वार्षिक प्रतिवेदन
Annual Report
2015-16

सिंचाई जल प्रबंधन पर
अखिल भारतीय समन्वित अनुसंधान परियोजना
All India Coordinated Research Project on Irrigation Water Management




भाकृअनुप - भारतीय जल प्रबंधन संस्थान

भारतीय कृषि अनुसंधान परिषद

भुवनेश्वर, ओडिशा, भारत

ICAR-Indian Institute of Water Management

(An ISO 9001:2008 Certified Organization)

Bhubaneswar-751023, Odisha, India

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Preface

The All India Coordinated Research Project on Irrigation Water Management has been instrumental in developing location specific irrigation water management technologies in different agro-ecological conditions in the country since its inception. The cooperating centres which are spread out in the country have been carrying out on station and on farm experiments for development and standardisation of replicable and cost effective technologies that not only improved water productivity, but also enhanced farmers' income and livelihood.

A number of replicable and cost effective technologies have been found out and extended to the farmers and line department personnels. The scientists working under the scheme of AICRP on IWM have also contributed to the implementation of flagship programmes on irrigation water management and contingency planning for different districts in the country. The capacity building programme on irrigation water management for different levels of stakeholders also have been taken up across the country by the cooperating centres.

This annual report depicts the results of the Irrigation Water Management experiments and extension for the year 2015-2016. The hard work undertaken by the scientists to generate location specific cost effective technologies and extend these technologies to the primary and secondary stakeholders deserves appreciation. I express my gratitude to Dr. S. Ayyappan, former Director General ICAR and Secretary DARE, Govt. of India and Dr. T. Mohapatra, Director General ICAR and Secretary DARE, Govt. of India, for their constant guidance, suggestions and support. I acknowledge the valuable suggestions and guidance provided by Dr. A.K. Sikka, former Deputy Director General (NRM) and Dr. S.K. Chaudhari, Assistant Director General (S&WM), ICAR. The team effort of Dr. Prabhakar Nanda, Dr. Mausumi Raychaudhuri, Principal Scientists of PCU of AICRP on IWM, Dr. O.P. Verma, Scientist (SS), Dr. Pragna Dasgupta, Research Associate and Ms. Sakshi Shiradhonkar, Senior Research Fellow is praiseworthy for compiling and editing this Annual Report of AICRP on Irrigation Water Management 2015-16.

Bhubaneswar **(S.K. Ambast)**

Contents

कार्यकारी सारांश

सिंचाई जल प्रबंधन पर अखिल भारतीय समन्वित अनुसंधान परियोजना के अंतर्गत वर्ष २०१५-१६ के दौरान विभिन्न केन्द्रों द्वारा पानी की उपलब्धता का आकलन, क्षेत्रीय स्तर पर भूजल उपयोग, दबाव सिंचाई पद्धति का मूल्यांकन, भूजल आकलन एवं पुन:भरण, अधिक मूल्य वाली एवं बागवानी फसलों में जल प्रबंधन, मिट्टी-पानी-पौधे एवं पर्यावरण के संबंध पर मूल अध्ययन एवं इनकी प्रतिक्रिया, नहरी एवं लवणीय भूजल का संयोजी उपयोग, उत्पादकता बढ़ाने के लिए जल निकासी अध्ययन, अधिक वर्षा वाले क्षेत्रों में वर्षा जल प्रबंधन आदि के क्षेत्र में अनुसंधान एवं प्रसार कार्य किया गया। वर्ष 2015-2016 की मुख्य उपलब्धियां का वर्णन नीचे प्रस्तुत किया गया है।

सिंचाई पानी की मांग, आपूर्ति पद्धति तथा भूजल उपयोग का आकलन

बेलवातगी केंद्र पर कपास की फसल में विभिन्न सिंचाई स्तरों के प्रयोग का अध्ययन किया गया। सिंचाई स्तर ०.८ IW/CPE अनुपात के प्रयोग से महत्वपूर्ण वृद्धि अवस्थाओं पर सिंचाई (१.५२ टन/हे) की तुलना में बेहतर कपास उपज (1.732 टन/हे.) प्राप्त हुई। लेकिन, क्रिटिकल वृद्धि अवस्थाओं पर सिंचाई उपचार से उच्च जल उपयोग दक्षता (3.12 किग्रा/हे.-मिमी) दर्ज हुई। समन्वित पौषक तत्व प्रबंधन से भी अधिक जल उपयोग दक्षता (3.23 किग्रा/हे-मिमी) प्राप्त हुई।

चिपलीमा केंद्र पर यह देखा गया कि यदि पूरे कमांड क्षेत्र में भले ही नहर से ४०% कम पानी छोड़ा जाये लेकिन फिर भी इससे सिंचाई उपलब्ध करवाई जा सकती है। यह तभी संभव है जब अधिक जल मांग वाली फसलों के अंतर्गत क्षेत्र को 8861 हेक्टेयर से 2975 हेक्टेयर तक कम किया जाये तथा मध्यम एवं निम्न जल मांग वाली फसलों के अंतर्गत क्षेत्र क्रमश: २१८० हेक्टेयर से ४८२० हेक्टेयर एवं 231 हेक्टेयर से 3471 हेक्टेयर)बढ़ा दिया जाये।

फैजाबाद केंद्र पर चांदपुर नहर शाखा के हेड, मध्य, एवं अंतिम छोर में गेहूँ की फसल में बेहतर जल प्रबंधन व्यवहार (5 X 10 मीटर आकार की क्यारियों के माध्यम से प्रति ६ सेमी सिंचाई) से किसानों द्वारा सामान्य सिंचाई की तुलना में क्रमश: 40.88, 40.36 एवं 39.68 क्विंटल/हे की उपज प्राप्त हुई। जबकि सामान्य सिंचाई से केवल 30.39, 30.91 एवं 29.65 क्विंटल/हे उपज ही हुई। इस प्रकार उचित जल प्रबंधन से 30.57-34.52% तक गेहूँ की उपज में वृद्धि हुई। हेड, मध्य, एवं अंतिम छोर में पानी खर्च दक्षता क्रमश: 174.04, 171.11 एवं 176.28 किग्रा/हे-मिमी प्राप्त हुई जबकि किसानों द्वारा सामान्य सिंचाई से 94.41, 96.02 एवं 92.11 किग्रा/हे-मिमी थी जो काफी कम थी

जोरहाट केंद्र पर खेत में प्रयोग से ज्ञात हुआ कि सरसों की फसल में फूल आने की अवस्था पर एकल सिंचाई (३०-३५ दिन) ने किसानों की पारंपरिक बारिश सिंचित फसल की तुलना में बहुत अच्छी दाना उपज बढ़ाई।

जूनागढ़ केंद्र पर ऊबेन बेसिन में १५ स्थलों पर ऊर्ध्वाधर बिजली लग प्रतिरोधकता तकनीक द्वारा जलभृतों का मानचित्रण किया गया। सभी सर्वेक्षण साइटों पर आम गहराई १५३.२ मीटर यानि ५१० फीट तक मान कर तुलना की गयी। सभी स्थलों के लिए उलटे ढलान के आउटपुट नक्शों की सहायता से ऊर्ध्वाधर जियोलोजीकल प्रोफाइल तैयार की गयी। बेसिन के जियोलोजिकल एवं हाइड्रोजियोलोजिकल गुणों का उपयोग कर ऊबेन बेसिन के हाइड्रोजियोलोजिकल नक्शे तैयार किए गए एवं हाइड्रोलोजी का भी अध्ययन किया गया। इस अध्ययन से पता चला कि सक्करबाघ स्थल पर 46.7 मीटर मोटाई की एक असीमित जलभृत एवं 5 सीमित जलवाहीयां उपस्थित है। सुखपुर, रणपुर, इवेनगर, परबधाम एवं पटाला स्थलों पर क्रमश: 13.3, 60, 20, 20 एवं 6.7 मीटर मोटाई की असमीमित जलवाहीयां उपस्थित थी जबकि क्रमश: 6, 3, 7, 7, 1 (153 मीटर मोटाई) की संख्या मे सीमित जलवाही स्तर पाए गए। इसी तरह, चोकी, वाडल, मखियाला एवं चोबारी स्थलों पर अध्ययन से पता चला कि वहाँ क्रमश: 20, 46.7, 6.7, एवं 20 मीटर मोटाई के असीमित जलवाही स्तर थे तथा क्रमश: 5, 2, 5 एवं 7 की संख्या में मौजूद है जिनमें से कुछ स्तर शहरी अपशिष्ट से प्रभावित थे।

उदयपुर केंद्र द्वारा एक अध्ययन से भीलबाड़ा जिले में जमीन स्तर के नीचे कुंओं की गहराई २०.०९ मीटर औसत के साथ 11.50 मीटर से 27.50 मीटर के बीच प्राप्त हुई। भीलवाड़ा में प्री-मानसून मौसम के दौरान गहरा जल स्तर एवं मानसून के बाद मौसम में उथला जल स्तर पाया गया। इस जिले में भूजल का पीएच दोनों वर्षों के लिए समान था। आम तौर पर, भीलवाड़ा में भूजल क्षारीय प्रकृति का है। भीलवाड़ा के भूजल की EC में बड़ा परिवर्तन मानसून मौसम के पहले एवं बाद दोनों वर्षों में पाया गया। उच्चतम ईसी पूर्व मानसून के मौसम में शाहपुरा ब्लॉक के तहत दर्ज हुई जबकि न्यूनतम ईसी कोटड़ी ब्लॉक में दर्ज हुई। वहाँ के भूजल में केटाइनों की मात्रा में भी जगह जगह परिवर्तन पाया गया लेकिन सोडियम केटायन प्रचुर मात्रा में था। एनायनों मे क्लोराइड की सर्वोच्च सांद्रता थी। अत: दो वर्षों के परिणाम के आधार पर यह निष्कर्ष प्राप्त हुआ कि मानसून के मौसम से पहले एवं बाद में भीलवाड़ा के भूजल की गुणवत्ता में सीमित प्रमुख कारक लवणता है। इस जिले के भूजल में सोडीसिटी की समस्या नहीं है। इसके अलावा, पूर्व मानसून के मौसम में 10-12.27% नमूनों में रेजीड्युल सोडियम कार्बोनेट की मात्रा>2.5 मिली इकविवेलेंट/लीटर थी जो स्थायी आधार पर सिंचाई के लिए अनुपयुक्त है।

दवाव सिंचाई पद्धति एवं फर्टिगेशन

बेलवातगी केंद्र पर ऊँची क्यारियों में युग्मित पंक्ति (45-120-45 सेमी) के साथ ड्रिप सिंचाई (१.० PET) का उपयोग करने से प्याज की उपज 48.83 टन/हे प्राप्त हुई। जबकि किसानों की सामान्य विधि तथा प्याज+मिर्च+कपास में 0.8 ET_0 पर सिंचाई से कम उपज मिली।

बेलवातगी केंद्र पर सूरजमुखी की फसल में महत्वपूर्ण वृद्धि अवस्थाओं पर ड्रिप सिंचाई के साथ 100:100:70 किग्रा नाइट्रोजन, फोस्फोरस एवं पोटाश उर्वरकों के प्रयोग से अधिक उपज (20.83 क्विंटल/हे) प्राप्त हुई। यह उपज सिंचाई स्तर 0.8 IW/CPE अनुपात एवं 110:110:80 किग्रा नाइट्रोजन, फोस्फोरस एवं पोटाश उर्वरकों के प्रयोग (20.02 क्विंटल/हे) की तुलना मे अधिक थी।

बेलवातगी केंद्र पर दो साल (2013-14 एवं 2014-15) के आंकड़ों के विश्लेषण से पता चला कि गेहूँ की फसल में 0.8 IW/CPE अनुपात से सिंचाई करने पर ०.६ IW/CPE अनुपात से सिंचाई (२१.८३ एवं ५७. ८३ क्विंटल/हे अनाज एवं पुआल उपज) की तुलना में अनाज एवं पुआल की उपज (22.10

क्विंटल/हे एवं 59.63 क्विंटल/हे) में वृद्धि हुई। सुझाए गए उर्वरक के स्तर+ गोबर खाद+२० किग्रा जिंक सल्फेट+२० किग्रा फेरस सल्फेट/हे के प्रयोग से अन्य उपचारों की तुलना में अनाज की उपज(26.89 क्विंटल/हे, चारा उपज (65.57 क्विंटल/हे) तथा जल उपयोग दक्षता (6.81 किलो/हे.-मिमी) में वृद्धि हुई। दोनों सिंचाई उपचारों में से पानी की बचत 0.6 IW/CPE अनुपात के साथ 15.08% अधिक थी।

बिलासपुर केंद्र पर प्याज की फसल में 60% CPE सिंचाई स्तर ने 80%, 100% एवं 120% CPE स्तरों की सिंचाइयों की तुलना में काफी अधिक उपज (263.96 क्विंटल/हे) उत्पादित की। जिंक-5 किलोग्राम/हे+ सल्फर 20 किलो/हे की दर से प्रयोग करने पर काफी अधिक बल्ब उपज(244.65 क्विंटल/हे) प्राप्त हुई। जल व्यय दक्षता 610.25 to 772.88 किग्रा/हे.-मिमी (2 से 7 सिंचाई) के साथ जल खपत 23.21 सेमी से 43.21 तक हुई। फसल में 7 सिंचाइयाँ देने पर अधिक शुद्ध लाभ रू. 244593/हे प्राप्त हुआ एवं इसके बाद ५ सिंचाइयों से शुद्ध लाभ रू. 228009/हे. था

कोयंबटूर केंद्र पर तमिलनाडु राज्य के पश्चिमी क्षेत्र के लिए उपयुक्त सिंचाई एवं फर्टिगेशन हेतु उप सतही ड्रिप सिंचाई पद्धति के मूल्यांकन पर अध्ययन किया गया। इससे पता चला कि ड्रिप सिंचाई में 90 सेमी दूरी की लेटरल का उपयोग करके 40% एवं 60% पीई (PE) सिंचाई स्तरों के साथ जल उपयोग दक्षता अधिकतम पायी गयी।

दापोली केंद्र पर चमेली की फसल के लिए कम दबाव वाली इनलाइन ड्रिप सिंचाई पद्धति को मानक प्रक्रिया का उपयोग कर उसकी हाइड्रोलिक दक्षता का मूल्यांकन करके स्थापित किया गया। माहवार औसत उपज आंकड़ों से यह पता चला कि चमेली की अधिकतम उपज (1800 किलोग्राम/हे) दिसंबर महीने के दौरान प्राप्त हुई। अधिकतम जल उपयोग दक्षता (151.9 किलोग्राम/हे-सेमी) फरवरी के महीने में तथा न्यूनतम मई के महीने में दर्ज हुई।

दापोली केंद्र पर ही आंवला की फसल में ड्रिप सिंचाई पद्धति के तहत सिंचाई एवं फर्टिगेशन स्तरों का अध्ययन किया गया। ड्रिप सिंचाई के माध्यम से 80% ETc पर सिंचाई एवं 100 उर्वरकों के फर्टिगेसन से अधिकतम फल उपज(5.76 किलो/पौधा एवं 7.13 किलो/पौधा) प्राप्त हुई। इसी उपचार संयोजन से अधिकतम जल उपयोग दक्षता 52.62 किलो/हे. सेमी प्राप्त हुई।

दापोली केंद्र द्वारा काजू की फसल में भी ड्रिप सिंचाई पद्धति के तहत सिंचाई एवं फर्टिगेशन स्तरों का अध्ययन किया गया। इन सिंचाई एवं फर्टिगेशन स्तरों ने पौधे की वृद्धि गुणों पर महत्वपूर्ण प्रभाव डाला। अधिकतम काजू उपज फर्टिगेशन के माध्यम से १०० ET स्तर पर सिंचाई (2.78 क्विंटल/हेक्टेयर)एवं 80% उर्वरकों (2.30 क्विंटल/हेक्टेयर) के प्रयोग से प्राप्त हुई।

ग्याशपुर केंद्र पर मीठी मक्का की फसल में भुट्टा उत्पादन एवं अच्छे गुणवत्ता मानकों के प्रदर्शन हेतु चार सिंचाई स्तरों एवं एकीकृत नाइट्रोजन प्रबंधन स्तरों का मूल्यांकन किया गया। इस अध्ययन के परिणामों से पता चला कि सतही सिंचाई से उच्चतम भुट्टा उपज (6.89 टन/हे) प्राप्त हुई जो कि 1.0 ETc स्तर (6.82 टन/हे)पर ड्रिप सिंचाई करने के बराबर थी। ड्रिप सिंचाई ने चीनी (6.3%), कुल चीनी (20.3%) एवं कुल घुलनशील ठोस (7.2%) जैसे गुणवत्ता मानकों में अधिकतम सुधार दिखाया। एकीकृत नाइट्रोजन प्रबंधन स्तरों में से 75% अकार्बनिक N+ 25% कार्बनिक N केंचुआ खाद के रूप में प्रयोग करने से उपज एवं गुणवत्ता मानकों में उत्कृष्ट वृद्धि प्राप्त हुई।

हिसार केंद्र पर गेहूँ की ड्रिप पद्धति के माध्यम से सिंचाई करने पर कुंड सिंचित ऊँची एवं नीची क्यारी पद्धति की तुलना में सिंचाई पानी की उत्पादकता 4.16 किलो अनाज/घन मीटर प्राप्त हुई। मिनी स्प्रिंकलर से सिंचाई करने पर यह 3.86 किलो दाना उपज/घन मीटर थी जबकि कुंड सिंचित ऊँची एवं क्यारी पद्धति में यह 3.43 किलो दाना उपज/घन मीटर तथा और पारंपरिक रोपण में सिंचाई के साथ सबसे कम (2.91 किलो दाना उपज/घन मीटर) थी।

हिसार में कपास की फसल में ड्रिप के माध्यम से 0.8 PE पर सिंचाई करने से कपास बीज उपज एवं जल उत्पादकता अधिक प्राप्त हुई। सतही सिंचाई की विधियों में से कुंड विधि द्वारा 0.75 IW/CPE अनुपात से सिंचाई करने पर कपास की उपज एवं जल उत्पादकता अधिक प्राप्त हुई। गेहूं के भूसे से 4-6 टन/हेक्टेयर की दर से पलवार का प्रयोग करने पर बिना पलवार की तुलना में अधिक उपज एवं जल उत्पादकता प्राप्त होती है।

जूनागढ़ में धनिया की फसल को इसकी वृद्धि अवस्थाओं पर सिंचाई पानी की कमी रखकर उपज प्रतिक्रिया का आकलन किया गया तथा जल उपयोग दक्षता एवं पानी बचत की गणना की गयी। ड्रिप सिंचाई पद्धति से धनिया की फसल की उच्चतम अनाज उपज (1,785.5 किलोग्राम/हे) एवं जैविक उपज (3,952.7 किलोग्राम/हे) तब प्राप्त हुई जब वृद्धि की पौधा विकास एवं फूल आने की अवस्थाओं में पानी की कोई कमी नहीं होने दी और 0.6 IW/CPE अनुपात से सिंचाई की गयी। इसी सिंचाई उपचार के साथ उच्चतम जल उपयोग दक्षता (४.०४ किग्रा/हे-मिमी) भी प्राप्त हुई। धनिया की फसल से अधिकतम उपज (1,663 किलोग्राम/हे) प्राप्त करने के लिए पानी की इष्टतम मांग ४१९ मिमी प्राप्त हुई।

कोटा केंद्र पर धान में सूक्ष्म सिंचाई की व्यवहार्यता के तहत यदि सिंचाई 125% PE स्तर पर की जाए तो काफी अधिक दाना उपज, जल उपयोग दक्षता एवं शुद्ध लाभ प्राप्त होता है।

कोटा केंद्र पर अधिकतम मटर उपज (19.98 क्विंटल/हे) 1.0 IW/CPE अनुपात से फव्वारा सिंचाई के तहत सिंचाई करने पर प्राप्त हुई। इसी तरह, उर्वरकों के स्तर 125% के प्रयोग से अधिकतम उपज (18.25 क्विंटल/हे) मिली।

भटिंडा केंद्र पर एक प्रयोग के परिणाम से पता चला कि अधिक कद्दू उपज (206.5 क्विंटल/हे) अन्य सिंचाई उपचारों की तुलना में नहर के पानी के उपचार में प्राप्त हुई एवं कद्दू का औसत वजन (714 ग्राम) भी अधिक था। लेकिन यह एक नहरी सिंचाई एवं एक भूजल सिंचाई से प्राप्त उपज के बराबर थी। अधिकतम पानी खपत दक्षता नहरी सिंचाई में थी एवं न्यूनतम खराब गुणवत्ता वाले टैंक के पानी से सिंचाई के साथ थी। अधिकतम ककड़ी उपज (133.0 क्विंटल/हे) नहर के पानी की सिंचाई से प्राप्त हुई जो अन्य सिंचाई उपचारों की तुलना में काफी अधिक थी। अधिकतम लौकी उपज (414.6 क्विंटल/हे) वहाँ प्राप्त हुई जहां नहर के पानी से सिंचाई की गयी।

मुरैना केंद्र पर बुआई की स्थायी चोड़ी क्यारी एवं कुंड सिंचाई विधि ने पारंपरिक बुआई एवं सिंचाई विधि की तुलना में गेहूँ की उपज (4.33 टन/हे), पुआल उपज (5.94 टन/हे), सकल लाभ (रु. 86,640/हे.), शुद्ध लाभ (रु. 56,030/हे.), लाभ:लागत अनुपात (2.83) एवं जल उत्पादकता में काफी अधिक वृद्धि हुई। उप सतही सिंचाई विधि से अन्य सिंचाई विधियों की तुलना में दाना उपज (4.38 टन/हे), पुआल उपज (5.96 टन/हे), सकल लाभ (रु. 87,520/हेक्टेयर), शुद्ध लाभ (रु. 53,620/हे.), लाभ:लागत अनुपात (2.64) एवं जल उत्पादकता (0.170 किलो दाना उपज/घन मीटर) में वृद्धि हुई।

मुरैना केंद्र पर ही धान की रोपण विधि एवं सिंचाई स्तरों के प्रयोग से अधिक दाना उपज (56 क्विंटल/हे) एवं चारा उपज (68.2 क्विंटल/हे) का उत्पादन हुआ। धान की पारंपरिक रोपण विधि में प्रत्यक्ष बुआई या पारंपरिक विधि की तुलना से काफी अधिक सकल लाभ, खेती लागत एवं कुल पानी का उपयोग हुआ जबकि अधिक शुद्ध लाभ, लाभ:लागत अनुपात एवं जल उत्पादकता धान की सीधी बुवाई के साथ दर्ज किए गए। उप सतही ड्रिप सिंचाई विधि में 1.25 IW/CPE अनुपात की सिंचाई के साथ फर्टिगेशन से अन्य सिंचाई उपचारों (पारंपरिक या केवल ड्रिप सिंचाई) की तुलना में अधिकतम दाना उपज (56.2 क्विंटल/हे.) चारा उपज (67.1 क्विंटल/हे.) एवं जल उत्पादकता प्राप्त हुई साथ ही अधिक सकल लाभ एवं शुद्ध लाभ भी प्राप्त हुआ। लेकिन कुल जल उपयोग पारंपरिक सिंचाई में अधिक हुआ तथा सबसे कम 1.0 IW/CPE अनुपात की सिंचाई के साथ हुआ।

पालमपुर केंद्र पर बैंगन की फसल में ग्रेविटी फेड ड्रिप सिंचाई के तहत सुझाए गए नाइट्रोजन, फोस्फोरस एवं पोटाश उर्वरकों की ७५% मात्रा का फर्टिगेशन द्वारा प्रयोग से कम सिंचाई जल उपयोग(47.96%) के कारण काफी अधिक पानी उपयोग दक्षता (1.8 गुना) प्राप्त हुई। सिंचाई अंतरालों ने बैंगन की उपज, सकल लाभ, शुद्ध लाभ एवं लाभ:लागत अनुपात पर कोई महत्वपूर्ण प्रभाव नहीं डाला। दो दिन के सिंचाई अंतराल से एक दिन (8.68%) या तीन दिन (4.28%) के सिंचाई अंतराल की तुलना में काफी अधिक जल उपयोग दक्षता प्राप्त हुई। फर्टिगेशन की आवृत्ति एक महीने में दो बार से सप्ताह (16.86%) में एक बार या सप्ताह में दो बार (8.44%) की तुलना में काफी अधिक बैंगन उपज एवं जल उपयोग दक्षता में वृद्धि में हुई।

पालमपुर केंद पर दोनों वर्षों के दौरान, सतही सिंचित (5 सेमी सिंचाई) प्याज की फसल में गोबर की खाद के साथ उचित नाइट्रोजन का रासायनिक खाद के माध्यम से प्रयोग के कारण केवल अकेले N के प्रयोग की तुलना में काफी अधिक हरी प्याज उपज (37.01 एवं 50.45%), प्राप्त हुई साथ ही अधिक सकल लाभ (37.02 एवं 50.46%), शुद्ध लाभ (1.62 एवं 2.14 गुना) तथा लाभ:लागत अनुपात (1.43 एवं 2.07 गुना) प्राप्त हुआ। फसल में दोनों वर्षों के दौरान, ड्रिप सिंचाई पद्धति के तहत १००% नाइट्रोजन की जगह वहाँ स्थानीय रूप से तैयार खाद (१% तरल जैव उर्वरक) का उपयोग किया गया जिसके परिणामस्वरूप अधिक प्याज उपज मिली तथा अधिक सकल एवं शुद्ध लाभ भी प्राप्त हुआ।

पंतनगर केंद्र द्वारा धान-पीली सरसों-लोबिया फसल अनुक्रम को लाइसीमीटर के तहत उगाया गया। सरसों की फसल में औसत पानी आवश्यकता ६८३.५३ मिमी एवं जल उपयोग दक्षता 6.51 किलोग्राम/हे-मिमी के साथ 44.14 क्विंटल/हे. की दाना उपज प्राप्त हुई। पीली सरसों की फसल ने 30 सेमी पानी स्तर गहराई पर अच्छा प्रदर्शन दिखाया। बाढ़ सिंचाई विधि की तुलना में स्प्रिंकलर विधि के तहत बीज उपज अधिक हुई। स्प्रिंकलर सिंचाई विधि में ०.५ IW/CPE अनुपात से अधिकतम जल उपयोग दक्षता प्राप्त हुई। गर्मी के मौसम में लोबिया फसल की दाना उपज 30 एवं 60 सेमी पानी स्तर गहराई में तुलनीय पायी गयी लेकिन 90 सेमी की गहराई (907 किलोग्राम/हे.) में काफी कम थी। भूजल योगदान एवं फसल में कुल पानी उपयोग 30 सेमी पानी स्तर गहराई में अधिकतम था लेकिन जल उपयोग दक्षता (0.79 किलोग/हे.-मिमी) सबसे कम थी।

परभाणी केंद्र पर वर्ष २०१४-१५ एवं २०१५-१६ में हल्दी की फसल में 1.0 PE पर सिंचाई की तुलना में 0.8 PE पर सिंचाई करने से अधिक ताजा प्रकंद उपज (295.7 एवं 351.4 क्विंटल/हे) हुई और अधिक सकल लाभ (4,06,560 एवं 5,62,304 रूपये/हे.) तथा शुद्ध लाभ (2,77,617 एवं 4,01,074 रूपये/हे.) भी प्राप्त हुआ। इस फसल में दोनों वर्षों के दौरान सुझाए गयी 120% उर्वरकों (240: 120: 120 किलोग्राम/हे नाइट्रोजन, फोस्फोरस एवं पोटाश) की मात्रा के प्रयोग से फर्टिगेशन के निचले स्तर की तुलना में काफी अधिक ताजा प्रकंद उपज (325.7 एवं 356.6 क्विंटल/हे.) प्राप्त हुई तथा अधिक सकल लाभ (4,4,7837 एवं 5,7,0493 रूपये/हे.) एवं शुद्ध लाभ (3,04,296 एवं ३94,818 रूपये/हे.) भी प्राप्त हुआ। इस फर्टिगेशन स्तर से अधिक जल उपयोग दक्षता (63.70 एवं 58.21 किलो/हे.-मिमी) दोनों के वर्षों के दौरान प्राप्त हुई।

परभाणी केंद्र पर वर्ष २०१४-१५ एवं २०१५-१६ में बैंगन की फसल में 0.8 PE स्तर पर सिंचाई करने पर सिंचाई के बाकी स्तरों की बजाय काफी अधिकतम फल उपज प्राप्त हुई। दोनों वर्षों के दौरान फर्टिगेशन के माध्यम से 100% नाइट्रोजन प्रयोग की तुलना में 80% नाइट्रोजन के प्रयोग से बैंगन की काफी अधिक फल उपज दर्ज की गई। इस फसल में 0.4 पीई पर सिंचाई करने से उच्च जल उपयोग दक्षता (139.16 एवं 91.29 किलोग्राम/हे-मिमी) प्राप्त हुई जबकि कम जल उपयोग दक्षता 1.0 PE (46.57 एवं 41.69 किलोग्राम/हे.-मिमी) सिंचाई स्तर के साथ दर्ज की गई।
पूसा समस्तीपुर केंद्र पर रबी मक्का की फसल में सिंचाई के विभिन्न स्तरों ने दाना उपज (७७ से ८६.८ क्विंटल/हे) को काफी प्रभावित किया। इस फसल में ०.६, ०.८ एवं १.० IW/CPE सिंचाई स्तरों के कारण क्रमशः 82.3, 84.8 एवं 86.8 क्विंटल/हे दाना उपज प्राप्त हुई जो सांख्यिकीय रूप से बराबर थी लेकिन ०.४ IW/CPE सिंचाई स्तर (77 क्विंटल/हे) से काफी बेहतर थी। गन्ने का चारा की पलवार या मक्का के फसल अवशेष की पलवार 5 एवं 10 टन/हे की दर से इस्तेमाल ने दाना उपज (८२.५ एवं ८५.२० टन/हे.) को काफी प्रभावित किया परंतु सांख्यिकीय रूप से एक-दूसरे के बराबर थी। और इसी तरह मक्का के फसल अवशेष की पलवार 5 एवं 10 टन/हे की दर से इस्तेमाल के कारण 83.9 एवं 87.3 क्विंटल/हे दाना उपज प्राप्त हुई जो लगभग एक समान थी लेकिन बिना पलवार की तुलना में काफी बेहतर थी। सिंचाई स्तर में वृद्धि (०.४ से १.० IW/CPE) के कारण जल उपयोग दक्षता (473.3 से 253.3 किलोग्राम/हे.-सेमी) में काफी कमी प्राप्त हुई। लेकिन पलवार के प्रयोग से जल उपयोग दक्षता में वृद्धि हुई।

