.19	0.20
Drip fertigation with 100% RDF	0.59	0.53	0.56	0.24	0.21	0.22
SEm±	0.02	0.01	0.01	0.01	0.01	0.00
CD (P=0.05)	0.05	0.04	0.03	0.02	0.02	0.01

4.3.5 Phosphorus uptake by seed and straw

It is evident from data (Table 4.12 and Fig. 4.7) that surface irrigation with conventional fertilization, remaining at par with drip irrigation with conventional fertilization at 50 per cent RDF, recorded significantly lower phosphorus uptake by seed and straw over other drip irrigated and fertigated treatments during both the years and in pooled data analysis.

The critical examination of data indicates that the drip fertigation at 100 per cent RDF recorded significantly highest phosphorus uptake by seed and straw over other treatments during individual years and in pooled analysis. On pooled basis, the magnitude of increase in phosphorus uptake by seed and straw due to drip fertigation at 100 per cent RDF was 161.9 and 204.4 per cent, respectively over surface irrigation with conventional fertilization.

Data reveals that drip fertigation at 100 per cent RDN, also registered higher phosphorus uptake by seed and straw and proved significantly superior to drip fertigation with conventional fertilization, drip fertigation (50 per cent and 75 per cent RDN as well 50 per cent and 75 per cent RDF) during both the years as well as in pooled analysis with the per cent increase of 113.8 and 132.9, respectively over surface irrigation with conventional.

4.3.6 Total Phosphorus uptake

Data in table 4.12 and fig. 4.7 shows a positive effect of drip irrigation with conventional fertilization or drip fertigation on total phosphorus uptake by fennel. Surface irrigation with conventional fertilization, being at par with drip irrigation at 50 per cent RDF with conventional fertilization, recorded significantly lower total phosphorus uptake by fennel over other drip irrigated and fertigated treatments during both the years and in pooled data analysis.

Table 4.12 Effect of drip irrigation and fertigation on phosphorus uptake in seed, straw and total uptake of fennel

Treatments	Phosphorus uptake (kg/ha)						Total phosphorus uptake (kg/ha)		
	Seed			Straw			2015-16	2016-17	Pooled
	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled			
Surface irrigation with CF (100% RDF)	5.8	5.0	5.4	6.2	4.7	5.5	12.1	9.7	10.9
Drip irrigation with CF (50%RDF)	6.7	5.8	6.2	7.0	5.5	6.2	13.7	11.2	12.5
Drip irrigation with CF (75% RDF)	8.7	7.7	8.2	9.5	7.5	8.5	18.2	15.2	16.7
Drip irrigation with CF (100% RDF)	10.3	9.0	9.6	11.2	9.0	10.1	21.5	18.0	19.7
Drip fertigation with 50% RDN	8.1	7.1	7.6	8.8	6.9	7.9	16.9	14.0	15.4
Drip fertigation with 75% RDN	10.5	9.4	10.0	11.8	9.6	10.7	22.3	19.0	20.7
Drip fertigation with 100% RDN	12.9	11.2	12.0	14.7	11.3	13.0	27.5	22.5	25.0
Drip fertigation with 50% RDF	10.0	8.8	9.4	11.2	9.2	10.2	21.2	18.0	19.6
Drip fertigation with 75% RDF	13.2	11.4	12.3	15.4	12.8	14.1	28.7	24.2	26.4
Drip fertigation with 100% RDF	15.9	13.2	14.5	18.3	15.0	16.7	34.2	28.2	31.2
SEm±	0.4	0.3	0.3	0.5	0.3	0.3	0.9	0.6	0.5
CD (P=0.05)	1.2	0.9	0.7	1.3	0.9	0.8	2.5	1.8	1.5

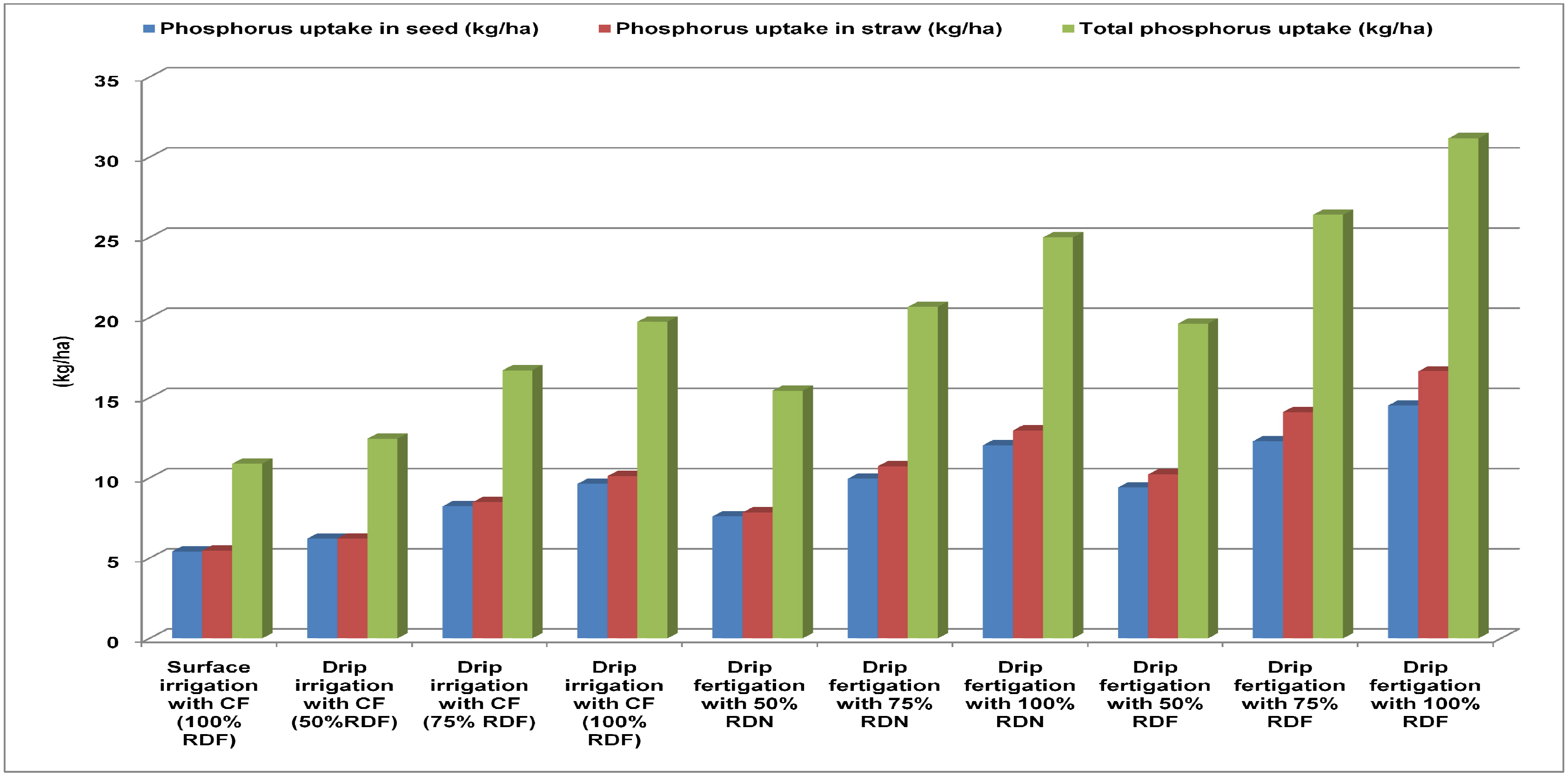


Fig. 4.7 Effect of drip irrigation and fertigation on phosphorus uptake by seed, straw and total uptake of fennel

The examination of data indicates that the drip fertigation at 100 per cent RDF recorded significantly highest total phosphorus uptake over other treatments during individual years and in pooled analysis. The mean increase in total uptake on basis of pooled data analysis was 168.4 per cent over surface irrigation with conventional fertilization.

Significantly higher total uptake of phosphorus was found with the drip fertigation at 100 per cent RDN as compared to drip irrigation with conventional fertilization as well as drip fertigation (50 per cent RDN as well as 50 per cent RDF) during both the years of experimentation as well as in pooled analysis. The per cent increase in total uptake due to drip fertigation at 100 per cent RDN was 122.3 over surface irrigation with conventional fertilization.

4.3.7 Potassium content in seed and straw

It is evident from data (Table 4.13) that significantly lowest potassium content in seed and straw was accumulated in surface irrigation with conventional fertilization as compared to that when it was grown with drip irrigation with conventional fertilization as well as fertigation, remaining at par with drip irrigation with conventional fertilization at 50 per cent RDF during the year of experimentation and in pooled data analysis.

The drip fertigation with 75 per cent RDF registered higher value of potassium content in seed and straw over other treatments. However, it was comparable to drip fertigation with 100 per cent RDF and 100 per cent RDN during both the years and in pooled mean analysis representing an increase of 43.0 and 43.1 per cent over surface irrigation with conventional fertilization.

Table 4.13 Effect of drip irrigation and fertigation on potassium content in seed and straw of fennel

Treatments	Potassium content (%)					
	Seed			Straw		
	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled
Surface irrigation with CF (100% RDF)	0.24	0.24	0.24	0.45	0.45	0.45
Drip irrigation with CF (50%RDF)	0.27	0.26	0.26	0.49	0.48	0.49
Drip irrigation with CF (75% RDF)	0.31	0.29	0.30	0.57	0.54	0.55
Drip irrigation with CF (100% RDF)	0.31	0.31	0.31	0.57	0.58	0.58
Drip fertigation with 50% RDN	0.28	0.28	0.28	0.52	0.52	0.52
Drip fertigation with 75% RDN	0.32	0.31	0.32	0.59	0.58	0.59
Drip fertigation with 100% RDN	0.32	0.32	0.32	0.60	0.59	0.59
Drip fertigation with 50% RDF	0.30	0.30	0.30	0.56	0.56	0.56
Drip fertigation with 75% RDF	0.35	0.35	0.35	0.64	0.64	0.64
Drip fertigation with 100% RDF	0.35	0.36	0.35	0.65	0.66	0.66
SEm±	0.01	0.01	0.01	0.02	0.02	0.02
CD (P=0.05)	0.04	0.03	0.03	0.07	0.06	0.04

Data in table 4.13 indicates that the drip fertigation at 100 per cent RDN, remaining at par with drip fertigation with 75 per cent RDN, drip irrigation with conventional fertilization with 100 per cent and 75 per cent RDF, recorded significantly higher potassium content in seed and straw over drip irrigation with conventional fertilization (50 per cent RDF) as well as drip fertigation (50 per cent RDN and 50 per cent RDF) during individual year and in pooled analysis. The potassium content increased with drip fertigation at 100 per cent RDN was 32.2 and 32.4 per cent in seed and straw of fennel over surface irrigation with conventional fertilization on pooled mean analysis basis.

4.3.8 Potassium uptake by seed and straw

It is evident from data (Table 4.14 and Fig. 4.8) that surface irrigation at 100 per cent RDF with conventional fertilization recorded significantly lower potassium uptake by seed (pooled basis) and straw over other drip irrigated and fertigated treatments during both the years and in pooled data analysis. However, it was comparable with drip irrigation with conventional fertilization at 50 per cent RDF by seed during 2015 and 2016.

The critical examination of data indicates that among drip irrigation as well as fertigation treatments, drip fertigation at 75 per cent RDF recorded significantly higher potassium uptake by seed and straw over other treatments and remained at par with drip fertigation at 100 per cent RDF during individual year and in pooled analysis. The potassium uptake increased with drip fertigation at 75 per cent RDF was 114.3 and 140.9 per cent over surface irrigation with conventional fertilization on pooled mean analysis basis.

It is clear from data that drip fertigation with 100 per cent RDN, being at par with drip fertigation with 75 per cent RDN, also registered significantly higher potassium uptake by seed and straw as compared to drip fertigation with conventional fertilization, drip fertigation (50 per cent as well as 50 per cent RDF). The increase in potassium uptake caused by drip fertigation at 100 per cent RDN was 88.4 and 104.1 per cent in seed and straw of fennel, respectively over surface irrigation with conventional fertilization on pooled mean basis.

Table 4.14 Effect of drip irrigation and fertigation on potassium uptake in seed, straw and total uptake of fennel

Treatments	Potassium uptake (kg/ha)						Total potassium uptake (kg/ha)		
	Seed			Straw			2015-16	2016-17	Pooled
	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled			
Surface irrigation with CF (100% RDF)	4.2	3.9	4.1	19.9	17.9	18.9	24.1	21.8	23.0
Drip irrigation with CF (50%RDF)	4.9	4.6	4.8	24.1	21.6	22.8	29.0	26.1	27.6
Drip irrigation with CF (75% RDF)	6.5	5.9	6.2	32.2	28.6	30.4	38.7	34.5	36.6
Drip irrigation with CF (100% RDF)	6.8	6.5	6.6	33.9	32.2	33.1	40.7	38.7	39.7
Drip fertigation with 50% RDN	5.7	5.5	5.6	28.4	26.5	27.4	34.1	32.0	33.0
Drip fertigation with 75% RDN	7.4	7.0	7.2	37.5	34.9	36.2	44.9	41.9	43.4
Drip fertigation with 100% RDN	7.9	7.4	7.7	41.1	37.4	38.6	49.1	44.8	46.9
Drip fertigation with 50% RDF	6.9	6.5	6.7	35.0	33.1	34.0	41.9	39.5	40.7
Drip fertigation with 75% RDF	8.9	8.5	8.7	46.8	44.3	45.6	55.7	52.8	54.3
Drip fertigation with 100% RDF	9.5	8.9	9.2	50.6	47.9	49.2	60.1	56.8	58.5
SEm±	0.3	0.2	0.2	1.3	1.1	0.9	1.6	1.3	1.0
CD (P=0.05)	0.8	0.7	0.5	4.0	3.6	2.5	4.4	3.9	3.0

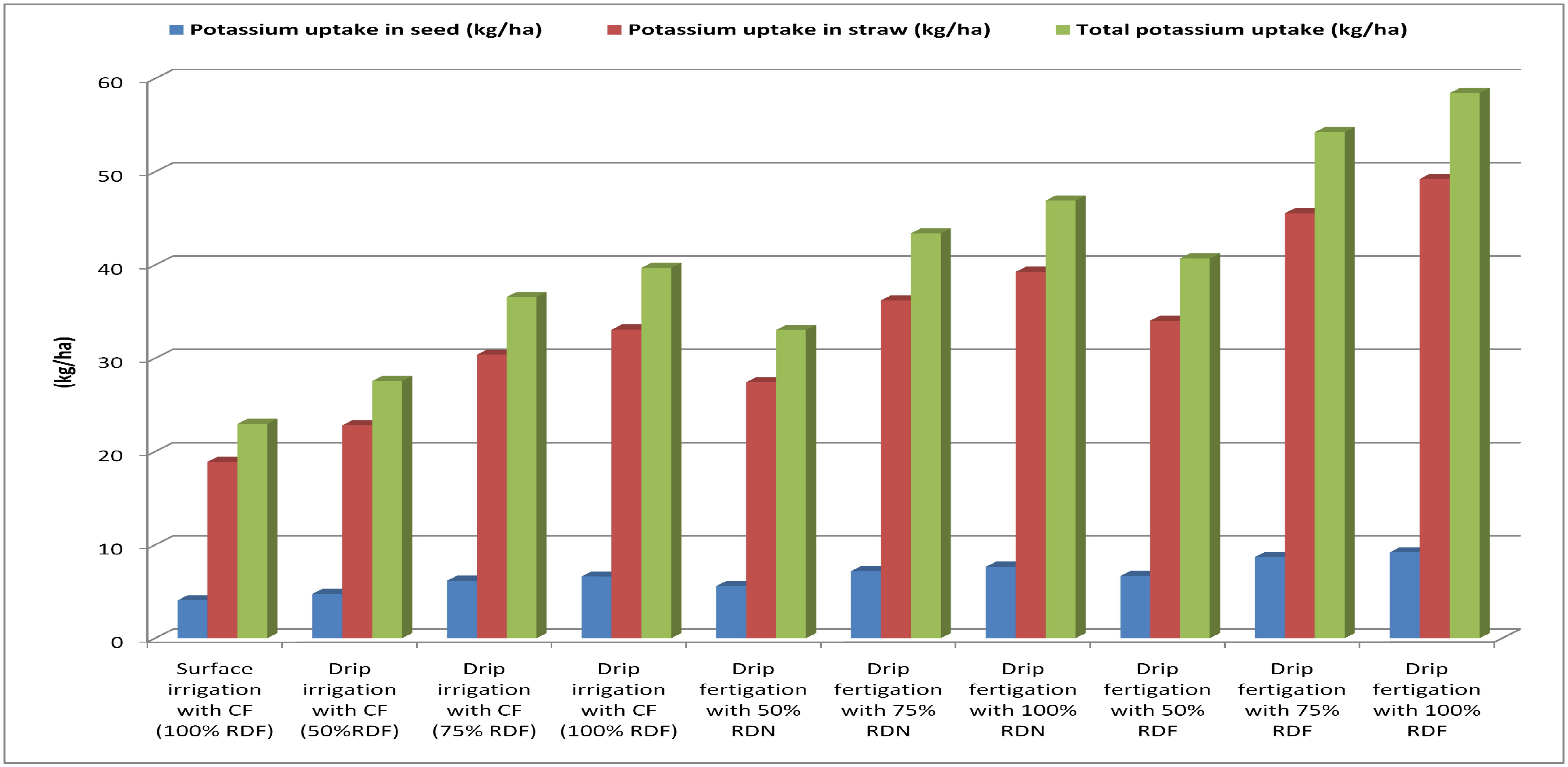


Fig. 4.8 Effect of drip irrigation and fertigation on potassium uptake by seed, straw and total uptake of fennel

4.3.9 Total potassium uptake

Data presented in table 4.14 and fig.4.8 reveals that surface irrigation with conventional fertilization obtained significantly less total potassium uptake over other drip irrigated and fertigated treatments during both the years and in pooled data analysis.