राहुरी केंद्र पर, गर्मियों के दौरान गेंदे की फसल में १००% PE एवं ८०% PE पर सिंचाई करने से 17.83 एवं 16.91 टन/हे फूल उपज प्राप्त हुई। गर्मियों में गेंदे की सिंचाई जल आवश्यकता 100% PE सिंचाई स्तर (70.26 सेमी) में अधिक थी एवं सबसे कम ४०% PE (28.11 सेमी) में थी। पानी का उपयोग (505.10 किलो/हे-सेमी) 100% PE सिंचाई स्तर में अधिक तथा 40% PE सिंचाई में सबसे कम पानी उपयोग (238.14 किलो/हे-सेमी) हुआ। इसीलिए ४०% PE सिंचाई से पानी की बचत 61.28% हुई और सबसे कम बचत (10.06%) 100% पीई सिंचाई स्तर से प्राप्त हुई। विभिन्न रोपण विधियों में से १२० सेमी दूरी की लेटरल के साथ ६० X १० सेमी की फसल ज्यामिती से 17.13 टन/हे. की उच्चतम फूल उपज प्राप्त हुई। इसी रोपण विधि में अधिकतम जल आवश्यकता (७१.७४ सेमी) की जरूरत पड़ी। इस फसल में 30-60 x 15 सेमी दूरी पर रोपण एवं 90 सेमी दूरी की लेटरल के साथ उच्चतम जल उपयोग दक्षता 434.30 किलो/हे.-सेमी प्राप्त हुई साथ ही 49.53% पानी की बचत भी हुई। जब 90 सेमी दूरी की लेटरल एवं 30-60 x 15 सेमी पर रोपण के साथ 40% PE पर सिंचाई की गयी तो रु. 11,42,299/हे का शुद्ध अतिरिक्त लाभ प्राप्त हुआ और शुद्ध लाभ प्रति सेमी जल उपयोग रु. 78,853 हुआ एवं जल उपयोग दक्षता 1113.68 किलो.हे.-सेमी प्राप्त हुई।

श्रीगंगानगर कृषि अनुसंधान स्टेशन पर मिर्च की फसल के तहत ३ वर्ष (रबी 2012-13 से 2014-15) तक ड्रिप सिंचाई पद्धति में पांच सिंचाई उपचारों (0.6, 0.8, 1.0, 1.2 ETc नीचे टनल के साथ, 1.0 ETc ऊंचे टनल के साथ एवं आदि कम सुरंग के बिना) एवं एक उपसतही सिंचाई उपचार का अध्ययन

आयोजित किया गया। इस अध्ययन में तीन साल के आंकड़ों के विश्लेषण से पता चला कि ड्रिप सिंचाई में १.० ETc स्तर के साथ फल उपज 354.34 क्वि/हे) तथा १.२ ETc स्तर के साथ 365.95 क्वि/हे प्राप्त हुई जो अन्य सिंचाई स्तरों की तुलना में काफी अधिक थी। लेकिन इन दोनों स्तरों से प्राप्त उपज सांख्यिकीय रूप से बराबर थी। इस प्रकार ड्रिप सिंचाई में १.० ETc स्तर नीचे टनल के साथ मिर्च की फसल के लिए उपयुक्त सिंचाई स्तर प्राप्त हुआ। इस सिंचाई स्तर से मिर्च की फसल ने 69.85% अधिक फल उपज उत्पादित की तथा साथ ही 24.12% सिंचाई पानी को बचाया। ड्रिप सिंचाई के साथ अधिकतम पानी खर्च दक्षता 51.1 किलोग्राम/हे.-मिमी 0.6 ETc सिंचाई स्तर में दर्ज की गयी उसके बाद ०.८ ETc सिंचाई स्तर में 48.7 किलोग्राम/हे.-मिमी हुई।

श्रीगंगानगर केंद्र पर मिर्च फसल में नीचे टनल के साथ फर्टिगेशन पर एक क्षेत्र प्रयोग तीन साल (2012-13 से 2014-15) तक रबी के दौरान आयोजित किया गया। आंकड़ों के विश्लेषण से पता चला कि विभिन्न उर्वरक उपचारों ने मिर्च की उपज को काफी प्रभावित किया। मिर्च की उच्चतम फल उपज 120% RD उर्वरक उपचार से प्राप्त हुई। इस उपचार से पारंपरिक उर्वरकों के प्रयोग की तुलना में 55.4% अधिक मिर्च की फल उपज में वृद्धि हुई। कुल इस उपचार में पानी का उपयोग, पारंपरिक व्यवहार (1077.3 मिमी) के मुकाबले 742.1 मिमी ही हुआ जिससे 44.9% पानी की बचत हुई। ड्रिप फर्टिगेशन उपचार के तहत उर्वरकों का 120% RD की दर से प्रयोग से शुद्ध मौसमी आय रु. 194167/हे प्राप्त हुई, जबकि पारंपरिक व्यवहार से आय केवल रु. 121000/हे ही प्राप्त हुई। संबंधित लाभ लागत अनुपात 1.51 एवं 1.39 था। इस प्रकार, 13 दिन के अंतराल पर 120% RD (84 किलो नाइट्रोजन, 60 किलो फोस्फोरस, एवं ६० किलो पोटाश/हे) की दर उर्वरकों का प्रयोग 9 बराबर विभाजन में मिर्च के लिए इष्टतम फर्टिगेशन उपचार प्राप्त हुआ।

वर्षा जल संचयन एवं उपयोग

अल्मोड़ा केंद्र पर वर्षा अपवाह से भरे टैंकों का उपयोग सब्जी एवं अनाज फसलों को सफलतापूर्वक उगाने के लिए किया जा सकता है। सब्जियों के लिए अधिकतम क्षेत्र रबी सीजन के दौरान एवं न्यूनतम क्षेत्र खरीफ के दौरान आवंटित किया जा सकता है। कृत्रिम पुनःभरण से भूजल स्तर में वृद्धि टैंकों की स्थापना के समय से पहले की तुलना में 129.1% तक हुई। अल्मोड़ा जिले के तीन गांवों में इसकी कुल क्षमता 2777 घन मीटर तक पहुंच गयी। सूक्ष्म फव्वारा सिंचाई एवं संशोधित सूक्ष्म फव्वारा सिंचाई पद्धति को पानी बचाने के लिए तथा सिंचाई के तहत और अधिक क्षेत्र बढ़ाने के लिए छह किसानों के खेतों पर स्थापित किया गया।

कोयंबटूर केंद्र पर अवर भवानी परियोजना (LBP) के अंतर्गत ऑपरेशन रिसर्च प्रोजेक्ट ने बताया कि बेहतर जल प्रबंधन तकनीकों से किसानों द्वारा पारंपरिक तरीके से मूँगफली उगाने की तुलना में हेड, मध्यम एवं अंतिम छोर में पानी की बचत 24 -31% के बीच हुई। इसके अलावा जल उपयोग दक्षता भी 3.82 किलो/हे-मिमी से 4.12 किलो/हे-मिमी तक प्राप्त हुई।

दापोली केंद्र पर आम की फसल में एप्लीकेटर के माध्यम से 75% PE स्तर की सिंचाई के कारण काफी अधिक फल उपज (23.16 किलो/पौधा) प्राप्त हुई। जबकि 50% RDF+ पेकलोब्यूटराजेल (PBZ)+ 40 किग्रा गोबर की खाद के प्रयोग से 20.79 किग्रा/पौधा फल उपज प्राप्त हुई। अधिकतम जल उपयोग दक्षता (35.52 किलो/हे-सेमी) एप्लीकेटर के माध्यम से 50% PE सिंचाई स्तर + 100% RDF + PBZ के प्रयोग से प्राप्त हुई। जल उपयोग दक्षता पर परिणामों से संकेत मिलता है कि पानी की कमी के मामले में आम की पैदावार को 60 सेमी सिंचाई पानी के प्रयोग के साथ असिंचित फसल की तुलना में २१% तक बढ़ाया जा सकता है।

फैजाबाद केंद्र पर विशेष भूमि संसोधन पद्धतियों के अंतर्गत मेंथा की फसल को ऊंची क्यारी रोपण (युग्मित पंक्ति के साथ 70 सेमी क्यारी एवं 20 सेमी कुंड) के तहत उगाने पर काफी अधिक जड़ी बूटी पैदावार (177.73 क्विंटल/हे) एवं तेल उपज (130.96 लीटर/हे) प्राप्त हुई। मेंथा की रोपण विधियों जैसे मेड़ रोपण, तीन पंक्तियों के साथ ऊंची क्यारी रोपण (100 सेमी क्यारी एवं 35 सेमी कुंड) एवं समतल क्यारी रोपण से क्रमश: 164.30, 150.13 एवं 132.13 क्विंटल/हे की जड़ी बूटी उपज प्राप्त हुई। सिंचाई स्तर 1.2 IW/CPE से 181.14 क्विंटल/हे. की अधिकतम जड़ी बूटी एवं तेल उपज (128.04 लीटर/हे.) प्राप्त हुई जो अन्य सिचाई स्तरों (०.६ एवं ०.८ IW/CPE) की तुलना में काफी अधिक थी। सिंचाई स्तर 1.0 IW/CPE से यह उपज 172.95 क्विंटल/हे थी। युग्मित पंक्ति के साथ ऊंची क्यारी रोपण पद्धति से जल उपयोग दक्षता 45.69 किलो/हे.-मिमी प्राप्त हुई।

जम्मू केंद्र पर खरीफ 2015 में हल्की बनावट वाली मिट्टी के तहत बासमती धान में वैकल्पिक गीली एवं सुखी सिंचाई प्रबंधन का अध्ययन करने के लिए ट्यूब डिवाइस के माध्यम से पानी मापने संबंधी एक ऑन स्टेशन प्रयोग आयोजित किया गया। इस प्रयोग में बासमती धान की किस्म बासमती - 370 को 20 X 10 सेमी की दूरी के साथ रोपित किया गया। ट्यूब के अंदर पानी के स्तर के उपचार के अनुसार जमीन के स्तर से नीचे 7, 10 एवं 15 सेमी तक गिरने पर इस क्षेत्र में पानी से 7 सेमी की सिंचाई की गयी। वहाँ किसानों द्वारा पारंपरिक सिंचाई विधि में धान के खेत में सामान्यतया 7 सेमी सिंचाई पानी भरा जाता है।

असम राज्य के जोरहाट में नींबू वृक्षारोपण के नीचे भूमि में उप सतह जल निकासी माध्यम से उच्च जल स्तर के निकास के लिए एक प्रयोग किया गया। इस प्रयोग में पीवीसी पाइपों एवं बांस से बने पाइपों को छिद्रित करके खनिज (मोटी रेत) एवं जैविक (धान का भूसा) परत के ऊपर रखा गया। गहरी खुली नाली का नियंत्रण उपचार के रूप में उपयोग में लिया गया। जल निकास गुणांक के अवलोकन से पता चला कि उच्चतम जल निकास गुणांक (4.28 सेमी/घंटा) खनिज के आवृत साथ पीवीसी पाइपों का उपयोग करने से प्राप्त हुआ। जैविक आवृत के साथ बांस पाइप लगाने पर 0.669 सेमी/घंटा के रूप में निम्नतम जल निकास गुणांक प्राप्त हुआ। बरसात के मौसम के दौरान प्लास्टिक पाइपों ने आवृत सामग्री के बगैर भी भूमि में पानी के स्तर को अन्य उपचारों की तुलना में बेहतर तरीके से कम किया। इन्ही पाइपों का रबी मौसम में सिंचाई पानी उपलब्ध कराने के लिए भी इस्तेमाल किया गया।

कोटा केंद्र पर सोयाबीन: अरहर (४:२) अंतरसस्य पद्धति से प्राप्त तीन साल के आँकड़ों के विशेषण से पता चला कि काफी अधिक सोयाबीन बीज उपज (1286 किलो/हे) प्राप्त हुई जो सोयाबीन: अरहर (३:२) अंतरसस्य पद्धति से प्राप्त उपज के बराबर थी। सोयाबीन: अरहर (४:२) अंतरसस्य पद्धति के साथ अधिकतम जल उपयोग दक्षता (२९.७५ किग्रा/हे.-सेमी) दर्ज हुई।

मृदा-पानी-पौधे संबंध पर आधारभूत अध्ययन

बेलवातगी केंद्र पर सूरजमुखी-अरहर फसल अनुक्रम में एकीकृत पोषक तत्व प्रबंधन का अध्ययन किया गया (वर्ष २०१३-१४ एवं २०१४-१५)। सूरजमुखी फसल में वर्ष 2013-14 के दौरान ०.६ IW/CPE स्तर से सिंचाई करने पर काफी अधिक उपज (18.14 क्विंटल/हे), सकल आय (रू 58,968/हे), शुद्ध आय (रू. 43,593) एवं लाभ:लागत अनुपात (3.84) में

वृद्धि हुई। दोनों वर्षो का एक साथ विश्लेषण करने पर इस सिंचाई स्तर से अधिक सकल लाभ (रु 69247/हेक्टेयर), शुद्ध लाभ (रू 50,519/हे.) एवं लाभ:लागत अनुपात (3.73) प्राप्त हुआ तथा जल उपयोग दक्षता (5.97) प्राप्त हुई। इस पूरी फसल पद्धति (खरीफ में सूरजमुखी एवं रबी मौसम के दौरान अरहर) में दोनों फसलों की खेती की उन्नत विधियों (RPP) के साथ 0.6 IW/CPE स्तर पर सिंचाई के कारण शुद्ध लाभ (वर्ष 2013 के दौरान रु. 1,01196/हे और वर्ष 2014 के दौरान रु. 1,02,493) प्राप्त हुआ।

बेलवातगी केंद्र पर दो साल (वर्ष 2014-15 एवं 2015-16) में किए गए प्रयोग से प्राप्त आँकड़ों का एक साथ विश्लेषण करने पर पता चला कि उर्वरक के स्तर RPP (RDF+FYM)+25 किलो $FeSO_4$/हेक्टेयर+ 0.75% $FeSO_4$ छिड़काव (30DAS)+0.5% चुना के प्रयोग से अन्य स्तरों की तुलना में काफी दाना उपज (19.26 क्विंटल/हे), डंठल उपज (47.89 क्विंटल/हे एवं जल उपयोग दक्षता (6.35 किलो/हे.-मिमी) बढ़ी। सिंचाई के दो स्तरों (0.8 IW/CPE अनुपात एवं महत्वपूर्ण वृद्धि अवस्थाओं में सिंचाई में से महत्वपूर्ण वृद्धि अवस्था में सिंचाई के साथ औसत जल बचत 18.23% हुई।

बिलासपुर केंद्र पर गेहूँ की फसल में उर्वरकों की 100: 60: 40 NPK किलोग्राम/हेक्टेयर की मात्रा के प्रयोग से 60:40:20 एवं 80:50:30 NPK किग्रा/हे. की तुलना में काफी अधिक दाना उपज (41.83 क्विंटल/हेक्टेयर) का उत्पादन हुआ। इस फसल में 2 एवं 3 सिंचाईयों के प्रयोग की तुलना में 5 सिंचाईयों के साथ काफी अधिक दाना उपज (43.17 क्विंटल/हे.) प्राप्त हुई। कुल 2 से 5 सिंचाइयों के अंतर्गत 16.38 से 34.38 सेमी सिंचाई पानी खर्च हुआ तथा 125.56 से 218.74 किलो/हे.-सेमी की पानी खर्च दक्षता प्राप्त हुई। इन 5 सिंचाइयों से उच्चतर शुद्ध लाभ रु. 41067/हे. प्राप्त हुआ।

बिलासपुर केंद्र पर मसूर की किस्म-AK 75 के लिए क्रॉप इवेपोट्रान्स्पिरेसन (ETc) 16.62 सेमी मापा गया। फसल गुणांक (Kc)117 दिनों की फसल अवधि (अंकुरण से परिपक्वता) के लिए 0.71 के औसत मूल्य के साथ 0.32-0.98 के बीच पाया गया। कुल संभावित इवेपोट्रान्स्पिरेसन (अनुमानित ET_o) 22.49 सेमी का अनुमान लगाया गया। कुल 24.47 सेमी पैन वाष्पीकरण (EVP) की गणना की गयी।

चिपलीमा केंद्र पर प्याज की फसल में सिंचाई का समय निर्धारण एवं पोषक तत्व प्रबंधन के अनुकूलन के लिए प्रयोग आयोजित किया गया। दो साल के प्रयोग के परिणामों ने सुझाव दिया कि 40 किलो सल्फर/हे के प्रयोग से 19.42 टन/हे बल्ब उपज एवं 10.48% कुल घुलनशील ठोस का उत्पादन प्राप्त हुआ। इसके अलावा, जब 1.2 की IW/CPE अनुपात के सिंचाई स्तर से 19.36 टन/हे बल्ब उपज प्राप्त हुई। उच्चतम जल उपयोग दक्षता (291.78 किलो/हे. सेमी) सिंचाई स्तर IW/CPE अनुपात के साथ प्राप्त हुई।

चलाकुड़ी केंद्र पर केले की फसल में अलग-अलग नमी स्तरों के तहत मिट्टी में पोषक तत्व गतिशीलता का अध्ययन किया गया। वर्तमान में उपस्थित उर्वरकों की दर की तुलना में 75% फोस्फोरस एवं 125% पोटाश उर्वरकों का प्रयोग करने पर 17.5% तक उपज में वृद्धि हुई। इस प्रयोग से सुझाव प्राप्त हुआ कि वर्तमान में 115 ग्राम फोस्फोरस /पौधा को 86 ग्राम/पौधा तक कम किया जा सकता है।

ग्यासपुर केंद्र पर गेहूँ की फसल में विभिन्न सिंचाई स्तरों (20, 40 एवं 60% उपलब्ध मिट्टी की नमी) एवं उर्वरकों स्तरों (0, 80:40:40, 120: 60: 60 एवं 160: 80: 80 किलो N: P_2O_5: K_2O/हे) का रेतीली दोमट मिट्टी में अध्ययन किया गया। सिंचाई के उच्च आवृत्ति स्तर यानि 20% उपलब्ध मिट्टी की नमी (3334 किग्रा/हे) एवं सिंचाई के मध्यम आवृत्ति के साथ 40% उपलब्ध मिट्टी की नमी (3182 किग्रा/हे) स्तर के साथ लगभग बराबर उपज प्राप्त हुई। उर्वरकों के 160: 80: 80 किग्रा/हेक्टेयर N:P_2O_5:K_2O की मात्रा के प्रयोग से 3863 किलो/हे उच्चतम दाना उपज प्राप्त हुई जो 120: 60: 60 किग्रा/हे N:P_2O_5: K_2O उर्वरक स्तर से प्राप्त उपज 3611 किग्रा/हे) के समतुल्य थी।

मुरैना केंद्र पर उड़द की फसल में अधिकतम बीज (1,238 किलो/हे) एवं पुआल उपज (2,455 किलो/हे) 125% RDF के प्रयोग के साथ प्राप्त हुई। आर्थिक विश्लेषण ने बताया कि अधिकतम सकल लाभ (रु. 59,068/हे), शुद्ध लाभ (रु. 43,588/हे) तथा लाभ:लागत अनुपात (3.82) भी 125% RDF से प्राप्त हुआ। इस प्रकार, यह निष्कर्ष निकाला गया कि चंबल के वर्षा आधारित क्षेत्रों की रेतीली दोमट मिट्टी में 125% RDF के उपयोग के द्वारा उड़द की फसल से स्थायी उत्पादकता एवं लाभप्रदता प्राप्त की जा सकती है।

परभाणी केंद्र पर ड्रिप सिंचाई पद्धति के माध्यम से गर्मियों में मूंगफली की फसल में 1.0 PE स्तर पर सिंचाई करने पर अन्य सिंचाई स्तरों की तुलना में काफी अधिक सूखी फली उपज (4211 एवं 4449 किलोग्राम/हे) प्राप्त हुई तथा सकल लाभ (रु. 1,79,054 एवं 1,87,532/हे) एवं शुद्ध लाभ (रु. 95,461 एवं 1,02,949/हे) प्रयोग के दोनों वर्षों के दौरान प्राप्त हुआ। इस फसल में पारदर्शी पॉलीथीन पलवार का प्रयोग करने पर अन्य पलवार की तुलना में काफी अधिक सूखी फली पैदावार (4370 एवं 4658 किलोग्राम/हे) प्राप्त हुई साथ ही सकल लाभ (रु. 1,85,729 एवं 1,96,130/हे) एवं शुद्ध लाभ (रु. 86,310 एवं 95,881/हे) भी प्राप्त हुआ। सिंचाई स्तर 0.6 PE से उच्चतर जल उपयोग दक्षता (7.15 एवं 8.10 किलोग्राम/हे.-मिमी) प्राप्त हुई जबकि कम WUE (3.75 एवं 4.39 किलोग्राम/हे. मिमी) सिंचाई स्तर 1.2 PE से प्राप्त हुई। दोनों वर्षों के दौरान पारदर्शी पोलिथीन पलवार के प्रयोग से 6.24 एवं 6.84 किलोग्राम/हे.-मिमी जल उपयोग दक्षता प्राप्त हुई।

राहुरी केंद्र पर ड्रिप पद्धति के तहत रबी प्याज की फसल में ETc के अनुसार प्रति दूसरे दिन सिंचाई उपज, गुणवत्ता, पानी की बचत, दक्षता एवं भंडारण आदि के अध्ययन के लिए अच्छी पायी गयी। इसके बाद माइक्रो स्प्रिंकलर द्वारा सिंचाई करना भी अच्छा पाया गया। एकीकृत पौषक तत्व प्रबंधन स्तरों के बीच 10 टन/हे गोबर की खाद के साथ उर्वरकों की 100% सुझाई गयी दर (100: 50: 50 किलो/हे NPK) उपज, गुणवत्ता एवं भंडारण के अध्ययन के लिए सबसे अच्छा पाया गया। उर्वरकों की 100% सुझाई गयी दर के साथ वर्मीकम्पोस्ट के प्रयोग का भी सुझाव दिया गया।

शिलोंग केंद्र पर उत्पादन में वृद्धि एवं संसाधनों के संरक्षण के लिए धान आधारित फसल पद्धति में जुताई एवं फसल अवशेष प्रबंधन के प्रभाव का मूल्यांकन हेतु एक क्षेत्र प्रयोग आयोजित किया गया। बिना फसल अवशेष हटाये जीरो टीलेज के साथ अवशेष हटाकर पारंपरिक जुताई की तुलना में धान की उपज में 17.2% वृद्धि हुई तथा अगले मौसम में रबी फसलों जैसे सरसों, मटर एवं बैंकव्हीट की उपज में क्रमश: 34.6%, 16.4% 27.4% तक काफी वृद्धि हुई। रबी फसलों यानि सरसों एवं मटर में बिना जुताई के साथ पारंपरिक जुताई की तुलना से उच्चतम जल उपयोग दक्षता 35.9% एवं 16.3% तक प्राप्त हुई।

श्रीगंगानगर कृषि अनुसंधान स्टेशन पर खरीफ के दौरान वर्ष 2015 में कपास की रोपाई की उपयुक्त दिनांक का पता लगाने, जल उपयोग, रोपित कपास में जल उपयोग दक्षता एवं आर्थिक आय के मूल्यांकन के लिए खेत में एक प्रयोग आयोजित किया गया। इस प्रयोग के परिणामों से पता चला कि यदि पास में नहर है तो समय पर बुआई संभव नहीं है। अत: इस कारण को ध्यान में रखकर फसल की बुवाई प्लास्टिक की थैलियों में की गयी और बाद

में खेत में 30 मई तक बाढ़ सिंचाई के साथ तथा 10 जून तक ड्रिप सिंचाई पद्धति के साथ की गयी जिससे उपज में कोई नुकसान न हो सके। ड्रिप सिंचाई पद्धति के साथ 30 मई, 10 जून एवं 20 जून तक रोपित कपास की फसल से सीधी बुआई की तुलना में 16.19, 27.13 एवं 9.56 % से अधिक उपज प्राप्त हुई। इन तिथियों पर ड्रिप सिंचित फसल ने बाढ़ सिंचाई की तुलना में 22.67%, 35.54% एवं 27.35% अधिक बीज कपास उपज उत्पादित की।

उदयपुर जिले के कमांड क्षेत्र में उपलब्ध भूमि एवं जल संसाधनों के प्रति इकाई क्षेत्र से उत्पादन में वृद्धि करने या खेती के तहत अधिक क्षेत्र बढ़ाने के उद्देश्य हेतु अध्ययन शुरू किया गया। क्रॉपवाट (CROPWAT, FAO Model, 1992) का उपयोग करके फसलों की मासिक शुद्ध पानी जरूरतों की गणना की गई। इसी मॉडल के उपयोग से ET_o की गणना पेनमान मोंटीथ विधि द्वारा मासिक आधार पर की गई। एफएओ दिशा निर्देशों का उपयोग करके कमांड क्षेत्र की मुख्य फसलों के लिए फसल गुणांक विकसित किए गए। कमांड क्षेत्र की प्रमुख फसलों जैसे मक्का, सोयाबीन, मूँग, गेहूँ, सरसों, चना एवं जौ के लिए मासिक पानी आवश्यकता क्रमशः 534.89 मिमी, 453.71 मिमी, 362.69 मिमी, 391.36 मिमी, 268.17 मिमी, 306.86 मिमी एवं 267.62 मिमी के रूप में प्राप्त हुई।

स्थायी फसल उत्पादन के लिए सतही एवं भूजल जल संसाधनों का संयुक्त उपयोग

बिलासपुर केंद्र पर डेयरी के सतह पानी के प्रयोग से धान की अधिक दाना उपज (36.57 क्विंटल/हे) एवं डेयरी सतह पानी+नलकूप पानी से सिंचाई के कारण 34.07 क्विंटल/हे का उत्पादन हुआ। पोषक तत्व प्रबंधन के तहत 100% RDF के प्रयोग से 75% RDF एवं 75% RDF +भूरी खाद की तुलना में काफी अधिक उपज (36.79 क्विंटल/हे) उपज प्राप्त हुई, लेकिन यह उपज 75% RDF+हरी खाद (36.70 क्विंटल/हे) एवं 75% RDF+ BGA (35.99 क्विंटल/हे) के बराबर थी। डेयरी के सतह पानी एवं डेयरी सतह पानी+नलकूप पानी के प्रयोग से शुद्ध लाभ रु. 32605/हे एवं रु. 28,897/हे प्राप्त हुआ।

चिपलीमा केंद्र पर धान गहनता पद्धति में एकीकृत खरपतवार प्रबंधन के विभिन्न तरीकों का संशोधित पानी व्यवस्थाओं के तहत मूल्यांकन किया गया। दो साल के आंकड़ों के विश्लेषण ने बताया कि पानी प्रयोग एवं एकीकृत खरपतवार प्रबंधन के तरीकों का दाना उपज पर महत्वपूर्ण प्रभाव पड़ा। खरपतवार निराई के एक दिन पहले खेत में 5 सेमी पानी भरने से 5.21 टन/हे की काफी अधिक दाना पैदावार का उत्पादन हुआ। एक पूर्व एवं एक अंकुरण बाद शाकनाशी जैसे प्रेटीक्लोर एवं ओक्सेडाइजिल के प्रयोग से 5.45 टन/हे की काफी अधिक दाना उपज प्राप्त हुई।

चिपलीमा केंद्र पर मक्का-मूंग फसल पद्धति में उपज एवं पानी उत्पादकता पर सिंचाई स्तर एवं फसल ज्यामिति के प्रभाव का अध्ययन करने के लिए प्रयोग आयोजित किया गया। मक्का को मूंग के साथ अंतरसस्य (2:2 अनुपात में) के रूप में उगाने पर 1:1 अनुपात अधिक मक्का तुल्य उपज (48.65 क्विंटल/हे) प्राप्त हुई एवं अधिक लाभ लागत अनुपात (2.28) प्राप्त हुआ। जबकि 1:1 अनुपात के साथ 47.35 क्विंटल/हे उपज प्राप्त हुई एवं 1.99 लाभ:लागत अनुपात प्राप्त हुआ।

फैजाबाद केंद्र पर रोपित धान से अन्य रोपण विधियों की तुलना में सबसे अधिक उपज 41.45 क्विंटल/हे प्राप्त हुई। धान की ड्रम बुआई विधि से 36.83 क्विंटल/हे की उपज मिली जो जीरो टिल मशीन से बुआई एवं सूखे के दौरान पडल्ड स्थिति के तहत अंकुरित बीजों का छिड़काव विधि की तुलना में अधिक थी। सिंचाई प्रबंधन के तहत यदि खेत में भरे पानी के सूखने के एक दिन बाद 7 सेमी की सिंचाई की जाए तो अन्य सिंचाई स्तरों की बजाय 44.90 क्विंटल/हे की काफी अधिक उपज एवं 6.25 किग्रा/हे.-मिमी जल उपयोग दक्षता प्राप्त होती है। लेकिन जब खेत में भरे पानी के सूखने के 4, 7 एवं 10 दिनों के बाद 7 सेमी सिंचाई की जाती है तो क्रमशः 40.29, 31.70 एवं 24.32 क्विंटल/हे की घटते क्रम में उपज प्राप्त हुई। धान की रोपाई विधि से 7.39 किलो/हे.-मिमी जल उपयोग दक्षता प्राप्त हुई।

जोरहाट केंद्र पर इस जिले के लिए मानसून पूर्व भूजल संभावना को रिमोट सेंसिंग एवं भौगोलिक सूचना पद्धति (GIS) का उपयोग करके चित्रित किया गया। भूजल संसाधन मेप का निर्माण क्षेत्र अनुसार भूजल संभावना की जानकारी पर प्रकाश डालते हुए इस जिले के 2852 वर्ग मीटर क्षेत्र के लिए पूरा किया गया। भूमि के नीचे भूजल स्तर गहराई 6.16 से 6.82 मीटर के तहत अधिकतम क्षेत्र (739.50 वर्ग किमी) पाया गया एवं न्यूनतम क्षेत्र (78.34 वर्ग किमी) 4.20-4.95 मीटर की भूजल स्तर गहराई के साथ था। भूजल संसाधन की गहराई, पानी दोहन के लिए उपयुक्त पंप का चयन एवं इस प्रकार के पंपों की इकाई क्षेत्र को सिंचित करने की क्षमता को नक्शे के रूप में तैयार किया गया।

जूनागढ़ केंद्र पर लगातार 10 दिन तक अधिकतम वर्षा होने एवं 1 से 5 दिनों के बरसाती तूफान के कारण छत से संचित पानी की अनुमानित लागत का रुपए 42-88 प्रति वर्ग मीटर छत क्षेत्र अनुमान लगाया गया। अच्छी तरह से 1 दिन की अधिकतम वर्षा के लिए पुनःभरण कुंए के साथ भंडारण टैंक क्षमता संयोजन से संकेत प्राप्त हुआ कि छत के प्रति वर्ग मीटर क्षेत्र के लिए 0.02 घन मीटर आकार वाले बफर भंडारण टैंक की आवश्यकता है। छत से पानी अपवाह हेतु वार्षिक औसत, सबसे ज्यादा एवं 10 साल रिटर्न अवधि का 0.62, 0.1, 1.94 एवं 0.96 घन मीटर प्रति वर्ग मीटर छत के रूप में आकलन किया गया। इस पद्धति की लागत प्रति वर्ग मीटर छत क्षेत्र के लिए रु. 44.85 प्राप्त हुई। छत पानी अपवाह के संप में पुनःभरण एवं संचयन से पता चला कि कुल 0.54 घन मीटर प्रति वर्ग मीटर छत क्षेत्र से 0.16 घन मीटर जल ने भूमि में पुनःभरण के लिए योगदान दिया एवं 0.38 घन मीटर जल सम्प में संचित हुआ। इस पद्धति की लागत रुपये 119.26 प्रति वर्ग मीटर छत क्षेत्र आती है। छत के क्षेत्र के लिए वार्षिक अपवाह गुणांक 0.74 के रूप में निर्धारित किया गया।

लुधियाना केंद्र पर पता लगाया गया कि दक्षिण पश्चिम पंजाब के क्षेत्र-1 के लिये वर्ष 1998 में प्रति 1000 हेक्टेयर क्षेत्र बिजली पंप सेट घनत्व 301 था जो बढ़कर वर्ष 2014 में 659 हो गया। तथा क्षेत्र 2 में यह वर्ष 1998 में 92 था एवं इस अध्ययन की अवधि के दौरान वर्ष 2014 में बढ़कर 184 हो गया। प्रथम जोन में भूजल ड्राफ्ट में 29,258 से 52,335 हेक्टेयर मीटर तक वृद्धि हुई जबकि द्वितीय जोन के तहत भूजल ड्राफ्ट में मानसून के मौसम के दौरान 11,597 से 20,760 हेक्टेयर मीटर तक वृद्धि हुई। प्रथम एवं द्वितीय जोन के अंतर्गत मानसून के मौसम के बाद भूजल ड्राफ्ट में क्रमशः12578 से 22756 हेक्टेयर मीटर एवं 4890 से 10154 हेक्टेयर मीटर तक की वृद्धि हुई। दक्षिण-पश्चिम पंजाब में पंप द्वारा भूजल दोहन के लिए समग्र आवश्यक ऊर्जा वर्ष 1998 में 1158 MkWh थी जो बढ़कर वर्ष 2014 में 5216 MkWh तक पहुँच गयी यानि ऊर्जा में 90% तक की वृद्धि हुई।

Executive Summary

During the year 2015 - 2016, 26 centres carried out research and extension work in the field of assessment of water availability, groundwater recharge, groundwater use at regional level, evaluation of pressurized irrigation system, groundwater assessment and recharge, water management in horticultural and high value crops, basic studies on soil, water, plant relationship and their interaction, conjunctive use of canal and underground saline water, drainage studies for enhancing water productivity, enhancing productivity by multiple use of water, rainwater management in high rainfall areas. Salient achievements thru the year 2015-2016 are enlisted below.