The critical examination of data indicates that among the various drip irrigation and fertigation levels, drip fertigation at 100 per cent RDF produced significantly maximum total potassium uptake over other treatments during 2015-16 and 2016-17 as well as on basis of pooled mean of observed data over two years (Table 4.14). The per cent increase in potassium content on pooled data basis with drip fertigation at 100 per cent RDF was 154.5 over surface irrigation with conventional fertilization.

Further data indicates that the drip fertigation with 100 per cent RDN, remaining at par with drip fertigation with 75 per cent RDN, also improved significantly more total potassium uptake over drip irrigation with conventional fertilization, drip fertigation with 50 per cent RDN as well as 50 per cent and 75 per cent RDF, registered an increase of 104.3 per cent over surface irrigation with conventional fertilization on pooled basis.

4.3.10 Volatile oil content in seed

The examination of data (Table 4.15 and Fig. 4.9) indicates that surface irrigation with conventional fertilization, being statistically at par with drip irrigation at 50 per cent RDF with conventional fertilization, brought about significantly lower improvement in volatile oil content in fennel seed over other drip irrigated and fertigated treatments during both the years and in pooled data analysis.

Table 4.15 Effect of drip irrigation and fertigation on volatile oil content, oil yield and protein content of fennel

Treatments	Volatile oil content in seed (%)			Oil yield (kg/ha)			Protein content in seed (%)		
	2015-16	**2016-17**	**Pooled**	**2015-16**	**2016-17**	**Pooled**	**2015-16**	**2016-17**	**Pooled**
Surface irrigation with CF (100% RDF)	1.1	1.0	1.1	17.3	16.3	17.6	7.6	6.3	6.9
Drip irrigation with CF (50%RDF)	1.1	1.1	1.1	21.1	19.8	20.4	8.1	6.4	7.3
Drip irrigation with CF (75% RDF)	1.3	1.3	1.3	27.5	26.0	26.7	10.0	7.4	8.7
Drip irrigation with CF (100% RDF)	1.4	1.3	1.4	29.8	27.8	28.8	11.3	9.2	10.3
Drip fertigation with 50% RDN	1.3	1.2	1.3	25.7	24.2	25.0	9.4	8.3	8.8
Drip fertigation with 75% RDN	1.4	1.4	1.4	33.5	31.8	32.7	10.7	10.1	10.4
Drip fertigation with 100% RDN	1.6	1.6	1.6	38.7	36.3	37.5	12.8	11.9	12.3
Drip fertigation with 50% RDF	1.4	1.4	1.4	31.8	30.0	30.9	10.2	8.8	9.5
Drip fertigation with 75% RDF	1.6	1.6	1.7	42.3	39.9	41.1	11.3	10.9	11.1
Drip fertigation with 100% RDF	1.8	1.8	1.8	47.5	44.0	45.7	13.4	12.2	12.8
SEm±	0.1	0.1	0.0	1.2	1.0	0.8	0.4	0.4	0.3
CD (P=0.05)	0.2	0.1	0.1	3.7	3.0	2.3	1.2	1.1	0.8

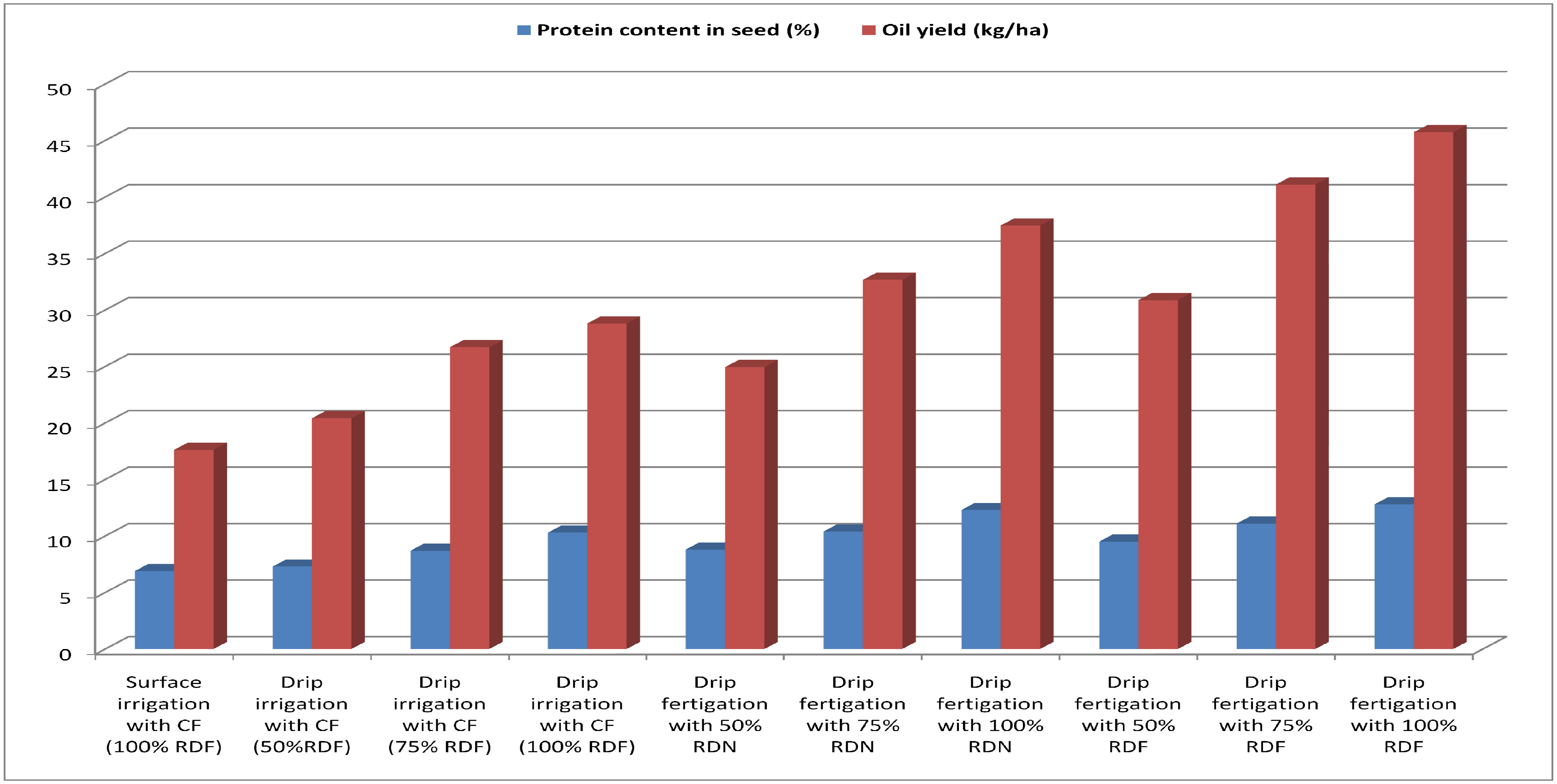


Fig. 4.9 Effect of drip irrigation and fertigation on protein content in seed and oil yield of fennel

It is visible from the data that among different drip irrigation and fertigation treatments, drip fertigation at 75 per cent RDF recorded significantly higher volatile oil content in seed over other treatments, however, it was at par with drip fertigation at 100 per cent RDF and 100 per cent RDN during both the years. The drip fertigation at 100 per cent RDF recorded significantly highest volatile oil content in fennel seed which was superior over surface irrigation with conventional fertilization by 67.6 per cent in pooled mean analysis.

A reference to data shows that the drip fertigation at 100 per cent RDN, remained at par with drip fertigation with 75 per cent RDN, also found significant increase in volatile oil content over drip irrigation with conventional fertilization, drip fertigation at 50 per cent RDN as well as 50 per cent RDF during two years of investigation and in pooled mean analysis 100 per cent RDN was proved significant superiority over 75 per cent RDN.

In terms of per centage, drip fertigation was 100 per cent RDN improved volatile oil content by 47.6 per cent over surface irrigation with conventional on the basis of pooled analysis of data.

4.3.11 Oil yield

From the data in table 4.15 and fig. 4.9, it is apparent that drip irrigation with conventional fertilization or drip fertigation had a significant effect on the oil yield of fennel over surface irrigation with conventional fertilization during both the years and pooled basis

It is evident from data that among different drip irrigation and fertigation treatments, drip fertigation at 100 per cent RDF, produced significantly highest oil yield in fennel seed over rest of the treatments which was found to enhance the oil yield to the extent of 159.4 per cent over surface irrigation with conventional fertilization during both the years of investigation and in pooled data analysis.

Data shows that the drip fertigation at 100 per cent RDN, also recorded statistically higher oil yield of fennel over drip irrigation with conventional fertilization, drip fertigation with 75 per cent and 50 per cent RDN as well as 50 per cent RDF during individual years and in pooled analysis representing an increase of 112.6 per cent over surface irrigation with conventional fertilization on pooled mean basis.

4.3.12 Protein content in seed

Examination of data in table 4.15 indicates that surface irrigation with conventional fertilization, being at par with drip irrigation at 50 per cent RDF with conventional fertilization, recorded significantly lower protein content in fennel seed over other drip irrigated and fertigated treatments during both the years and in pooled data analysis.

Data in table 4.15 shows that the drip fertigation at 100 per cent RDF produced significantly highest protein content in seed over other treatments during individual year and in pooled analysis. The drip fertigation with 100 per cent RDF recorded 85.4 per cent increase in protein content over surface irrigation with conventional fertilization.

Data reveals that the drip fertigation with 100 per cent RDN, also significantly enhanced the protein content as compared to drip irrigation with conventional fertilization, drip fertigation with 75 per cent and 50 per cent RDN as well as 50 per cent RDF. The per cent increase of 78.5 in drip fertigation in 100 per cent RDN over surface irrigation with conventional fertilization (Table 4.15).

4.4 Soil moisture studies

4.4.1 Consumptive use of water (Cu)

A perusal of data in table 4.16 reveals that surface irrigation and drip irrigation with conventional fertilization and drip fertigation at various fertilizer levels could not cause perceptible variation in consumptive use of water in fennel.

4.4.2 Water use efficiency

The examination of data (Table 4.16) indicates that surface irrigation with conventional fertilization, being at par with drip irrigation at 50 per cent RDF with conventional fertilization, recorded statistically lower water use efficiency compared to other drip irrigated and fertigated treatments during both the years and in pooled data analysis.

It is visible from the data that among drip irrigation and fertigation at different fertility levels, drip fertigation at 75 per cent RDF, remaining at par with drip fertigation with 100 per cent RDF and 100 per cent RDN recorded significantly higher water use efficiency over other treatments. The per cent increase in water use efficiency due to drip fertigation with 75 per cent RDF was 50.1 over surface irrigation with conventional fertilization on the basis of pooled data over years.

Data reveals that drip fertigation with 100 per cent RDN, being at par with drip fertigation at 50 per cent RDF and 75 per cent RDN, also recorded significantly higher water use efficiency over drip irrigation with conventional fertilization and drip fertigation with 50 per cent RDN. The respective increases on pooled basis in water use efficiency due to drip fertigation with 100 per cent RDN was 43.2 per cent over surface irrigation with conventional fertilization.

Table 4.16 Effect of drip irrigation and fertigation on consumptive use and water use efficiency of fennel

Treatments	Consumptive use (mm)			Water use efficiency (kg/ha-mm)		
	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled
Surface irrigation with CF (100% RDF)	389	455	422	4.4	3.6	4.1
Drip irrigation with CF (50%RDF)	386	440	413	4.8	4.0	4.4
Drip irrigation with CF (75% RDF)	385	442	414	5.5	4.6	5.0
Drip irrigation with CF (100% RDF)	388	445	417	5.7	4.7	5.2
Drip fertigation with 50% RDN	379	435	407	5.4	4.5	4.9
Drip fertigation with 75% RDN	386	437	412	6.0	5.1	5.6
Drip fertigation with 100% RDN	387	436	412	6.4	5.3	5.8
Drip fertigation with 50% RDF	389	439	414	5.9	4.9	5.4
Drip fertigation with 75% RDF	390	442	416	6.6	5.6	6.1
Drip fertigation with 100% RDF	391	435	413	6.9	5.8	6.3
SEm±	12	17	10	0.2	0.2	0.1
CD (P=0.05)	NS	NS	NS	0.6	0.5	0.4

4.4.3 Fertilizer use efficiency

A perusal of data in table 4.18 indicates that fertilizer use efficiency was significantly reduced with increase in fertilizer levels upto 100 per cent RDF through drip irrigation as well as fertigation. Surface irrigation with conventional fertilization at 100 per cent RDF was observed significantly lowest fertilizer use efficiency as compared to drip irrigation and fertigation at different fertilizer levels during both the years and pooled mean basis.

Data further indicates that among drip irrigation with conventional fertilization and fertigation, the drip fertigation at 50 per cent RDF, observed significantly highest fertilizer use efficiency as compared to other drip irrigated and fertigated treatments during both the years and pooled mean basis. The per cent increase in fertilizer use efficiency with drip fertigation at 50 per cent RDF was 163.9 over surface irrigation with conventional fertilization on the basis of pooled mean.

The examination of data indicates that drip fertigation with 50 per cent RDN, also observed significantly higher fertilizer use efficiency as compared to drip fertigation (75 per cent and 100 per cent RDF as well as 75 per cent RDN and 100 per cent RDN) and drip irrigation with conventional fertilization. On pooled mean basis, the magnitude of increases due to drip fertigation at 50 per cent RDN was 138.1 per cent over surface irrigation with conventional fertilization.

5.4.4 Water saving and yield increase

It is evident from data in table 4.17 that water used in drip irrigation and fertigation at different fertility levels was 413, 474 and 443 mm with 18.8, 19.0 and 18.9 per cent water saving over surface irrigation with conventional fertilization at 100 per cent recommended dose of fertilizers during both the years and pooled mean basis.

Table 4.17 Effect of drip irrigation and fertigation on water used and water saving of fennel

Treatments	Water used (mm)			Water saving (%)		
	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled
Surface irrigation with CF (100% RDF)	509.0	585.0	547.0	0.0	0.0	0.0
Drip irrigation with CF (50%RDF)	413.5	474.0	443.8	18.8	19.0	18.9
Drip irrigation with CF (75% RDF)	413.5	474.0	443.8	18.8	19.0	18.9
Drip irrigation with CF (100% RDF)	413.5	474.0	443.8	18.8	19.0	18.9
Drip fertigation with 50% RDN	413.5	474.0	443.8	18.8	19.0	18.9
Drip fertigation with 75% RDN	413.5	474.0	443.8	18.8	19.0	18.9
Drip fertigation with 100% RDN	413.5	474.0	443.8	18.8	19.0	18.9
Drip fertigation with 50% RDF	413.5	474.0	443.8	18.8	19.0	18.9
Drip fertigation with 75% RDF	413.5	474.0	443.8	18.8	19.0	18.9
Drip fertigation with 100% RDF	413.5	474.0	443.8	18.8	19.0	18.9

Table 4.18 Effect of drip irrigation and fertigation on fertilizer use efficiency

Treatments	Fertilizer use efficiency (kg/ha)		
	2015-16	**2016-17**	**Pooled**
Surface irrigation with CF (100% RDF)	13.2	12.6	12.9
Drip irrigation with CF (50%RDF)	28.6	27.2	27.9
Drip irrigation with CF (75% RDF)	21.7	20.7	21.2
Drip irrigation with CF (100% RDF)	16.9	16.3	16.6
Drip fertigation with 50% RDN	31.5	29.9	30.7
Drip fertigation with 75% RDN	23.9	22.8	23.3
Drip fertigation with 100% RDN	19.0	17.9	18.4
Drip fertigation with 50% RDF	34.9	33.2	34.1
Drip fertigation with 75% RDF	26.5	25.1	25.8
Drip fertigation with 100% RDF	20.8	19.3	20.0
SEm±	1.2	1.0	0.8
CD (P=0.05)	3.4	3.1	2.2

4.5 Economics

4.5.1 Net returns

A perusal of data (Table 4.19 and Fig. 4.10) reveals that the net returns of fennel significantly influenced by drip irrigation with conventional fertilization as well as fertigation over surface irrigation with conventional fertilization, wherein drip irrigation with conventional fertilization at 50 per cent RDF was at par with surface irrigation with conventional fertilization on the basis of pooled data of two years as well as during both years of study.

Data shows that the drip fertigation at 75 per cent RDF exhibited significantly higher net returns of fennel, whereas it remained equally effective with drip fertigation at 100 per cent RDF and 100 per cent RDN during individual year and in pooled analysis. On the basis of pooled mean, the net returns received with drip fertigation with 75 per cent RDF (₹ 154162/ha) was higher by ₹ 55959/ha over surface irrigation with conventional fertilization. This represented an increase of 57.0 per cent over surface irrigation with conventional fertilization.