Assessment of irrigation water demand and system supply and groundwater use

At Belvatagi, among different irrigation levels, higher cotton yield (1.73 t/ha) was recorded in 0.8 IW/CPE ratio which was significantly superior to irrigation at critical stages which gave yield of 1.52 t/ha. In irrigation level, higher water use efficiency (3.12 kg/ha-mm) was recorded with irrigation at critical stages. Among INM (Integrated Nutrient Management) levels, higher water use efficiency was recorded to be 3.23 kg/ha-mm.

At Chiplima, it was observed that it is feasible to provide irrigation to the entire command area even if the canal releases are reduced by 40%. This can be achieved by reducing cropping area under heavy duty crops from 8861 ha to 2975 ha and increasing the area under medium duty crops (from 2180 ha to 4820 ha) while light duty crops (from 231 to 3471 ha).

At Faizabad, the improved water management practice (6cm water per irrigation through checks of 5 x 10 m) gave higher wheat yield of 4.09, 4.04 and 3.97 t/ha at head, middle and tail end respectively of Chandpur distributary in comparison to farmers practice in which these were 3.04, 3.09 and 2.97 t/ha, respectively. Thus, about 30.57-34.52% higher wheat yield was obtained over farmer's practice of wheat crop. The water expense efficiency (WEE) was found to be highest (176.28 kg/ha-cm) at head followed by middle and tail end at which it was 174.04 kg/ha-cm and 171.11 kg/ha-cm, respectively.

At Jorhat, the ORP indicated that single irrigation applied at flowering stage of the crop (30-35 DAS) was very much encouraging in increasing the seed yield of rapeseed over the farmers conventional rainfed crop.

At Junagadh, the aquifer mapping in the Uben basin was carried out at fifteen sites by vertical electrical sounding resistivity technique. Comparison was made between all survey sites considering common depth up to 153.2 m i.e. 510 ft. The vertical geological profiles were prepared for all sites from the output maps of inverse slope. Hydrogeological Maps and hydrogeology of Uben basin were prepared using GIS, geological and hydrogeological properties of basin. The investigation showed that Sakkarbaugh site had unconfined aquifer thickness of 46.7 m with 5 confined aquifers. At Sukhpur, Ranpur, Evenagar, Parabdham and Patala site, 13.3 m, 60 m, 20 m, 20 m and 6.7 m thick unconfined aquifers while 6, 3, 7, 7, 1 (deeper than 153 m) confined aquifers were found, respectively. Similarly, the investigations carried out at Choki, Vadal, Makhiyala and Chobari revealed that unconfined aquifers of 20 m, 46.7 m, 6.7 m, 20 m thickness and 5, 2, 5, 7 respectively exists, few of which were affected by city effluents.

At Udaipur, the depth of open dug wells in the Bhilwara district ranges from 11.50 m to 27.50 m and the average well depth was found 20.09 m below ground level. Deeper water table in pre-monsoon seasons and shallow water table in post monsoon seasons was found in Bhilwara. The pH of the groundwater in Bhilwara continued to be similar for both the years. Generally, groundwater in Bhilwara is alkaline in nature. The large variation in EC of groundwater of Bhilwara was observed in pre- and post-monsoon seasons as well as in both the years. The highest average EC was recorded in Shahpura block in pre monsoon seasons, whereas the minimum average EC was recorded in Kotri block. The cations of groundwater of Bhilwara varied from place to place but the sodium was the predominated ion amid the cations. Amongst the anions, chloride was recorded to have highest concentration. Based on two years' results, it can be inferred that the major limiting factor in groundwater quality of Bhilwara in pre- and post-monsoon season was salinity. Further, 10% to 12.27% samples have RSC value > 2.5 meq/l in pre-monsoon seasons which is unsuitable for irrigation on sustainable basis.

Pressurised irrigation system and fertigation

At Belvatagi, growing of onion using drip irrigation with raised bed @ 1.0 ET_O along with paired row (45-120-45 cm) recorded significantly higher yield (48.83 t/ha) over farmers method and onion + chilli + cotton grown with 0.8 ET_O.

At Belvatagi, based on the first year results (2015-16) the treatment at critical stage drip irrigation with 100:100:70 kg/ha NPK recorded higher yield (2.08 t/ha) as compared to 0.8 IW/CPE ratio of irrigation with 110:110:80 kg/ha NPK (F_3) (2.0 t/ha).

At Belvatagi, the two years pooled data (2013-14 and 2014-15) indicated that irrigation @ 0.8 IW/CPE ratio significantly increased grain yield (2.21 t/ha) and straw yield (5.96 t/ha) as compared to 0.6 IW/CPE ratio (grain yield 2.18 t/ha and straw yield 5.78 t/ha). The fertilizer levels increased the grain yield (2.69 t/ha), straw yield (6.56 t/ha and water use efficiency (6.81 kg/ha-mm) with the RDF + FYM + 20 kg/ha $ZnSO_4$+ 20 kg/ha $FeSO_4$ application as compared to rest of treatments. Between two irrigation treatments (0.8 IW/CPE and 0.6 IW/CPE) the average (2013-14 and 2014-15) amount of water saving was 15.08% with 0.6 IW/CPE ratio.

At Bilaspur, the bulb yield of onion at 60% CPE irrigation produced significantly higher yield (26.39 t/ha) than irrigation at 120%, 100% and 80% CPE. Application of 5 kg/ha Zn + 20 kg/ha S produced significantly higher bulb yield (244.65 t/ha) than control. Water expanse varies from 23.21 cm to 43.21 cm (2 to 7 irrigations) and water expense efficiency varies from 610.25 to 772.88 kg/ha-cm among the treatments. Higher net return of Rs.244593 was found with 7 irrigations followed by 5 irrigation (Rs.228009).

At Coimbatore, the study on evaluation of suitable irrigation and fertigation schedulefor SSI in Sub-Surface Drip Irrigation for Western Zone of Tamil Nadu revealed WUE was the maximum in the treatments drip irrigation at 40% of PE and 60% of PE with lateral spacing of 90 cm. The other treatments recorded lower water use efficiencies because of increased water use due to increased lateral spacing of 150 cm.

At Dapoli, the low pressure inline drip irrigation system was installed to evaluate its hydraulic performance using the standard procedure for jasmine (*Jasminum sp.*). From the month-wise average yield data it was found that, the maximum yield of jasmine (1800 kg/ha) was observed during the month of December. The maximum WUE (151.9 kg/ha-cm) was observed in the month of February and minimum in the month of May.

At Dapoli, the maximum Aonla fruit yield was observed under the irrigation level of 80% ET_c through drip (5.76 kg/plant) and 7.13 kg/plant under 100% RDF fertigation level. The maximum WUE of 52.62 kg/ha-cm was observed in interaction effects of 80% ET_c and 100% RDF treatment combination.

At Dapoli, irrigation and fertigation levels had significant effect on yield of cashew plants during its 5th year of growth. The treatment 100% ET through drip recorded significantly highest cashewnut yield (0.28 t/ha) over rest while 80% RDF through drip recorded significantly highest (0.23 t/ha) cashew nut yield as compared to other fertigation levels.

At Gayeshpur, the results of the study showed that surface irrigation produced the highest cob yield (6.89 t/ha), being at par with drip irrigation at 1.0 ET_c (6.82 t/ha). Drip system displayed maximum improvement of reducing sugar (6.3%), total sugar (20.3%) and total soluble solids (7.2%). Conjunctive use 75% inorganic N plus 25% organic N as vermicomost showed excellence in promoting yield and quality parameters. The interaction showed that maximum yield of 9.32 t/ha was obtained from surface irrigation with 75% inorganic N plus 25% organic N as vermicompost, while maximum WUE of 25.67 kg/ha-mm was accomplished with drip irrigation at 0.6 ET_c with 100% N inorganic N.

At Hisar, the water productivity of applied irrigation water was 4.16 kg/m^3 with irrigation applied through drip planted under FIRBS. It was 3.86 kg/m^3 with irrigation through mini-sprinklers, 3.43 kg/m^3 under FIRBS and lowest (2.91 kg/m^3) with conventional planting and irrigation.

At Hisar, the irrigation applied at 0.8 PE through drip resulted in highest seed cotton yield and water productivity. Among the surface methods irrigation at 0.75 IW/CPE by furrow method yielded higher seed cotton yield as well as water productivity. Mulching with wheat straw @ 4 or 6 t/ha produced similar yield and water productivity but was considerably superior to no mulch.

At Junagadh, the yield response of coriander crop under stage wise stress condition was assessed and WUE and water saving is computed. The highest grain yield (1785.5 kg/ha), biological yield (3952.7 kg/ha) and WUE (4.04 kg/ha-mm) of coriander crop could be obtained when no stress condition was maintained in development and flowering stage and irrigated at 0.6 IW/CPE ratio during grain setting stage with drip irrigation. The optimum water requirements for the coriander crop was found as 419 m for obtaining the maximum yield of 1663 kg/ha.

At Kota, under feasibility of micro irrigation in rice, irrigation at 125% PE gave significantly higher grain yield, WUE and net return of paddy.

At Kota, the maximum pea yield (19.98 t/ha was obtained under sprinkler irrigation at IW/CPE ratio of 1.0, similarly 125% of recommended dose of fertilizer produced maximum yield (1.83 t/ha).

At Bathinda, the results revealed that maximum curd yield (20.65 t/ha) and average curd weight (714 g) was obtained in CW (canal water) treatment and was significantly higher than other treatments except 1CW:1TW treatment. Maximum water expense efficiency (WEE) was in CW treatment followed by 1 CW: 1 TW and lowest in poor quality TW (Tubewell) treatment. Maximum cucumber yield (13.3 t/ha) was obtained in CW treatment and is significantly higher than other treatments. Maximum WEE was in CW treatment followed by 1 CW: 1 TW and lowest in poor quality TW treatment. The results revealed that maximum bottle gourd yield (41.5 t/ha) and numbers of fruits per plant (10.8) of bottle guard were obtained in the treatment where canal water was used for irrigation and was significantly higher than other treatments except 1 CW: 1 TW treatment.

At Morena, the permanent broad bed and furrow (BBF) method of sowing resulted in highest grain yield (4.33 t/ha) and straw yield (5.94 t/ha), gross returns (Rs.86,640 t/ha), net profit (Rs.56,030 t/ha), B:C ratio (2.83) and water productivity of wheat was achieved compared with traditional method of sowing and irrigation. The maximum grain (4.38 t/ha) and straw yield (5.96 t/ha), gross returns of Rs.87,520 t/ha, net returns of Rs.53,620 t/ha, B:C ratio 2.64 and water productivity (0.170 kg/m^3) were registered under sub-surface irrigation method compared with other method of irrigation.

At Morena, the method of establishment of paddy and irrigation schedule sproduced high ergrain (5.6 t/ha) and stover yield (6.82 t/ha) of paddy. The significantly higher gross returns, cultivation cost and total water use recorded under conventional method of transplanting compared with direct or conventional method of seeding, whereas, higher net returns, B:C ratio and water productivity were recorded with direct seeding of paddy. The sub-surface irrigation at 1.25 IW/CPE ratio with fertigation produced higher grain (5.62 t/ha) and stoveryield (6.71 t/ha) over other irrigation treatments. The maximum gross returns and net returns were recorded under sub-surface drip irrigation at 1.25 IW/CPE ratio with fertigation compared with traditional or drip irrigation at 1.00 IW/CPE ratio. The total water-use was maximum under traditional method of irrigation and minimum with sub-surface drip irrigation at 1.0 IW/CPE ratio with fertigation, whereas reverse trend was found in water productivity.

At Palampur, the brinjal crop grown with 75% of recommended NPK fertigation under gravity fed drip irrigation resulted in significantly higher WUE (1.8 times) due to lower irrigation water use (47.96%) than recommended practices. Irrigation interval of two days resulted in significantly higher WUE than irrigation interval of either one day (8.68%) or three day (4.28%). Fertigation frequency oftwice a month resulted in significantly higher brinjal yield and WUE than fertigation frequencies of once a week (16.86%) and twice a week (8.44%).

At Palampur, during both the years, in surface irrigated onion (5 cm water depth), application of recommended nitrogen through chemical fertilizer along with application of recommended FYM resulted in significantly higher green onion yield (37.01 and 50.45%), gross returns (37.02 and 50.46%), net returns (1.62 and 2.14 times) and B:C ratio (1.43 and 2.07 times) than application of recommended nitrogen through chemical fertilizer. During both years, in crop raised under drip irrigation (0.6 PE), substitution of 100% of recommended N with locally prepared liquid manure which was enriched with 1% liquid biofertilizer (E100) resulted in highest green onion yield, gross returns, net returns and B:C ratio.

At Pantnagar, rice-yellow mustard-cowpea rotation was taken in the lysimeters.The average yield of rice 4.4.1 t/ha was obtained with an average water requirement of 683.53 mm and WUE as 6.51 kg/ha-mm. Yellow mustard performed better at 30 cm water table depth. The seed yield was more under sprinkler method than flood method. The maximum WUE was obtained with sprinkler method and at 0.5 IW/CPE ratio of 0.50. During hot summer months cowpea was taken up. The grain yield of cowpea was comparable at 30 and 60 cm water table depths, but considerably lower at 90 cm depth (907 kg/ha). The groundwater contribution and total crop water use was maximum at 30 cm water table depth but had lowest WUE (0.79 kg/ha-mm).

At Parbhani, higher fresh rhizome yield (29.57 and 35.14 t/ha), GMR (Rs.4,06,560 and Rs.5,62,304 per ha) and NMR (Rs.2,77,617 and Rs.4,01,074 per ha) of turmeric were obtained with irrigation at 0.8 PE except irrigation at 1.0 PE during 2014-15 and 2015-16 respectively. The application of 120% RDF, (240:120:120 NPK kg/ha) produced significantly higher fresh rhizome yield (Rs.32.57 and 35.66 t/ha), GMR (Rs.4,4,7837 and Rs.5,7,0493 per ha) and NMR (Rs.3,04,296 and Rs.3,94,818 per ha) than lower levels of fertigation. Higher WUE (63.70 and 58.21 kg/ha-mm) was observed with irrigation at 0.6 PE during both the years of experimentation and it gradually decreased with increase in irrigation level.

At Parbhani, irrigation at 0.8 PE recorded significantly maximum fruit yield of brinjal over rest of irrigation levels during both the years of experimentation (2014 and 2015). Application of 80% N through fertigation recorded significantly maximum fruit yield of brinjal except 100% N through fertigation during both the years of experimentation. Application of irrigation at 0.4 PE recorded higher WUE (139.16 and 91.29 kg/ha-mm) while minimum WUE was observed in irrigation at 1.0 PE (46.57 and 41.69 kg/ha–mm) during both the years of experimentation.

At Pusa, *rabi* maize rain yield due to I_1=0.4 (8.23 t/ha), 1_2=06 (8.48 t/ha) and I_3=08 (8.68 t/ha) were statistically at par and both were significantly superior to I_4 (7.7 t/ha). Mulching with either sugarcane (S/C) trash or maize stubble @ 5 and 10 t/ha) also, significantly influenced the grain yield. Grain yield recorded with (S/C) trash mulch @ 5 t/ha (8.25 t/ha) and 10 t/ha (8.52 t/ha) were statistically at par with each other and likewise, grain yield recorded with maize stubble mulch @ 5 t/ha (8.39 t/ha) and 10 t/ha (8.73 t/ha) were at par but all the mulched plots were significantly superior to no mulch plot (7.47 t/ha). WUE decreased significantly with each increasing levels of irrigation from I_1 (473.3 kg/ha-cm) to I_4 (253.3 kg/ha-cm). However, with mulching WUE value of 369.3 kg/ha-cm was recorded in sub-plot treatment M_4 Maize stubble @ 10 t/ha which was statistically at par with other treatments involving application of mulch except S/C trash @ 5 t/ha. All the mulched plots were significantly superior to no mulch.

At Rahuri, yield of summer marigold was significantly higher (17.83 t/ha) when irrigation at 100% PE next in order of sequence was 80% PE (16.91 t/ha). Water requirement of summer marigold was higher at 100% PE of irrigation (70.26 cm) and lowest was at 40% PE irrigation (28.11 cm). Water use of summer marigold was higher (505.10 kg/ha-cm) at 40% PE irrigation and lowest was at 100% PE irrigation (238.14 kg/ha-cm). Water saving was higher (61.28%) at 40% PE irrigation and lowest (10.06%) at 100% PE of irrigation. Marigold planted at 60 x 10 cm with lateral spacing 120 cm recorded highest yield of flower 17.13 t/ha, WUE 434.30 kg/ha-cm with water saving of 49.53%. The net extra income was received when summer marigold was planted at 30-60 x 15 cm with lateral spacing 90 cm and 40% PE of irrigation Rs.11,42,299 per ha same trend was observed in case of net profit per cm of water use Rs.78,853 and WUE 1113.68 kg/ha-cm.

At Sriganganagar, the fruit yield of chilli (35.43 t/ha recorded with drip irrigation at 1.0 ET_c (LT) was statistically at par with that of 1.2 ET_c Low Tunnel (LT) (36.59 t/ha) and significantly higher than other treatments tested in the study. Thus drip irrigation at 1.0 ET_c with low tunnel was found optimum irrigation schedule for chilli. It gave 69.85% higher fruit yield of chilli and saved 24.12% irrigation water over conventional surface irrigation with low tunnel and 101.63% higher fruit yield of chilli and saved 5.45% irrigation water over 1.0 ET_c without low tunnel. The maximum WEE of 51.1 kg/ha mm was recorded with drip irrigation at 0.6 ET_c followed by 48.7 kg/ha mm at 0.8 ET_c.

At Sriganganagar, a field experiment was conducted on fertigation in chilli under low tunnel during three consecutive years from *rabi* 2012-13 to 2014-15 at ARS. The highest fruit yield of chilli was recorded with 120% RD which out yielded rest of the treatments. This treatment increased fruit yield of chilli by 55.4% over conventional practice. The total water used in this treatment was 742.1 mm as against 1077.3 mm in conventional practice. There was saving of 44.9% water in comparison to conventional practice. The net seasonal income under 120% RD drip fertigation treatment was Rs.194167 against Rs.121000 with conventional practice. The respective benefit cost ratios were 1.51 and 1.39. Thus, 120% RD (i.e. 84 kg N, 60 kg P_2O_5 & 60 K_2O/ha) in 9 equal splits at an interval of 13 days was found optimum fertigation schedule for chilli.

Rainwater harvesting and utilization

At Almora, runoff fed tanks can be successfully utilized for growing vegetable and cereal crops. The highest area can be allotted to vegetables during *kharif* and lowest during *rabi* season. The artificial recharging enhanced spring discharge by 129.1% in comparison to discharge recorded before the inception of treatments. The total capacity reached up to 2777 m^3 in three villages of Almora district.

At Coimbatore, Operation Research Project on improved water management practices in LBP (Lower Bhavani Project) revealed the water saving in improved water management practice over farmer's practices of raising groundnut range from 24-31% in head, middle and tail reaches of the canal. Also, the WUE increased from 3.82 kg/ha-mm to 4.12 kg/ha-mm in head, middle and tail reaches, respectively.

At Dapoli, the significantly highest (23.16 kg/plant) mango fruit yield was found in treatment irrigation at 75% of PE through applicator while the maximum (20.79 kg/plant) fruit yield was found in the treatment 50% RDF+PBZ+40 kg FYM. The maximum WUE (35.52 kg/ha-cm) was found in treatment combination 50% PE through applicator + 100% RDF + PBZ. The results on water use efficiency indicated that in case of water scarcity, the mango yield can be increased by about 21% with the application of 60 cm water as compared to no irrigation.

At Faizabad, land configuration in the form of raised bed planting of mentha (in paired row on 70 cm bed and 20 cm furrow) gave the significantly higher yield of herb (17.77 t/ha) over rest of the treatments. The herb yield recorded under ridge planting, raised bed planting with three rows (100 cm beds and 35 cm furrow) and flatbed planting were 16.43, 15.01 and 13.21 t/ha, respectively. The irrigation level 1.2 IW/CPE gave the maximum herb yield of 18.11 t/ha which was significantly higher over other levels of irrigation (0.6 and 0.8 IW/CPE) except 1.0 IW/CPE irrigation level in which it was 17.29 t/ha. Paired row raised bed planting system also recorded the higher value of WUE 45.69 kg/ha-mm.

At Jammu, on station experiment was carried out in *kharif* 2015 to study alternate wetting and drying irrigation regimes management in basmati rice through field water measuring tube device under light texture soil. When the water level inside the tube dropped to 7, 10 and 15 cm below the ground level, then field was irrigated with 7 cm of water. In conventional (i.e. farmers' practice) treatment of rice field was flooded with 7 cm of water as recommended.

At Jorhat, observation on drainage coefficient revealed that highest value of drainage coefficient (4.28 cm/h) was obtained for PVC pipe with mineral envelope followed by PVC pipe with organic envelope. Bamboo pipe with organic envelop resulted in the lowest drainage coefficient of 0.669. The plastic pipe irrespective of envelope material lowered the water table better than other treatments during the rainy season. The same pipes have been used in *rabi* season for providing irrigation water.

At Kota, the pooled data of three years revealed that maximum soybean seed yield (1286 kg/ha) obtained under irrigation at flowering and pod development stage where in only one irrigation was applied at pod development stage, because rainfall was received up to flowering stage. Significantly higher seed yield (1333 kg/ha) and water use efficiency (23.46 kg/ha cm) were recorded under foliar fertilization spray of 19:19:19 (5 g/l) at 30, 45, 60 and 75 DAS over rest of foliar fertilization treatments.

At Kota, significantly higher soybean equivalent yield (1663 kg/ha) was recorded under soybean + pigeonpea (4:2) intercropping system, which was found at par with soybean + pigeonpea (3:2) intercropping system. Maximum WUE (29.75 kg/ha-cm) was also observed under soybean + pigeonpea (4:2) intercropping system.

Basic Studies on soil–water–plant relationship

At Belvatagi, investigations on the (Integrated Nutrient Management) in sunflower-chickpea crop sequence were initiated during 2013-14 and continued on 2014-15. The crop receiving irrigation level at 0.6 IW/CPE recorded significantly higher sunflower yield (1.81 t/ha), gross income (Rs.58,968 per ha), net income (Rs.43,593) B:C ratio (3.84) during 2013. The former treatment also recorded higher gross returns (Rs.69,247) and net returns (Rs.50,519) B:C ratio (3.73) and WUE (5.97) in pooled analysis. In whole cropping system applying of irrigation given at 0.6 IW/CPE with RPP for both crops (Sunflower during *kharif* followed by chickpea during *rabi* season) recorded higher net returns (Rs.1,01,196 during 2013 and Rs.1.02,493 during 2014).

At Belvatagi, experimental results indicated that fertilizer levels had significantly increased grain yield (1.93 t/ha), stalk yield yield (4.79 t/ha) and water use efficiency (6.35 kg/ha-mm) with the application RPP + 25 kg/ha $FeSO_4$ + 0.75% $FeSO_4$ spray (30 DAS) + 0.5% lime as compared to rest of treatments. Between two irrigation treatments (0.8 IW/CPE and irrigation at critical stage) the average (two years 2014-15 and 2015-16) amount of water saving is 18.23% with irrigation at critical stage of crop.

At Bilaspur, the application of 100:60:40 NPK produced significantly higher grain yield (4.18 t/ha) of wheat than the application of 60:40:20 and 80:50:30 NPK kg/ha. Provision of 5 irrigations produced significantly higher grain yield (4.32 t/ha) than the application of 3 irrigations and 2 irrigations but at par with 4 irrigations. Water expense varies from 16.38 to 34.38 cm with water expense efficiency 125.56 to 218.74 kg/ha-cm in 5 irrigations to 2 irrigations. Higher net return of Rs.41,067 was found with 5 irrigations.

At Bilaspur, total crop evapotranspiration (ET_c) of lentil variety K-75 was 16.62 cm. The crop coefficient (K_c) range was 0.32-0.98 with average value of 0.71 for cropping period of 117 days (emergence to maturity). The total potential evapotranspiration (ET_0, estimated) was 22.49 cm. The total pan evaporation (PE) was 24.47 cm.

At Chiplima, under the experiment on optimising irrigation scheduling and nutrient management for onion, the two years results suggested that application of 40 kg/ha S produced significantly highest bulb yield of 19.42 t/ha and total soluble solids of 10.48%. Further, highest bulb yield of 19.36 t/ha was obtained when the irrigation was scheduled at IW/CPE ratio of 1.2. The highest water use efficiency (291.78 kg/ha-cm) was observed at irrigation schedule IW/CPE of 0.8.

At Chalakudy, the study on soil nutrient dynamics under varying moisture regimes in banana showed that P at 75% and K at 125% of RDF increased yield by 17.5% over the present recommendation. The results suggest that the recommendation of P_2O_5 could be reduced to 86 g per plant instead of the present 115 g per plant.

At Gayeshpur, maximum grain yield of 3344 kg/ha was obtained with high frequency of irrigation at 20% of ASM, which was at par with moderate frequency of irrigation at 40% of ASM (3182 kg/ha). Similarly, the highest grain yield of 3863 kg/ha was recorded with 160:80:80 kg/ha $N:P_2O_5:K_2O$ fertilizer level, but was at par with 120:60:60 kg/ha $N:P_2O_5:K_2O$ fertilization (3611 kg/ha).

At Morena, the maximum seed (1,238 kg/ha) and straw (2,455 kg/ha) yields of blackgram were obtained with 125% RDF. Economic analysis indicated that the maximum gross returns (Rs.59,068 per ha), net returns (Rs.43,588 per ha) and B:C ratio (3.82) were observed with 125% RDF which accruing higher profit. Thus, it was concluded that productivity profitability and sustainable yield of blackgram could be obtained by use of 125% RDF in sandy loam soils of Chambal commend area under rainfed conditions.