The examination of data indicates that drip fertigation with 100 per cent RDN (₹ 146901/ha), being at par with drip fertigation with 75 per cent RDN, also attained significantly higher net returns over drip irrigation with conventional fertilization (50, 75 and 100 per cent RDF) and fertigation with 50 per cent RDN as well as 50 per cent RDF by ₹ 48698/ha corresponding to 49.6 per cent over surface irrigation with conventional fertilization.

4.5.2 B : C ratio

A reference to data (Table 4.19 and Fig. 4.10) reveals that surface irrigation with conventional fertilization, being at par with drip irrigation with conventional fertilization (75 per cent and 100 per cent RDF) and fertigation with 75 per cent RDN and 50 per cent RDF, recorded significantly higher

B:C ratio over drip irrigation with conventional fertilization at 50 per cent RDF and drip fertigation with 50 per cent RDN during the year of 2015-16 and 2016-17 as well as pooled basis.

Among different drip irrigation and fertigation treatments, drip fertigation with 75 per cent RDF registered significantly higher B:C ratio (3.13) over other treatments. However, it remained statistically at par with drip fertigation of 100 per cent RDF, 100 per cent RDN, 75 per cent RDN during both the years of experimentation as well as on the basis of pooled data. The drip fertigation with 75 per cent RDF recorded 9.4 per cent improvement in B:C ratio over surface irrigation with conventional fertilization.

Drip fertigation with 100 per cent RDN, being at par with drip fertigation with 75 per cent RDN, also recorded significantly higher B:C ratio over drip irrigation with conventional fertilization and drip fertigation with 50 per cent RDN and 50 per cent RDF registering an increase of 10.1 per cent over surface irrigation with conventional fertilization.

Table 4.19 Effect of drip irrigation and fertigation on net returns and B:C ratio of fennel

Treatments	Net returns (₹/ha)			B:C ratio		
	2015-16	**2016-17**	**Pooled**	**2015-16**	**2016-17**	**Pooled**
Surface irrigation with CF (100% RDF)	102073	94333	98203	2.9	2.8	2.9
Drip irrigation with CF (50%RDF)	99714	91355	95534	2.5	2.4	2.4
Drip irrigation with CF (75% RDF)	122570	113516	118043	2.8	2.7	2.7
Drip irrigation with CF (100% RDF)	129945	118371	124158	2.9	2.7	2.8
Drip fertigation with 50% RDN	116862	107385	112124	2.7	2.6	2.7
Drip fertigation with 75% RDN	141539	132093	136816	3.1	3.0	3.0
Drip fertigation with 100% RDN	153201	140601	146901	3.3	3.1	3.2
Drip fertigation with 50% RDF	134294	124167	129231	2.9	2.8	2.8
Drip fertigation with 75% RDF	159967	148357	154162	3.2	3.1	3.1
Drip fertigation with 100% RDF	168972	152016	160494	3.3	3.1	3.2
SEm±	5190	4756	3520	0.1	0.1	0.1
CD (P=0.05)	15550	14251	10095	0.2	0.2	0.2

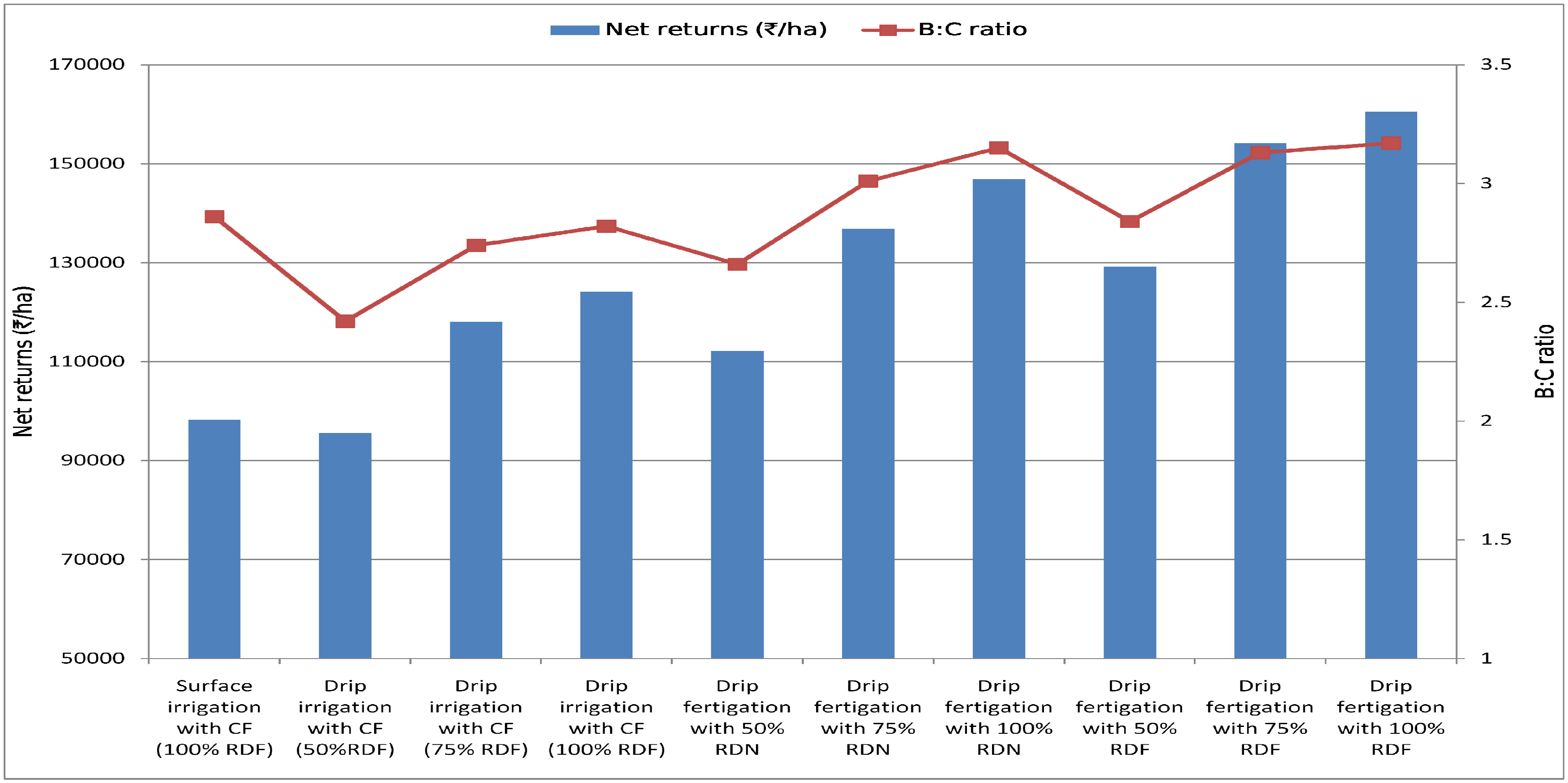


Fig. 4.10 Effect of drip irrigation and fertigation on net returns and B:C ratio of fennel

4.5.3 Correlation and regression studies

To study the relationship of seed yield with crop dry matter production, yield attributes and nutrient uptake by crop correlation and regression studies were made which are summarized in table 4.21.

4.5.3.1 Relationship between crop dry matter, yield and nutrient uptake by crop (X) and fennel seed yield (Y)

Simple correlation coefficients (r) were computed to study the relationship between fennel seed yield and the crop parameters namely, plant height and dry matter at harvest stage, umbels per plant, umbellets per umbel, seeds per umbel, test weight and N, P and K uptake by crop. It is obvious from the data that seed yield of fennel was significantly and positively correlated with all these growth and yield attributes (Tables 4.21). As such, the increase or decrease in these characters was found to be associated with a similar increase or decrease in seed yield. The regression coefficients (b) and regression equations were also worked out to quantify the amount of change in seed yield of fennel for a unit change in growth and yield attributes of crop and nutrient uptake. Pooled result showed that every unit increase in crop dry matter at harvest stage, branches per plant, chlorophyll content, umbels per plant, umbellets per plant, seeds per umbel, test weight and N, P and K uptake by crop increased the seed yield of fennel by 14.7, 334.4, 1092.1, 75.8, 88.6, 5.5, 450.9 and 11.3, 45.7 and 26.5 kg/ha, respectively in pooled analysis.

Table 4.21 Correlation coefficients (r) and regression equations for the relationship between seed yield (Y) (kg/ha) and growth, yield attributing characters and nutrient uptake by crop (Pooled Mean)

S.No.	Parameters	Correlation coefficient (r)	Regression equation $Y = a + b_y \times X$	R^2
1.	Plant height (cm)	0.998**	$Y = 241.973 + 18.386 X_1$	0.996
2.	Dry matter accumulation (g)	0.995**	$Y = -391.406 + 14.673 X_2$	0.989
3.	Branches per plant	0.998**	$Y = 215.795 + 334.430 X_3$	0.997
4.	Chlorophyll content (mg/g)	0.987**	$Y = 474.252 + 1092.106 X_4$	0.973
5.	Umbels per plant	0.994**	$Y = 254.792 + 75.794 X_5$	0.987
6.	Umbellets per umbel	0.992**	$Y = 310.681 + 88.573 X_6$	0.984
7.	Seeds per umbel	0.996**	$Y = 299.710 + 5.486 X_7$	0.992
8.	Test weight (g)	0.987**	$Y = -218.234 + 450.885 X_8$	0.973
9.	Total nitrogen uptake (kg/ha)	0.975**	$Y = 1326.174 + 11.321 X_9$	0.950
10.	Total phosphorus uptake (kg/ha)	0.982**	$Y = 1263.406 + 45.719 X_{10}$	0.965
11.	Total potassium uptake (kg/ha)	0.994**	$Y = 1100.168 + 26.487 X_{11}$	0.988

** Significant at 1 per cent level of significance

Chapter-5

DISCUSSION

In the course of presenting the results of the experiment entitled **"Response of Fennel (*Foeniculum vulgare* Mill.) to Drip Irrigation and Fertigation"** a significant variation under the criteria used for evaluating the treatment were observed due to the effect of different treatment. In this chapter, it is endeavoured to discuss the significant events or those assuming a definite pattern in respect of various parameters studied, so as to establish cause and effects relationship in the light of available literature and evidences.

5.1 Effect of environment : Years

The experiment conducted during 2015-16 recorded higher growth parameters, yield attributes and seed yield in comparison to the corresponding values of these characters recorded in 2016-17. It is an established fact that plants can express their genetic potential under certain range of environmental factors *i.e.,* weather conditions to which the plants are exposed during their life cycle as well as internal environment *i.e.,* availability of metabolites and nutrients. Since the crop was grown under identical level of management, the observed differences could be attributed to effect of weather conditions prevailing during the two crop seasons. Weather variability is one of the most significant factors influencing year to year crop production, even in high-yield and high technology agricultural areas (Kang *et al*., 2009). The profound influence of weather condition on crop growth and productivity is well recognized. A critical examination of weather data (Table 3.1) clearly showed that the crop season of first year (2015-16) witnessed higher mean maximum and minimum temperatures as well as evaporation that provided a better congenial environmental to the crop as compared to second year crop (2016-17). Similarly during first year crop season, the average bright sunshine hours were also higher especially during maturity period as compared to second year crop season. This might have provided better environment for photosynthesis and storage of produce in sink ultimately leading to higher crop production during first year in comparison to second year. Although intermittent rainfall received during second year was higher but the sunshine hours during later stages of crop growth were less, that may resulted in low photosynthates production compared to first year crop season. Singh and Bishnoi (2005) observed that variability in monthly and seasonal rainfall caused a set back in crop maturity of pearlmillet and clusterbean in *kharif* and gram and mustard in *rabi.* The estimated inter relationship between seed yield and various growth and yield attributes also substantiate strong dependence of yield on these parameters.

5.2 Growth parameters

The results revealed that drip irrigation with conventional fertilization and different fertigation treatments had favourable effect on growth and biomass production of fennel over surface irrigation with conventional fertilization. Surface irrigation with conventional fertilization, being at par with drip irrigation at 50 per cent RDF with conventional fertilization, recorded significantly inferior plant height at 35, 70, 105 DAS and at harvest over other drip irrigated and fertigated treatments (Table 4.2). Comparatively lower plant height of fennel under surface irrigation with conventional fertilization might be attributed to decrease in synthesis of metabolites and reduction in absorption and translocation of nutrients from soil to plant. The physiological response of plants by decreased cell division and cell elongation under moderate moisture stress at wider irrigation intervals might have also contributed to reduced fennel height under surface irrigation. The similar results were obtained by Ram Pratap *et al.* (2010) and Kakade *et al*. (2017).

Among different drip irrigation and fertigation treatments, drip fertigation at 75 per cent RDF, observed statistically higher plant height at 35 DAS and at harvest, which was on par with drip fertigation at 100 per cent RDF and 100 per cent RDN. While, at 70 and 105 DAS 100 per cent RDF through drip fertigation, registered significantly highest plant height over other treatments. It is well known fact that sufficient soil moisture for progressive plant growth is maintained by drip irrigation, which leads to better development of photosynthetic area and accelerate photosynthetic rate. Another reason for this is that growth and development phases in fennel is synchronized under well watered and nutritional conditions, more of photosynthetic is diverted toward vegetative growth rather than fruiting parts.

Application of fertilizers in fertigation, nutrients were effectively utilized, as there was direct contact with the root system with negligible nutrient loss through leaching. Under drip fertigation due to favourable soil water balance and effective absorption and utilization of available nutrients without wide fluctuations resulting in higher plant height of fennel. The results concur the findings of Shinde *et al*. (2006). The favourable increase in plant height due to drip fertigation was reported by Bhalerao *et al*. (2011). Godara *et al.* (2013) also reported that drip irrigation and fertigation at different fertilizer levels increases plant height of fennel. Similar results were observed by Ayyadurai and Manickasundaram (2014).

Significantly minimum dry matter accumulation was observed in surface irrigation with conventional fertilization, except drip irrigation with conventional fertilization (50per cent RDF) at 35, 70, 105 DAS and at harvest (Table 4.3). It is an established fact that the soil water deficiency inhibits leaf expansion and stem elongation in plants through its reduction of relative turgidity. Reduced water supply also causes closure of stomata which raises the plant temperatures consequently increases respiration leading to higher break down of assimilates and ultimately poor growth and reduced dry matter accumulation under surface irrigation with conventional fertilization. These results are in agreement with the finding of Tanaskovik *et al*. (2011). Hucheng *et al*. (2014) showed that the dry matter accumulation of ginger has reduced by 17.94 per cent in surface irrigation with conventional fertilization comparing with drip irrigation with conventional fertilization.

Among different drip irrigation and fertigation treatments, Drip fertigation at 75 per cent RDF, being at par with drip fertigation at 100 per cent

RDF and 100 per cent RDN, significantly improved dry matter accumulation at 35, 70, 105 DAS and at harvest over other treatments. It is well established fact that where sufficient soil moisture for continued growth is maintained by providing drip irrigation it leads to greater development of green tissue area and results in a higher photosynthetic assimilation. As a result, plant growth improves leading to higher accumulation of the total dry matter. This might be due to drip fertigation, fertilizers applied in desired split dose throughout the growing period according to the crop requirement so that the losses were minimized and opportunity was provided to take more nutrients, which reflected on higher dry matter production in the present study. The similar results were reported by Vanitha (2008).

Another reason is increased availability of nutrients in the soil solution ensuing in the increased uptake of these nutrients by plants (Table 4.3) and better translocation of assimilates from source to sink, resulting in higher dry matter accumulation by plant. Chanthai *et al.* (2013) reported that the fertigation promoted faster growth and resulted to more tomato dry matter accumulation compared to conventional fertilization. Ayyadurai and Manickasundaram (2014) also reported that application of N and K in more split through drip fertigation enhanced the dry matter production.

Drip irrigation with conventional fertilization and fertigation, except of drip irrigation with 50 per cent RDF as conventional fertilization, recorded significantly higher number of branches per plant and chlorophyll content of fennel over surface irrigation with conventional fertilization (Table 4.4). The drip fertigation at 75 per cent RDF, being at par with drip fertigation at 100 per cent RDF and 100 per cent RDN, observed significantly maximum number of branches per plant and total chlorophyll content over rest treatments. It is mainly due to the water content and optimum nutrients make the crop to maintain its chlorophyll content in sufficient range so that higher chlorophyll content was obtained. These results are in agreement with the finding of Honnappa *et al.* (2017) and Kanwar *et al.* (2018) in fenugreek. The drip fertigation at 75 per cent RDF, being at par with drip fertigation at 100 per cent

RDF and 100 per cent RDN, observed significantly maximum crop growth rate over rest treatments (Table 4.5) The higher CGR in drip fertigation was due to higher dry matter production at different growth stages due to favourable soil water and nutrient environment throughout the crop growth stages. Similar results were reported by Anusha (2015) and Kombali *et al.* (2017).

5.3 Yield attributes and yield

The drip irrigation with conventional fertilization and fertigation at different fertilizer levels were significantly influenced the yield components *viz.*, umbels per plant, umbellets per umbel, seeds per umbel, test weight of fennel (Table 4.7). The drip irrigation with conventional fertilization as well as fertigation except drip irrigation with conventional fertilization (50 per cent RDF), recorded significantly higher yield components over surface irrigation with conventional fertilization. The reasons of low yield components in surface irrigation with conventional fertilization may be due to the crop has to undergo water stress during last few days before next irrigation, coupled with aeration problem during first few days immediately after irrigation. Moreover, due to heavy application of irrigation water the nutrients must have got leached down the root zone. Another possible reason was the high weed infestation observed between the crop rows. Dingre *et al*. (2012) showed that surface irrigation with conventional fertilization with 100 per cent RDF resulted into12 to 74 per cent decrease in the productivity of onion seed as compared to drip fertigation with 75 per cent RDF. Similar findings were observed by Kapoor *et al.* (2014) and Jayakumar *et al*. (2014).

The drip fertigation at 75 per cent RDF, being at par with drip fertigation at 100 per cent RDF and 100 per cent RDN, significantly increased yield components over other treatments and represented an increase of umbels per plant by 51.9 per cent, umbelletes per umbel by 67.9 per cent, seeds per umbel by 63.0 per cent, test weight by 37.8 per cent over surface irrigation with conventional fertilization (Table 4.7). This might be due to the fact that adequate nutrients supplied from these treatments created more conducive environment for the roots to absorb the nutrients more effectively, when compared to surface irrigation treatment. The growth parameters were also higher under drip fertigation treatments, which might have contributed to higher yield parameters. The increase in yield attributes was due to increased NPK availability, uptake and better crop growth at higher levels of NPK (Patel et al., 2009). Similar findings were observed by Shedeed *et al*. (2009), Badra and Yazied (2010). Agrawal *et al*. (2018b) registered that yield attributing characters were significantly increased by drip irrigation and fertigation due to continuous water and nutrient supply as per the requirement of the crop and promoted more nutrient uptake, retained more water in the root zone and increased crop water use efficiency thereby increasing yield of the cabbage.

Surface irrigation with conventional fertilization recorded significantly lower seed, straw and biological yields (1677, 4206 and 5883 kg/ha) of fennel over drip irrigation with conventional fertilization as well as fertigation except drip irrigation with conventional fertilization (50 per cent RDF) (Table 4.8).The decrease in fennel seed yield with surface irrigation with conventional fertilization was mainly attributed by lesser and inconsistent availability of soil moisture and nutrients which resulted in the poorer crop growth, yield components and ultimately reflected on the seed and straw yields of fennel. Similar results were reported by Krishnasamy *et al*. (2012) and Pawar *et al*. (2013).

The analysed pooled data revealed that yield of fennel was significantly improved with drip fertigation with 75 per cent RDF. However, it remained statistically at par with drip fertigation of 100 per cent RDF as well as 100 per cent RDN. Drip fertigation at 75 per cent RDF increased seed (2516 kg/ha) by 50.0 per cent, straw (7098 kg/ha) by 68.8 per cent and biological yields (9613 kg/ha) by 63.4 per cent over surface irrigation with conventional fertilization (Table 4.8). The increase in plant height, dry matter, branches per plant and chlorophyll content by 55.9, 37.8, 55.7 and 62.7 per cent over surface irrigation with conventional fertilization. The per cantage increase in umbels per plant by 51.9 per cent, umbelletes per umbel by 67.9 per cent, seeds per umbel by 63.0 per cent and test weight by 37.7 per cent in fertigation therefore, increase in seed, straw and biological yields over surface irrigation irrigation. The yield increase in drip irrigation is due to frequent water application through drip irrigation results in favourable micro climate and keeps constantly soil moisture near to field capacity which helps in increasing the yield. The placement of nutrients just near the base of plant through fertigation became quite useful as there was no leaching loss and the optimum soil moisture which was prevailing within crop root zone resulted in a better utilization of applied nutrients.

Reproduction and seed development are seriously affected by moisture and nutrients stress in fennel. The most critical period with respect to water and nutrients stress begins with the appearance of pollen mother cell, which decides the number of seed setting in umbels. The damage occurred to reproductive stage due to water and nutrients deficiency may not recover with supply of water and nutrients at another stage of crop. In fact seed yield is the function of several yield components, which are depended on complementary interaction between vegetative and reproductive growth of crop. Similar findings were also observed by Jat *et al*. (2011), Sharma and Kaushal (2015) and Singh *et al.* (2018) in Pigeon pea. Results of present study are close related with the findings of Magare *et al.* (2018) who observed that seed cotton yield was recorded significantly highest under 100 per cent RDF through drip fertigation over 100 per cent RDF through soil fertilization.

5.4 Nutrient content, uptake and quality

Drip irrigation with conventional fertilization and increasing levels of fertigation resulted in increase in the nitrogen, phosphorus and potassium content in fennel seed and straw. Surface irrigation with conventional fertilization, remaining at par with drip irrigation at 50 per cent RDF with conventional fertilization, observed significantly lower nitrogen, phosphorus and potassium contents in fennel seed and straw over other drip irrigated and fertigated treatments (Tables 4.9, 4.11 and 4.13). The reason for lower content of nutrients in surface irrigation with conventional fertilization, application of large quantity of fertilizers as a single dose resulted in higher volatilization losses, restricted the mineralization of nutrients and resulted lower the availability of nutrients during later growth stages of crop. These results corroborate the findings of Gundlur *et al*. (2013) and Fanish (2013).

The drip fertigation at 100 per cent RDF, recorded the significantly maximum nitrogen, phosphorus contents in fennel seed and straw registering an increase of 84.7, 73.5 and 72.1, 70.8 per cent over surface irrigation with conventional fertilization (Table 4.9 and 4.11). The potassium content was significantly higher in 75 per cent RDF in seed and straw (Table 4.13). The content and availability of various nutrients in the soil for plant uptake depends on soil solution phase which is mainly determined by soil moisture availability. The higher available soil moisture provided due to continuous water supply under drip irrigation led to higher availability of nutrients in the soil and thereby increased the nutrient uptake under drip fertigation levels in splits was the result of increased biomass production due to continuous availability of water and nutrients to the crop. An application of nitrogen and phosphorus given through fertigation not only stimulated vegetative growth and foraging capacity of roots, but also encouraged the absorption and translocation of more nutrients under higher drip fertigation levels and ultimately increased their accumulation in vegetative plant parts. These results are in close conformity with findings of Jayakumar *et al.* (2014) and Harish *et al.* (2018).

Surface irrigation at 100 per cent RDF with conventional fertilization, being at par with drip irrigation at 50 per cent RDF with conventional fertilization, recorded significantly lower nitrogen, phosphorus and potassium uptake by fennel seed and straw over other drip irrigated and fertigated treatments (Table 4.10, 4.12 and 4.14). In the present study, surface irrigation could have influenced the absorption and uptake of nutrients by fennel seed and straw in several ways *viz.,* reduced water supply could have decreased root growth and thus decreased absorption of nitrates, it might have decreased nitrification of the soil nitrogen and thereby decreased its availability to the plants, it might have decreased the availability of plant root to absorb nitrogen by affecting the metabolic activity of the plants. Similarly, phosphorus and potassium uptake in grain and straw was restricted in water stress condition because of reduced upward movement of nutrient by mass flow and diffusion restricted development of stem and inflorescences of fennel. The surface irrigation with conventional fertilization registered lowest value of quality parameters of sugarcane (Pawar *et al*. 2013).These results are in consonance with the finding of (Malve, 2017).

The drip fertigation at 100 per cent RDF recorded the significantly maximum nitrogen, phosphorus, potassium uptake and total uptake of seed and straw over other treatments (Table 4.10, 4.12 and 4.14). Significantly increased total nitrogen uptake by 201.5 per cent, total phosphorus uptake by 168.4 per cent and total potassium uptake by 154.5 per cent were observed with drip fertigation with 100 per cent RDF over surface irrigation with conventional fertilization. The applied nitrogen, phosphorus in soluble form in fertigation treatments may have been distributed better through root zone of fennel than conventional fertilization and producing more available amounts for plant uptake. Increased nutrient contents in fertigation might also be due to improved nutritional environment in the rhizosphere as well as in the plant system leading to enhanced translocation of nutrients in plant parts along with irrigation water. Since the nutrient uptake is a function of its content in crop plant and seed and straw yields of the crop. Hebbar *et al.* (2004) reported that fertigation using water soluble fertilisers contribute to the increased availability of N, P and K in the 0-30 cm soil depth and reduce leaching of NO_3 – N and K. These results are also in tune with the findings of Singh *et al.* (2009), who opined that increased in nitrogen and phosphorus content in both grain and straw with increased in total dry matter production and nitrogen, phosphorus application induced a positive influence on the development of vegetative cells and grains thereby increasing uptake.

Surface irrigation with conventional fertilization, being at par with drip irrigation at 50 per cent RDF with conventional fertilization, recorded significantly lower protein content in fennel seed over other drip irrigated and fertigated treatments (Table 4.15). It may be due to the reduction in the nitrogen content of plant due to the reduction in water and nutrient uptake under water stress condition in surface irrigation, this is the probable reason for low protein content in surface irrigation with conventional fertilization. These results are in harmony with those obtained by Abdelraouf *et al*. (2019).

The drip fertigation at 100 per cent RDF produced significantly highest protein content in fennel seed over other treatments (Table 4.15) in the present investigation because of increased nitrogen content in seed which might be the result of increased availability of nitrogen to plants. Another reason for higher nitrogen content might be due to increased activity of nitrate reductase enzyme. Higher nitrogen in seed is directly responsible for higher protein because it is a primary component of amino acids which constitute the basis of protein. Bhunia *et al.* (2005) also observed similar findings. Abdelraouf *et al.* (2019) investigated that the decreasing of fertigation levels from 100 to 50 per cent NPK of the recommended fertilizer doses significantly decreased protein content in wheat. These results are in accordance with Patil *et al*. (2014) in cluster bean and Harisha *et al*. (2017b) in fenugreek.

Surface irrigation with conventional fertilization, being statistically at par with drip irrigation at 50 per cent RDF with conventional fertilization, brought about significantly lower improvement in essential oil content and oil yield (1.05 per cent and 17.63 kg/ha) in fennel seed over other drip irrigated and fertigated treatments.

Among different drip irrigation and fertigation treatments, drip fertigation at 75 per cent RDF (1.65 per cent), recorded significantly highest essential oil content in seed. However, it was at par with drip fertigation at 100 per cent RDF and 100 per cent RDN. Whereas, in respect of oil yield, drip fertigation at 100 per cent RDF (45.74 kg/ha) proved significantly superior over rest of the treatments which was found to enhance the oil yield to the extent of 159.44 per cent over surface irrigation with conventional fertilization (Table 4.15). The increase in oil content due to increase in levels of fertigation was due to bolder seeds of fennel produced by increasing levels of fertigation as evident from increased test weight with higher moisture level. The oil yield, being the function of oil content of seed and seed yield, also increased significantly. Results of present study are closely related with the findings of Bharati and Prasad (2003) in mustard.

5.5 Soil moisture studies

The water saving under drip irrigation was due to low application rate at frequent intervals matching the actual crop water needs at various stages. Surface irrigation with conventional fertilization, being at par with drip irrigation at 50 per cent RDF with conventional fertilization, recorded statistically lower water use efficiency compared to other drip irrigated and fertigated treatments. Drip fertigation at 75 per cent RDF recorded significantly the highest water use efficiency over other treatments, however, it was at par with drip fertigation at 100 per cent RDF and 100 per cent RDN during the year of 2015, 2016 and pooled mean basis (Table 4.16). The per cent increase in water use efficiency due to drip fertigation with 75 per cent RDF was 50.1 over surface irrigation with conventional fertilization. Water use efficiency was higher under drip irrigation with conventional fertilization and fertigation treatments compared to surface irrigation with conventional fertilization was mainly due to considerable saving of irrigation water, greater increase in yield of crops and higher nutrient use efficiency. Ardell (2006) reported that application of nitrogen and phosphorus fertilizer increases crop yields, thereby increasing crop water use efficiency. Adequate levels of essential plant nutrients are needed to optimize crop yields and water use efficiency. Similarly this was in agreement with Ramah (2008). Similar findings have also been reported by Sharma *et al.* (2012). They reported that maximum water use efficiency was noted in the treatment which was irrigated with drip at 60 per cent Etc and the lowest water use efficiency was noted in the conventional irrigation system. Pawar *et al.* (2013) also reported superiority of drip fertigation over conventional fertilization in terms of water use efficiency and saving of fertilizers. Ughade and Mahadkar (2014) reported maximum field water use efficiency in drip fertigation. Agrawal *et al*. (2018a) observed that the application of irrigation water through drip irrigation method appreciably improved water use efficiency approximately 3.6 times higher than surface irrigation method in tomato.

5.6 Fertilizer use efficiency

Drip irrigation with conventional fertilization as well as drip fertigation significantly influenced the fertilizer use efficiency of fennel. Drip fertigation with 50 percent recommended dose of fertilizer (50 per cent nitrogen and phosphorus) resulted in significantly highest fertilizer use efficiency and the lowest fertilizer use efficiency was recorded by surface irrigation with conventional fertilization (Table 4.18). This was due to better availability of moisture and nutrients throughout the growth stages in drip fertigation system leading to better uptake of nutrients and production of fennel. In fertigation nutrient use efficiency could be as high as 90 per cent compared to 40-60 per cent in conventional fertilization Solaimalai *et al*. (2005). The study of Hebbar *et al*. (2010) reported that fertigation can reduce the loss of NO_3^- and K^+ at the deeper level than the root zone which led to more available nutrients to plants in the root zone. This led to more fertilizer use efficiency of fertigation than conventional fertilization. Fertilizer use efficiency in drip irrigation and fertigation increases as a result of controlled and regular application of fertilizer (Yadav *et al*., 2012). Kumari and Kaushal (2014) conducted an experiment on drip fertigation in sweet pepper which resulted in saving of fertilizer up to 25 per cent. Controlled watering through drip and efficient nutrient management through fertigation, not only improves the production but quality as well due to better control over soil and water borne diseases (Singh and Pandey, 2014).

5.7 Economics

It is evident from data (Table 4.19) that drip irrigation with conventional fertilization as well as fertigation at different fertility levels enhanced the net returns and B:C ratio as compared to surface irrigation with conventional fertilization. The drip fertigation at 75 per cent RDF, exhibited significantly highest net returns of fennel, whereas it remained equally effective with drip fertigation at 100 per cent RDF and 100 per cent RDN. The net returns received with drip fertigation with 75 per cent RDF (₹ 154162/ha) was higher by ₹ 55959/ha over surface irrigation with conventional fertilization. This represented an increase of 57.0 per cent over surface irrigation with conventional fertilization (Table 4.19). The higher B:C ratio obtained under the drip fertigation due to higher yield produced under these system with minimum losses of water. Soil nutrients were efficiently utilized by the plants in drip fertigation. The total cost of production increased in drip irrigation and fertigation due to additional cost of drip system and high market cost of water soluble fertilizers. The cost involved under this treatment was comparatively lower than its additional income, which led to more returns under this treatment. Pawar *et al*. (2013) also reported superiority of drip fertigation over conventional fertilization in terms of productivity and economics of sugarcane. Ankush and Singh (2017) also studied the effect of drip fertigation on economics of tomato and obtained maximum net return (₹ 220115.43/ha) and B: C ratio (2.40) with 75 per cent PE through drip irrigation and application of 75 per cent RDF through drip fertigation.

Chapter-6

SUMMARY AND CONCLUSION

The field experiment entitled **"Response of Fennel (*Foeniculum vulgare* Mill.) to Drip Irrigation and Fertigation"** was conducted during two consecutive *Rabi* seasons of 2015-16 and 2016-17 at Agronomy Farm, S.K.N. College of Agriculture, Jobner (Rajasthan). The results presented and discussed in preceding chapters are summarized as under.

6.1 Growth parameters

6.1.1 Plant stand per metre row length of fennel at 35 days and at harvest was not affected significantly due to drip irrigation and fertigation at different fertilizer levels.

6.1.2 The drip fertigation at 75 per cent RDF, observed statistically higher plant height at 35 DAS and at harvest, which was on par with drip fertigation at 100 per cent RDF and 100 per cent RDN. While, at 70 and 105 DAS, 100 per cent RDF through drip fertigation, registered significantly highest plant height over other treatments. Further data indicated that the drip fertigation with 100 per cent RDN, being at par with drip fertigation at 75 per cent RDN, also recorded significantly higher plant height over drip irrigation with conventional fertilization, drip fertigation with 50 per cent RDN and 50 per cent RDF.

6.1.3 Drip fertigation at 75 per cent RDF, being at par with drip fertigation at 100 per cent RDF and 100 per cent RDN, significantly improved dry matter accumulation at 35, 70, 105 DAS and at harvest over other treatments. However, above mentioned treatment was also on par with 75 per cent RDN at 30 and 105 DAS. Data further indicated that the drip fertigation with 100 per cent RDN, registered significantly higher dry matter accumulation as compared to drip irrigation with conventional fertilization and fertigation at 50 per cent RDN. However it was at par with fertigation of 75 per cent RDN as well as 50 per cent RDF. On the basis of pooled mean the treatment of drip fertigation with 100 per cent RDN showed its significant superiority over fertigation with 50 per cent RDF at 70 and 105 DAS.