At Parbhani, application of irrigation through drip at 1.0 PE recorded significantly higher dry pod yield (4211 and 4449 kg/ha), GMR (Rs. 1,79,054 and Rs. 1,87,532 per ha) and NMR (Rs.95,461 and Rs. 1,02,949 per ha) of summer groundnut during both the years of experimentation than rest of the irrigation treatments. With regard to mulches, significantly maximum dry pods yield (4370 and 4658 kg/ha), GMR (Rs.1,85,729 and Rs.1,96,130 per ha) and NMR (Rs.86,310 and Rs.95,881 per ha) of summer groundnut was noticed in transparent polythene mulch as compared to rest of the mulches during both the years of experimentation. Higher water use efficiency (7.15 and 8.10 kg/ha-mm) was obtained in irrigation level 0.6 PE while lower WUE (3.75 and 4.39 kg/ha-mm) was observed in irrigation level 1.2 PE. In case of mulches during both the years of experimentation, higher WUE (6.24 and 6.84 kg/ha-mm) was observed in transparent polythene mulch followed by black polythene mulch (5.61 and 6.51 kg/ha-mm).

At Rahuri, the drip irrigation at alternate day as per ET_c was found to be the best for *rabi* onion yield, quality, water saving and efficiency and storage studies followed by micro sprinkler irrigation on alternate day as per ET_c. Amongst the INM treatments, the 100% recommended dose of fertilizer (100:50:50 kg/ha NPK) along with 10 tonnes of FYM t/ha was found to be the best with respect to yield, quality and storage studies followed by 100% recommended dose of fertilizers along with application of vermicompost on N basis of FYM.

At Shillong, field experiment was conducted to evaluate the effect of tillage and residue management in rice based system for increased production and resource conservation. Zero tillage with residue retention resulted in significantly higher yield of rice (17.2%) and succeeding *rabi* crops, mustard (34.6%), pea (16.4%) and buckwheat (27.4%) as compared to that of conventional tillage with residue removal. The highest WUE for mustard and pea was recorded under zero tillage for *rabi* crops, which was 35.9% and 16.3% higher over conventional tillage.

At Sriganganagar, in case of canal closure or some other reason if sowing was not possible in time, then the crop may be raised in plastic bags and transplanted in field up to 30th May with flood irrigation and 10th June with drip irrigation without yield losses. Transplanted cotton crop with drip irrigation on 30th May, 10th June and 20th June gave 22.67%, 35.54% and 27.35% higher seed cotton yield over direct sown on these dates with drip irrigated crop and 16.19, 27.13 and 9.56% higher yield over transplanted cotton crop on these dates with flood irrigation, respectively.

At Udaipur, the monthly crop water requirements for the major crops of the command area like maize, soybean, greengram, wheat, mustard, gram and barley were 534.89 mm, 453.71 mm, 362.69 mm, 391.36 mm, 268.17 mm, 306.86 mm, and 267.62 mm, respectively.

Conjunctive use of surface and groundwater resources for sustainable crop production

At Bilaspur, dairy surface water produced higher rice grain yield (3.66 t/ha) followed by that with Dairy surface water + Tubewell water (3.41 t/ha). Under different nutrient managements 100% RDF gave significantly higher yield (3.68 t/ha) than 75% RDF and 75% RDF + Brown manure but at par with 75% RDF + Green manure (3.67 t/ha) and 75% RDF + BGA (3.6 t/ha). Higher net return Rs.32605 was found under Dairy surface water followed by Dairy surface water + Tubewell water (Rs.28897 per ha).

At Chiplima, different integrated weed management practices were evaluated under modified water regimes in system of rice intensification. The pooled mean of two years indicated that the water application and integrated weed management practices had significant effect on the grain yield. Application of 5 cm standing water on the day before the weeding operation produced significantly highest grain yield of 5.21 t/ha. Application of one pre- and one post-emergence herbicide i.e., Pretilachlor and Oxadiargyl, respectively recorded significantly highest grain yield of 5.45 t/ha.

At Chiplima, the results of the two years of the experiment to study the effects of water regimes and crop geometry on yield and water productivity in maize–greengram intercropping system suggested that surface irrigation at 0.8 IW/CPE recorded the highest maize equivalent yield (4.4 t/ha) followed by irrigation at 0.90 IW/CPE (4.4 t/ha). Maize intercropped with greengram in 2:2 rows ratio recorded the highest maize equivalent yield (4.86 t/ha) and benefit cost ratio (2.28), followed by 1:1 row ratio with maize equivalent yield of 4.74 t/ha and B:C ratio of 1.99.

At Faizabad, transplanted rice recorded highest yield of 4.15 t/ha which was higher over rest of the planting methods of rice. Drum seeding of rice gave the second highest yield of 3.68 t/ha which was also higher over planting with zero tillage machine and seeding under dry condition but at par with that of broadcasting of sprouted seeds under puddled condition. Irrigation schedule had significant effect on rice crop yield and days after disappearance of ponded water (DADPW) irrigation schedule. 7 cm irrigation at 1-DADPW recorded significantly higher yield of rice (44.90 t/ha) over other irrigation schedules in which 7 cm irrigation was applied at 4, 7 and 10 DADPW and the rice yield was 4.03, 3.17 and 2.42 t/ha, respectively. The transplanting method of rice recorded the highest WUE 7.39 kg/ha-mm while irrigation level 7 cm irrigation at 1 DADPW recorded WUE 6.25 kg/ha-mm.

At Jorhat, a groundwater prospect mapping using Remote Sensing and Geographic Information System (GIS) as tool for demarcating the potential groundwater resource during pre-monsoon season for the entire Jorhat district covering 2852 km^2 was completed highlighting with area-wise groundwater potential information in the form of map. Maximum area (739.50 km^2) was observed in groundwater table depth of 6.16–6.82 m bgl and minimum (78.34 km^2) in groundwater table depth of 4.20-4.95 m bgl. Based on the depth of groundwater resource, selection of pump suitable for lifting water and possibility of using such pump to irrigate unit area were prepared in the form of map.

At Junagadh, the estimated cost of harvesting roof water storms of consecutive 1 to 5 days maximum rainfall for 10 years return period in sump varies from Rs.42 to 88 per m^2 of roof. The capacity of storage tank in combination with recharge well found for 1 day maximum rainfall indicated that the buffer storage tank of 0.02 m^3/m^2 of roof was required. The annual average, lowest, highest and 10 years return period of roof water runoff was determined as 0.62, 0.1, 1.94 and 0.96 m^3/m^2 of roof. The cost of system was Rs.44.85 per m^2 of roof area. The observations of roof water runoff recharged and collected in the sump showed that, out of 0.54 m^3/m^2 per square meter of roof area, 0.16 m^3 was contributed to groundwater recharge and 0.38 m^3 was collected in to sump. The system cost was Rs.119.26 per m^2 of roof area. The annual runoff coefficient for roof area was 0.74.

At Ludhiana, the electrical pump set density per 1000 ha in south-west Punjab was 301 in 1998 and increased to 659 in 2014 for zone 1 and was 92 in 1998 and increased to 184 in 2014 for zone II during the study period. In zone I, the groundwater draft increased from 29258 to 52335 ha-m, whereas in zone II groundwater draft increased from 11597 to 20760 ha-m during the monsoon season. In non-monsoon season, the groundwater draft increased from 12578 to 22756 ha-m and from 4890 to 10154 ha-m in zone I and zone II, respectively. The overall energy required for groundwater pumping in south-west Punjab was 1158 MkWh in 1998 which increased to 5216 MkWh (90%) in 2014.

Introduction

All Indian Coordinated Research Project on Water Management and All India Coordinated Research Project on Groundwater Utilisation were merged to be rechristened as All India Coordinated Research Project on Irrigation Water Management during the XII Plan and are operating in 26 centres. There are multiple locations under Tamil Nadu Agricultural University (Bhavanisagar, Madurai, Coimbatore), Jawaharlal Nehru Krishi Viswa Vidyalaya, Jabalpur (Powarkheda and Jabalpur), Punjab Agricultural University, Ludhiana (Bathinda and Ludhiana) centres.

Revised mandates of AICRP on Irrigation Water Management after merger of AICRP on WM and AICRP on GWU are as follows:

1. Assessment of surface and groundwater availability and quality at regional level and to evolve management strategies using Decision Support Systems (DDS) for matching water supply and demand in agricultural production systems
2. Design, development and refinement of surface and pressurized irrigation systems including small holders' systems for enhancing water use efficiency and water productivity for different agro-ecosystems
3. Management of rainwater for judicious use and to develop and evaluate groundwater recharge technologies for augmenting groundwater availability under different hydro-geological conditions
4. Basic studies on soil-water-plant-environment relationship under changing scenarios of irrigation water management
5. To evolve management strategies for conjunctive use of surface and groundwater resources for sustainable crop production

List of existing centres and their controlling institutions under AICRP on Irrigation Water Management

Table 1. Centres and their controlling Universities

S.No.	Location of the Centre	Controlling University/ICAR Institute
1.	Almora	VPKAS, Almora
2.	Bathinda, Ludhiana	PAU, Ludhiana
3.	Belvatagi	UAS, Dharwad
4.	Bhavanisagar, Madurai, Coimbatore	TNAU, Coimbatore
5.	Bilaspur, Raipur	IGKVV, Raipur
6.	Chalakudy	KAU, Thrissur
7.	Chiplima	OUAT, Bhubaneswar
8.	Dapoli	BSKKV, Dapoli
9.	Faizabad	NDUAT, Faizabad
10.	Hisar	CCSHAU, Hisar
11.	Jammu	SKUAST, Jammu
12.	Jorhat	AAU, Jorhat
13	Junagadh	JAU, Junagadh
14	Gayeshpur	BCKVV, Mohanpur
15.	Kota	Agricultural University Kota
16.	Morena	RVSKVV, Gwalior

17.	Navsari	NAU, Navsari
18.	Palampur	CSKHPKVV, Palampur
19.	Pantnagar	GBPUAT, Pantnagar
20.	Parbhani	VNMAU, Parbhani
21.	Powarkheda	JNKVV, Jabalpur
22.	Pusa	RAU, Pusa
23.	Rahuri	MPKV, Rahuri
24.	Shillong	ICAR Research Complex for NEH region
25.	Sriganganagar	SKRAU, Bikaner
26.	Udaipur	MPUAT, Udaipur

Irrigation Commands under AICRP on Irrigation Water Management

The locations of the centres of AICRP on Irrigation Water Management catering to different irrigation commands and agro ecological regions in the country are given in Table 2.

Table 2. Agro-ecological region-wise distribution and irrigation commands represented by the centres of AICRP on Irrigation Water Management

Region No.	Agro-ecological region	State	Irrigation region	Centre	Controlling command organization
1	Western himalayas, cold arid ecoregion with shallow skeletal soils	J & K	Jammu Tawi		
2	Western plains, Kachchh and parts of Kathiawar peninsula, hot ecoregion with desert and saline soils	Punjab Haryana Rajasthan Gujarat	Bhakra Bhakra IGNP	Bathinda Hisar Sriganganagar	PAU CCSHAU SKRAU, Bikaner
3	Deccan plateau, hot arid ecoregion, with red and black soils	A.P. Karnataka			
4	Northern plains and central highlands including Aravalis, hot semi-arid ecoregion with alluvium-derived soils	Punjab Haryana Gujarat Rajasthan U.P. M.P.	Chambal	Morena	RVSKVV
5	Central (Malwa) highlands, Gujarat plains and Kathiawar Peninsula, hot semi-arid ecoregion, with medium and deep black soils	Rajasthan M.P. Gujarat	Chambal	Kota	MPUAT, Udaipur

6	Deccan plateau, hot semi-arid ecoregion, with shallow and medium (with inclusion of deep black soils)	A.P. Maharashtra Karnataka	Mula Jayakwadi Malaprabha	Rahuri Parbhani Belvatagi	MPKV UAS, Dharwad
7	Deccan (Telangana) plateau and Eastern Ghats, hot semi-arid ecoregion, with red & black soils	A.P.			
8	Eastern Ghats, TN uplands and Deccan (Karnataka) plateau, hot semi-arid ecoregion with red loamy soils	A.P. Karnataka Tamil Nadu	Lower Bhavani Periyar Vaigai	Bhavani- sagar Madurai	TNAU TNAU
9	Northern plain hot subhumid (dry) ecoregion, with alluvium derived soils	Bihar Punjab U.P.	Sharda Canal Sharda Sahayak	Pantnagar Faizabad	GBPUAT NDUAT
10	Central highlands (Malwa, Bundelkhand & eastern Satpura) hot humid ecoregion, with black and red soils	M.P. Mahara- shtra	Tawa	Powarkheda	JNKVV
11	Eastern plateau (Chhattisgarh), hot subhumid ecoregion, with red and yellow soils	U.P. Bihar Chhattisgarh	Hasdeo Bango	Bilaspur	IGKVV
12	Eastern (Chhotanagpur) Plateau & Eastern Ghats, hot subhumid ecoregion, with red and lateritic soils	Bihar A.P. M.P. Odisha	Hirakud	Chiplima	OUAT
13	Eastern plains, hot subhumid (moist) ecoregion, with alluvium-derived soils	U.P Bihar	Gandak	Pusa	RAU
14	Western Himalayas, warm sub-humid (to humid with inclusion of perhumid) ecoregion with brown forest & podzolic soils	J & K H.P. U.P.	Ravi & Tawi	Jammu Palampur Almora	SKUAST HPKVV VPKAS
15	Bengal and Assam plains, hot sub-humid (moist) to humid (inclusion of perhumid) ecoregion, with alluvium-derived soils	Assam Meghalaya Manipur W.B.	Jamuna DVC	Jorhat Gayeshpur	AAU BCKV

16	Eastern Himalayas, warm per-humid ecoregion, with brown & red hill soils	Sikkim W. B. Arunachal Pradesh			
17	North-eastern Hills (Purvachal) warm perhumid ecoregion with red & lateritic soils	Arunachal Pradesh Nagaland Manipur Mizoram Tripura Meghalaya	Shillong		ICAR-Complex for NEH
18	Eastern coastal plain, hot subhumid to semi-arid ecoregion with coastal alluvium-derived soils	W.B. Odisha A.P. Tamil Nadu Pondicherry			
19	Western Ghats & Coastal Plain, hot humid-perhumid ecoregion, with red, lateritic and alluvium-derived soil	Gujarat Kerala Karnataka	Ukai-Kakarpar Chalakudy	Navsari Chalakudy	NAU KAU
20	Inlands of Andaman-Nicobar and Lakshwadweep, hot, humid to per-humid island ecoregion, with red loamy and sandy soils	Laksha-dweep Andaman & Nicobar Islands (UT)			

Locality Characteristics of the Centres under AICRP on Irrigation Water Management

Locality characteristics in terms of soil, water table, annual rainfall, source of irrigation, etc. for each AICRP centre are given in Table 3.

Table 3. Locality characteristics of AICRP centres in irrigation commands

Centre name	Soil type	Depth of water table (m)	Annual rainfall (mm)	Source of irrigation	Irrigation water quality
Belvatagi	Sandy loam to clay	Very deep	556	Canal	Good
Bhavanisagar	Red sandy loam to clay loam	3-10 m	702	Canal	Good
Bilaspur	Sandy loam to clay	>2 m	1249	Canal	Good
Chalakudy	Loamy sand to sandy loam, slightly acidic	>2 m	3146	Canal	Good
Chiplima	Sandy loam to sandy clay loam	0.2-5 m	1349	Canal	Good

Faizabad	Silty loam to silty clay loam	3-4 m	1163	Canal Tubewell	Good
Hisar	Loamy sand to sandy loam	0.4-1 m	430	Canal Tubewell	Good
Jammu	Sandy loam to silty loam	>4 m	1175	Canal	Good
Jorhat	Sandy loam to sandy clay loam, slightly acidic	0-15 m	1985	Canal Tubewell	Good
Bathinda	Loamy sand to sandy loam	1.0-4 m	400	Canal Tubewell	Good
Kota	Clay loam to clay	0.7-2 m	777	Canal	Good
Madurai	Sandy loam to clay loam	0.5-2 m	858	Canal	Good
Gayeshpur	Sandy loam to clay loam	0.2-2 m	1315	Canal Tubewell	Good
Morena	Sandy loam to sandy clay loam	5-15 m	875	Canal Tubewell	Good
Navsari	Clayey	1-5 m	1418	Canal	Good
Pantnagar	Sandy loam to clay loam	0.5-3 m	1370	Canal Tubewell	Good
Parbhani	Medium to deep black clayey	>3 m	879	Canal	Good
Powarkheda	Clay loam to clayey	1-5 m	1285	Canal	Good
Pusa	Sandy loam	2-6 m	1200	Canal Tubewell	Good
Rahuri	Deep black clayey	2-5 m	523	Canal	Good
Sriganganagar	Loam to silty clay loam	>10 m	276	Canal Tubewell	Good

Theme 1

Assessment of surface water and groundwater availability and quality at regional level and to evolve management strategies using decision support system (DSS) for matching water supply and demand in agricultural production systems

1.1. Bathinda

Matching and Reconciliating Water Supply with Crop Water Demands in Consideration of Crop Diversification and Water Application

The Balluana minor of the Behman distributory of Bathinda branch was selected to evaluate irrigation system performance and to work out intervention for improvement of irrigation system and its management, improved and sustainable crop and water productivity. Canal water was monitored and month-wise opening and duration of water flow from November, 2014 to October, 2015 was recorded. Canal running days varied from 0 to 31 days in different months with the highest in the month of May, 2015 and the lowest in December, 2014 and January, 2015.

During *rabi* 2014-15, total rainfall received was 148.4 mm and wheat was the main crop at all the nine outlets. The variation in total effective rainfall and calculated water requirement and relative water supply (RWS) for different *rabi* crops in the cultivable command area (CCA) are presented in table 1.1.1 and 1.1.2. RWS below one indicated that there was need to replace large part of the area under wheat by barley, gram and raya, which require less water to match the water supply with water requirement during *rabi* season at both outlets.

During *kharif* 2015, total rainfall received was 399.6 mm and cotton was the main crop at all the outlets. The variation in total effective rainfall and calculated water requirement and RWS for different *kharif* crops in the CCA are presented in table 1.1.2 and 1.1.3. RWS below one indicated towards increasing supply of water or replacing high water requirement crops with low water consuming crops like cotton, guar and bajra.

1.2. Sriganganagar

Matching and Reconcilliating Water Supply with Crop Water Demands in Consideration of Crop Diversification and Water Application

The Khetawali distributory (KWD) was selected to evaluate performance of irrigation system and work out improvement of the irrigation system and its management for improved and sustainable productivity to ensure equitable economic growth of the area. The KWD has 24 outlets, out of which 16 outlets are in KWD system itself, 6 outlets are in Khetawali minor (KWM) system and 2 outlets are in Amarpura minor (ARM) system. The design discharge of KWD system, KWM and ARM were 74.64, 17.05 and 4.0 cusec, respectively. On Farm Development (OFD) working in the command has made appreciable contribution in terms of extending irrigation to larger area, improving water distribution and water availability to individual farmers, but coverage under OFD work was not as per norms and maintenance was poor. In IGNP system, irrigation water was supplied to farmers through the main watercourse after framing 'turn' of warabandi. The requirement of warabandi, although in terms of equity was fulfilled to a certain extent but, in practice, farmers at head reaches get more water as compared to the tail enders. Sometimes, when the canal is closed without completing its full turn, the farmers at tail end do not receive the water of their turn. The supply of main canal was distributed to different branches or distributaries in accordance with the supply and demand on different channels. The system also eliminates the possibility of complete drought in pocket areas. But in reality there was no match of actual flowing of canal water and canal regulation forecasted earlier.

The experiment conducted during *kharif* 2015 was reported. Different crops having varying water requirements were grown in the systems during this season (Table 1.2.1). The canal water flow in Khetawali distributory system during *kharif* 2015 was for 88 days. The flow in KWD, KWM and APM systems of Khetawali distributory was recorded as 72 cusec, 14.9 cusec and 2.5 cusec, respectively during most of the time but for 19 days it was less than designed capacity. The relative water supply was less than one in KWD and KWM systems and more than 1.0 in APM system (Table 1.2.2). The area covered by A. cotton crop was maximum in the distributory, followed by guar, groundnut and paddy. Some area was also under fodder crops. The overall relative water supply was 0.82. It is necessary to replace part of the area under A. cotton by guar or groundnut in order to match water supply with water requirement during season in all the irrigation systems.

Table 1.1.1. Crop-wise area (ha), water requirement (ha-cm) in *rabi* 2014-15

Outlet No.	Wheat		Raya/Chickpea		Barley		Vegetable		Orchard		Fodder and others		Total	
	Area	Water	Area	Water	Area	Water	Area	Water	Area	Water	Area	Water	Area	Water
3758/R	612.5	30624.4	2.0	75.8	0.5	22.0	6.3	378.4	3.0	178.1	36.4	2183.3	660.6	33462.0
14025/L	551.4	27572.2	2.2	85.7	0.2	10.7	1.1	65.5	2.7	163.1	45.1	2708.1	602.7	30605.4
14040/R	531.0	26549.6	2.1	82.6	0.2	10.3	1.1	63.1	2.6	157.1	43.5	2607.7	580.5	29470.3
18163/R	526.9	26343.8	2.1	81.9	0.2	10.2	1.0	62.6	2.6	155.9	43.1	2587.5	576.0	29241.8
20170/L	786.6	39328.6	1.5	57.7	0.3	15.1	2.2	133.9	23.5	1407.6	40.1	2406.4	854.2	43349.2
25000/L	647.4	32367.7	0.4	15.5	0.0	0.0	2.2	132.8	34.6	2076.0	32.8	1967.4	717.4	36559.4
26630/L	718.2	35908.3	0.4	17.2	0.0	0.0	2.5	147.3	38.4	2303.1	36.4	2182.6	795.8	40558.5
35977/TL	733.1	36656.3	8.0	307.5	3.1	134.7	0.8	49.6	20.0	1199.3	38.5	2308.3	803.5	40655.7
35977/TR	480.2	24010.6	4.6	178.0	2.3	99.5	0.4	25.9	10.3	620.1	22.8	1368.9	520.7	26303.1

Table 1.1.2. Relative water supply (RWS) during *rabi* and *kharif* 2014-15

Outlet No.	CCA (ha)		Canal water diverted (ha-cm)		Effective rainfall (ha-cm)		Total water supply (ha-cm)		Water requirement (ha-cm)		RWS	
	Rabi	*Kharif*	*Rabi*	*Kharif*	*Rabi*	*Kharif*	*Rabi*	*Kharif*	*Rabi*	*Kharif*	*Rabi*	*Kharif*
3758/R	660.6	660.6	3159.8	8476.2	9803.6	26398.4	12963.4	34874.5	33462.0	64570.3	0.387	0.540
14025/L	602.9	602.9	2836.1	7607.9	8946.4	24090.3	11782.5	31698.2	30605.4	62445.2	0.385	0.508
14040/R	580.5	580.5	2728.2	7318.4	8614.6	23196.8	11342.8	30515.2	29470.3	60129.1	0.385	0.507
18163/R	576.0	576.0	2712.8	7277.1	8547.8	23017.0	11260.6	30294.1	29241.8	59663.0	0.385	0.508
20170/L	854.2	854.2	4007.5	10750.3	12676.5	34134.2	16684.0	44884.5	43349.2	80108.0	0.385	0.560
25000/L	717.4	717.4	3360.1	9013.7	10645.6	28665.7	14005.7	37679.4	36559.4	55826.1	0.383	0.675
26630/L	795.8	795.8	3730.0	10006.0	11810.1	31801.4	15540.2	41807.4	40558.5	61932.7	0.383	0.675
35977/TL	803.5	803.5	3776.3	10130.0	11923.3	32106.3	15699.6	42236.3	40655.7	63013.1	0.386	0.670
35977/TR	520.7	520.7	2450.7	6574.2	7726.9	20806.4	10177.6	27380.6	26303.1	44030.2	0.387	0.622
Total	6111.6	6111.6	28761.4	77153.7	90695.0	244216.3	119456.4	321370.1	310205.3	551717.8	0.385	0.582

Table 1.1.3. Crop-wise area (ha), water requirement (ha-cm) in *kharif* 2015

Outlet No.	Cotton		Rice		Guar/Moong		Vegetable		Orchard		Fodder and others		Total	
	Area	Water	Area	Water	Area	Water	Area	Water	Area	Water	Area	Water	Area	Water
3758/R	295.2	22438.6	261.8	36656.5	49.2	2212.0	9.3	558.1	4.4	263.9	40.7	2441.3	660.6	64570.3
14025/L	229.4	17433.0	290.0	40605.5	40.0	1798.9	4.1	245.8	5.4	324.9	34.0	2037.1	602.9	62445.2
14040/R	220.9	16786.4	279.3	39099.4	38.5	1732.2	3.9	236.7	5.2	312.9	32.7	1961.5	580.5	60129.1
18163/R	219.2	16656.3	277.1	38796.3	38.2	1718.8	3.9	234.9	5.2	310.5	32.4	1946.3	576.0	59663.0
20170/L	363.4	27617.3	308.5	43187.1	109.1	4911.3	13.4	802.5	24.1	1443.6	35.8	2146.3	854.2	80108.0
25000/L	428.1	32539.2	96.3	13486.6	118.2	5317.6	13.9	834.9	35.3	2119.3	25.5	1528.5	717.4	55826.1
26630/L	475.0	36098.5	106.9	14961.9	131.1	5899.3	15.4	926.2	39.2	2351.2	28.3	1695.7	795.8	61932.7
35977/TL	547.5	41609.6	94.7	13259.5	102.1	4593.8	15.2	914.5	20.0	1200.9	23.9	1434.8	803.5	63013.1
35977/TR	314.8	23924.8	108.7	15214.5	62.8	2824.1	7.4	444.5	10.3	620.8	16.7	1001.6	520.7	44030.2

Table 1.2.1. Area covered by different crops and their respective irrigation water requirement under different systems during *kharif* 2015

System	Desi Cotton	A. Cotton	Guar	Bajra	Moong	Fodder	Til	Paddy	Orchard	Ground -nut	Total
Area (ha)											
KWD	44	1509	804	4	13	55	22	203	15	12	2681
KWM	7	554	102	-	2	23	2	57	1	748	1496
APM	7	39	48	-	1	5	2	-	-	2	104
Total	**58**	**2102**	**954**	**4**	**16**	**83**	**26**	**260**	**16**	**762**	**4281**
Water requirement (ha-cm)											
KWD	2970	114684	30552	164	358	2255	605	28420	900	720	181628
KWM	473	42104	3876	0	55	943	55	7980	60	44880	100426
APM	473	2964	1824	0	28	205	55	0	0	120	5668
Total	**3915**	**159752**	**36252**	**164**	**440**	**3403**	**715**	**36400**	**960**	**45720**	**287722**

Table 1.2.2. Relative water supply (RWS) during *kharif* 2015

Name of system	Canal water diverted (ha-cm)	Water available at field (ha-cm)	Effective rainfall (ha-cm)	Total water supply (ha-cm)	Water requirement (ha-cm)	RWS
KWD	105132.0	65160.8	93835	158995.8	181628	0.88
KWM	28588.2	18393.7	52360	70753.7	100426	0.70
APM	5211.8	3257.4	3640	6897.4	5668	1.22
Total system	138932.0	86811.9	149835	236646.9	287722	0.82

1.3. Faizabad

1.3.1. Studies on Diversification of Cropping System under Poor Availability of Irrigation Water at Tail End of Chandpur Distributory

Rice crop is adversely affected at the tail end of Chandpur distributary due to shortage of water during certain growth timings. An effort was made to diversify cropping system and find out feasible crops/cropping system under poor availability of irrigation water so as to sustain higher level of production under water scarce situation in farmers' field for four consecutive years (2012 to 2015). Pigeonpea and urd, which require less water, were considered for cropping system diversification.

The average yield of crops raised under the experiment during four consecutive years (2012-15) and their equivalent pigeonpea yield given in table 1.3.1 and 1.3.2 indicated that the maximum average pigeonpea equivalent yield was recorded when pigeonpea crop was planted on raised bed in paired rows (50 cm) with intercropping of direct sown rice in Sunken beds at farmers field under poor availability of canal water at tail end of the distributory. The economics of the crop production showed that the intercropping system of pigeonepa with rice which was based on rainfed cultivation was found most remunerative as it gave the maximum net return of Rs.60,272.00 per ha. Hence, intercropping of pigeonpea (on raised bed in paired row, 50 cm) with direct sown rice (in sunken beds, 5 rows) is recommended as diversified cropping system under poor availability of canal water at tail end of the distributory being highest yielding and most economical cropping system.

Table 1.3.1.Average crop yield under diversified cropping system at tail end of Chandpur distributory during *kharif* 2012-15

Year	Average grain yield (t/ha)			
	Pigeonpea, flat bed	Pigeonpea, paired row on raised bed	Rice (Upland direct sown)	Pigeonpea paired row on raised bed + rice (2:5)
2012	1.24	1.43	2.34	1.34+1.42
2013	1.32	1.78	2.65	1.53+1.71
2014	1.40	1.86	2.79	1.69+1.77
2015	1.43	1.88	2.62	1.60+1.68
Mean	1.35	1.75	2.60	1.54+1.65

Table 1.3.2. Pigeonpea equivalent yield and monetary return under different cropping system at tail end of Chandpur distributory

Treatments	Pigeonpea equivalent yield (t/ha)	Cost of cultivation (Rs./ha)	Gross return (Rs./ha)	Net return (Rs./ha)
Pigeonpea flat bed	1.65	14500.00	56532.00	42032.00
Pigeonepapaired rows on raised bed	1.74	18500.00	72870.00	54370.00
Rice (Upland direct sown)	0.84	16500.00	35112.00	18612.00
Pigeonpea paired rows on raised bed + rice (2:5)	2.07	26500.00	86772.00	60272.00

Another cropping system at 5 locations on farmers' field at tail end of Chandpur distributory also showed similar results. Maximum pigeonpea equivalent yield (2.42 t/ha) was found when pigeonpea was sown in paired row with intercropping of urd (3 lines) on raised beds(Table 1.3.3). The yield was significantly higher than rest of the treatments. The economics of crop production (Table 1.3.4) also envisaged that this treatment accrued the maximum net return. Thus, intercropping of urd (3 rows on beds) with pigeonpea in paired row at 50 cm on beds was recommended as diversified cropping system under poor availability of canal water particularly at tail end of the distributory.

Table 1.3.3. Average crop yield under diversified cropping system at tail end of Chandpur distributoryduring *kharif* 2012-2015

Year	Average grain yield (t/ha)			
	Pigeonpea on flat bed	Pigeonpea in paired row on raised bed	Pigeonpea in paired row on raised bed + Rice in sunken bed	Pigeonpea in paired row on raised bed + Urd on raised bed
2012	1.25	1.78	1.51 + 2.91	1.54 + 1.02
2013	1.32	1.82	1.63 + 2.01	1.63 + 0.88
2014	1.42	1.95	1.69 + 1.97	1.71 + 0.91
2015	1.38	1.87	1.67 + 2.03	1.71 + 0.90
Mean	1.34	1.86	1.63 + 2.23	1.65 + 0.93

Table 1.3.4. Pigeonpea equivalent yield and monetary return under different cropping system at tail end of Chandpur distributory

Treatment	Pigeonpea equivalent yield (t/ha)	Cost of Cultivation (Rs./ha)	Gross Return (Rs./ha)	Net Return (Rs./ha)
Pigeonpea on flat bed	1.34	14500.00	56406.00	41906.00
Pigeonpea in paired row on raised bed	1.86	17500.00	77910.00	60410.00
Pigeonpea in paired row on raised bed + Rice in sunken bed	2.34	27500.00	98322.00	70822.00
Pigeonpea in paired row on raised bed + Urd on raised bed	2.42	21500.00	101724.00	80224.00

1.4. Pantnagar

Optimal Cropping Pattern under Normal Rainfall

The optimal utilization of land and water resources in Nanakmatta canal command under different rainfall probability conditions was studied. The Nanakmatta canal was located in Sitarganj *tehsil* of Udham Singh Nagar district of Uttarakhand state. The Nanakmatta canal originates from Nanak Sagar dam located about 12 km away from the *Tehsil* headquarter. The head discharge of the canal was (1.642 cumec) 58 cusec and total length of canal was 13.664 km. The total Cultural Command Area (CCA) of the canal is 1236 ha.

The rainfall data of 42 years (1970-2012) were collected from the nearest observatory located at GBPUA&T, Pantnagar. The probability distribution of rainfall was carried out by categorizing the data into 52, 12 and one data set, respectively, for weekly, monthly and annual distribution and by using DISTRIB 2.12 software. Normal, log-normal, Pearson, log-pearson and gumbel distributions were considered in the analysis. It was found that the weekly and annual data sets were best-fit into log-normal distribution whereas the Pearson distribution fitted well on the monthly data sets. The average annual rainfall and the rainfall at 50 % probability level were considered as the two levels of variable rainfall conditions, since the annual rainfall record indicated that in 40.47 % cases the normal rainfall (average ± 19%) was received in the study area whereas the % of below normal and above normal rainfall was found as 33.33 and 26.20 %, respectively. The annual rainfall at 50 % probability level was estimated as 1479.93 mm against 1548.29 mm average rainfall.

The Nanakmatta canal operates on a predefined schedule, worked out by the State Irrigation Department, based on the availability of water in the reservoir. The operation schedule varied from 15 days to 30 days per month. Based on the previous records of the Irrigation Department the average canal water availability at field head in the command was worked out and it was found varying from 4893.15 ha-cm during month of January to 34129.7 ha-cm during month of August. In the study area the available annual draft under normal and 50 % probability rainfall conditions was estimated as 28798.80 and 28106.64 ha-cm, respectively.

The optimization of the models, under different rainfall conditions, was performed in LINGO. In Step 1, under each rainfall conditions the problem was solved as a linear programming model by taking one objective at a time. From Step 1, the corresponding values of each objective were determined for each derived solution. The values of objective functions are known as positive ideal solutions. The best (Z_U – upper bound) and worst (Z_L – Lower bound) values for each objective were calculated under different rainfall conditions. Based on the upper and lower bound of the objective functions, the linear membership function were formulated for each objective functions and the equivalent linear programming model for the fuzzy objective problem were formulated for different rainfall conditions.

The optimal resource utilization plan for maximization of net return from the crop activities and maximization of land use under normal and 50 % probability rainfall conditions for the Nanakmatta canal command system is presented in table 1.4.1.

Table 1.4.1. Optimal cropping pattern under normal rainfall and 50 % probability in the Nanakmatta canal system command

Kharif (July – October)			*Rabi* (October – March)		
Crop	Area (ha)		Crop	Area (ha)	
	Normal rainfall	50 % probability		Normal rainfall	50 % probability
Paddy	698.7	600.9	Wheat	540.4	311.9
Sugarcane	15.0	15.0	Sugarcane	15.0	15.0
Maize	100.0	100.0	Berseem	80.0	80.0
Cow pea	45.0	45.0	Potato	377.3	475.1
Potato (season overlapping)	377.3	475.1	Fallow	223.3	353.9
Total	**1236.0**	**1236.00**	**Total**	**1236.0**	**1236.0**
Total groundwater used (ha-cm)	28798.8	28106.6	Total groundwater used (ha-cm)	28798.8	28106.6
Total canal water used (ha-cm)	64966.4	91990.0	Total canal water used (ha-cm)	64966.4	91990.0
Surplus canal water (ha-cm)	101523.10	75338.1	Surplus canal water (ha-cm)	101523.1	75338.1
Annual net return from the command (Rs.)	84615170.0	75981111.0	Annual net return from the command (Rs.)	84615170.0	75981111.0
Annual net return from the command-existing (Rs.)	83801345.0	-	Annual net return from the command-existing (Rs.)	83801345.0	-
Total sown area (ha)	**1856.4**	**1627.9**	**Total sown area (ha)**	**1856.4**	**1627.9**

It has been observed that under normal rainfall conditions, the fuzzified optimal plan, resulted in annual return of Rs. 84.615 million against net sown area of 1856.40 ha for optimized value ë=0.5855. A total of 101523.10 ha-cm of canal flow remained unutilized during low demand months (July, August and September) however, the groundwater was completely utilized with maximum use during month of October. The fuzzified optimal plan, under 50 % probability rainfall, resulted in annual return of Rs. 75.981 million against net sown area of 1627.90 ha at optimized value of ë=0.5525. A total of 75338.16 ha-cm of canal flow remained unutilized during low demand months which indicated that more than 25 % canal water was consumed to cater irrigation water demand as compared to that under normal rainfall conditions. More area could be brought under sowing through re-scheduling of canal water flows during higher water demanding months namely February, March, October and November. This will not only increase the net return but will also increase the net sown area in the command and reduce the burden over the groundwater draft. The irrigation department was informed about the re-scheduling of the canal flows during the months of peak demand (October, November and January) to reduce the burden over the groundwater.

1.5. Junagadh

1.5.1 Aquifer Mapping of Uben River Basin

Aquifer mapping of Uben river basin was conducted by vertical electrical sounding resistivity technique. The geological formations of fifteen sites were characterized and hydrogeological properties at different sites were estimated and presented in table 1.5.1. The resistivity survey was conducted at fifteen different sites namely, Sakkarbaugh, Sukhpur, Ranpur, Parabdham, Evenagar, Patala, Choki, Vadal, Makhiyala, Chobari, Satalpur, Goladhar, Ravani-Rupavati, Fareni and Bava-Pipaliya with validation site at Thana Pipali (Fig. 1.5.1) and based on electrical resistivity values of different layers collected from the literature, geological formations were determined.

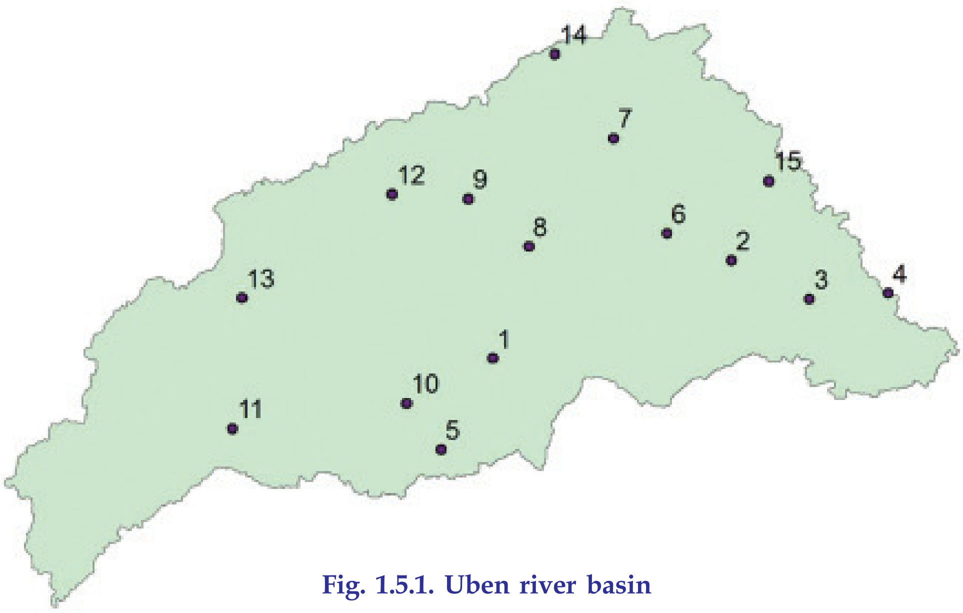


Fig. 1.5.1. Uben river basin

1. Sakkarbaugh: Situated nearby city boundary of Junagadh in north-east side, here thickness of unconfined aquifer was found 46.7 m, and had 5 confined aquifers out of one had contaminated water, may be affected by city effluents
2. Sukhpur: has 13.3 m of unconfined aquifer and 6 confined aquifers
3. Ranpur: had 60 m thick unconfined aquifer and 3 confined aquifers
4. Parabdham: had 20 m of unconfined aquifer and 6 confined aquifers
5. Evenagar: had 20 m of unconfined aquifer and 5 confined aquifers
6. Patala: had 6,7 m of unconfined aquifer and no confined aquifers within 153 m depth but have one aquifer deeper than that
7. Choki: had 20 m of unconfined aquifer and 4 confined aquifers
8. Vadal: had 46.7 m thick unconfined aquifer and 2 confined aquifers
9. Makhiyala: had 46.7 m very deep unconfined aquifer, has 2 confined aquifers
10. Chobari: Situated on western boundary of Junagadh, had 20 m thick unconfined aquifer and 7 confined aquifers, out of which two hasd contaminated water that may be affected by city effluents
11. Satalpur: had 46.7 m thick unconfined aquifer and 3 confined aquifers, one of which had large thickness of 73 m
12. Goladhar: had 39.9 m thick unconfined aquifer and 4 confined aquifers
13. Ravani-rupavati: had 26.7 m thick unconfined aquifer and 3 confined aquifers. But basaltic layer was not found
14. Fareni: has 39.9 m thick unconfined aquifer and 3 confined aquifers
15. Bava pipalia: had 33.3 m thick unconfined aquifer and 6 confined aquifers

    Validation: validation of method was done with farmer participatory approach. Survey was carried out and geological profile was prepared and extended to farmer where borewell was drilled by farmers
16. Thanapipali: had 39.98 m thick unconfined aquifer and 6 confined aquifers. As per farmers' opinion, almost same geology (70 – 75 %) was found as obtained in resistivity survey map. This validates the technique

Table 1.5.1. Hydrogeological properties at different sites in Uben basin

Sr. No.	Location	Thickness of UCA (m)	Resultant vertical hyd. cond. of UCA, k_{yuc} (m/s)	Resultant horizontal hyd. cond. of UCA, k_{xuc} (m/s)	Resultant horizontal hyd. cond. CA, k_{xc} (m/s)	Resultant horizontal hyd. cond., Overall k_{xuc} (m/s)	Resultant vertical hyd. cond., all Aquifers, k_{yall} (m/s)
1	Sakkarbaugh	46.62	7.00E-06	0.006482947	0.00387976	0.005185414	5.07E-08
2	Sukhpur	13.32	3.00E-06	0.004538363	0.00363189	0.003782969	6.99E-07
3	Ranpur	59.99	3.00E-06	0.002018549	0.004539113	0.003026573	6.92E-07
4	Parabdham	19.98	3.00E-06	0.0030266	0.0034919	0.0034047	6.22E-07
5	Evenagar	19.98	7.04E-09	1.00E-06	0.0051875	0.0042724	5.04E-08
6	Patala	6.66	1.50E-06	1.50E-06	0	1.50E-06	2.88E-06
7	Choki	19.99	4.51E-06	0.0060522	0.001398	0.0022708	4.98E-08
8	Vadal	46.62	7.00E-06	0.0064829	3.00E-06	0.0045383	6.16E-07
9	Makhiyala	6.66	1.50E-06	1.50E-06	0.0090752	0.0085082	6.76E-07
10	Chobari	19.99	2.25E-06	0.0030246	0.0052944	0.0048404	1.76E-08
11	Satalpur	46.63	2.60E-06	0.0013	0.0014	0.00136	2.00E-06
12	Goladhar	39.99	3.00E-06	0.00303	0.00248	0.00267	1.20E-06
13	Ravani.Rupavati	26.64	2.40E-06	2.63E-06	0.0009102	0.0006509	3.00E-06
14	Fareni	39.93	6.00E-06	0.0060486	0.0090752	0.0074254	4.67E-07
15	Bava-Pipaliya	33.31	2.50E-06	0.0018163	0.0060512	0.0041259	6.11E-07
	Validation site						
16	Thana Pipali	39.97	3.601E-06	0.0045375	0.0073743	0.0066006	6.423E-07

UCA = unconfined aquifer, CA = confined aquifer, hyd. cond. = hydraulic conductivity

It is observed from the hydrogeology of the Uben basin (Table 1.5.1) that water harvesting structures may be encouraged around Ranpur, Goladhar, Bavapipaliya and Vadal where thickness of unconfined aquifer was found highest and varied from 37 to 60 m, which is middle part of basin in North of Junagadh. Highest horizontal hydraulic conductivity of unconfined aquifer 0.0065 m/s was observed around middle belt starting from Sakkarbaugh, Vadal, choki, Makhiyala up to Fareni. The area may be encouraged for shaft recharging. Highest horizontal hydraulic conductivity of confined aquifer 0.0091 m/s was observed around Makhiyala and Fareni. Arc shaped belt passing through Makhiyala to Fareni may be encouraged for the tubewell recharging. Whereas it was found lowest 3.00E-06 m/s near Vadal and zero at Patala here no confined aquifer was observed within 500 ft depth. Highest vertical hydraulic conductivity of unconfined aquifer 7.00E-06 m/s was observed in middle belt from Sakkarbaugh, Vadal up to Fareni the area may be encourage for surface water harvesting structures for recharging unconfined aquifer.

1.5.2 Assessment of Potential Water Resources of Aji River Basin

A study has been initiated to assess the different hydrogeological balance components of Aji river basin using SWAT model. Aji is the most important river of Saurashtra. Aji River and dam, situated at a distance of 8 kms, are the main source of water supply to the city of Rajkot. It is situated between latitude 22°15′34″ N and longitude of 70°50′56″ E. Its length is 164 km with 2130 km^2 catchment area. Some of the major tributaries of Aji are the Nyari, Lalapari, Khokaldadi, Banked and the Dondi. The River originating from hills of sardhar near Atkot, to its mouth at the Gulf of Kutch in Ranjitpara of Jamnagar district. There are four dams on Aji River. Aji-I, Aji-II, Aji-III and Aji-IV dams are situated on Aji River having catchment area having 142 km^2, 452 km^2, 1378 km^2 and 1772 km^2, respectively.

The digital data namely Satellite images of IRS P6 of sensor LISS III and 90 m SRTM DEM was collected from BISAG, Ganbdhinagar and available historical hydro-metrological data was collected from the State Water data Centre, Gandhinagar and Main Dry farming Research Station, JAU, Targhadiya for the Aji basin. The various maps for different themes like land use, soil, drainage and slope were prepared using remote sensing and GIS software. For the climate change analysis, the RCM data for the control period and future scenarios were collected from IITM, Pune. The other inputs were digital data of land use, soil types and topography, reservoir details, soil and channel properties etc. The SWAT outputs were analyzed. The water balance components like rainfall, runoff, evapotranspiration and groundwater recharge were computed using SWAT model for the basin and the times series data were analyzed.

Majority area of the basin has clay soil (Fig. 1.5.2) and the highest area was found under agricultural land. The trunk order of the basin is only 4. The drainage density and stream density are also low indicating the poor drainage of the basin (Fig. 1.5.3). More than 2/3 of the basin area is having slope up to 4% and the highest area (35.1%) was found under slope range of 2-4% (Fig. 1.5.4). The monsoon seasonal rainfall, runoff, evapotranspiration and groundwater recharge in the Aji basin were found as 632 mm, 170 mm, 248 mm and 124 mm, which were found increasing significantly at 12.61 mm/year, 5.37 mm/year, 1.40 mm/year and 5.48 mm/year, respectively (Fig. 1.5.5).

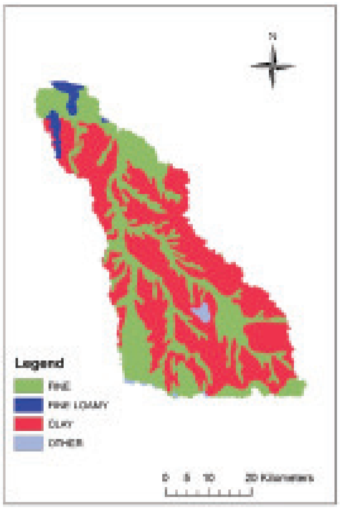


Fig. 1.5.2.
Soil map of Aji basin

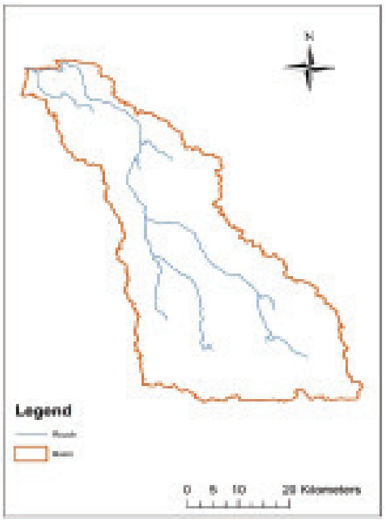


Fig. 1.5.3.
Drainage map of Aji basin

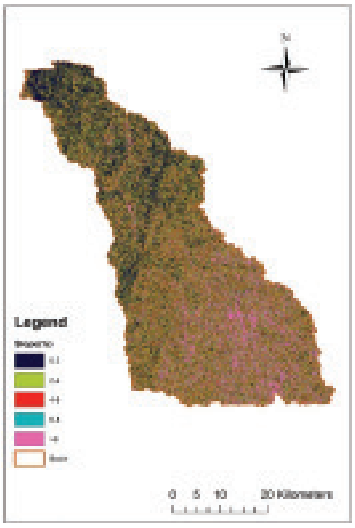


Fig. 1.5.4.
Slope map of Aji basin

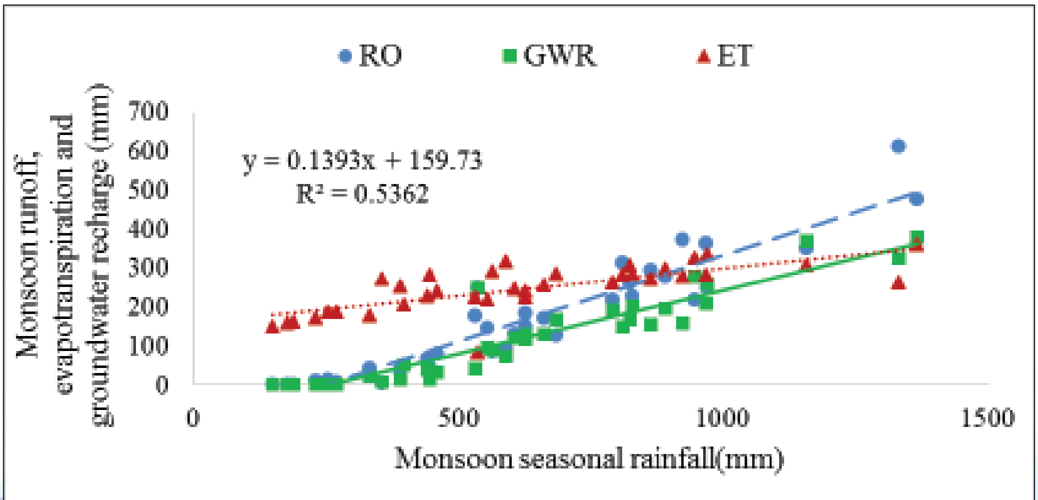


Fig. 1.5.5. Effects of monsoon rainfall on monsoon runoff, evapotranspiration and groundwater recharge

1.6. Ludhiana

1.6.1. Decision Support System for Assessing the Groundwater Quality and Behaviour of Water Table in Bathinda

The quality of groundwater and groundwater table behaviour of Bathinda District was assessed. A Decision Support System (DSS) was developed for providing information on groundwater suitability for irrigation. The DSS was developed using 'PHP' server side scripting language for assessing the groundwater quality and water table behaviour in Bathinda. Water quality classification was done on the basis of the combined effect of electrical conductivity (EC) and residual sodium carbonate (RSC) of the groundwater samples. The home screen of DSS displays the groundwater quality maps of Bathinda district for the first and second half of the year from the year 2006 to 2013 of Bathinda district (Fig. 1.6.1 and Fig. 1.6.2). In DSS, the first step is the information of farmer. Enter the First name, Last name, Contact no of the farmer and village. Then select the district, village of the farmer and block and click on result. It will display EC and RSC value.

It will tell whether EC and RSC are safe, marginal or critical and give the combined category of groundwater quality. Depending upon the category classification the water management practice to be followed will be displayed. Water table depth and trend of water table rise/fall of the village will also be displayed. The developed decision support system gave present water table depth, trend of rise/fall of water table and present water quality along with proper water management advice for use of that water for irrigation.

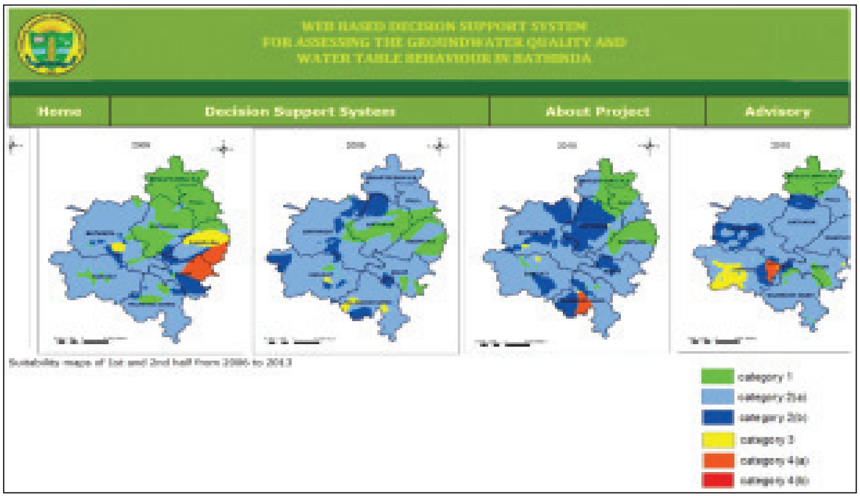


Fig. 1.6.1.Screen shot of the home screen of Decision Support System

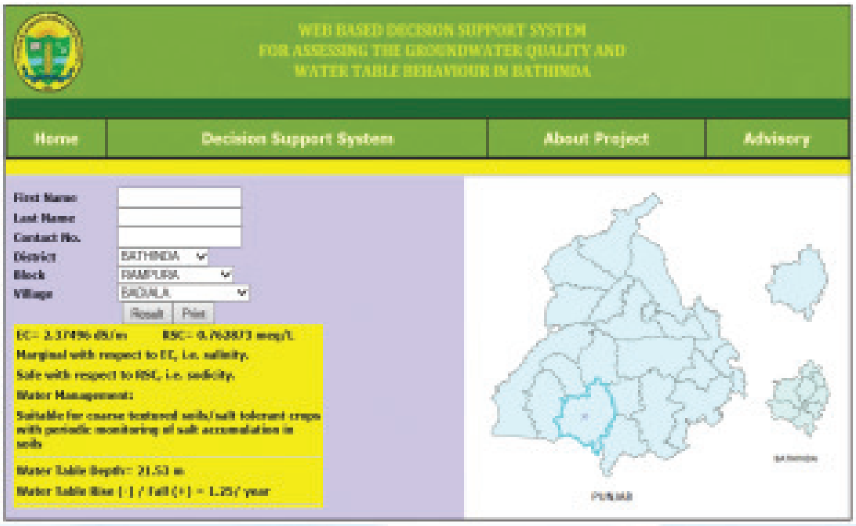


Fig. 1.6.2. Screen shot of working of Decision Support System for Rampura block

1.6.2. Groundwater Simulation of Southwest Punjab for Management of Water Resources

Initiative was taken to develop management strategies for controlling the rising water table in south-west Punjab through water balance studies and groundwater modelling. The study area is located in the part of Ferozepur, Muktsar and Faridkot districts covering an area of about 6,51,079 ha in Indo-Gangatic basin. Slope of this region is from northeast to southwest. The region is bounded on western side by Sutlej; towards south by Rajasthan boundary (Indira Gandhi Canal) and towards east by Sirhind feeder. The first step in groundwater modeling process was to develop a conceptual model of the region and information relating to spatial discretization and grid design. Extensive datasets on the aquifer lithology (structural contours, bore logs, and aquifer properties), piezometric levels, groundwater draft, climatic data, canal network and their L-sections were collected. Borehole data was procured from Punjab Remote Sensing Centre Ludhiana. Arc Hydro Groundwater (AHGW) geodatabase design was used for representing groundwater datasets within ArcGIS. Water table depth was collected for the period 1998 to 2015, from Directorate of Water Resource & Environment and Directorate of Agriculture to study the groundwater behaviour in south-west Punjab. The Map and XY location of the observation wells is shown in fig. 1.6.3. A three layer model (0-100 m), having 138 rows and 103 columns for the proposed study was developed. A constant grid spacing of 1 x 1 km was used to discretize the area (Fig. 1.6.4). The boundary of the aquifer was approximated in a linear stepwise fashion. The observed hydraulic head values in June 1998 used as initial conditions were interpolated at the center of each of the grid using krigging technique. A stress period of 365 days will be used to observe the yearly affect of recharge and draft on groundwater system.

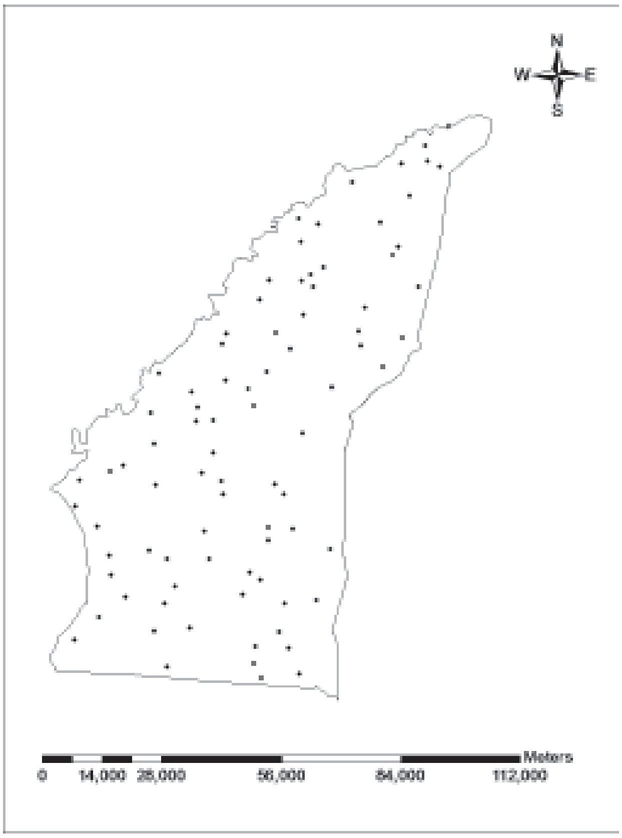


Fig. 1.6.3. The location map of observation wells in south west Punjab

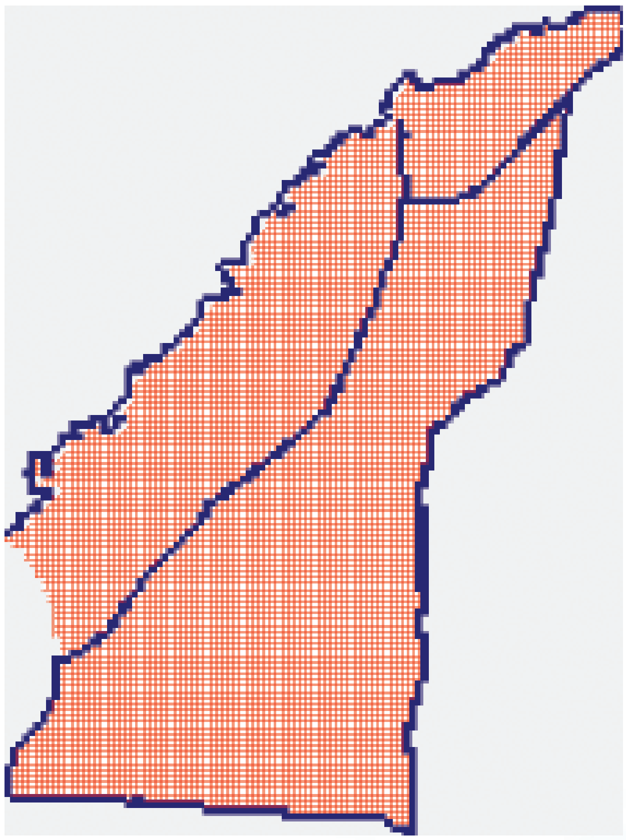


Fig. 1.6.4. Discretization of the study area (red - active; blue - constant head; grey - inactive)

1.7. Coimbatore

1.7.1. Assessment of Water Availability in the Kugalur Distributory of LBP Command Area and to Devise Interventions for Matching Water Supply with the Integral Production Systems and Demand

Studies on the selected distributory located at 33.1.580 miles from the Lower Bhavani Project (LBP) reservoir was continued this year (2015-16). The study area is situated at 45 km from Agricultural Research Station, Bhavanisagar and 4 km from Gobichettipalayam. The distributory map is depicted in fig. 1.7.1. The design discharge of the selected distributory at 33.01.580 miles was 82.8 cusec. The vent of the distributory is 4'3" x 2'6" and an allowance of 0.14 cusec (0.17 %) was given for seepage and transportation losses. Water was released from the reservoir for irrigation during the report period in the odd turn sluices from 11.01.2015 to 16.04.2015 for the irrigated dry crop and for even turn sluices from 16.8.2015 to 2.1.2016 for wetland crop of rice. In the study area of 978.84 ha during Jan - Dec 2015 odd turn, different crops like sugarcane, banana, tapioca, rice, maize, groundnut, gingelly, tobacco, vegetable, coconut, cotton and mulberry were cultivated which works out to 72.59 % of cropped area. On an average, 27.41 % of land was kept fallow due to insufficient water in the wells during off-season; some of the area are converted in to real estate sites and also delayed reach of canal water in farther ends of the vents to limited extent. The total command area for the second turn in the selected distributory 33.1.580 is 1949.27 ha. Even though no water supply in this odd turn wet crop area, 61.59 % of area was brought under cropping due to recharged canal water to the well. The reduction in cropped area to 55.84 ha in this period of May–Aug was mainly due to reduced water levels in the well resources.