6.1.4 The drip fertigation at 75 per cent RDF, being at par with drip fertigation at 100 per cent RDF and 100 per cent RDN, observed significantly maximum number of branches per plant and total chlorophyll content over rest treatments. It was further noted that drip fertigation with 100 per cent RDN, also gave significantly higher branches per plant and chlorophyll content in fennel as compared to drip irrigation with conventional fertilization, drip fertigation at 50 per cent, 75 per cent RDN as well as 50 per cent RDF.

6.1.5 The drip fertigation at 75 per cent RDF, being at par with drip fertigation at 100 per cent RDF and 100 per cent RDN obtained significantly highest crop growth rate over rest of the treatments. Whereas, on pooled mean basis the drip fertigation at 100 per cent RDF, recorded significantly highest crop growth rate in fennel during the period of 0-35 DAS, 35-70 DAS, 70-105 DAS and 105 DAS - at harvest. It is further evident from data that drip fertigation with 100 per cent RDN also recorded the higher crop growth rate and proved significantly superior to drip irrigation with conventional fertilization as well as fertigation at 50 per cent RDN. However, the above treatment remained at par with drip fertigation at 75 per cent RDN and 50 per cent RDF but in pooled mean 100 per cent RDN was also significant with 50 per cent RDF.

6.1.6 Drip irrigation with conventional fertilization and fertigation treatments at different fertilizer levels could not bring significant improvement in relative growth rate during the period of 35-70 DAS, 70-105 DAS and 105 DAS-at harvest of fennel over surface irrigation with conventional fertilization.

6.2 Yield attributes and yield

6.2.1 Drip fertigation at 75 per cent RDF, being at par with drip fertigation at 100 per cent RDF and 100 per cent RDN, produced significantly higher number of umbels per plant over other treatments. Drip fertigation with 100 per cent RDN, remaining at par with drip fertigation with 75 per cent RDN as well as 50 per cent RDF, also recorded the significantly higher number of umbels per plant over drip irrigation with conventional fertilization and drip fertigation with 50 per cent RDN.

6.2.2 Drip fertigation at 75 per cent RDF, being at par with drip fertigation at 100 per cent RDF as well as 100 per cent RDN, registered significantly increased umbellets per umbel over other treatments during the year of 2015-16. Whereas, on the basis of pooled data for two years and in the year of 2016-17 drip fertigation at 100 per cent RDF, observed statistically highest umbellets per umbel. Drip fertigation at 100 per cent RDN significantly enhanced umbellets per umbel as compared to drip irrigation with conventional fertilization, drip fertigation at 75 per cent and 50 per cent RDN as well as 50 per cent RDF.

6.2.3 The drip fertigation at 75 per cent RDF, being statistically at par with drip fertigation at 100 per cent RDF and 100 per cent RDN, significantly increased seeds per umbel among drip irrigation and fertigation treatments. The drip fertigation at 100 per cent RDN significantly improved seeds per umbel over drip irrigation with conventional fertilization and drip fertigation at 50 per cent RDN but the same was at par with drip fertigation at 75 per cent RDN and 50 per cent RDF.

6.2.4 Drip fertigation at 75 per cent RDF, being at par with drip fertigation at 100 per cent RDF and 100 per cent RDN, gave significantly higher test weight over other treatments during both the years but in pooled mean analysis drip fertigation at 75 per cent RDF was also at par with 75 per cent RDN. The further examination of data indicated that significantly higher test weight also attained with drip fertigation at 100 per cent RDN over drip irrigation with conventional fertilization as well as fertigation with 50 per cent RDN. However, the difference was non significant when compared with drip fertigation at 75 per cent RDN as well as 50 per cent RDF.

6.2.5 Drip fertigation with 75 per cent RDF, registered significantly higher seed yield (2516 kg/ha). However, it remained statistically at par with drip fertigation of 100 per cent RDF as well as 100 per cent RDN. Data further showed that drip fertigation with 100 per cent RDN, being at par with drip fertigation with 75 per cent RDN and 50 per cent RDF, also recorded significantly higher seed yield over drip irrigation with conventional fertilization and drip fertigation with 50 per cent RDN.

6.2.6 Application of 75 per cent RDF through drip had significantly higher straw yield over other treatments. However, the difference was non significant when compared with drip fertigation at 100 per cent RDF as well as100 per cent RDN. Drip fertigation at 100 per cent RDN, the straw yield of fennel (6607 kg/ha) was not significantly induced as compared to drip fertigation at 75 per cent RDN as well as 50 per cent RDF, whereas, drip irrigation with conventional fertilization and fertigation with 50 per cent RDN exhibited significant reduction in straw yield as compared to above mentioned treatment.

6.2.7 The drip irrigation and fertigation at different recommended doses of fertilizers could not bring significant improvement in harvest index of fennel over surface irrigation with conventional fertilization.

6.3 Nutrient content, uptake and quality

6.3.1 The drip fertigation at 100 per cent RDF, remained at par with drip fertigation with 100 per cent RDN, recorded higher nitrogen content in fennel seed and straw over other treatments. Data further indicated that drip fertigation with 100 per cent RDN, registered significantly higher nitrogen content in fennel seed as compared to drip irrigation with conventional fertilization, drip fertigation with 75 per cent RDN and 50 per cent RDN as well as 50 per cent RDF.

6.3.2 Drip fertigation at 100 per cent RDF, showed higher phosphorus content in fennel seed and straw over other treatments. Drip fertigation with100 per cent RDN, also registered significantly higher phosphorus content in fennel seed and straw as compared to drip fertigation with conventional fertilization, drip fertigation (50 per cent and 75 per cent RDN) as well as 50 per cent RDF. However, above treatment was non significant with drip irrigation with conventional fertilization at 100 per cent RDF during the year of 2016.

6.3.3 The drip fertigation at 100 per cent RDF, recorded higher nitrogen uptake by fennel seed and straw. The further examination of data indicated that drip fertigation with 100 per cent RDN, also improved higher nitrogen uptake by fennel seed and straw as compared to drip fertigation with conventional fertilization, drip fertigation (50 per cent and 75 per cent RDN) as well as 50 per cent RDF.

6.3.4 The drip fertigation at 100 per cent RDF recorded higher total nitrogen uptake over other treatments. Drip fertigation with 100 per cent RDN registered significantly higher total nitrogen uptake as compared to drip fertigation with conventional fertilization, drip fertigation 50 per cent RDN as well as 50 per cent RDF. However, it was remained at par with drip fertigation with 75 per cent RDF.

6.3.5 The drip fertigation at 100 per cent RDF, recorded highest phosphorus uptake by fennel seed and straw over other treatments. Drip fertigation at 100 per cent RDN, also registered higher phosphorus uptake and proved significantly superior to drip fertigation with conventional fertilization, drip fertigation (50 per cent and 75 per cent RDN) and 50 per cent RDF.

6.3.6 The drip fertigation at 100 per cent RDF recorded highest total phosphorus uptake over other treatments. Significantly higher total uptake of phosphorus was found with the drip fertigation at 100 per cent RDN as compared to drip irrigation with conventional fertilization as well as drip fertigation (50 per cent RDN as well as 50 per cent RDF).

6.3.7 The drip fertigation with 75 per cent RDF registered highest value of potassium content in seed and straw over other treatments. However, it was comparable to drip fertigation with 100 per cent RDF and 100 per cent RDN. Drip fertigation at 100 per cent RDN, remaining statistically at par with drip fertigation with 75 per cent RDN, drip irrigation with conventional fertilization with 100 per cent and 75 per cent RDF, recorded significantly higher potassium content in seed and straw over drip irrigation with conventional fertilization (50 per cent RDF) as well as drip fertigation (50 per cent RDN and 50 per cent RDF).

6.3.8 Drip fertigation at 75 per cent RDF recorded highest potassium uptake by seed and straw over other treatments and remained at par with drip fertigation at 100 per cent RDF. Further, drip fertigation with 100 per cent RDN, being at par with drip fertigation with 75 per cent RDN, also registered significantly higher potassium uptake by seed and straw as compared to drip fertigation with conventional fertilization, drip fertigation (50 per cent as well as 50 per cent RDF).

6.3.9 The drip fertigation at 100 per cent RDF produced maximum total potassium uptake over other treatments during 2015-16 and 2016-17. Drip fertigation with 100 per cent RDN, remaining at par with drip fertigation with 75 per cent RDN, also improved significantly more total potassium uptake over drip irrigation with conventional fertilization, drip fertigation with 50 per cent RDN as well as 50 per cent and 75 per cent RDF.

6.3.10 The drip fertigation at 75 per cent RDF, recorded highest essential oil content in fennel seed over other treatments. However, it was at par with drip fertigation at 100 per cent RDF and 100 per cent RDN. A further reference to data (Table 4.4) showed that the drip fertigation at 100 per cent RDN, remaining at par with drip fertigation with 75 per cent RDN, also caused significant increase in essential oil content over drip irrigation with conventional fertilization, drip fertigation at 50 per cent RDN as well as 50 per cent RDF.

6.3.11 Drip irrigation with conventional fertilization or drip fertigation had a significant effect on the oil yield of fennel over surface irrigation with conventional fertilization. Among different drip irrigation and fertigation treatments, drip fertigation at 100 per cent RDF, produced highest oil yield in fennel seed over rest of the treatments. The drip fertigation at 100 per cent RDN, recorded statistically higher oil yield of fennel over drip irrigation with conventional fertilization, drip fertigation with 75 per cent and 50 per cent RDN as well as 50 per cent RDF.

6.3.12 The drip fertigation at 100 per cent RDF, produced highest protein content in fennel seed over other treatments. Data further revealed that the drip fertigation with 100 per cent RDN, also significantly enhanced the protein content of fennel as compared to drip irrigation with conventional fertilization, drip fertigation with 75 per cent and 50 per cent RDN as well as 50 per cent RDF.

6.4 Soil moisture studies

6.4.1 Surface irrigation and drip irrigation with conventional fertilization and drip fertigation at various fertilizer levels could not cause perceptible variation in consumptive use of water in fennel.

6.4.2 Drip fertigation at 75 per cent RDF, recorded higher water use efficiency over other treatments, however, it was at par with drip fertigation at 100 per cent RDF and 100 per cent RDN. Data further revealed that drip fertigation with 100 per cent RDN, being at par with drip fertigation at 50 per cent RDF and 75 per cent RDN, also recorded significantly higher water use efficiency over drip irrigation with conventional fertilization and drip fertigation with 50 per cent RDN.

6.5 Economics

6.5.1 The drip fertigation at 75 per cent RDF, exhibited significantly higher net returns of fennel, whereas it remained equally effective with drip fertigation at 100 per cent RDF and 100 per cent RDN. The further examination of data indicated that drip fertigation with 100 per cent

RDN, being at par with drip fertigation with 75 per cent RDN, also attained significantly higher net returns over drip irrigation with conventional fertilization (50 per cent, 75 per cent and 100 per cent RDF) and fertigation with 50 per cent RDN as well as 50 per cent RDF.

6.5.2 Among different drip irrigation and fertigation treatments, drip fertigation with 75 per cent RDF, registered significantly higher B:C (3.13). However, it remained statistically at par with drip fertigation of 100 per cent RDF as well as 100 per cent RDN, 75 per cent RDN and surface irrigation. Data further showed that drip fertigation with 100 per cent RDN, being at par with drip fertigation with 75 per cent RDN and surface irrigation, also recorded significantly higher B : C ratio over drip irrigation with conventional fertilization and drip fertigation with 50 per cent RDN and 50 per cent RDF.

Conclusion

Based on results of two years experimentation, it seems logical to conclude that

1. Drip irrigation and fertigation are an effective way to improve growth, yield, quality and water and fertilizer use efficiency of fennel as compared to surface irrigation and conventional fertilization, respectively.
2. Application of 75 per cent recommended dose of fertilizers (90-40-0 kg/ha) through drip fertigation produced significantly higher seed yield (2516 kg/ha) and net returns (₹ 154162 /ha) over surface irrigation, conventional fertilization as well as other levels of drip fertigation.
3. Therefore, it is recommended that fennel should be grown with drip fertigation of 75 per cent recommended dose of fertilizers.

BIBLIOGRAPHY

A.O.A.C.1990. Official Method of Analysis. Association of Official Analytical Chemists, 1608. Broadnon Drive, Champaign, Illinois, USA.

Abdelraouf, R.E., El Habbasha, F., Taha and Refaie, K.M. 2019. Effect of irrigation water requirements and fertigation levels on growth, yield and water use efficiency in wheat. *Journal of Scientific Research* **16** (4) : 441- 450.

Agrawal, N., Tamrakar, S. K. and Tiwari, R. B. 2018. Impact of fertigation through drip on the cultivation of tomato. *International Journal of Current Microbiology and Applied Sciences* **7** : 4528-4535.

Agrawal, N., Tamrakar, S. K., Tripathi, M. P. and Tiwari, R. B. 2018. Response of cabbage under different levels of irrigation and fertigation through drip. *International Journal of Current Microbiology and Applied Sciences* **6** : 750-759

Ajmalkhan, S. 2000. Effect of irrigation, plant geometry and density under drip-cum-fertigation system on tomato crop (*Lycopersicon esculentum* Mills.) M.Sc. (Ag). Thesis, Tamil Nadu Agricultural University, Coimbatore (T.N.) INDIA.

Ananta, B. 2006. Effect of solid soluble fertilizer applied through fertigation on growth and yield of tomato. *Vegetable Science* **33** (1) : 26-28.

Ankush and Singh, S.K. 2017. Yield, quality, nutrient and water use efficiency of tomato as affected by different fertigation rates through drip irrigation system. *Indian Journal of Agricultural Research* **51** (5) : 478-482

Anonymous, 2017-18. State Agriculture/Horticulture Department/DASD Khozhikkode. Spices Board of India.

Anusha, S., Nagaraju, B.C., Shankaralingappa, Sheshadri, T., Channabasavegowda, R., Shankar, A.G. 2015. Influence of fertigation intervals and fertilizer combinations on growth and yield of direct seeded drip irrigated aerobic rice. *Ecoscan* **9** (1, 2) : 299-303.

Ardell D. Halvorson. 2006. Water use efficiency under different cropping situation. *Annals of Agricultural Research* **27**(5) :115-118.

Arnon, D.I. 1949. Copper enzymes in isolated chloroplast I polyphenol oxidase in *Beta vulgaris. Plant Physiology* **24** : 1-15.

Aujla, M.S., Thind, H.S. and Buttar, G.S. 2007. Fruit yield and water use efficiency of eggplant as influenced by different quantities of nitrogen and water applied through drip and furrow irrigation. *Scientia Horticulture* **112** : 142-148.

Ayyadurai, P. and Manickasundaram, P. 2014. Growth, nutrient uptake and seed cotton yield as influenced by foliar nutrition and drip fertigation in cotton hybrid. *International Journal of Agriculture Science* **10** (1) : 276-279.

Badr, M., Abouhussein, S., El-Tohamy, W. A. and Gruda, N. 2010. Nutrient uptake and yield of tomato under various methods of fertilizer application and levels of fertigation in arid lands. *Gesunde Pflanzen* **62** (1) : 11-19.

Badra, M.A. and Yazied, A.E. 2010**.** Effects of fertigation frequency from sub-surface drip irrigation of tomato yield grown on sandy soils. *Australian Journal Basic Applied Science* **1** : 279-285.

Bandyopadhyay, P.K., Mallick, S. and Rana, S.K. 2005. Water balance and crop coefficient of summer grown peanut (*Arachis hypogaea* L.) in humid tropical region of India. *Irrigation Science* **23**: 161-169.

Barua P. and Hazarika R. 2014. Studies on fertigation and soil application methods alongwith mulching on yield and quality of Assam lemon (*Citrus limon* L. Burmf.). *Indian Journal of Horticulture* **71** (2) : 190-196.

Baskaran, R. and Kavimani, R. 2010. Effect of drip fertgation on growth and yield of cotton. *World Cotton Research Conference on Technologies for Prosperity.* ***Pp. 76.***

Bhalerao, P.D., Gaikwad, G.S. and Imade, S.R. 2011. Productivity and nutrient uptake of Bt-cotton (*Gossypium hirsutum*) as influenced by precision in application of irrigation and fertilizer. *Indian Journal of Agronomy* **56** (2) : 150-153.

Bhanu Rekha, K., Govind Reddy, M., Mahavishnan K. and Bhanu Murthy, V. B. 2009. Moisture extraction pattern of bhindi (*Abelmoschus esculentus* L.moench) as influenced by various levels of drip fertigation. *Indian Journal of Agricultural Research* **43** (1) : 69-72.

Bharati, V. and Prasad, U.K. 2003. Effect of irrigation and sulphur on growth and yield of Indian mustard (*Brassica juncea). Indian Journal of Agricultural Sciences* **73** (1) : 38-40.

Bibe, S.M., Jadhav, K.T. and Chavan, A.S. 2017. Response of irrigation and fertigation management on growth and yield of maize. *International Journal of Current Microbiology and Applied Sciences* **6** (11) : 4054-4060.

Brahma, S., Borbora, D., Phookan, Kachari, M., Kumar, T., Hazarika and Das K. 2010. Growth, yield and economics of broccoli under different levels of nitrogen fertigation. *Indian Journal of Horticulture* ***67*** *(Special Issue) :* 279-282.