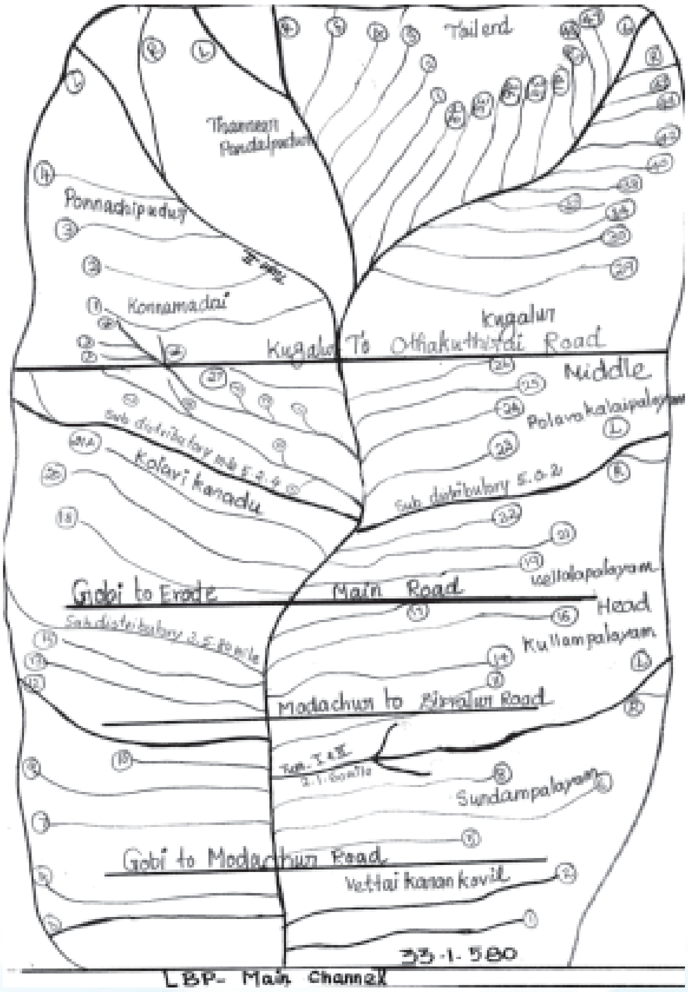


Fig. 1.7.1. Distributory map at 33.1.580

The improvement in cropped area to 66.10 % might be due to the rainfall of 592 mm during this period coupled with water availability in adjacent odd turn sluices (which facilitates well water resource in this area). During the even turn, in the study area of 632.86 ha different crops like sugarcane, banana, rice, tapioca, etc., were cultivated. Out of this total area, 61.18 % area was brought under cropping. On an average, 38.82 % area was kept fallow due to non-availability of water in this turn area and also insufficient water in the wells. The important soil series that are found to occur in LBP area are Irugur and Chikkarasamplayam series. The dominant series is Irugur (Typic Ustorthents), a red non–ca lcareous soil developed from weathered gneisses. The study revealed that the pH and EC of the soils from all the head, middle and tail reaches were found to have low salt and neutral in pH. Among the three reaches, the bulk density, infiltration rate, field capacity and permanent wilting point were high in tail reaches. The available N was low in all the reaches. Available P was high in the head reaches and medium in other reaches. The available K was high in head and tail reaches whereas medium in the middle reach. The water samples were collected from the selected wells of head, middle and tail reaches of the distributory. The samples were analysed for total soluble salts, calcium, magnesium, carbonate ions and bicarbonate ions and found to be normal for irrigation purpose (Table 1.7.1).

Table 1.7.1. Chemical properties of the water of selected distributor

Reach	pH	EC (dS/m)	Carbonate (meq/l)	Bicarbonate (meq/l)	Ca (ppm)	Mg (ppm)	Total soluble salts (ppm)
Head	6.8	0.23	1.10	0.82	26	9.2	395
Middle	6.9	0.25	1.15	0.88	28	9.8	368
Tail	7.5	0.28	1.30	0.91	25	11.5	375

Since there was no rainfall during Jan and February 2015, there was steady decline of water depth in almost all the wells upto August 2015. Water table gradually raised from August 2015 and reached near ground level (GL) to GL in almost all the wells of head, middle and tail reaches of odd turn command (Fig.1.7.2). This was mainly because of recharged water during odd turn water supply for irrigated dry crops coupled with heavy rainfall during north east monsoon. During this period and upto December 2015, water table in the head reach wells reached GL since main canal is running very near (i.e. within 2 km). Water table depth in the middle reach well was at GL to 6 feet depth and in the tail reach well the water table was at GL to 13 feet depth.

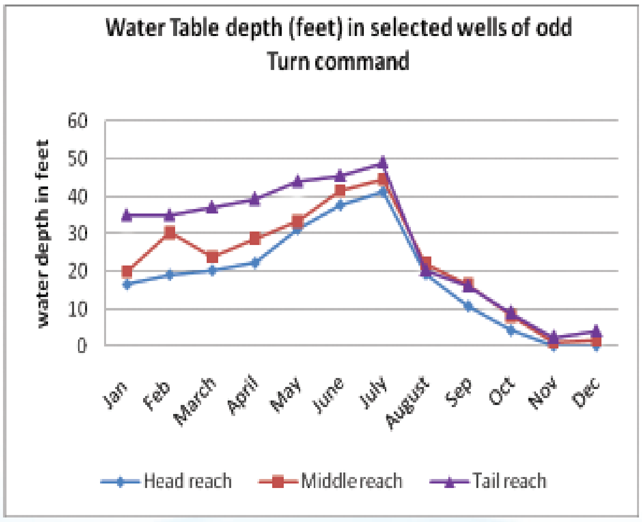


Fig. 1.7.2. Water table depth in selected wells of odd turn sluice command

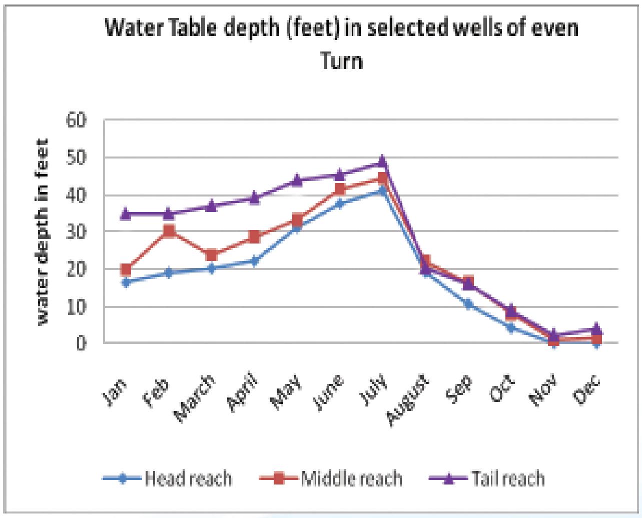


Fig. 1.7.3. Water table depth in selected wells of even turn sluice command

1.7.2. Study on Groundwater Balance to Assess the Quantity of Water Available for Development in the Amaravati Basin

Groundwater resources for irrigation on pilot basis using secondary data in the Amaravathi basin was assessed and evaluated. The Amaravathi basin lies between the latitude 10 06 –51" N and 11 02– 10"N and longitudes 77 03– 24" E and 78 13– 06" E. It has a catchment area of 8280 sq. km constituting four districts *viz.*, Coimbatore, Dindigul, Karur and Tirupur in Tamil Nadu. The basin is bounded by the Vaigai basin on the south, Noyyal basin on the north, Parambikulam and Aliyar basin on the west and Ayyalur basin and Kadavur hills on the east. The basin is more or less fan shaped and has a length of about 188 km from west to east and an average width of 81 km from the south to north (Fig. 1.7.4).

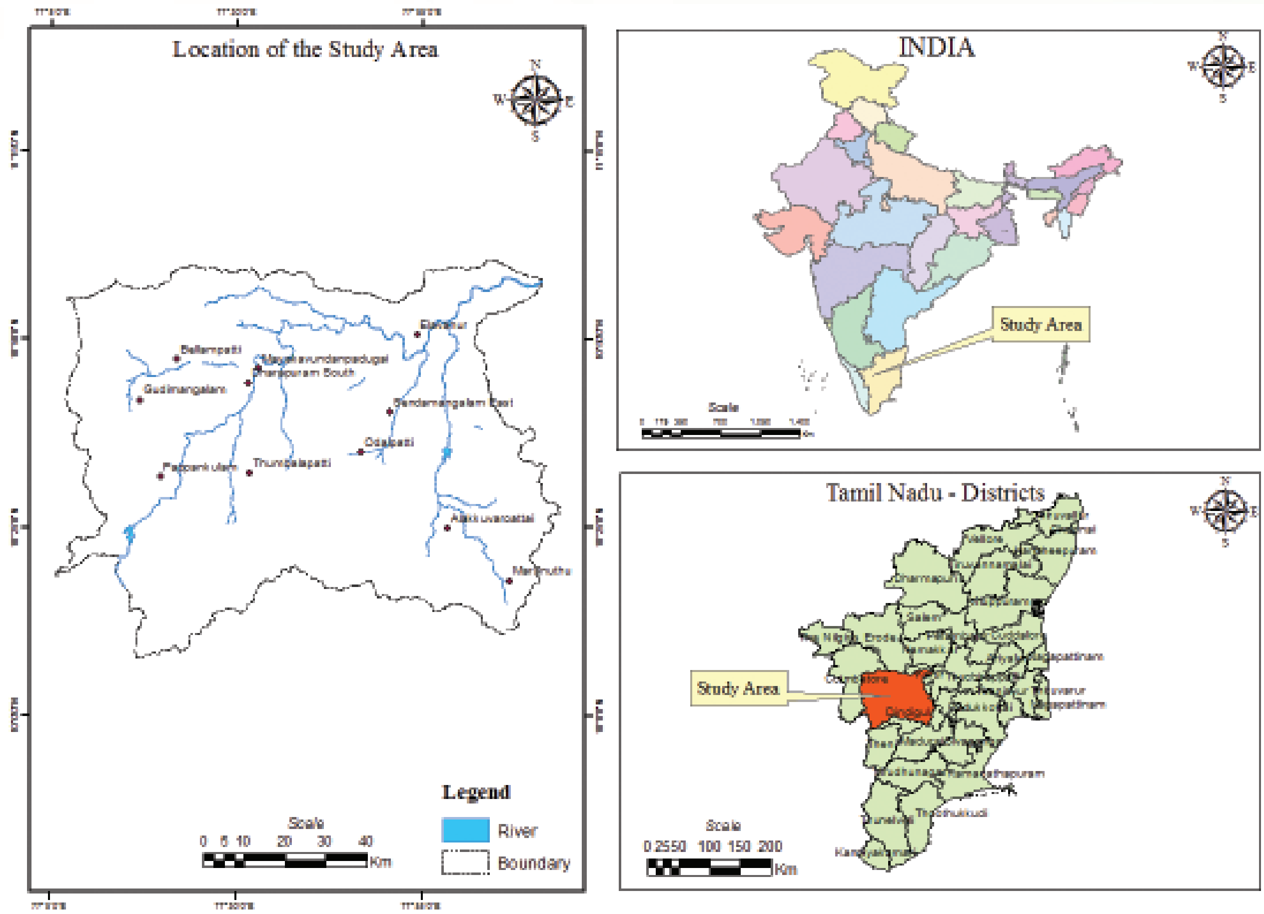


Fig 1.7.4. Location of Amaravati River Bain

The average annual rainfall of the basin is 962.3 mm. The highest monthly mean of daily maximum temperature is around 40.6ºC in April and the lowest monthly mean of daily minimum temperature is 22.4ºC during January at Coimbatore (Peelamedu). The monthly potential evapotranspiration value varies from as low as 66 mm in November to as high as 130.9 mm in May. The present study was aimed at delineating groundwater recharge areas using GIS techniques. The multiple parameter analysis for delineating groundwater recharge sites in the study area were done by Multiple Influencing Factor (MIF) technique. In this study, seven spatial parameters such as geology, geomorphology, slope, land use and land cover, lineament density, drainage density and soil texture are analyzed by MIF approach. The flowchart shows the methodology adopted for the present study which was used for fulfilling the objectives of the study (Fig. 1.7.5).

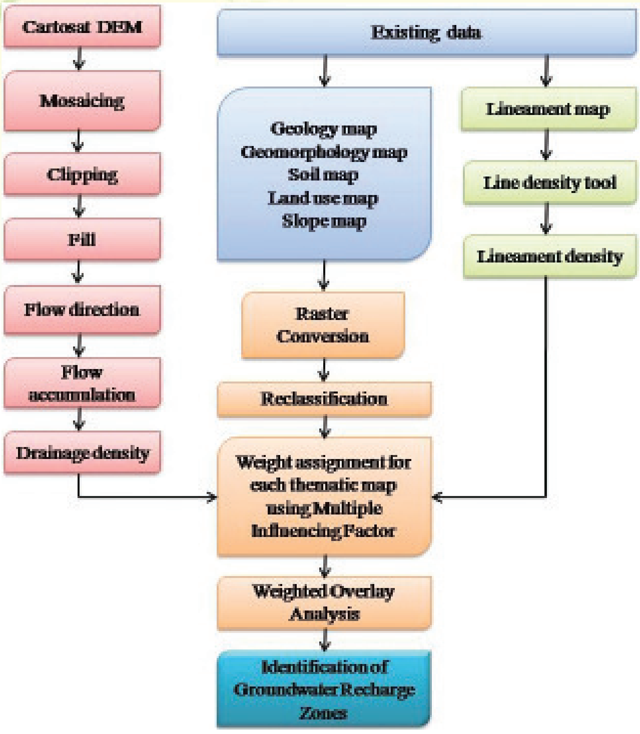


Fig. 1.7.5. Flow chart showing methodology adopted to identify potential groundwater recharge zones

The SRTM DEM (30 m) data was obtained from Bhuvan (ISRO's geo-portal) and was used to develop drainage density map. Existing data of geology, geomorphology, soil, land use and slope were converted from '.shp' format to raster format using polygon to raster tool and a cell size of 30 m was applied to all the maps during conversion. Then all the maps were projected to WGS 1984 Transverse Mercator. Lineament map was converted to lineament density (km/km^2) map using line density tool of spatial analysis tool. Each parameter was assigned weights from 1 to 4 scales as per the degree of contribution to the central theme (Patil and Mohite, 2014). The logic of assigning weightage to each polygon of each theme is given in table 1.7.2.

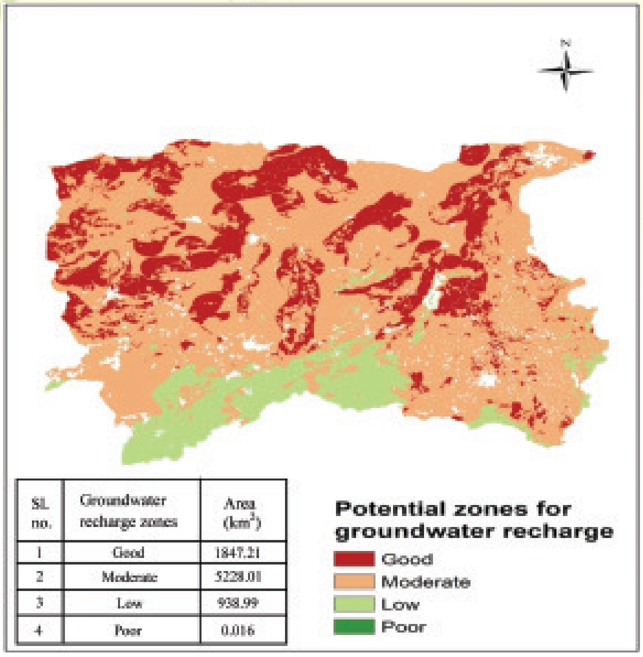
Table 1.7.2. Logic of assigning weightage

Sl. No.	Rank	Logic value
1.	1	High contribution to central theme
2.	2	Moderate contribution to central theme
3.	3	Low contribution to central theme
4.	4	Least contribution to central theme

The study area comprises of:

- Sandy loam, sandy clay loam and clay soils dominate the study area, which occupy around 27%, 25% and 15%, respectively of the total area and very meager of total area is occupied by sandy and loamy soil
- Both buried and weathered pediplain occupies around 79% of the total study area and minimum area of 1% was occupied by reservoirs, flood plain and bazada
- Geological formation of hornblende biotite gneiss occupies 73% of the total area and minimum by Charnockite 21%
- The crop land occupied the maximum (58%) of area followed by plantation which was 13%. Minimum area was observed as barren rocky/ stoney waste, reservoirs, salt affected areas, coastal wetlands etc which was <1% of the total area
- Majority of the area falls under 0-5% slope category which was around 81% of the total area followed by 35-50% covering 9% of the study area. Minimum area about 1% of the total area comes under 5-10% slope category
- Maximum of about 69 % of total area had lineament and the rest 31 % without lineament.
- The drainage density of the basin was calculated to be 0.58 km/km^2

The high recharge areas correspond to alluvial plains, areas with lineaments, which coincide with the gentle slope (0-5%). Some parts of the blocks such as Vellakoil, Dharapuram, Sandayam, Vedasandur, Aravakurichi were identified as good groundwater recharge areas. The moderate recharge areas correspond to landuse/land cover unit of agricultural fallow land, scrub land and slope of 0-5% which comprise of 5228.01 km^2. Parts of the blocks such as Vadamadurai, Shanarpatti, Dindugal, Udumalpettai, Kundadam, Thoppampatti, etc., were subjected to moderate groundwater recharge zones. The low recharge zones mainly comprise of structural hills, land use / land cover unit of plantation, soil classes in the hydrological soil group C and high degree of slope which contributes high runoff. Some parts of the blocks such as Kodaikanal, Reddiyarrchattiram, Attur, Oddanchatram, Palani, etc., were subjected to low groundwater recharge. The poor groundwater recharge zones were identified to be less than 1% (Fig. 1.7.6).



SL no.	Groundwater recharge zones	Area (km^2)
1	Good	1847.21
2	Moderate	5228.01
3	Low	938.99
4	Poor	0.016

Fig. 1.7.6. Potential groundwater recharge zones

1.7.3. Assessment of Surface and Groundwater Quality and Wastewater Reuse in Amaravati Basin and Developing Management Strategies for Agriculture

The surface and groundwater quality in Amaravati basin in different seasons and the extent of poor quality water irrigation and soils affected through remote sensing and GIS techniques. Amaravati river basin at the downstream of Karur Town is severely polluted due to discharge of partially treated effluent by the textile bleaching and dyeing units. There are 487 units and they treat the effluent either in individual effluent treatment plant (IETP) or common effluent treatment plant (CETP). Daily about 14600 m^3 of coloured effluent with total dissolved solids (TDS) in the range of 5,000-10,000 mg/l is let into river Amaravati. The ranges of mean values of the groundwater quality parameters are as follows: pH = 7.52 to 8.90, EC = 0.26 to 2.41 dS/m, Ca^{2+} = 1.21 to 6.42, Na^+ = 1.54 to 8.71 meq/L, HCO_3^- = 9.48 meq/L, Cl^- = 0.47 to 4.74 meq/L, SO_4^{2-} = 0.71 to 6.94 meq/L. The Residual Sodium Carbonate (RSC) was negative and is well below the critical limit (5 meq/L) in most of the samples. The groundwater samples in the tail end of the Amaravati river basin near Aravakurichi Nagampalli and Karur areas, showed deviation from water quality standards 65.7 % (EC – high salinity 0.75 - 2.25 dS/m) and 25.7 % medium salinity class (0.25 – 0.75 dS/m) 5.71 very high salinity (> 2.25 dS/m) indicating groundwater contamination. Hence, proper care must be taken to avoid any contamination of groundwater and its quality monitored periodically.

- With regard to irrigation suitability based on EC and Sodium Absorption Ratio (SAR), it was observed that groundwater in the tail end of the basin was under high salinity hazard and medium alkali hazard when used for irrigation.
- Proper soil management strategies are to be adopted in the major part of the district while using groundwater for irrigation.
- The heavy metals content in most of the soil samples are below detectable limit only few samples contained very less amount of heavy metals (0 – 0.5 ppm).
- Water level, in the wells / bores ranged from 600 to 900 feet below ground level.
- Water table depth varied from 10 to 20 feet during north-east monsoon 2014.
- Fluctuation in the water table depth was observed and it varied according to the season and rainfall.

1.8. Chalakudy

Evaluation of Surface and Groundwater Quality across the State of Kerala and its Effect on Vegetation

Based on the survey, 14 sampling locations were identified along course of river from high ranges to lowland areas and samples of water and sediments were collected from these locations. Sampling was done soon after the monsoon (rains were received till November 2015) season. Locations 1-6 belong to high ranges; locations 7-12 are midlands, where coconut, tapioca, banana, vegetables, nutmeg, pepper, etc. are mainly grown and irrigated; and locations 13-14 belong to lowlands/midlands with paddy, coconut, vegetables, banana, tapioca, nutmeg crops raised by farmers in homesteads. Samples were collected and analysed in three phases: during November 2014, April 2015 (Table 1.8.1) and December 2015 (Table 1.8.2). During Nov 2014, all samples were safe for irrigation purpose. In Kathikudam, calcium content was as high as 88.58 ppm. Presence of heavy metal nickel was also observed. Lead was found in all the samples. Presence of E. coli was found in Valparai, Athirappilly, Sree Sakthi Paper mills, Chalakudy and Parakadavu. During analysis of second phase samples, it was found that two locations Elanthikkara and Kathikudam need interventions. Soil in

Elanthikkara area was saline due to sea water intrusion (Table 1.8.1). Previously, farmers used to make sand bridge to prevent intrusion and make water safe for irrigation. Now, check dam (Regulator cum Bridge) has been constructed to prevent intrusion to a great extent. In Kathikudam, effluents from the factory affected various parameters like TDS, EC, SAR, etc. Presence of heavy metals (Ni, Pb) also reported, though not significant to affect quality of irrigation water (Table 1.8.1).

Table 1.8.1. Quality parameters of water samples collected from different locations during April 2015

Location	pH	EC (dS/m)	HCO_3^- (meq/l)	TDS (ppm)	SAR	RSC (meq/l)	Boron (ppm)	Nickel (ppm)	Lead (ppm)	Calcium (ppm)	Sodium (ppm)
Elanthikkara	6.79	**1.0**	1.0	12.41 ppt.	4.98	2.73	0.033	0.145	0.213	3.0	**104.7**
Kanakkankadav	6.45	0.5	1.4	99.02	1.08	2.39	0.023	-	-	1.82	8.0
Parakadavu	6.46	0.62	0.1	94.26	1.09	2.17	-	0.008	-	2.9	10.4
Annamanada	6.52	0.21	0.4	87.31	0.66	1.61	-	-	-	4.00	6.8
Kathikudam	6.94	**0.9**	1.2	**12.12 ppt**	**8.17**	1.56	0.026	0.066	0.016	**12.13**	**97.4**
Moozhikkakadav	6.55	0.52	1.1	56.8	0.42	2.87	-	-	-	2.28	4.5
Athirapilly water falls	6.56	0.2	0.3	55.94	0.40	1.09	-	-	-	3.06	4.2
CRDS	6.50	0.12	1.0	77.99	0.43	0.9	-	-	-	4.39	5.0
Sree Sakthi Paper mills	6.86	0.06	1.36	41.08	0.26	3.65	-	-	-	5.62	3.1
Chalakudy	6.75	0.04	0.5	48.81	0.30	3.29	-	-	-	4.92	3.4
Peringalkuthu Reservoir	6.78	0.2	0.8	49.01	0.23	2.75	0.009	0.061	-	5.02	2.6
Perumbara	6.74	0.03	0.8	40.03	0.31	2.33	-	-	-	5.39	2.9
Upper Sholayar	6.84	0.7	1.72	57.19	1.33	4.86	-	-	-	4.36	3.8
Valparai	6.86	0.01	1.5	33.30	0.13	1.74	0.042	-	-	4.98	1.7

Table 1.8.2. Quality parameters of water samples collected from different locations during December 2015

Location	pH	ECO^{3-} (meq/l)	TDS (ppm)	Dissolved oxygen (mg/l)	Total bacteria (10^3 CFU/ ml)	Total Fungi (10^3 CFU/ ml)	Total Actinomy-cetes (10^3 CFU/ml)	Total coliforms (MPN values)
Elanthikkara	6.35	1.4	5.42 ppt	2.97	3	7	0	0
Kanakkankadav	7.28	1.4	106.4	3.76	25	0	0	28
Parakadavu	6.55	1.6	85.41	3.86	1	0	0	0
Annamanada	6.65	1.4	80.89	4.57	2	5	0	0
Kathikudam	6.23	3.6	7.56 ppt	1.93	151	5	5	460
Moozhikkakadav	7.32	1.6	54.87	4.90	3	0	0	0
Chalakudy	6.85	4.8	46.90	5.21	1	0	0	0
Sree sakthi paper mills	7.54	3.2	50.25	5.57	5	0	0	1100
CRDS	7.49	4.41	38.82	5.95	7	0	0	460
Athirapilly water falls	7.60	1.44	38.99	6.35	14	0	0	1100
Peringalkuthu reservoir	7.49	4.41	40.31	5.60	1	0	0	93
Perumbara	7.13	1.8	49.54	6.20	2	0	1	460
Upper Sholayar	7.2	3.0	65.34	4.19	200	1	0	1100
Valparai	7.51	5.76	74.02	5.44	10	0	0	460

1.9. Hisar

1.9.1. Dynamics of Water Resources - Impact on Hydro-dynamic Equilibrium in Haryana

The experiment was conducted to quantify district-wise/region-wise water availability from different resources, estimate district-wise water requirement and analysing the impact of water availability on productivity of major crops in Haryana. Since 1974, the water table in the state is monitored in June (pre-monsoon) and October (post-monsoon) through a network of well distributed observation points numbering 2021. Water table fluctuation from 1979 to 2015 is shown in fig. 1.9.1. The average water table in the state in 1974 was 9.19 m which went down to 17.75 m in 2015. The amount of rainwater availability calculated based on geographical area, culturable and cropped area and average annual rainfall in the state was 21522, 17419 and 16610 MCM, respectively.

Field demonstrations were conducted at farmers' fields on two outlets of Sarsana minor of Balsamand Distributary during *rabi* 2014-15 and *kharif* 2015. District-wise water requirement of major *kharif* and *rabi* crops was estimated for the area under each crop (Table 1.9.2).

Table 1.9.1. District-wise rainfall and water table fluctuation in Haryana

District	Rainfall (mm)				Water table fluctuation (cm)			
	2012	2013	2014	2015	2012	2013	2014	2015
Ambala	496	884	596	926.9	-89	-18	-19	-26
Bhiwani	256	211	227	317.9	-98	166	-164	-19
Faridabad	343	595	305	701.4	-101	-161	-22	10
Fatehabad	135	249	102	186.1	-128	-85	-55	-65
Gurgaon	555	385	174	457.7	109	-258	-15	-56
Hisar	198	230	101	194.5	-11	46	-1	-27
Jhajjar	207	330	370	508.9	-39	10	26	74
Jind	225	371	244	454.2	-109	-78	-2	-50
Kaithal	171	320	189	358.0	-120	-119	-59	-137
Karnal	344	492	343	624.4	-102	-43	-39	-34
Kurukshetra	382	600	325	759.3	-232	-184	-40	-79
Mewat	350	490	286	734.6	234	-196	21	-4
Mohindergarh	402	287	225	256.0	-78	-122	50	22
Palwal	428	327	198	426.7	-38	-32	-23	-6
Panchkula	586	482	284	630.4	-206	60	-51	-43
Panipat	240	211	239	513.4	-147	-21	20	-83
Rewari	440	484	547	594.3	-86	-107	-39	-128
Rohtak	170	143	80	260.4	-38	30	30	-39
Sirsa	148	165	158	208.9	-50	-8	-65	-127
Sonepat	368	531	225	633.8	-2	-70	42	-21
Y.nagar	644	1100	560	957.4	-135	6	37	-39

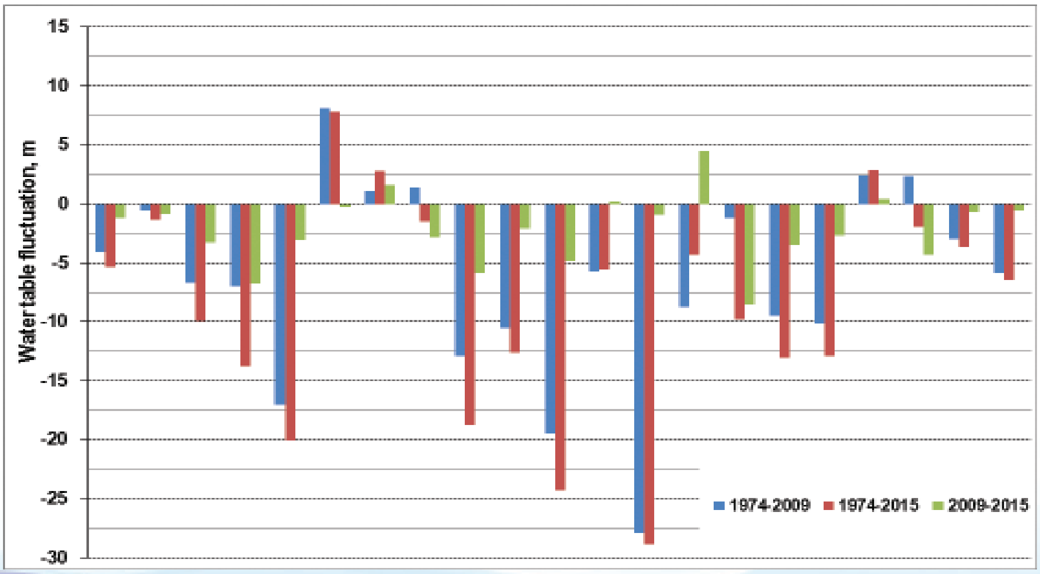
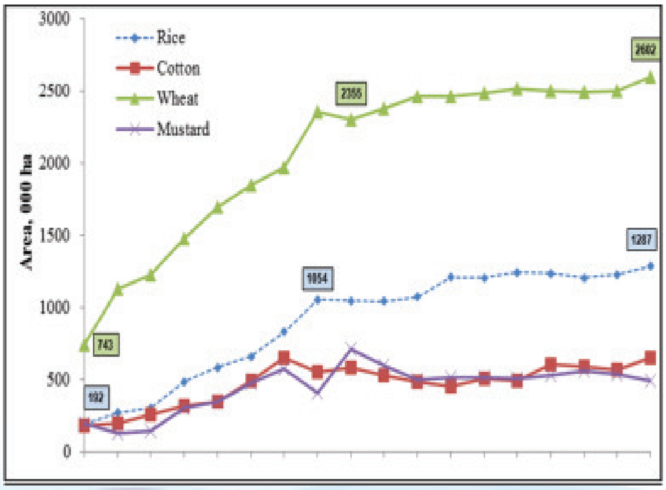


Fig 1.9.1. Groundwater table depth (June) and fluctuation over the years in Haryana

Table 1.9.2. Total water and irrigation requirement (MCM) of *kharif* and *rabi* crops during 2014-15

District	Water requirement	Effective rainfall (mm)	Irrigation requirement
Ambala	1467.4	722.9	744.4
Bhiwani	3605.2	587.4	3017.7
Faridabad	324.5	89.0	235.5
Fatehabad	3546.1	308.7	3237.4
Gurgaon	479.7	99.7	380.0
Hisar	4113.0	351.5	3761.5
Jhajjar	1633.5	418.6	1214.9
Jind	2999.1	729.1	2270.0
Kaithal	2726.6	510.2	2216.5
Karnal	2810.4	868.1	1942.2
Kurukshetra	1916.0	568.5	1347.5
Mewat	848.0	216.4	631.6
Mohindergarh	1213.5	284.5	929.0
Palwal	1103.1	202.2	900.9
Panchkula	247.2	77.7	169.5
Panipat	1309.3	260.4	1048.9
Rewari	947.5	444.1	503.4
Rohtak	1341.1	118.7	1222.4
Sirsa	5184.6	550.8	4633.8
Sonepat	1868.4	408.3	1460.1
Yamunanagar	1486.5	688.8	797.6
State	**41170.6**	**8505.7**	**32664.8**

The water requirement of *kharif* season crops during 2014-15 was estimated to be 16554.6, 1799.2, 48.8, 355.2, 5604.5 and 976.5 MCM for rice, bajra, maize, jowar, cotton and sugarcane crops, respectively. In addition an amount of 831.1 MCM was estimated to be required by miscellaneous crops *viz.*, *kharif* pulses, fodder vegetables etc. The total amount of water required by *kharif* season crops was estimated to be 26169.8 MCM. The water requirement of wheat, chickpea, barley and *rabi* oilseeds during 2014-15 was estimated to be 12314.1, 203.6, 125.8 and 1778.5 MCM. In addition an amount of 578.8 MCM was estimated for miscellaneous crops like, berseem as green fodder, *rabi*pulses, fenugreek, fruits and vegetables. Thereby, the total water requirement during *rabi* season of 2014-15 was estimated to be 15000.7 MCM. The total irrigation water requirement of the state of the during the *rabi* and *kharif* seasons of 2014-15 was estimated to be 32664.8 million cubic metre (MCM) while the effective rainfall was 8505.7 MCM. It clearly indicates that to harvest high yields of field crops irrigation water need to be applied. The irrigation requirement in the western and southern districts was estimated to be high as compared to northern districts. In the southern districts, the irrigation requirement was more during *rabi* than during *kharif* season, while in central and northern rice growing districts, the irrigation requirement was more during *kharif* than *rabi* season. The area under high water requiring cropping system *viz.*, rice and wheat has increased sharply since 1966-67 till 2000-01 (Fig. 1.9.2). The area under cotton and mustard has also increased till 2000-01 but after that it remained almost static. On the other hand there has been a drastic decline in the area under low water requiring crops *viz.*, chickpea from 1062 to 65 thousand hectare during *rabi* season and pearlmillet from 893 to 387 thousand hectare during *kharif* season (Fig. 1.9.2).



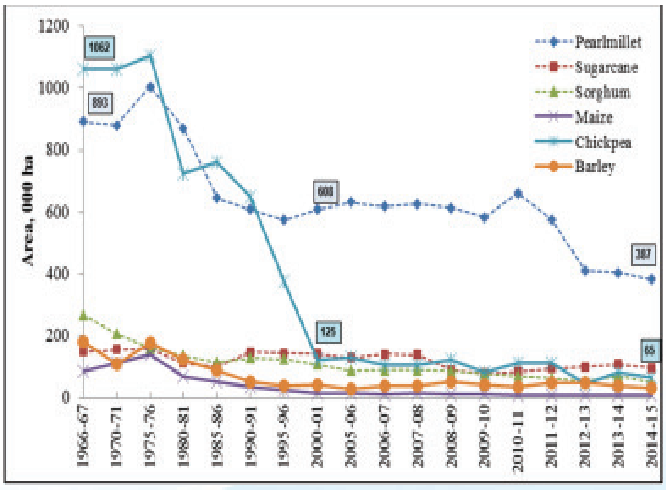


Fig. 1.9.2. Change in area under major crops from 1966-67 to 2014-15

On-farm intervention: Field demonstrations were conducted at farmers' fields on two outlets, 10000R and 14920L of Sarsana minor of Balsamand Distributary during *rabi* 2014-15 and *kharif* 2015. Details of the outlets are given in table 1.9.3.

Table 1.9.3. Details of farmers' field outlets for field demonstrations

Outlet No.	Villages	GA (acres)	CCA (acres)	Water allowance (cusec/1000 acres)	Discharge (cusec)
10000R	Aryanagar	581.2	558.20	2.40	1.45
14920L	Gangwa, Tokas	910.0	730.45	2.40	1.75

Technology interventions for Outlet No. 14920L were FIRBS in wheat, drip irrigation in cotton and drip irrigation and mulching in vegetables crops. Technology interventions for Outlet No. 10000R were drip irrigation in cotton and conjunctive use of ground saline and canal water. Six field demonstrations were conducted on Outlet No. 14920L on FIRBS sowing and irrigation in wheat during 2014-15. The average grain yield was 4001 kg/ha which was higher by 78 kg (2.01 %) over conventional sowing and surface irrigation (Table 1.9.4). Under FIRBS, the amount of irrigation water applied was 2.1 cm (10.5 %) less as compared to surface flood methods. Water productivity at the six farmers' fields varied between 145.5 to 212.7 kg/ha-cm with surface flood method while it varied between 210.7 to 242.9 kg/ha-cm with FIRBS and thus the increase in water productivity varied from 12.9 to 15.6 %. The average increase in water productivity was calculated to be 14.0 kg/ha-cm with FIRBS.

Table 1.9.4. Wheat grain yield, amount of irrigation water applied and saved, and increase in water productivity (WP) during 2014-15

Field No.	Grain yield (kg/ha)		Irrigation water applied (cm)		Increase in yield (%)	Water saved (%)	Increase in WP (%)
	Surface	FIRBS	Surface	FIRBS			
1	4160	4230	20.3	18.2	1.68	10.3	13.4
2	4030	4075	23.1	20.2	1.12	12.6	15.6
3	3850	3960	18.1	16.3	2.86	9.9	14.2
4	3725	3830	18.3	16.5	2.82	9.8	14.0
5	3680	3750	17.5	15.8	1.90	9.7	12.9
6	4090	4160	20.8	18.6	1.71	10.6	13.7
Mean	**3923**	**4001**	**19.7**	**17.6**	**2.01**	**10.5**	**14.0**

Cotton was also planted under drip during *kharif* 2015. The drip laterals and inline drippers were placed at spacing of 120 cm and 40 cm, respectively. The seeds were hand dibbed in dry soil and irrigation was applied. The seed cotton yield, irrigation water applied of the nine fields on 14920R and 10000L outlets is presented in table 1.9.5. The results clearly indicate that a significant edge of drip irrigation enhanced seed cotton yield as well as water productivity under semi-arid agro-ecological conditions.

Table 1.9.5. Seed cotton yield, amount of irrigation water applied and saved during 2015

Field No.	Seed cotton yield (kg/ha)		Irrigation water applied (cm)		Increase in yield (%)	Water saved (%)
	Surface	Drip	Surface	Drip		
Outlet 14920R						
1	1835	2150	24.3	16.2	17.2	33.3
2	1950	2210	23.8	15.3	13.3	35.7
3	1980	2180	21.6	15.0	10.1	30.6
4	1740	1960	19.8	14.7	12.6	25.8
Mean	**1876**	**2125**	**22.4**	**15.3**	**13.3**	**31.3**
Outlet 10000L						
1	1725	1925	21.8	17.3	11.6	20.6
2	1820	1980	23.6	18.1	8.8	23.3
3	1640	1840	22.4	15.7	12.2	29.9
4	1460	1620	19.7	14.3	11.0	27.4
5	1780	1860	20.4	16.3	4.5	20.1
Mean	**1685**	**1845**	**21.58**	**16.34**	**9.6**	**24.3**
Mean of outlets	**1781**	**1985**	**22.0**	**15.8**	**11.5**	**27.8**

1.10. Jorhat

1.10.1. Arsenic Level in Groundwater, Paddy Soil and Rice Plant-A Micro Level Study from Titabar Area of Jorhat District, Assam

Arsenic accumulation in rice is viewed as a new disaster and presence of high level of arsenic in rice is becoming a potential threat in rice growing belt. Therefore, level of arsenic in groundwater of Titabar block was studied. Forty-two samples each from soil and water were collected from different locations of Titabar subdivision covering 7 villages. The sources of the water samples were PHE outlet, STW, hand tubewell, etc. Sixty-seven % samples from three villages, Nagajanka, Bacha bihari and Garmuria gaon, showed arsenic contamination based on the benchmark value of National Drinking Water Standard. The remaining four villages, Katoni, Kathpar, Borera and Deka gaon had only 50 % samples contaminated.

For most of the paddy soils arsenic content in groundwater (GW) ranged from 0.029 to 0.117 µg/ml resembling with 29 to 117 ppb, which showed far above the critical value of 10 ppb set by WHO (Fig. 1.10.1). Highest concentration was noticed towards north-western part of Titabar and comparatively lowest value was recorded in eastern part of central Titabar. In addition to GW arsenic content, fluoride levels across the whole Titabar block were determined showing maximum area below threshold value of fluoride contamination set by WHO (0.6 – 1.2 µg/ml). Data analysis and preparation of soil fertility map using GIS is in process. Collection of rice plant samples for its arsenic content along with the development of low cost technology to correct arsenic intake by the rice crop is in the verge of addressing the problem.

Arsenic content	Area (km²)
In groundwater (μg/ml)	
0.029-0.049	183.12
0.049-0.056	132.47
0.056-0.066	130.44
0.066-0.078	104.43
0.078-0.117	82.43
In soil (μg/g)	
0.428-0.667	195.98
0.667-0.755	122.55
0.755-0.892	96.36
0.892-1.025	119.23
1.025-1.33	98.77

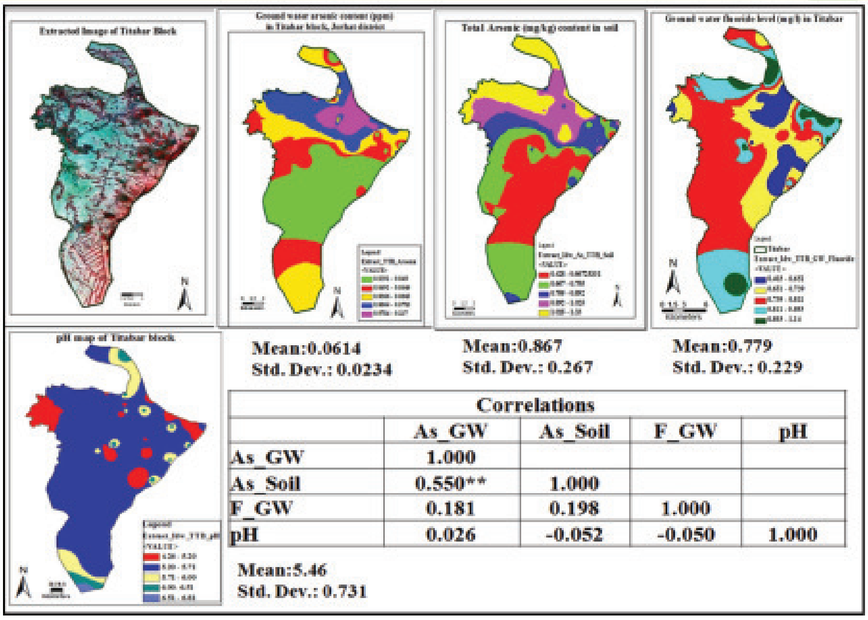


Fig. 1.10.1. Area under different ranges of arsenic in groundwater and soil

1.10.2. Assessment of Fluoride Content in Soil and Irrigation Water of Margherita Subdivision, Tinsukia District, Assam

Recently, the issue of fluoride contamination in groundwater has been raised in most of the shallow tubewell (STW) command areas. Shallow tubewell has been banned totally in the entire subdivision and farmers' of Margherita under Tinsukia district. Forty-one water samples were collected from different locations of VLEW areas of Margherita subdivision to measure fluoride and arsenic. It was found that fluoride contents were below the permissible limits by WHO have been reported in large number of samples. Nearly 80% samples had fluoride concentration less than 0.15 mg/L while 7% had more than 0.2 mg/L. Highest fluoride concentration estimated was 0.872 mg/L and lowest was 0.029 mg/L. High fluoride content of 0.5 mg/L was observed in more than 7.3 % samples.

The arsenic data revealed that ~ 44% samples were in the low range (< 30 ppb), 34 % samples in the medium range (30-40 ppb) and 17 % samples in the higher range (40-50 ppb).

1.11. Udaipur

Assessment of Groundwater Quality of Bhilwara District of Rajasthan

The present study was undertaken to assess groundwater quality of Bhilwara district. Ten open dug wells were selected randomly from each of the eleven blocks and groundwater samples were collected in pre-monsoon season (May-June) and post-monsoon season (November-December) of 2014 and 2015. Water quality parameters were analysed and pH, EC, cations and anions are presented in fig. 1.11.1 to 1.11.4.

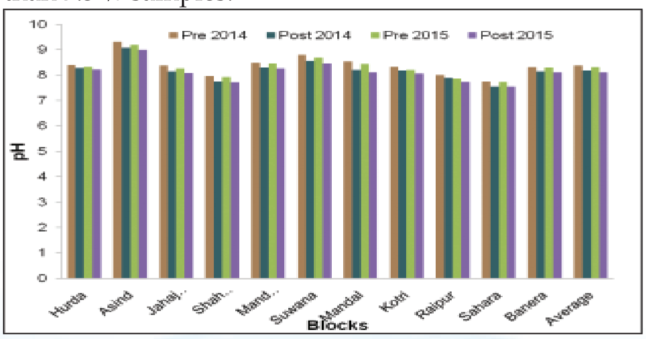


Fig. 1.11.1. Average pH of different blocks of Bhilwara district

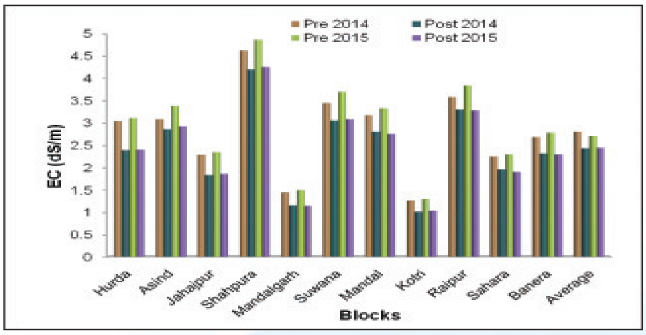


Fig. 1.11.2. Average EC of different blocks of Bhilwara district

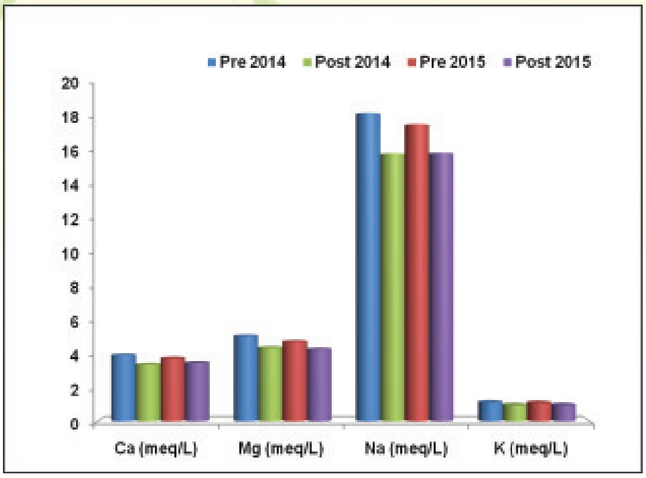


Fig. 1.11.3. Average cations of different blocks of Bhilwara district

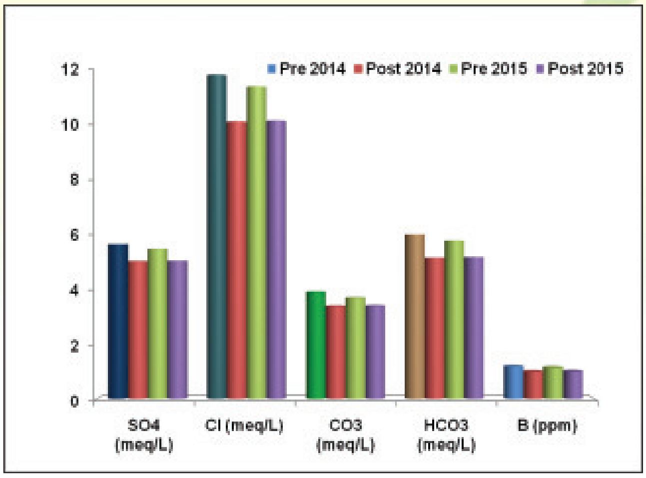


Fig. 1.11.4. Average anions of different blocks of Bhilwara district

Both pre- and post- monsoon samples were also classified into different levels of salinity, sodicity and alkalinity, as per the USDA classification of irrigation (Table 1.11.1). In pre-monsoon seasons, samples under class C_2 can be used for irrigation of moderate salt tolerant crops in soils having moderate drainage. Samples under class C_3 cannot be used on soils with restricted drainage but salt tolerant varieties can be grown with special management for salinity control. Samples under class C_4 is not suitable for irrigation for sustainable crop production. In post-monsoon seasons, number of samples in class C_2 increased and those in classes C_3 and C_4 decreased. This clearly indicated that large number of groundwater samples of Bhilwara district shifted from higher to lower salinity conditions in post-monsoon seasons of both the years. This may be attributed to the rainwater recharge in groundwater. During the post-monsoon seasons extent of alkalinity (RSC) reduced considerably in all the samples. From the two-year data, it may be inferred that salinity is the major limiting factor affecting groundwater quality of Bhilwara district in both pre- and post-monsoon seasons. Sodicity problem is not prevailing in the groundwater. Only 10.0 to 12.27 % samples having RSC value >2.5 meL^{-1} in pre-monsoon seasons are unsuitable for meq/L irrigation on sustainable basis.

Table 1.11.1. Classification of groundwater of Bhilwara district for irrigation suitability

Water	Water samples			Water samples		
	Pre-monsoon 2014	Pre-monsoon 2015	Mean	Post-monsoon 2014	Post-monsoon 2015	Mean
SALINITY (EC)						
C_1 (<0.25)	0	0	0	0	0	0
C_2 (0.25-0.75)	10 (9.1%)	6 (5.5%)	8 (7.3%)	29 (26.36 %)	27 (24.54 %)	28 (25.45 %)
C_3 (0.75-2.25)	56 (50.9%)	55 (50.0%)	55.5 (50.5 %)	43 (39.1 %)	46 (41.8 %)	44.5 (40.5 %)
C_4 (>2.25)	44 (40.0%)	49 (44.6%)	46.5 (42.3 %)	38 (34.6 %)	37 (33.6 %)	37.5 (34.1 %)

SODICITY (SAR)						
S_1 (<10)	82 (74.6%)	79 (71.8%)	80.5 (73.2%)	83 (75.5%)	83 (75.5%)	83 (75.5%)
S_2 (10-18)	17 (15.5%)	23 (20.9%)	20 (18.2%)	22 (20.0%)	21 (19.09%)	21.5 (19.5%)
S_3 (18-26)	8 (7.3%)	5 (4.6%)	6.5 (5.9 %)	4 (3.6 %)	5 (4.6 %)	4.5 (4.1%)
S_4 (>26)	3 (2.7%)	3 (2.7%)	3 (2.7%)	1 (0.9%)	1 (0.9%)	1 (0.9%)
ALKALINITY (RSC)						
A_1 (<1.25)	83 (75.5%)	73 (66.4%)	78 (70.91 %)	82 (74.55 %)	82 (74.55 %)	82 (74.55 %)
A_2 (1.25-2.5)	18 (16.3%)	19 (17.3%)	18.5 (16.81 %)	17 (15.45 %)	17 (15.45 %)	17 (15.45 %)
A_3 (>2.5)	9 (8.2%)	18 (16.4%)	13.5 (12.27 %)	11 (10.00 %)	11 (10.00 %)	11 (10.00 %)

1.12. Jammu

Optimization of Land and Water Resources of Tawi - Lift Canal Command Area of Jammu (18,000 ha) for Rice-Wheat Sequence

This is a new experiment conducted with to benchmark Tawi-Lift canal command infrastructure system and determine performance indicators for *kharif* crop. Tawi-lift canal command has eleven main distributaries having command area of approximately 18,000 ha under main and other majors and minors of the system. Major cropping pattern in the Tawi-lift canal command is Basmati-cum-coarse rice during *kharif* season with gross water requirement of 1500 mm diverted from the canal. Distributary-wise canal water diverted and relative water supplies within the command area during *kharif* 2015 is presented in table 1.12.1.

Table 1.12.1. Relative water supplies (RWS) within Tawi-Lift command during *kharif* 2015

Identified distributary	Canal water divereted (ha-cm)	*Water available at field (ha-cm)	Effective rainfall (ha-cm)	Total water supply (ha-cm)	Water requirement (ha-cm)	RWS
Main Tawi Canal	594864	416405	410872	827277	1932000	0.43
D-1	97978	58787	8166	66953	38400	1.74
D-2	97978	58787	20735	79522	97500	0.81
D-3	97978	58787	13143	71930	61800	1.16
D-4	13997	8398	3509	11907	16500	0.72
D-5	118973	71384	13813	85197	64950	1.31
D-6	20995	12597	7847	20444	36900	0.55
D-7	20995	12597	3860	16457	18150	0.91
D-8	20995	10497	11771	22268	55350	0.40
D-8A	55987	27993	11420	39413	53700	0.73
D-8B	39312	19656	9283	28939	43650	0.66
D-8C	9072	4536	15854	20390	74550	0.27
D-9	24192	9677	10782	20459	50700	0.40
D-10	123984	49594	29348	78942	138000	0.57
D-11	102816	41126	40991	82117	192750	0.42

* The water available at field as per field observations at 70% of canal water supply in main Tawi, 60% from D-1 to D-7, 50% from D-8 to D-8C and 40% from D-9 to D-11.

Benchmarking of irrigation infrastructure of Tawi-Lift command through RS and GIS technique:

The method applied was geo-referencing of toposheet, digitization of distributaries from SOI-toposheet and ground truthing by field visits/GPS surveys to cross check and data validation. Digitization of Tawi-lift map has given insight regarding irrigation infrastructure of the irrigation system (Fig. 1.12.1).

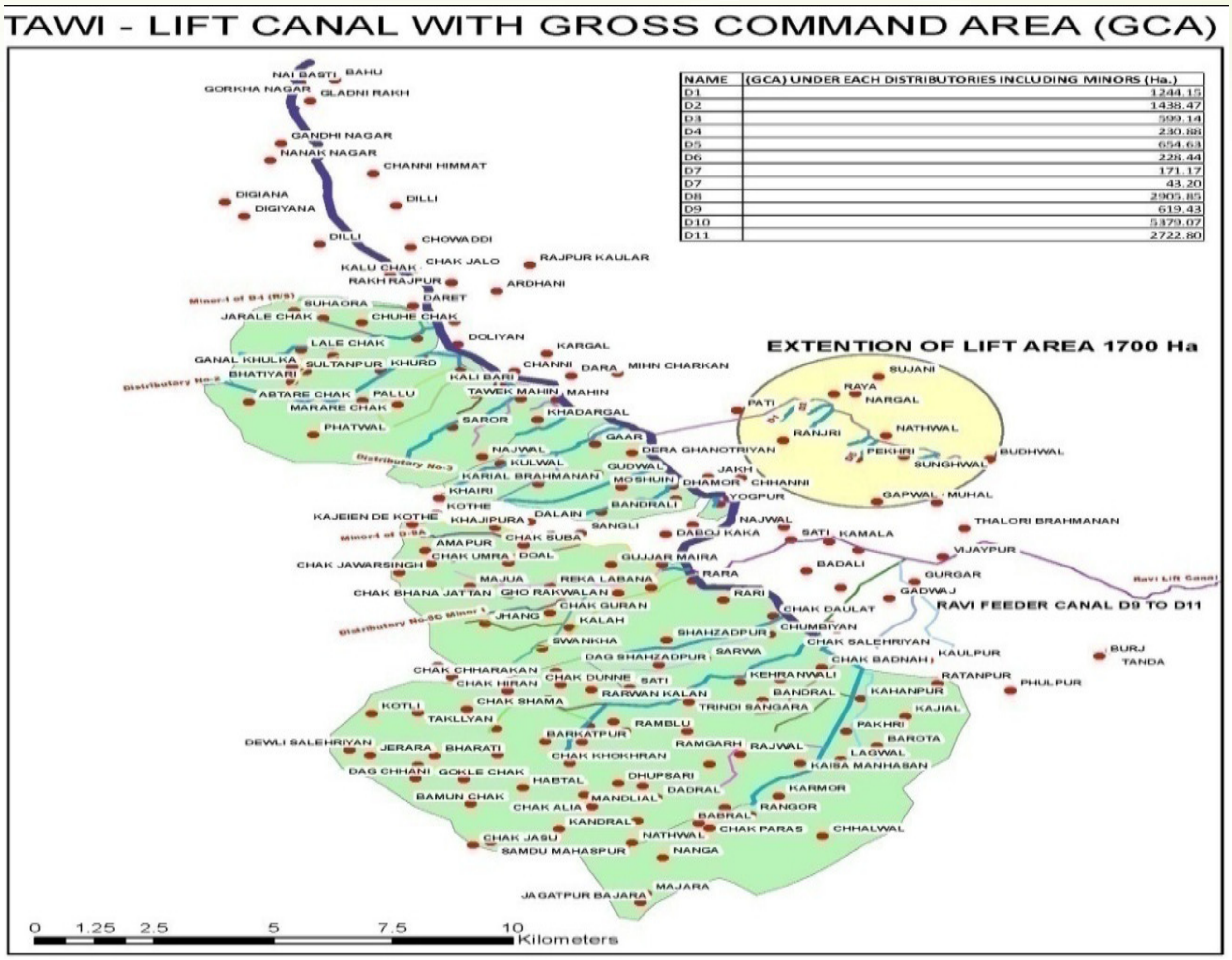


Fig. 1.12.1. Benchmarking of irrigation infrastructure of Tawi-Lift command through RS and GIS technique

1.13. Chiplima

Assessment of Water Availability at Regional Level and to Develop Interventions for Matching Water Supply with Agricultural Production System

Retamunda Branch Canal was selected to analyse distributary-wise deficit-surplus of canal water in the command area for rabi season. Detailed deficit-surplus and scenario analyses with four scenarios revealed that except for the Sukha distributary, all the distributaries face water deficit, with rice being grown in the entire command area. Further, it was observed that about 98 % of the total command area can be irrigated to maintain the optimality of water use (Scenario - I). However, there would be surplus water in the command area of Kebar distributary even if the entire CCA is cultivated with heavy duty crops. The results revealed that 100 % of command area of the system can be irrigated, if the designed cropping pattern under Scenario – II could be followed. Though the total command area can be provided irrigation under this scenario, there would be marginal reduction in average rate of net return per hectare of the irrigated area compared to the previous scenario. It is observed that the cropping pattern obtained under Scenario – III would give more net return than that of the first two scenarios, with provision of irrigation for 100 % of the CCA with increased average rate of net return per hectare. The optimal allocation of areas under different types of crops under Scenario – IV suggests that for maximum net return from the command area, with 100% land utilization, no low duty crop may be taken. The summary of the scenario analysis is presented in table 1.13.1. Optimization of cropping pattern under the scenarios II, III and IV with modified water availabilities of 90 %, 75 % and 60 % to assess their feasibility and adaptability is shown in table 1.13.2.

It may be concluded that all the outlets are operating under sub-optimal conditions. As a measure of non-structural intervention, optimal cropping pattern under four different scenarios for each outlet were determined to minimize the demand-supply gap. All the outlets of the system can be operated optimally with the adoption of the designed cropping pattern in the command areas of the distributaries except for the Kebar Distributary. Further, it is feasible to provide irrigation to the entire command area even if the canal releases are reduced by 40 %.