Brahma, S., Borbora, D., Phookan, Barua, P. and Saikia, L. 2010. Effect of drip-fertigation on performance of tomato under Assam conditions. *Indian Journal of Horticulture* **67**(1) : 56-60.

Castellanosa, M.T., Tarquis, A.M., Ribas, F., Cabello, M.J., Arced, A. and Cartagena, M.C. 2013. Nitrogen fertigation: An integrated agronomic and environmental study. *Agricultural Water Management* **120** : 46– 55.

Chandel, J.S., Chauhan N. and Gaur, J.A. 2013. Effect of fertigation on growth, yield, fruit quality and fertilizer use efficiency of kiwi fruit (Actini diadeliciosa). *Indian Journal Agricultural Science* **78** : 389-393.

Chanthai, S., Machikowa,T., Wonprasaid, S. and Boonker N. 2013. Effects of fertigation, water application frequency and soil amendment on tomato production. *Acta Horticulture* **9** :187-196.

Chesnin, L. and Yein, C.H. 1950. Turbidimetric determination of available sulphates. (In) *Proceedings of Soil Science Society of America* **15** : 149-151.

Ciba, C. and Syamala, M. 2017. Drip Fertigation's Effect on Nutrient Contents of Chiili (*Capsicum annuum*). *International Journal of Current Microbiology and Applied Sciences* **6** (11) : 3314-3320.

Dastane, N.G. 1972. A practical manual for water use research in agriculture. Nav Bharat Prakashan Poona, India, pp 22-24.

Dingre, S.K., Pawar, D.D. and Kadam, K.G. 2012. Productivity, water use and quality of onion (*Allium cepa*) seed production under different irrigation scheduling through drip. *Indian Journal of Agronomy* **57** : 186-190.

Fanish, A.S. and Muthukrishnan P. 2011. Economic viability of drip fertigation in maize (*Zea mays* L.) based intercropping system. *Madras Agricultural Journal* **98** (10-12) : 339-343.

Fanish, A.S., Muthukrishnan, P. and Manoharan, S. 2011. Drip fertigation in maize (*Zea mays*) based intercropping system. *Indian Journal of Agricultural Research* **45** (3) : 233 – 238.

Fanish, S.A. 2013. Nutrient distribution under drip fertigation systems. *World Journal of Agricultural Sciences* **9** (3) : 277-283, 2013

Fisher, R.A. 1950. *Statistical Methods for Research Workers*. Oliver and Boyd, Edinburg, London, pp 57-63.

Fisher, R.A. and Yates, F. 1963. *Statistical Tables*. Oliver and Boyd, Edinburgh, London, pp 44-56.

Godara, S.R., Verma, I.M., Gaur, J. K., Bairwa, S. and Yadav, P.K. 2013. Effect of different levels of drip irrigation along with various fertigation levels on growth, yield and water use efficiency in fennel (*Foeniculum vulgare* Mill.) *The Asian Journal Of Horticulture* **8** (2). 115-120.

Goswami, S.B., Sarkar, S. and Mallick, S. 2006. Crop growth and fruiting characteristics of Brinjal as influenced by gravity drip. *Indian Journal of Plant Physiology* **11**: 190-194.

Gundlur, S.S. Rajkumara, S. Neelkant, J.K., Ashoka, P. and Kot 2013. Water and nutrient requirement of Bt. Cotton under Malprabha command, Maharastra. *Journal of Agriculture Sciences* **26** (3) : 368-371.

Gupta, A.J., Chatoo, M.A. and Singh, L. 2015. Drip irrigation and fertigation technology for improved yield, quality, water and fertilizer use efficiency in hybrid tomato. *Journal of Agriculture Search* **2** (2) : 94 - 99.

Gupta, A.J., Feza Ahmad, M. and Bhat, F.N. 2010. Studies on yield, quality, water and fertilizer use efficiency of capsicum under drip irrigation and fertigation. *Indian Journal of Horticulture* **67** (2) : 213-218.

Haneef, M., Kaushik, R.A., Sarolia, D.K., Mordia, A. and Dhakar, M. 2014. Irrigation scheduling and fertigation in maize under high density planting system. *Indian Journal of Agronomy* **71** (1) : 45-48.

Harish, J., Pawar, D.D., Kale, K.D., Hasure, R.R. and Dingre, S.K. 2018. Nutrient availability in Bt. cotton under drip fertigation. *International Journal of Current Microbiology and Applied Sciences* **7** (4) : 2319-7706.

Harisha C.B., Diwakar Y., Aishwath O. P., Singh R., and Asangi H. 2017a. Soil fertility and micronutrient uptake by fennel (*Foeniculum vulgare* Mill.) as influenced by micronutrients fertilization. *Environment and Ecology* **35** (1B) : 514 - 518.

Harisha, C.B., Honnappa, A. and Singh, R. 2017b. Impact of drip irrigation and fertigation on residual soil nutrient status, nutrient uptake and nutrient use efficiency of fenugreek under semi arid conditions. *International Journal of Pure and Applied Bioscience* **5** (2) : 661 - 667.

Hebbar, S.S., Ramachandrappa, B.K., Nanjappa,H.V. and Prabhakar, M. 2004. Studies on NPK drip fertigation in field grown tomato (*Lycopersicon esculentum* Mill). *European Journal of Agronomy* **21**: 117-127.

Hebbar, S.S., Ramachandroppa, B.K. And Nanjappa, H.V. 2010. Productivity, water use and quality tomato (*Lycopersicon esculentum* Mill.) of seed production under different irrigation scheduling through drip. *Indian Journal of Agronomy* **57**: 186- 190.

Honnappa A., Harisha, C.B. and Singh, R. 2017. Precision irrigation and fertigation for higher productivity and water use efficiency in fenugreek (*Trigonella foenum-graecum* L.) in semi arid conditions of Rajasthan. *The Bioscan, (Supplement on Agronomy)* **12** (1) : 591 - 594.

Hucheng, A.R., Reddy, A., Santosh, D.T. and Tiwari, K.N. 2014. Effect of irrigation systems and integrated nutrient management on growth, yield and quality of ginger (*Zingiber officinale* rosc.). *International Journal of Current Microbiology and Applied Sciences* **6** (2) : 1471-1483.

Imamsaheb, S.J., Patil, M.G., Naik, M.K., Hussain, Abbas S. and Ayyangoudar, M.S. 2011. Yield, yield components and quality of processing tomato (*Solanum lycopersicum* L.) genotypes as influenced by different levels of fertigation. *Environment & Ecology* **29** (1A) : 229-232.

Jackson, M.L. 1973. Soil Chemical Analysis. Prentice Hall of India Pvt. Ltd., New Delhi.

JACKSON, M.L. 1958. SOIL CHEMICAL ANALYSIS. *PRANTICE HALL ENC. N.J., U.S.D.A.*

Jan Rumpel, J. 2007. Effect of drip irrigation and fertigation on growth and yield of onion. *Vegetable Crops Research Bulletin* **50** : 31-39.

Jat, R., Wani, S., Sahrawat, K., and Piara Singh, D., 2011. Fertigation in vegetable crops for higher productivity and resource use efficiency. *Indian Journal of Fertilizer* **7** : 22-37.

Jayakumara, M., Surendranb , U., and Manickasundaramc, P. 2014. Drip fertigation effects on yield, nutrient uptake and soil fertility of Bt

Cotton in semi arid tropics. *International Journal of Plant Production* **8** (3), ISSN: 1735-6814.

Jena, P. and Aladakatti, Y.R. 2018. Effect of conventional and water soluble fertilizers through fertigation on growth, physiology and yield of bt cotton. *International Journal of Current Microbiology and Applied Sciences* **7** : 752-759.

Kachwaya, D.S. and Chandel, J.S. 2015. Effect of fertigation on growth, yield and nutrients content of capsicum (*Capsicum annum* L. IOSR). *Indian Journal of Agricultural Sciences* **85** (10) : 1319–23.

Kakade, U.S., Lomesh A., Mohurle, J.P. Deshmukh and Anita B.C. 2017. Effect of drip fertigation on growth, yield and economics of pigeonpea. *International Journal of Pure Applied Bioscience* **5** (5) : 1092-1098.

Kakade, U.S., Mohurle, L.A., Bhale, V.M., Deshmukh, J.P. and Gaud, V.V. 2018. Response of split application of nutrients through fertigation on nutrients uptake, nutrient and water use efficiency and yield of pigeon pea. *International Journal of Current Microbiology and Applied Sciences* **6** : 826-833.

Kang, Y., Khan, S. and Xiaoyi, Ma. 2009. Climate change impacts on crop yield, crop water productivity and food security. A Review. *Progress in Natural Science* **19** :1665-1674.

Kanwar, K., Harisha, C.B., Singh, R. and Aadityendra 2018. Growth, seed yield, protein content and water use efficiency of fenugreek (*Trigonella foenum – graceum* L.) as influenced by drip irrigation regimes and fertigation levels. *International Journal of Current Microbiology and Applied Sciences* **7** (8).62-67.

Kapoor, R. Sanjiv, K. S., Sanjay, K. S., Kumar, A. and Saroch, K. 2014. Effect of varying drip irrigation levels and NPK fertigation on soil water dynamics, productivity and water use efficiency of cauliflower in wet temperate zone of Himachal Pradesh. *Indian Journal of Soil Conservation* **4** : 249- 254.

Kapoor, R., Sandal, S.K., Sharma Sanjay, K., Kumar, A. and Saroch, K. 2013. Effect of varying drip irrigation levels and NPK fertigation on soil water dynamics, productivity and water use efficiency of cauliflower (*Brassica oleracea* var. Botrytis. in wet temperate zone of Himachal Pradesh. *Indian Journal of Soil Conservation* **42** : 249-254.

Karangiya, B.A., Mashru, H.H. and Vadher, H.M. 2019. Response of wheat (*Triticum aestivum* L.) under drip fertigation system. *International Journal of Current Microbiology and Applied Sciences* **8** (6) : 2519-2526.

Karthika, N. and Ramanathan, S.P. 2019. Effect of drip fertigation on growth, physiological parameters and grain yield of rice grown in Cauvery new delta zone of Tamil Nadu. *International Journal of Chemical Studies* **7** (3) : 2758-2761

Kaushal, A., Patole, R. and Singh, K. G. 2012. Drip irrigation in sugarcane: A review, Agriculture Review, **33** : 211–219.

Kavino, M., Kumar, N., Soorianathasundaram, K. and Jeyakumar, P. 2008. Effect of fertigation on the growth and development of maize under high density planting system. *Indian Journal of Agronomy* **61** : 39-41.

Khan, M.M., Shivashankar, K., Krishna Manohar, R., Sree Rama, R. and Kasiyanna 2003. Fertigation in horticultural crops. In: Proc. *Advances in Micro Irrigation and Fertigation* : 181-197.

Kombali, G., Nagaraju, T., Sheshadri, M.N., Thimmegowda and Mallikarjuna, G.B. 2017. Effect of water soluble fertilizers on growth and yield of drip irrigated aerobic rice. *International Journal of Agricultural Science* **9** (15): 4101-4103.

Krishnamoorthy, C., Rajamani, K. and Kumar, N. 2013. Effect of fertigation through drip and micro sprinkler on physiological parameters in cocoa (*Theobroma cacao* L.). *Madras Agricultural Journal* **100** (1-3) : 153-159.

Krishnasamy, S., Mahendran, P. P., Gurusamy, A. and Babu, R. 2012 . Optimization of Nutrients for Hybrid Maize Under Drip Fertigation System. *Madras Agricultural Journal* **99** (10-12) : 799-802.

Kumar, H., Kotoky, U. and Devee, A. 2013. Effect of drip fertigation on growth and yield of cauliflower. *Asian Journal of Horticulture* **8** (2) : 534-536.

Kumari, R. and Kaushal, A. 2014. Drip fertigation in sweet pepper: *A Review. International Journal of Engineering Research and Applications* **4** (8) : 144-149.

Kusuma, M.V., Venkatesha, J., Ganghadarappa, P.M., Hiremath, J.S., Mastiholi, A.B. and Manjunatha, G. 2019. Effect of integrated nutrient management on growth and yield of fennel (*Foeniculum vulgare* Mill.). *International Journal of Current Microbiology and Applied Sciences* **8** (1) : 2319 - 7706.

Lindsay, W.L. and Norvell, W.A. 1978. Development of DTPA soil test for Zn, Fe, Mn and Cu. *Soil Science Society of American Journal* **42** : 421-428.

Magare, P. N., Katkar, R. N. and Jadhao, S. D. 2018. Effect of fertigation on yield, quality and soil fertility status under cotton grown in Vertisol. *International Journal of Chemical Studies,* **6** (2) : 42-46.

Magdi, A.T., Salim E. M. and Ghamry, A. M. 2011. Integrated effects of bio and mineral fertilizers and humic substances on growth, yield and nutrient contents of fertigated cowpea (*Vigna unguiculata* L.) grown on sandy soils. *Journal of Agronomy* **10** (1) : 34- 39.

Malve, S. 2017. Impact of drip irrigation and N-fertigation scheduling on wheat (*Triticum aestivum*) under semi-arid tropical environment. *Indian Journal of Agricultural Sciences* **87**(5) : 580-588.

Meena, M., Sagarka, B.K. and Man, M.K. 2017. Influence of drip irrigation along with nitrogen levels on yield attributes, yield and quality parameters of rabi drill fennel (*Foeniculum vulgare* Mill). *International Journal of Current Microbiology and Applied Sciences* **6** (5) : 2115-2121.

Menaria, B.L. and Maliwal, P.L. 2007. Maximization of seed yield in transplanted fennel (*Foeniculum vulgare* Mill.). *Journal of Spices and Arometic Crop* **16** (1) : 46 - 49.

Metson, A.J. 1956. Methods of Chemical Analysis for Soil Survey Samples. *New Zealand Soil Bureau Bulletin* **12** : 208.

Mevada, K.D., Gamar, P., Ombase, K.C., Bhadane, R.S. and Patel, P.D. 2018. Influence of integrated nutrient management on yield, quality and nutrient status of drilled *rabi* fennel (*Foeniculum vulgare* Mill.). *Journal of Pure and Applied Microbiology* ***11*** (2) : 90 – 93.

Ngouajio, M. Guangyao, W. and Ronald, G. 2007. Withholding of drip irrigation between transplanting and flowering increases the yield of field grown tomato under plastic mulch. *Agricultural water management* **87**: 285-291

Nijamudeen, M. S., Singh, M., Khanna, M., Singh, B., Singh, R. Pandey, R. N. and Hasan, M. 2013. N and K fertilizer application rate under drip-fertigation for greenhouse grown sweet pepper. *Indian Journal of Horticulture* **70** (1) : 54-59.

Olsen, S.R., Cole, V.C., Watamable, F.S. and Dean, L.A. 1954. Estimation of available phosphorus in soil by extraction with $NaHCO_3$. *Circular*. United States Department of Agriculture, pp. 939.

Padmaja, B. and Malla Reddy, M. 2018. Drip irrigation and fertigation effects on aerobic rice (*Oryza sativa*) in semi-arid conditions of Telangana State, India. *International Journal of Current Microbiology and Applied Sciences* **7** (8) : 1156-1171.

Patel, R.A., Patel, J.J. and Patel, A.S. 2010. Seed yield and net returns of drip irrigated late *kharif* castor (*Ricinus communis* L.) as influenced by plant geometry and nitrogen levels. *International Journal of Agricultural Sciences* **6** (2) PP: 449.

Patel, D.B., Patel, R.H. and Patel, R.B. 2009. Effect of irrigation, mulching and fertigation on yield and yield attributes of okra (*Abelmoschus esculentus*). *Indian Journal of Agriculture Science* **79** (1) : 12-15.

Patil, K.V.O. and Das, J.C. 2015. Effect of Drip Irrigation and Fertilizer Management on Capsicum (*Capsicum annum* L. IOSR). *Journal of Agriculture Veterinary Science* **8** (1) : 10-13.

Patil, S.J., Patel, B.M., Raval, C.H., Patel, K.I., Patel, P.B., Patel P.M. and Vekaria, L.C. 2014. Response of vegetable clusterbean (*Cymompsis tetragonaloba* L. Taub.) to fertigation of P and K. *Legume Research* **37** (4): 420- 423.

Pawar, D.D., Dingre, S.K. and Surve, U.S. 2014. Split application of nutrients through fertigation in *Bt* cotton. *Journal of Cotton Research and Development* **28** (2): 238-242.

Pawar, D.D. and Dingre, S.K. 2013. Influence of fertigation scheduling through drip on growth and yield of maize in western Maharashtra. *Indian Journal of Agronomy* **70** (2) *: 200-205.*

Pawar, D.D., Dingre, S.K. and Surve, U.S. 2013. Growth, yield and water use in sugarcane (*Saccharum officinarum*) under drip Fertigation. *Indian Journal of Agronomy* **58** (3) : 396 - 401.

Piper, C.S. 1950. Soil and Plant Analysis. The University of Adelide, Australia. International Service Publisher Inc., New Delhi, pp.47-79.

Pramanik, S. and Patra, S. K. 2015. Effect of drip *vis-à-vis* surface irrigation on yield, nutrient uptake, water use efficiency and quality of sugarcane. *Indian Journal of Agronomy* **72** (1) : 7-13*.*

Radford, P.J. 1967. Growth analysis formulae-their use and abuse. *Crop Science,* 7 : 171-175.

Rajak, D., Mittal H.K., Bhakar, S.R., Lakhawat, S. S., Jain, H. K. and Yadav, K. K. 2015. Effect of drip irrigation and fertigation levels on growth, yield and water use efficiency of cabbage. *Green Farming* **6** (6) : 25-30.

Rajaraman, N., Verma, S. and Rajput, B.S. 2010. Effect of drip tape placement depth and irrigation level on yield of coriander. *Agricultural Water Manage*ment **88** : 209 – 223.

Rajendran, K. and Arunvenkatesh, S. 2014. Nutrient dynamics under drip fertigation in cotton. *Indian Journal of Agronomy* **2** (1-2) : 37-41.

Ram Pratap, Meena, N.L. and Balbir Singh 2010. Productivity and nutrient content of fennel (*Foeniculum vulgare* Mill.) as influenced by different levels of nitrogen and sulphur. *National Seminar on Precision Farming in Horticulture*, 479.

Ramah, K. 2008. Study on drip irrigation in maize (*Zea mays* L.) based cropping system. Ph.D., Thesis, TNAU, Coimbatore, India, pp 55-59.

Ramah, K., Santhi, P. and Ponnuswamy, K. 2011. Economic viability of drip fertigation in maize(*Zea mays* L.) based cropping system. *Madras Agricultural Journal* **97** (1-3): 12-16.

Ramniwas, Kaushik, R.A., Sarolia, D.K., Sunil Pareek and Singh, V. 2012. Effect of irrigation and fertigation scheduling on growth and yield of Brinjal. *African Journal of Agriculture Research* **7** (47) : 6350- 6356.

Rao, D. K. and Subramanyam, K. 2009. Effect of nitrogen fertigation on growth and yield of maize under low rainfall zone. *Agriculture Science Digest* **29** (2).

Rathore, P.S. and Gaur, J.K. 2010. Pressurized irrigation. A need based innovation in precision farming National seminar on precision farming in horticulture. 18 December, 2010 Jhalawar (Rajasthan).

Ravikumar, V., Vijayakumar, G., Simunek, J., Chellamuthu, S. Santhi, R. and Appavu, K. 2011. Evalution of fertigation scheduling using a vadose zone flow and transport model. *Agricultural Water Management* **98** : 1431- 1440.

Reddy, J.S.V. and Krishnamurthy, R. 2017. Yield, nutrient and water use efficiency and economics of maize as influenced by levels of irrigation and fertigation. *An Asian Journal of Soil Science* **12** : 181-186.

Reitemier, R.F. 1943. Semi-micro analysis of saline soils solution. *Indus and Engin. Chem. Analyt.* Ed. **15** : 393-402.

Richards, L.A. (Ed.) 1954. Diagnosis and improvement of saline and alkali soils. *United States Department of Agronomy, Hand Book No.* 60, Washington, DC, USA, pp 43-49.

Richards, L.A. 1968. Diagnosis and improvement of saline and alkali soils. *United States Department of Agronomy, Hand Book No.* 60 Oxford and IBH Publication Company, New York, pp. 66-69.

Richter, C. 2004. Fertigation of onion crops by using surface irrigation in Sudan. Rural poverty reduction through research for development. *Deutscher Tropentag*, **6** (4) : 5-7.

Roy, S.S., Khan, M.S.I. and Pall, K.K. 2011. Nitrogen and phosphorus efficiency on the fruit size and yield of capsicum. *Journal of Experimental Sciences* **2** : 32-37.

Sadarunnisa, S., Madhumathi, C., Hari Babu, K., Sreenivasulu, B., Rama Krishna, M. 2010. Effect of fertigation on growth and yield of tomato. *Acta Horticulture* 851: 61.

Sampathkumar, T, and Pandian, B.J. 2010. Effect of Fertigation Frequencies and Levels on Growth and Yield of Maize. *Madras Agricultural J*ournal **97** (7-9): 245-248.

Sampathkumar, T. and Pandian, B.J. 2011. Nutrient uptake rate and relationship with grain yields of hybrid maize under drip fertigation. *Madras Agricultural J*ournal **98** (4-6) : 151-153.

Savitha, B. K., Paramaguru, P. and Pugalendhi, L. 2010. Effect of drip fertigation on growth and yield of onion. *Indian Journal of Horticulture* **67**(Special Issue) : 334-336.

Selim, S.M., Ebtsam, M.M., Abdella, Tawfik, M.S.H. and Abou- Sreea, A.I. 2013. Effect of sowing date, sow spacing and bio-fertilizer on yield and oil quality of fennel plant (*Foeniculum vulgare* Mill.). *Australian Journal of Basic and Applied Sciences* **7** (2) : 882 – 894.

Selvakumar, T. 2006. Performance evaluation of drip fertigation on growth, yield and water use in hybrid chilli (*Capsicum annuum* L.). (Ph.D.) Thesis, Tamil Nadu Agricultural University, Coimbatore, T.N. (INDIA).

Sharmasarkar, C. F., S. Sharmasarkar, S.D. Miller, G.F. Vance, R. Zhang. 2001. Assessment of drip and flood irrigation on water and fertilizer use efficiencies for sugar beets. *Journal of Agriculture Water Management* **46** : 241-251.

Sharma, P. and Kaushal, A. 2015. Economics of growing okra under drip fertigation. *Indian Journal of Science and Technology* **8** (35).

Sharma, S., Halder, A., Patra, S. K. and Ray, R. 2012. Effect of drip irrigation and nitrogen fertigation on water use efficiency (WUE) and cost economics of guava cv. *Khaja, Prog Horti*, **44** : 136-141.

Shedeed, S.I., Zaghlout, S.M. and Yassen, A.A. 2009. Effect of method and rate of fertilizer application under drip Irrigation on yield and nutrient uptake by tomato. *Ozean Journal of Applied Sciences* **2** (2):51-56.

Shinde, P.P., More, V.G., Ramteke, J.R. and Chavan, S.A. 2002. Response of brinjal to fertigation. *Journal of Maharashtra Agriculture University* **27** (3) : 260-262.

Shinde, P.P., More, V.G., Ramteke, J.R. and Chavan, S.A. 2006. Effect of drip irrigation and fertigation on growth, yield and quality of brinjal. *Journal of Maharashtra Agriculture University* **27** (3) : 260-262.

Shruthi M. K., Sheshadri, T. and Yogananda, S. B. 2018. Performance of Hybrid Maize as Influenced by Fertigation Management Practices.

International Journal of Current Microbiology and Applied Sciences **7** (3):13-17.

Shruti, M. Y. and Aladakatti, Y.R. 2017. Effect of drip irrigation and fertigation on yield, economics and water use efficiency of *Intra-Hirsutum* Bt Cotton. *Journal of Farm Science* **30** (2) : 185-189.

Singandhupe, B. R., Roy, S.N., and Patil, N.G. 2005. Fertigation studies and irrigation scheduling in drip irrigation system in maize crop. *Europian Journal of Agronomy* **19** : 327-340.

Singandhupe, R.B., James, B.K., Edanna, Anthony, Nanda, P. and Behera, M.S. 2007. Response of fertigation and mulching on growth and fruit yield of pointed gourd (*Trichosanthes dioica*). *Indian Journal of Agricultural Sciences* **77** (1) : 8-13.

Singh , G. K. Yadav, R. L. and Shukla, S. K. 2010. Effect of planting geometry, nitrogen and potassium application on yield and quality of ratoon sugarcane in sub-tropical climatic conditions. *Indian Journal of Agricultural Sciences* **80** (12) : 1038 -1042.

Singh, A.K. and Pandey, A.K. 2014. Dynamics of anthracnose disease of chilli in responses to water and nitrogen management under drip and flood irrigation. *Journal of Agriculture Research* **1** (3) : 151-160.

Singh, I.D. and Stoskopf, Y.C. 1971. Harvest index in cereals. *Agronomy Journal* **63** : 224-226.

Singh, R. and Bishnoi, O.P. 2005. Effect of rainfall variability on crop maturity in arid regions of Haryana-A case study. *International Journal of Tropical Agriculture* **1** (4): 317-324.

Singh, V., Sharma, S.P., Spehia, S.R. and Kumar, P. 2018. Influence of irrigation methods and fertilizer levels on productivity of pigeonpea

(*Cajanus cajan* L. Millsp.). *Indian Journal of Agriculture Sciences* **82** : 117–121.

Singh, Y., Singh, C.S., Singh, A., Singh A.K and Singh, K. 2005. Fertigation a key for Hi-Tech Agriculture. *Agriculture Water Management* **52** (7): 128-149.

Snedecor, G. W. and Cochran, W.G. 1968. Statistical methods. Oxford and IBH Publication Company, New Delhi, pp. 62-69.

Snell, P.D. and Snell, G.T. 1949. *Colorimetric methods of analysis*, 3rd Edn. II Van Nostrand Co. Inc., New York.

Soil Survey Staff, 1975. Soil Taxonomy : A basic system of soil classification for making and interpreting soil surveys. USDA Hand Book No. 16 pp. 436.

Solaimalai, A., Baskar, M., Sadasakthi, A. and Subburamu, K. 2005. Fertigation in high value crops. *Agriculture Revision* **26** (1) : 1-13.

Sonu, Harisha, C.B., Singh, B., Diwakar, Y., Aishwath, O.P., Singh, R., Rothore, S.S. and Asangi, H. 2016. Impact of micronutrients application on growth and yield attributes of fennel (*Foeniculum vulgare* Mill.). *International Journal of Seed Spices* **6** (1) : 54 - 65.

Subbiah, B.V. and Asija, G.L. 1956. A rapid procedure for the estimation of available nitrogen in soils. *Current Science,* **XXV**(8): 259-260.

Tanaskovik, V., Cukaliev, O., Romić, D., and Ondrašek, G. 2011. The influence of drip fertigation on water use efficiency in tomato crop production. *Agriculture Conspectus Scientificus* **76** : 57-63.

Tumbare, A.D. and Bhoite, B.U. 2002. Effect of solid soluble fertilizer applied through fertigation on growth and yield of chilli (*Capsicum annum*). *Indian Journal of Agriculture Sciences* **72** (2) : 109-111.

Tumbare, A.D. and Nikam, D.R. 2004. Effect of planting and fertigation on growth and yield of green chilli (*Capsicum annuum* L.). *Indian Journal of Agriculture Sciences* **74** (5) : 242-245.

Ughade, S. R. and Mahadkar, U. V. 2014. Effect of planting density, irrigation and fertigation levels on water saving and water use efficiency of brinjal (*Solanum melongena* L.). *Advance Research Journal of Crop Improvement* **5** (2) : 114-117.

Vanita, C.B. 2008. Optimal nitrogen application for direct seeding early rice. *Indian Journal of Agricultural Sciences* **16** : 346-350.

Veeranna, H. K. 2000. Effect of drip irrigation on nutrient uptake, water use efficiency and quality of dry chilli. *South Indian Horticulture* **49** : 101-103.

Veeranna, H.K., Kgalakabdul, A.A. and Sujith, G.M. 2001. Effect of fertigation with normal and water soluble fertilizers compared to drip and furrow methods on yield, fertilizer and irrigation water use efficiency in chilli. *Micro Irrigation* 461-466.

Veeraputhiran, R. Balasubramanian, R., Pandian, B. J. Chelladurai, M. Tamilsevi, R. and Ranganathan, V. G. 2012. Effect of sub surface drip fertigation on cane yield, water use efficiency and economics of sugarcane. *Madras Agricultural Journal* **99** (4-6) : 255 – 258.

Veeraputhiran, R.O.S., Kandasamy and Sunder Singh, S.D. 2002. Effect of drip irrigation and fertigation on growth and yield of hybrid cotton. *Journal of Agriculture Resource Management* **1** (20) : 88 – 97.

Viets, Jr. F.C. 1961. Fertilization and efficient use of water. *Advances in Agronomy* **14**: 223-264.

Vijayakumar, G., Tamilmani, D. and Selvaraj, P. K. 2010. Irrigation and Fertigation Scheduling under drip Irrigation in Brinjal crop. *Indian Journal of Bioresource Management* **1**: 72-76.

Watson, D.J. 1958. The dependence of net assimilation rate on leaf area index. *Annals of Botany*, London, **22**(85) : 37-54.

Yadav, B. S. and Chauhan, R.P.S. 2016. Drip Fertigation Technology for Enhancing Water and Nutrient Use Efficiency in Arid Agro-ecosystem of Irrigated North-Western Rajasthan. *Annals of Arid Zone* **55** (3 & 4) : 139-145.

Yadav, H.K., Pathak, A. and Sujith, A.M. 2012. Effect of fertigation and irrigation methods on yield, water and fertilizer use efficiencies in chilli. *South Indian Horticulture* **49** : 101-104.

NNEXURE -I

Analysis of variance (MSS) for plant stand/meter row length

Source of variation	d.f.	Mean sum of squares			
		Plant stand/meter row length			
		35 DAS		At harvest	
		2015-16	2016-17	2015-16	2016-17
Replication	2	0.801	0.777	0.007	0.848
Treatment	9	0.094	0.104	0.127	0.127
Error	18	0.158	0.153	0.085	0.133

* Significant at 5 % level of significance

ANNEXURE -II

Pooled analysis of variance (MSS) for plant stand/meter row length

Source of variation	d.f.	Mean sum of squares	
		Plant stand/meter row length	
		35 DAS	At harvest
Replication within year (R/Y)	4	0.789	0.428
Treatment	9	0.197*	0.251*
Year	1	953.583	935.201
YT	9	0.101	0.130
Pooled Error	36	0.155	0.109

* Significant at 5 % level of significance

ANNEXURE -III

Analysis of variance (MSS) for plant height

Source of variation	d.f.	Mean sum of squares							
		Plant height (cm)							
		35 DAS		70 DAS		105 DAS		At harvest	
		2015-16	2016-17	2015-16	2016-17	2015-16	2016-17	2015-16	2016-17
Replication	2	6.44	292.34	0.08	3.98	0.80	32.07	3.41	156.44
Treatment	9	773.11*	807.84*	13.74*	17.75*	85.59*	97.35*	393.90*	433.78*
Error	18	36.96	44.13	0.48	0.61	3.81	4.85	18.63	23.50

* Significant at 5 % level of significance

ANNEXURE -IV

Pooled analysis of variance (MSS) for plant height

Source of variation	d.f.	Mean sum of squares			
		Plant height (cm)			
		35 DAS	70 DAS	105 DAS	At harvest
Replication within year (R/Y)	4	149.39	2.03	16.44	79.93
Treatment	9	1578.48*	31.34*	182.69*	827.10*
Year	1	329135.82	4338.54	34551.29	169867.96
YT	9	792.94	15.90	91.71	414.42
Pooled Error	36	40.55	0.54	4.33	21.06

* Significant at 5 % level of significance

ANNEXURE -V

Analysis of variance (MSS) for dry matter accumulation /metre row length

Source of variation	d.f.	Mean sum of squares							
		Dry matter accumulation /metre row length (g)							
		35 DAS		70 DAS		105 DAS		At harvest	
		2015-16	2016-17	2015-16	2016-17	2015-16	2016-17	2015-16	2016-17
Replication	2	0.068	4.089	1.445	70.344	5.496	267.483	15.513	754.944
Treatment	9	4.209*	3.678*	118.124*	106.272*	449.167*	404.099*	1267.729*	1140.528*
Error	18	0.541	0.620	9.705	10.578	36.905	40.221	104.160	113.521

* Significant at 5 % level of significance

ANNEXURE -VI

Pooled analysis of variance (MSS) for dry matter accumulation /metre row length

Source of variation	d.f.	Mean sum of squares			
		Dry matter accumulation /metre row length (g)			
		35 DAS	70 DAS	105 DAS	At harvest
Replication within year (R/Y)	4	2.079	35.895	136.490	385.228
Treatment	9	7.876*	224.120*	852.214*	2405.290*
Year	1	4996.292	85402.229	324741.976	916551.754
YT	9	3.955	112.474	427.684	1207.096
Pooled Error	36	0.580	10.141	38.563	108.840

* Significant at 5 % level of significance

ANNEXURE -VII

Analysis of variance (MSS) for branches per plant and chlorophyll content

Source of variation	d.f.	Mean sum of squares			
		Branches per plant		Chlorophyll content (mg/g)	
		2015-16	2016-17	2015-16	2016-17
Replication	2	0.815	0.633	0.001	0.001
Treatment	9	2.274*	2.421*	0.226*	0.197*
Error	18	0.162	0.120	0.002	0.002

* Significant at 5 % level of significance

ANNEXURE -VIII

Pooled analysis of variance (MSS) for branches per plant and chlorophyll content

Source of variation	d.f.	Mean sum of squares	
		Branches per plant	Chlorophyll content (mg/g)
Replication within year (R/Y)	4	0.724	0.001
Treatment	9	4.690*	0.423*
Year	1	1023.136	72.641
YT	9	2.352	0.212
Pooled Error	36	0.141	0.002

* Significant at 5 % level of significance

ANNEXURE -IX
Analysis of variance (MSS) for crop growth rate (CGR)

Source of variation	d.f.	Mean sum of squares							
		Crop growth rate (g/m^2/day)							
		0-35 DAS		35-70 DAS		70-105 DAS		105-At harvest	
		2015-16	2016-17	2015-16	2016-17	2015-16	2016-17	2015-16	2016-17
Replication	2	0.003	0.002	0.034	0.024	0.053	0.038	0.104	0.074
Treatment	9	0.003*	0.003*	0.064*	0.058*	0.087*	0.078*	0.170*	0.153*
Error	18	0.001	0.000	0.007	0.005	0.010	0.007	0.020	0.014

* Significant at 5 % level of significance

ANNEXURE -X
Pooled analysis of variance (MSS) for crop growth rate

Source of variation	d.f.	Mean sum of squares			
		Crop growth rate (g/m^2/day)			
		0-35 DAS	35-70 DAS	70-105 DAS	105-At harvest
Replication within year (R/Y)	4	0.003	0.029	0.046	0.089
Treatment	9	0.006*	0.121*	0.165*	0.322*
Year	1	4.079	40.070	62.919	122.580
YT	9	0.003	0.061	0.083	0.161
Pooled Error	36	0.001	0.006	0.009	0.017

* Significant at 5 % level of significance

ANNEXURE -XI
Analysis of variance (MSS) for relative growth rate (RGR)

Source of variation	d.f.	Mean sum of squares					
		Relative growth rate (mg/g/day)					
		35-75 DAS		75-105 DAS		105 – at harvest	
		2015-16	2016-17	2015-16	2016-17	2015-16	2016-17
Replication	2	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
Treatment	9	0.0001*	0.0001*	0.0001*	0.0001*	0.0001*	0.0001*
Error	18	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001

* Significant at 5 % level of significance

ANNEXURE -XII
Pooled analysis of variance (MSS) for relative growth rate (RGR)

Source of variation	d.f.	Mean sum of squares		
		Relative growth rate (mg/g/day)		
		35-75 DAS	75-105 DAS	105 – at harvest
Replication within year (R/Y)	4	0.0001	0.0001	0.0001
Treatment	9	0.0001*	0.0001*	0.0001*
Year	1	0.0356	0.0089	0.0193
YT	9	0.0001	0.0001	0.0001
Pooled Error	36	0.0001	0.0001	0.0001

* Significant at 5 % level of significance

ANNEXURE -XIII

Analysis of variance (MSS) for yield attributes

Source of variation	d.f.	Mean sum of squares							
		Umbels/plant		Umbellets per umbel		Seeds per umbel		Test weight (g)	
		2015-16	2016-17	2015-16	2016-17	2015-16	2016-17	2015-16	2016-17
Replication	2	14.221	14.078	8.553	9.747	149.183	2557.748	0.160	0.649
Treatment	9	48.282*	41.930*	32.063*	33.860*	8576.361*	8728.706*	1.190*	1.328*
Error	18	3.187	2.808	1.602	1.975	468.338	511.087	0.092	0.127

* Significant at 5 % level of significance

ANNEXURE -XIV

Pooled analysis of variance (MSS) for yield attributes

Source of variation	d.f.	Mean sum of squares			
		Umbels/plant	Umbellets per umbel	Seeds per umbel	Test weight (g)
Replication within year (R/Y)	4	14.150	9.150	1353.466	0.405
Treatment	9	90.084*	65.782*	17278.915*	2.508*
Year	1	19192.320	13220.158	3492440.344	840.056
YT	9	45.234	33.102	8678.685	1.269
Pooled Error	36	2.997	1.789	489.712	0.110

* Significant at 5 % level of significance

ANNEXURE -XV

Analysis of variance (MSS) for seed, straw, biological yields and harvest index

Source of variation	d.f.	Mean sum of squares							
		Seed yield (kg/ha)		Straw yield (kg/ha)		Biological yield (kg/ha)		Harvest index (%)	
		2015-16	2016-17	2015-16	2016-17	2015-16	2016-17	2015-16	2016-17
Replication	2	116494.06	104318.02	853165.97	1085402.26	1600165.36	1412727.12	18.59	18.94
Treatment	9	284408.37*	240284.20*	3291878.97*	3074061.33*	5509857.03*	5028421.13*	1.46	2.59
Error	18	23127.35	20670.32	170889.28	195594.04	319643.11	280268.63	3.65	3.74

* Significant at 5 % level of significance

ANNEXURE -XVI

Pooled analysis of variance (MSS) for seed, straw, biological yields and harvest index

Source of variation	d.f.	Mean sum of squares			
		Seed yield (kg/ha)	Straw yield (kg/ha)	Biological yield (kg/ha)	Harvest index (%)
Replication within year (R/Y)	4	110406.04	969284.11	1506446.24	18.77
Treatment	9	523361.60*	6359621.48*	10526841.91*	3.93
Year	1	141486667.82	1042544547.30	1952116852.60	21962.21
YT	9	263677.26	3189288.97	5280575.35	2.14
Pooled Error	36	21898.83	183241.66	299955.87	3.69

* Significant at 5 % level of significance

ANNEXURE -XVII

Analysis of variance (MSS) for N content, uptake by seed and straw and total uptake

Source of variation	d.f.	Mean sum of square									
		N content (%)				N uptake (kg/ha)				Total N uptake (kg/ha)	
		seed		Straw		Seed		Straw			
		2015-16	2016-17	2015-16	2016-17	2015-16	2016-17	2015-16	2016-17	2015-16	2016-17
Replication	2	0.032	0.030	0.010	0.008	26.287	15.426	36.345	26.205	124.421	71.519
Treatment	9	1.645*	1.265*	0.051*	0.034*	1410.397*	940.972*	684.021*	452.153*	4035.897*	2684.015*
Error	18	0.009	0.009	0.002	0.002	7.711	4.744	7.732	5.589	30.558	14.214

* Significant at 5 % level of significance

ANNEXURE -XVIII

Pooled analysis of variance (MSS) for N content, uptake by seed and straw and total uptake

Source of variation	d.f.	Mean sum of square				
		N content (%)		N uptake (kg/ha)		Total N uptake (kg/ha)
		Seed	Straw	Seed	Straw	
Replication within year (R/Y)	4	0.031	0.009	20.857	31.275	97.970
Treatment	9	2.893*	0.083*	2325.943*	1120.831*	6646.912*
Year	1	68.847	12.465	36854.443	46223.562	165369.374
YT	9	1.473	0.044	1201.112	583.430	3432.956
Pooled Error	36	0.009	0.002	6.228	6.660	22.386

* Significant at 5 % level of significance

ANNEXURE -XIX

Analysis of variance (MSS) for P content, uptake by seed and straw and total uptake

Source of variation	d.f.	Mean sum of square									
		P content (%)				P uptake (kg/ha)				Total P uptake (kg/ha)	
		Seed		Straw		Seed		Straw			
		2015-16	2016-17	2015-16	2016-17	2015-16	2016-17	2015-16	2016-17	2015-16	2016-17
Replication	2	0.005	0.003	0.001	0.000	2.199	1.390	2.719	1.477	9.808	5.733
Treatment	9	0.018*	0.014*	0.003*	0.002*	28.940*	19.732*	43.829*	31.066*	143.927*	99.946*
Error	18	0.001	0.001	0.000	0.000	0.479	0.260	0.603	0.282	2.156	1.082

* Significant at 5 % level of significance

ANNEXURE -XX

Pooled analysis of variance (MSS) for P content, uptake by seed and straw and total uptake

Source of variation	d.f.	Mean sum of square				
		P content (%)		P uptake (kg/ha)		Total P uptake(kg/ha)
		Seed	Straw	Seed	Straw	
Replication within year (R/Y)	4	0.004	0.001	1.795	2.098	7.770
Treatment	9	0.032*	0.005*	48.174*	74.247*	241.714*
Year	1	5.583	0.880	2765.960	3287.325	12070.701
YT	9	0.016	0.003	24.835	38.095	124.094
Pooled Error	36	0.001	0.000	0.370	0.443	1.619

** Significant at 1 % level of significance

ANNEXURE -XXI

Analysis of variance (MSS) for K content, uptake by seed and straw and total uptake

Source of variation	d.f.	Mean sum of square									
		K content (%)				K uptake (kg/ha)				Total K uptake (kg/ha)	
		Seed		Straw		Seed		Straw			
		2015-16	2016-17	2015-16	2016-17	2015-16	2016-17	2015-16	2016-17	2015-16	2016-17
Replication	2	0.002	0.002	0.007	0.006	1.029	0.753	26.207	18.825	37.619	27.110
Treatment	9	0.003*	0.004*	0.012*	0.013*	8.255*	7.567*	275.440*	263.328*	379.000*	360.046*
Error	18	0.000	0.000	0.001	0.001	0.208	0.141	5.394	3.545	7.719	5.095

* Significant at 5 % level of significance

ANNEXURE -XXII

Pooled analysis of variance (MSS) for K content, uptake by seed and straw and total uptake

Source of variation	d.f.	Mean sum of square				
		K content (%)		K uptake (kg/ha)		Total K uptake (kg/ha)
		Seed	Straw	Seed	Straw	
Replication within year (R/Y)	4	0.002	0.007	0.891	22.516	32.365
Treatment	9	0.007*	0.025*	15.799*	538.056*	738.093*
Year	1	2.753	9.495	1335.613	34206.690	49060.091
YT	9	0.004	0.013	7.934	270.096	370.476
Pooled Error	36	0.000	0.001	0.174	4.470	6.407

** Significant at 1 % level of significance

ANNEXURE -XXIII

Analysis of variance (MSS) for volatile oil content, oil yield and protein content

Source of variation	d.f.	Mean sum of square					
		Volatile oil content in seed (%)		**Oil yield (kg/ha)**		**Protein content in seed (%)**	
		2015-16	**2016-17**	**2015-16**	**2016-17**	**2015-16**	**2016-17**
Replication	2	0.045	0.036	21.723	15.660	1.952	1.206
Treatment	9	0.138*	0.158*	249.756*	226.468*	64.261*	49.428*
Error	18	0.009	0.007	4.596	2.963	0.502	0.348

* Significant at 5 % level of significance

ANNEXURE -XXIV

Pooled analysis of variance (MSS) for Volatile oil content, oil yield and protein content

Source of variation	d.f.	Mean sum of square		
		Volatile oil content in seed (%)	**Oil yield (kg/ha)**	**Protein content in seed (%)**
Replication within year (R/Y)	4	0.040	18.691	1.579
Treatment	9	0.294*	475.515*	113.001*
Year	1	57.580	28261.398	2689.337
YT	9	0.149	238.822	57.532
Pooled Error	36	0.008	3.779	0.425

** Significant at 1 % level of significance

ANNEXURE -XXV

Analysis of variance (MSS) for consumptive use and water use efficiency

Source of variation	d.f.	Mean sum of squares			
		Consumptive use (mm)		Water use efficiency (kg/ha-mm)	
		2015-16	2016-17	2015-16	2016-17
Replication	2	707.921	5355.971	0.191	0.602
Treatment	9	34.667*	110.133*	1.791*	1.382*
Error	18	402.661	832.587	0.110	0.092

* Significant at 5 % level of significance

ANNEXURE -XXVI

Pooled analysis of variance (MSS) for consumptive use and water use efficiency

Source of variation	d.f.	Mean sum of squares	
		Consumptive use (mm)	Water use efficiency (kg/ha-mm)
Replication within year (R/Y)	4	3031.946	0.396
Treatment	9	91.733*	3.156*
Year	1	5201554.800	855.712
YT	9	125.467	1.602
Pooled Error	36	617.624	0.101

* Significant at 5 % level of significance

ANNEXURE -XXVII

Analysis of variance (MSS) for fertilizers use efficiency

Source of variation	**d.f.**	**Mean sum of squares**	
		Fertilizers use efficiency (kg/ha)	
		2015-16	**2016-17**
Replication	2	18.615	10.745
Treatment	9	137.030*	125.365*
Error	18	4.214	3.117

* Significant at 5 % level of significance

ANNEXURE -XXVIII

Pooled analysis of variance (MSS) for fertilizers use efficiency

Source of variation	d.f.	**Mean sum of squares**
		Fertilizers use efficiency (kg/ha)
Replication within year (R/Y)	4	14.680
Treatment	9	262.234*
Year	1	16015.222
YT	9	131.358
Pooled Error	36	3.666

* Significant at 5 % level of significance

ANNEXURE -XXIX
Analysis of variance (MSS) for net returns and B:C ratio

Source of variation	d.f.	Mean sum of squares			
		Net returns (₹/ha)		B:C ratio	
		2015-16	2016-17	2015-16	2016-17
Replication	2	402241287	338798026	0.105	0.086
Treatment	9	1648929616*	1350354114*	0.194*	0.161*
Error	18	80797234	67861975	0.025	0.020

* Significant at 5 % level of significance

ANNEXURE -XXX
Pooled analysis of variance (MSS) for net returns and B:C ratio

Source of variation	d.f.	Mean sum of squares	
		Net returns (₹/ha)	B:C ratio
Replication within year (R/Y)	4	370519656	0.095
Treatment	9	2988502855*	0.353*
Year	1	490769887718	249.436
YT	9	1510422741	0.179
Pooled Error	36	74329605	0.023

* Significant at 5 % level of significance

Appendix -XXXI

A. Common cost of Cultivation of fennel (excluding cost of individual treatment)

S. No	Details of particular	Unit/ha	Rates (`/Unit)	Expenditure (`/ha)
1.	Field preparation			
	i. Disc ploughing by tractor	One	2000	2000
	ii. Disc harrowing by tractor	One	1600	1600
	iii. Planking by tractor	One	400	400
2.	Manures and fertilizers			
	i. FYM	100q/ha	30/q	3000
	ii FYM application charges	5 mandays	320	1600
3.	Seed	10 kg	150/ kg	1500
4.	Sowing by tractor	One	1200	1200
5.	Preparation of seed bed	11 mandays	320	3520
6.	Hoeing, weeding (two) & thinning	25 mandays	320	8000
7.	Plant protection			
	i. Chloropyriphos	4 lit.	250/ lit.	1000
	ii. Imidacloprid	0.5 lit.	700/ lit.	350
	iii. Bavistin	30 g	78/100 g	24
	iv. karathene	0.5 lit.	2400/ lit.	1200
	v. Spraying charges	2 mandays	320	640
8.	Harvesting (umbel picking)	25 mandays	320	8000
9.	Threshing and cleaning	25 mandays	320	8000
10.	Misc.			236
11.	**Total**			**42270**

B Rates of treatments input and output

S. No.	Input and output	
1	Cost of N through urea	₹12.85/kg
2	Cost of P_2O_5 through SSP	₹40.00/kg
3	Cost of P_2O_5 through urea phosphate	₹154.12/kg
4	Elemental sulphure	₹43.33/kg
5	Cost of drip system	₹18500/ha
6	Surface irrigation cost (11 irrigation)	₹ 700/irrigation
7	Drip irrigation cost (467.2 mm water used)	₹ 10/mm irrigation
8	Sale price of fennel seed	₹ 90.00/kg

Appendix-XXXII
Economics of treatments 2015-16

Treatments	Common cost (₹)	Treatment cost (₹)	Total cost (₹)	Seed yield (kg/ha)	Straw yield (kg/ha)	Gross returns (₹/ha)	Net returns (₹/ha)	B:C ratio
Surface irrigation with CF (100% RDF)	42270	10457	52727	1720	4391	154800	102073	2.94
Drip irrigation with CF (50%RDF)	42270	25200	67470	1858	4873	167184	99714	2.48
Drip irrigation with CF (75% RDF)	42270	25564	67834	2116	5666	190404	122570	2.81
Drip irrigation with CF (100% RDF)	42270	25929	68199	2202	5931	198144	129945	2.91
Drip fertigation with 50% RDN	42270	25350	67620	2050	5455	184482	116862	2.73
Drip fertigation with 75% RDN	42270	25639	67909	2327	6354	209448	141539	3.08
Drip fertigation with 100% RDN	42270	25929	68199	2460	6877	221400	153201	3.25
Drip fertigation with 50% RDF	42270	28132	70402	2274	6242	204696	134294	2.91
Drip fertigation with 75% RDF	42270	29963	72233	2580	7306	232200	159967	3.21
Drip fertigation with 100% RDF	42270	31794	74064	2700	7736	243036	168972	3.28

Appendix-XXXIII
Economics of treatments 2016-17

Treatments	Common cost (₹)	Treatment cost (₹)	Total cost (₹)	Seed yield (kg/ha)	Straw yield (kg/ha)	Gross returns (₹/ha)	Net returns (₹/ha)	B:C ratio
Surface irrigation with CF (100% RDF)	42270	10457	52727	1634	4021	147060	94333	2.79
Drip irrigation with CF (50%RDF)	42270	25200	67470	1765	4503	158825	91355	2.35
Drip irrigation with CF (75% RDF)	42270	25564	67834	2015	5296	181350	113516	2.67
Drip irrigation with CF (100% RDF)	42270	25929	68199	2073	5561	186570	118371	2.74
Drip fertigation with 50% RDN	42270	25350	67620	1945	5081	175005	107385	2.59
Drip fertigation with 75% RDN	42270	25639	67909	2222	5984	200002	132093	2.95
Drip fertigation with 100% RDN	42270	25929	68199	2320	6337	208800	140601	3.06
Drip fertigation with 50% RDF	42270	28132	70402	2162	5932	194569	124167	2.76
Drip fertigation with 75% RDF	42270	29963	72233	2451	6889	220590	148357	3.05
Drip fertigation with 100% RDF	42270	31794	74064	2512	7266	226080	152016	3.05