Table 1.13.1. Summary of scenario analysis

Scenario	Cropping Pattern (ha)				Total CCA (ha)	Net Return cultivated (%)	NR (Rs. crores)	NR ('000) (Rs. /ha)
	Heavy	Medium	Low	Unculti-vated				
Scenario - I	9114.9	1596.7	357.4	203.6	11068.9	98.2	26.9	24.4
Scenario - II	8860.9	2180.3	231.3	0.0	11272.5	100.0	27.4	24.3
Scenario - III	8798.3	2399.4	74.8	0.0	11272.5	100.0	27.5	24.4
Scenario - IV	8768.4	2504.2	0.0	0.0	11272.5	100.0	27.6	24.5

Table 1.13.2. Effect of water availability on optimal cropping pattern

Scenario	Water availability (%)	Area under different crops (ha)			Net Return ('000) (Rs. / ha)	Decrease in NR (%)
		Heavy	Medium	Low		
II	100	8860.9	2180.3	231.3	24.3	-
	90	7645.7	2581.0	1045.8	23.6	3.0
	75	5656.9	3467.8	2147.7	22.5	7.5
	60	2974.9	4820.0	3477.6	21.1	13.1
III	100	8798.3	2399.4	74.8	24.4	-
	90	7493.2	3114.8	664.6	23.8	2.6
	75	Not feasible				
	60	Not feasible				
IV	100	8768.4	2504.2	0.0	24.5	-
	90	7227.3	4045.2	0.0	24.1	1.4
	75	4820.3	6396.1	56.1	23.5	3.7
	60	2017.9	8169.4	1085.2	22.3	8.7

1.14. Kota

Assessment of Water Availability and Deficit at Field Level for Manasgaon Distributary

For the Manasgaon distributary, monthly canal running days, water released, relative water supply and water availability at field level, for both *rabi* and *kharif* season during year 2014–15, are shown in table 1.14.1. Water supplied in the distributary during the month of November 2014, was maximum (17262.02 ha-cm) and minimum in October 2014 (9239.05 ha-cm). The relative water supply (RWS) was maximum in November (65.32 %) with 27 days, whereas in October 2014, with 15 days canal running, RWS was minimum (62.93 %). Average RWS during *rabi* 2014 (October 2014 to February 2015) was 64.13 %. The canal water availability at field level during *rabi* 2014-15 was 36655.45 ha-cm. During *kharif* 2015, canal running was nil. Area sown under different crops in the command of Manasgaon distributary is given in table 1.14.2. Total sown area during *rabi* season was 1075.02 ha, out of which wheat and mustard occupied maximum area. Similarly, during *kharif* season total sown area was 978.87 ha, out of which soybean and paddy were mostly grown. During *kharif*, heavy infestation of yellow mosaic virus was observed in the zone due to change in climatic conditions.

Reconciliation of demand at field level: Total water requirement of the area was calculated based on total irrigation water that the farmers applied for a particular crop, which was then added to the quantity of irrigation water supplied to all the crops. During *rabi* season, wheat, garlic and vegetables, while during *kharif* season paddy and vegetables consumed most of the water. Season-wise total water requirement level for the crops at field through canal and rain were computed to be 46310.3 and 53976.8 ha-cm during *rabi* and *kharif*, respectively. Total water deficit of 2654.85 ha-cm and 5944.80 ha-cm was observed during *rabi* and *kharif* seasons, respectively.

Table 1.14.1. Running days, designed and actual water released at head of Manasgaon distributary

Month	Running days	Water released (ha-cm)		Relative water supply (%)	Water availability at field level (ha-cm)
		Designed	Actual		
Oct-14	15	14681.09	9239.05	62.93	5081.48
Nov-14	27	26425.96	17262.02	65.32	9494.11
Dec-14	23	22511.00	14260.72	63.35	7843.40
Jan-15	19	18596.04	12035.07	64.72	6619.29
Feb-15	22	21532.26	13849.40	64.32	7617.17

Table 1.14.2. Area sown under different crops at Manasgaon distributary

Rabi		*Kharif*	
Crop	Area (ha)	Crop	Area (ha)
Wheat	821.7	Soybean	711.3
Coriander	20.8	Paddy	210.7
Gram	14.8	Maize	25.5
Mustard	167.1	Urd	26.3
Fenugreek	5.2	Vegetables	2.4
Garlic	35.9	Others	2.7
Berseem	3.2	-	-
Vegetables	4.2	-	-
Flowers	0.5	-	-
Other	1.7	-	-
Total	**1075.0**	**Total**	**978.9**

1.15. Belvatagi

Effect of Irrigation Duration on Salt Distribution in Ghataprabha Command Area

In Ghataprabha command area, long-term irrigation leads to increase in pH, EC, CEC, ESP and SAR of soils, which lead to decline in the productivity of crops (Table 1.15.1 and 1.15.2). It is recommended to make judicious use of irrigation water at farm level to improve water use efficiency. Reclamation of land using drainage systems to removal of salts is also recommended. Effort must be made to discourage surface irrigation for high water demanding crops like sugarcane. Sugarcane cultivation should be restricted to pressurized method of irrigation.

Table 1.15.1. Effect of different periods of irrigation on soil pH and salt distribution (Electrical Conductivity) in profile samples

Soil depth (cm)	Profile samples pH (1:2.5) Years of irrigation						Profile samples EC 1:2.5 (dS/m) Years of irrigation					
	Control	10-15	15-20	20-30	>30	Mean	Control	10-15	15-20	20-30	>30	Mean
0-20 (D_1)	7.75	8.11	8.09	8.35	8.41	8.14	0.30	0.52	0.74	0.84	0.79	0.62
20-40 (D_2)	7.88	7.87	8.32	8.29	8.53	8.18	0.47	1.36	1.33	1.13	1.33	1.12
40-60 (D_3)	7.61	8.34	8.31	8.42	8.41	8.22	0.24	0.76	1.32	1.88	1.95	1.23
60-80 (D_4)	7.95	8.18	8.30	8.38	8.54	8.27	0.87	2.16	2.45	2.12	2.99	2.12
>80 (D_5)	8.06	8.55	8.63	8.50	8.66	8.48	1.47	2.79	1.82	2.63	3.86	2.32
Mean	7.85	8.21	8.33	8.39	8.51	8.26	0.66	1.32	1.56	1.72	2.18	-
	SEm±			CD (P=0.05)			SEm±			CD (P=0.05)		
Years (Y)	0.06			0.16			0.10			0.29		
Depth (D)	0.06			0.16			0.10			0.29		
Y x D	0.13			0.36			0.23			0.65		

Table 1.15.2. Cation exchange capacity (CEC), exchangeable sodium percentage (ESP) and sodium adsorption ratio (SAR) of profile soil samples as influenced by irrigation

Soil depth (cm)	CEC [cmol(p+)/kg]						ESP (%)						SAR					
	Un-irriga-ted	Periods of irrigation (years)				Mean (years)	Un-irriga-ted	Periods of irrigation (years)				Mean (years)	Un-irriga-ted	Periods of irrigation (years)				Mean (years)
		10-15	15-20	20-30	>30			10-15	15-20	20-30	>30			10-15	15-20	20-30	>30	
0-20	51.73	52.53	54.52	55.54	57.66	54.77	8.15	9.75	8.69	12.38	11.69	10.13	1.64	1.55	2.86	2.18	3.04	2.26
20-40	49.54	55.27	55.17	56.38	55.71	53.88	6.74	11.65	10.64	13.06	12.37	10.89	1.99	1.64	2.33	2.61	3.71	2.46
40-60	50.54	55.38	56.12	56.94	56.76	54.96	8.87	9.37	12.94	10.08	13.94	11.04	2.91	2.08	2.99	3.29	4.42	3.14
60-80	53.96	54.76	56.38	58.39	58.61	56.37	9.80	12.18	13.35	14.05	15.95	13.07	2.02	3.33	2.74	4.43	5.58	3.62
>80	55.72	55.92	54.47	60.57	62.53	58.04	10.12	14.36	16.97	16.78	17.28	15.10	2.63	3.83	3.52	5.54	8.50	4.80
Mean	52.30	54.77	55.33	57.56	58.25	-	8.74	11.46	12.52	13.27	14.24	-	2.24	2.48	2.89	3.61	5.05	-
	SEm±			CD (P=0.05)			SEm±			CD (P=0.05)			SEm±			CD (P=0.05)		
P	0.82			2.30			0.75			2.09			0.37			1.03		
D	0.82			2.30			0.75			2.09			0.37			1.03		
P x D	1.83			5.14			1.67			4.68			0.83			2.31		

Theme 2

Design, development and refinement of surface and pressurized irrigation systems including small holders' systems for enhancing water use efficiency and water productivity for different agro-ecosystems

2.1. Palampur

2.1.1. Effect of Drip Irrigation and Fertigation Frequencies on Crop Growth, Water Use and Productivity of Summer Brinjal

The experiment was carried out for three consecutive years (2013 to 2015) in RBD with three irrigation intervals *viz.*, I_1- One, I_2- Two and I_3- Three and fertigation frequencies- Once a week (Every 7^{th}-8^{th} day), Twice a week (Every 4^{th}- 5^{th} day) and Twice a month (Every 15^{th}-16^{th} day) having three replications each. Recommended dose of fertilizer (RDF) (N:P:K::100:60:50) and FYM (10 Mg ha^{-1}) were applied as per package of practices. Surface irrigation of 5 cm ponded depth was applied at 7 days interval (control). Drip irrigation was given at 0.8 CPE. Fertigation was given at the rate of 75 % of the recommended NPK.

Irrigation interval (days): During 2015, irrigation interval had significant effect on economics of brinjal cultivation. Irrigation interval of three day had significantly higher brinjal yield than irrigation interval of two (6.09 %) and one day (12.47 %). The respective %ages for gross returns, net returns and B:C ratio were, 6.52 and 12.54, 14.00 and 29.21 and 14.28 and 30.0, respectively. During 2015, irrigation interval of three day had significantly higher water use efficiency than irrigation interval of two (5.17 %) and one day (17.32 %). For individual year and on mean (of three years) basis, the brinjal crop grown with 75 % of recommended NPK fertigation under gravity fed drip irrigation resulted in significantly higher water use efficiency (1.5, 2.0,1.9 and 1.8 times) due to lower irrigation water use (33.14, 52.33,52.00 and 47.96 %) than recommended practices.

Fertigation frequency: During all the years and on mean basis, twice a month fertigation resulted in significantly higher brinjal yield than fertigation at frequencies of once a week (13.50, 11.96, 26.70 and 16.86 %) and twice a week (9.99, 8.73, 6.25 and 8.44 %), respectively (Table 2.1.1). Similarly, twice a month fertigation resulted in significantly higher water use efficiency than fertigation once a week (16.89, 14.41, 28.89 and 19.28 %) and twice a week (15.12, 13.76, 12.46 and 14.00 %), respectively. Net returns were also significantly higher during all the years and on mean basis, when crops were fertigated at the frequency of twice a month than at the frequency of once (23.37, 24.19, 67.22 and 34.97 %) or twice (17.06, 17.60, 13.40 and 16.71 %) a week (Table 2.1.1). Twice a month fertigation also resulted in significantly higher B:C ratio than fertigation at frequencies of once a week (23.74, 24.24, 68.18 and 35.48 %) and twice a week (17.81, 18.27, 14.43 and 16.67 %), respectively.

Irrigation interval x Fertigation frequency: Irrigation interval interacted significantly with fertigation frequency during second year for brinjal yield, water use efficiency, gross returns, net returns and B:C ratio. Irrigation at two day interval and twice a month fertigation of brinjal crop resulted in highest brinjal yield. However, it was statistically similar to yield obtained by irrigating brinjal crop at an interval of one day and fertigating either twice a week or twice a month. Irrigation at two day interval and twice a month fertigation of brinjal crop resulted in significantly higher WUE than all other combinations of irrigation interval and fertigation frequency (Table 2.1.1). Irrigation at two day interval and twice a month fertigation of brinjal crop resulted in highest gross returns, net returns and B:C ratio. Therefore, it may be concluded that for saving irrigation water (47.96 %) and increasing WUE, brinjal crop should be irrigated with gravity fed drip irrigation system. For maximizing production, water use efficiency and economics gravity fed drip irrigated brinjal crop should be fertigated twice a month with 75 % of the recommended NPK.

Table 2.1.1. Interaction effect of irrigation interval and fertigation frequency on productivity, water use efficiency, net returns and B:C ratio of brinjal during 2014

Fertigation frequency	Irrigation interval (days)		
	One	Two	Three
Productivity (Mg/ha)			
Once a week	8.87	10.78	10.72
Twice a week	11.03	9.77	10.45
Twice a month	11.27	11.90	10.82
CD (P = 0.05)	-	0.96	-
Water use efficiency (kg/l)			
Once a week	3.10	3.88	3.65
Twice a week	3.82	3.38	3.48
Twice a month	4.03	4.36	3.75
CD (P = 0.05)	-	0.33	-
Net returns (Rs./ha)			
Once a week	56,288	85,451	84,526
Twice a week	88,713	69,901	80,338
Twice a month	92,476	1,02,351	86,176
CD (P = 0.05)	14,463	-	-
B:C ratio			
Once a week	0.73	1.12	1.11
Twice a week	1.16	0.91	1.05
Twice a month	1.21	1.34	1.13
CD (P = 0.05)	-	0.19	-

2.1.2. Effect of Liquid Manure Based Drip Fertigation on Water Use and Productivity of Onion

The experiment was carried out with various combinations of liquid manure, liquid biofertilizer and chemical fertilizer and surface irrigation. Results showed that during both the years, substitution of different proportion of recommended N with various liquid manures resulted in significantly higher green onion yield and economics of drip irrigated (0.6 PE) onion, as compared to crop fertilized with recommended nitrogen through chemical fertilizer either with or without recommended FYM and surface irrigated with water depth of 5 cm (Table 2.1.2). During both the years, in surface irrigated onion (5 cm water depth), application of recommended nitrogen through chemical fertilizer along with application of recommended FYM resulted in significantly higher green onion yield (37.01 and 50.45 %), gross returns (37.02 and 50.46 %), net returns (1.62 and 2.14 times) and B:C ratio (1.43 and 2.07 times) than application of recommended nitrogen through chemical fertilizer (Table 2.1.2). In both the years, crop raised under drip irrigation (0.6 PE), substitution of 100 % of recommended N with locally prepared liquid manure which was enriched with 1 % liquid biofertilizer (E100) resulted in highest green onion yield, gross returns, net returns and B:C ratio. However, the values of gross returns, net returns and B:C ratio so obtained were at par with values obtained with substitution of 100 % of recommended N with locally prepared liquid manure (L100). Value of B:C ratio obtained was also at par with substitution of 75 % of recommended N with locally prepared liquid manure and enriched with 1 % liquid biofertilizer (E75U25).

Water use Efficiency: Table 2.1.2. shows that during both years, in surface irrigated onion (5 cm water depth), application of recommended N through chemical fertilizer along with application of recommended FYM resulted in significantly higher water use efficiency than application of recommended N through chemical fertilizer due to significantly higher green onion yield in the former treatment. During both years, in crop raised under drip irrigation (0.6 PE), substitution of 100 % of recommended N with locally prepared liquid manure which was enriched with 1 % liquid biofertilizer (E100) resulted in highest WUE. However, during first year, substitution of 100 % of recommended N with locally prepared liquid manure (L100), substitution of 75 % of recommended N with locally prepared liquid manure enriched with 1 % liquid biofertilizer (E75U25), substitution of 100 % of recommended N with banana pseudo stem sap (B100) and substitution of 75 % of recommended N with locally prepared liquid manure (L75U25) resulted in statistically similar WUE. Likewise, during second year, substitution of 100 % of recommended N with locally prepared liquid manure (L100) also resulted in statistically similar WUE as obtained with substitution of 100 % of recommended N with locally prepared liquid manure which was enriched with 1 % liquid biofertilizer (E100).

Therefore, it may be concluded that onion crop should be irrigated at three day interval with cumulative PE of 0.6 % and fertigated with 100 % of recommended N with locally prepared liquid manure which was enriched with 1 % liquid biofertilizer (E100) for better production and economics.

Table 2.1.2. Effect of different treatments on productivity, water use and economics of green onion

Treatments*	Green onion yield (Mg/ha)		TWU (m^3/ha) (Rs/ha)		Water use efficiency (kg/l)		Gross returns (Rs/ha)		Net returns (Rs/ha)		B:C	
	2014	2015	2014	2015	2014	2015	2014	2015	2014	2015	2014	2015
B50U50	27.33	26.13	3.16	2.35	8.65	11.12	328000	313600	229096	213309	2.32	2.13
B75U25	28.33	27.70	3.16	2.35	8.97	11.79	340000	332400	241462	232236	2.45	2.32
B100	32.07	30.67	3.16	2.35	10.15	13.05	384800	368000	286628	267542	2.92	2.66
L50U50	28.00	27.40	3.16	2.35	8.86	11.66	336000	328800	237096	228509	2.40	2.28
L75U25	31.33	30.33	3.16	2.35	9.92	12.91	376000	364000	277462	264131	2.82	2.64
L100	34.00	33.00	3.16	2.35	10.76	14.04	408000	396000	309828	293398	3.16	2.87
E50U50	29.00	28.13	3.16	2.35	9.18	11.97	348000	337600	248596	237642	2.50	2.38
E75U25	32.67	31.80	3.16	2.35	10.34	13.53	392000	381600	292962	282214	2.96	2.84
E100	36.67	35.27	3.16	2.35	11.60	15.01	440000	423200	341328	320853	3.46	3.15
RF+FYM	21.47	21.77	1.31	1.20	16.39	18.14	257600	261200	148965	157564	1.37	1.53
RF	15.67	14.47	1.31	1.20	11.96	12.06	188000	173600	92115	73514	0.96	0.74
CD (P=0.5)	4.02	2.27	-	-	1.83	1.39	48283	27241	48283	28523	0.49	0.35

*B50U50 : Application of 50 % of recommended N through banana pseudo stems sap and remaining 50 % N through urea

B75U25 : Application of 75 % of recommended N through banana pseudo stems sap and remaining 25 % N through urea

B100 : Application of 100 % of recommended N through banana pseudo stems sap

L50U50 : Application of 50 % of recommended N through locally prepared liquid manure and remaining 50 % N through urea

L75U25 : Application of 75 % of recommended N through locally prepared liquid manure and remaining 25 % N through urea

L100 : Application of 100 % of recommended N through locally prepared liquid manure

E50U50 : Application of 50 % of recommended N through locally prepared liquid manure + 1 % liquid biofertilizers and remaining 50 % N through urea

E75U25 : Application of 75 % of recommended N through locally prepared liquid manure + 1 % liquid biofertilizers and remaining 25 % N through urea

E100 : Application of 100 % of recommended N through Locally prepared liquid manure + 1 % liquid biofertilizers

RF+FYM : 100 % of recommended N from chemical fertilizers and weekly surface irrigation of 5 cm

RF : 100 % of N from chemical fertilizers + FYM and weekly surface irrigation of 5 cm

Note : Drip irrigation was given at 0.6 CPE in first nine treatments

2.2. Dapoli

Effect of Irrigation and Fertigation Levels on Yield and Quality Parameters of Aonla, Cashew and Okra

Aonla

Three levels of drip irrigation I_1 (100 % ET_{crop}), I_2 (80 % ET_{crop}) and I_3 (60 % ET_{crop}) and three levels of fertilization F_1 (100 % RDF), F_2 (80 % RDF) and F_3 (60 % RDF) were applied on Aonla cultivar NA-7. Total amount of water applied to the crop under treatment I_1, I_2 and I_3 were 339, 271 and 203 mm, respectively. It resulted in water saving of 20 % and 40 % in I_2 and I_3

treatments, respectively over I_1 treatment for which the total amount of water applied equalled to ET_{crop}. Different levels of irrigation and fertigation had substantial effects on biometric parameters like height, girth of aonla plant. Treatments I_2 and F_1 have consistently shown highest height, girth and yield over other treatments. Further, among the interaction effects of irrigation and fertilizer, I_2F_1 showed significant effect on all the three plant parameters (Table 2.2.1).

Table 2.2.1. Interaction effects of irrigation and fertilizer on plant height, girth, yield and water use efficiency of aonla

Treatment	Plant height (cm)	Girth (cm)	Yield (kg/plant)	Total water applied (ha-cm)	WUE (kg/ha-cm)
I_1F_1	410	42.13	5.07	33.88	29.80
I_1F_2	369	37.59	4.60	33.88	27.15
I_1F_3	370	38.94	4.40	33.88	25.97
I_2F_1	459	53.63	7.13	27.10	52.62
I_2F_2	380	43.17	5.70	27.10	42.06
I_2F_3	397	42.43	4.43	27.10	32.69
I_3F_1	382	41.30	4.93	20.30	48.57
I_3F_2	363	39.63	4.37	20.30	42.90
I_3F_3	360	39.30	3.97	20.30	39.00
Mean of Control (rainfed) CD at 5%	300	37.13	2.26	-	-
I	12.0	2.65	0.21	-	-
F	25.0	1.24	0.27	-	-
I x F	54.0	2.73	0.59	-	-

Cashew

The experiment was carried out with similar irrigation and fertilizer treatments. Total amount of water applied to cashew crop under treatment I_1, I_2 and I_3 were 381, 305 and 228, respectively. It resulted in water saving of 20% and 40% in I_2 and I_3 over I_1 treatment, for which the total amount of water applied equalled to ET_{crop}. Different levels of irrigation and fertigation had substantial effects on quantitative parameters like height, girth, east-west (E-W) spread, north-south (N-S) spread and yield of cashew plant; and protein, reducing sugar and non-reducing sugar of cashew nut. The interaction effects of irrigation and fertilizer on the biometric parameters are shown in table 2.2.2.

Table 2.2.2. Interaction effects of irrigation and fertilizer on biometric parameters of cashew

Treatment	Plant height (m)	Girth (cm)	E-W spread (m)	N-S spread (m)	Protein (%)	Reducing sugar (%)	Non-reducing sugar (%)	Yield (t/ha)
I_1F_1	4.06	0.44	3.27	3.60	22.24	2.89	4.83	0.28
I_1F_2	3.67	0.38	3.60	3.81	21.32	2.37	4.04	0.29
I_1F_3	3.26	0.36	3.24	3.84	20.66	2.08	3.58	0.27
I_2F_1	3.96	0.39	3.31	3.43	21.44	2.18	4.47	0.20
I_2F_2	4.19	0.38	3.32	3.28	22.03	2.24	4.05	0.23
I_2F_3	3.83	0.39	3.07	3.04	20.54	2.13	4.08	0.22
I_3F_1	3.82	0.37	2.99	3.07	20.54	2.13	4.18	0.16
I_3F_2	3.53	0.37	2.95	2.98	20.34	1.82	3.94	0.17
I_3F_3	3.62	0.38	2.99	2.85	19.64	1.86	3.83	0.16
Control	2.87	0.03	-	2.52	-	-	-	0.09
CD at 5%								
I	0.29	0.02	0.18	0.21	1.16	0.37	0.18	0.03
F	0.23	0.02	0.17	0.15	0.75	0.19	0.27	0.02
I x F	0.39	0.04	0.30	0.26	0.30	0.33	0.47	0.04

2.3. Faizabad

Evaluation of Drip Irrigation with Surface Irrigation in Tomato and Zaid Okra

Tomato is mostly irrigated through flood irrigation method. High moisture has adverse effects on growth and development of the crop and affects the quality and production of tomato. Light irrigation through drip may help in increasing fertilizer and water use efficiency (WUE). Field experiment was conducted to find out suitable moisture regime for tomato production. Different treatments were tested to work out their respective water use efficiencies. Results obtained from the experiment are presented in table 2.3.1 and 2.3.2. Treatment I_5 recorded significantly higher tomato yield compared to other drip and surface irrigated treatments. Treatment I_5 had lower WUE than treatments I_6, I_7 and I_8, but higher WUE and ~10% more water saving than I_1, I_2, I_3 and I_4. Thus it may be concluded that drip irrigation @ 60% PE with 100% N (I_5) may be recommended for tomato production. As there is no significant difference between yield of tomato in I_5 and I_6, it may be said that nitrogen doses (100% and 75%) did not have significant effect on yield of tomato under drip irrigation treatments; rather the difference in yield was due to difference in irrigation treatment.

Commercial value of okra crop grown in zaid season is quite high as compared to *kharif* crop season. But shrinking of groundwater has raised concern on i) reduction in irrigation water supply and ii) loss of unused water during okra cultivation. Experiment was conducted using surface and drip irrigation treatments with similar objectives as that for tomato. Drip irrigation @ 80% of PE with 100% N fertigation (I_3) gave the significantly higher yield of okra over other irrigation treatments, except for drip irrigation @ 80% with 75% N fertigation (I_4). This clearly indicated that the nitrogen dose (100 % and 75 %) did not affect the yield of okra significantly under drip irrigation treatments. It may be concluded that drip irrigation @ 80 % PE with 100 % N may be recommended for *zaid* okra cultivation because the treatment consumes substantially less amount of water, saves more water (Table 2.3.1), produces higher yield and higher WUE than surface irrigation.

Table 2.3.1. Irrigation applied and water saving in tomato and okra under different treatments of drip and surface irrigation

Treatments	Irrigation water applied (mm)		Water saving (%)	
	Tomato	Okra	Tomato	Okra
0.8 IW/CPE	400.00	300	-	19.05
1.0 IW/CPE	-	420	-	-
80% of PE	172.00	212	57.00	49.52
60% of PE	129.00	159	67.75	62.14
40% of PE	86.00	-	78.50	-

Table 2.3.2. Tomato crop yield and water use efficiency under different treatments of drip and surface irrigation

Treatments	Tomato yield (t/ha)		Water use efficiency (kg/ha-mm)	
I_1- 0.8 IW/CPE with 100 % N	25.53	4.68	63.83	15.58
I_2- 1.0 IW/CPE with 100 % N	-	5.03	-	11.96
I_2- 0.8 IW/CPE with 75 % N	23.36	-	58.41	-
I_3- Drip irrigation @ 80 % PE with 100 % N	31.35	6.88	182.27	32.43
I_4- Drip irrigation @ 80 % PE with 75 % N	30.05	6.25	174.67	29.48
I_5- Drip irrigation @ 60 % PE with 100 % N	32.86	5.63	254.70	35.38
I_6- Drip irrigation @ 60 % PE with 75 % N	31.62	5.25	245.12	33.02
I_7- Drip irrigation @ 40 % PE with 100 % N	28.05	-	326.16	-
I_8- Drip irrigation @ 40 % PE with 75 % N	26.50	-	308.14	-
CD at 5 %	1.66	0.97	-	-

2.4. Hisar

Demonstration on Mini-Sprinkler, FIRBS and FIRBS-Drip in Wheat

Performance of mini-sprinkler of 6 m wetting diameter, FIRBS with drip and FIRBS without drip were tested in wheat under semi-arid conditions. From table 2.4.1 and fig. 2.4.1 it is evident that FIRBS-drip is the most economical irrigation system in terms of water use components and beneficial in terms of grain yield. FIRBS-drip may be suggested to grow wheat in semi-arid conditions.

Table 2.4.1. Water use components and yield parameters of wheat under different methods of irrigation

Irrigation method	SMD (cm)	GWC (cm)	Irriga-tion (cm)	Total water used (cm)	Tiller per m^2	Grains per ear	Test wt (g)	Yield (kg/ha)
Mini-sprinklers	5.4	4.1	14.3	39.6	382	42.2	38.6	5520
FIRBS	6.7	5.6	15.2	42.9	386	42.6	37.8	5220
FIRBS-Drip	5.1	3.5	13.4	38.3	398	44.6	37.6	5577
Conventional	7.4	5.4	17.4	44.7	378	42.7	37.5	5063
SEm±	-	-	-	-	3.63	0.32	0.24	61.3
CD (p=0.05)	-	-	-	-	12	1.03	0.8	199

SMD- soil moisture depletion, GWC- groundwater contribution
Note: Water table depth of the field varied 95 to 145 cm during the crop season

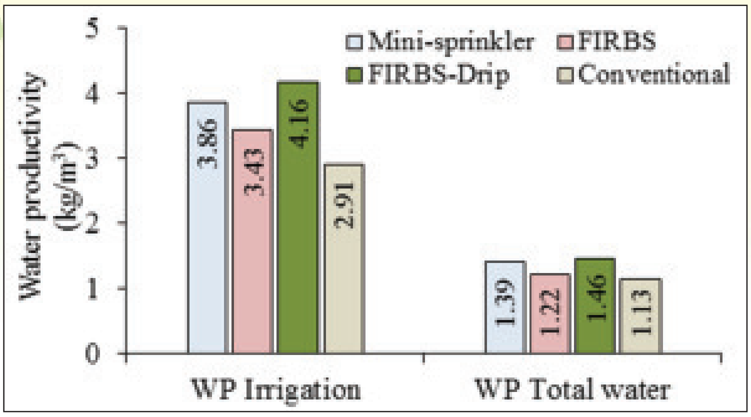


Fig. 2.4.1. Water productivity (WP) with different methods of irrigation

2.5. Jammu

2.5.1. Evaluation of Raised and Sunken Bed Technique for Waterlogged Areas of Canal Commands of Jammu

Due to high rainfall in monsoon and delivery of excess water through canal irrigation systems at disaggregated canal command level, 20,000 ha (out of precious one lakh hectares) of irrigated belt of Jammu as well as many low-lying agriculture farms in Jammu and Kashmir remain waterlogged through dry as well as wet seasons. As a result, the farmers can hardly grow any other crop than rice. A strategy was taken with an aim to upscale water productivity of the farmers' fields by planting cash crops that can grow well under such water logged conditions in the J&K state. Six raised beds (Dimension: 86.0 m x 9.0 m), 9 sunken beds (Dimension: 86.0 m x 9.0 m x 1.5 m) and one farm pond (Dimension: 90.0 m x 30.0 m x 2.0 m) were developed. Seven treatments including T_1- Rice-Wheat/Berseem (Existing Practice), T_2- Vegetables on Raised Bed and Fish in Sunken Bed, T_3- Vegetables + Fruit Crop on Raised Bed and Fish in Sunken Bed, T_4- Vegetables + Fruit Crop on Raised Bed and Fish + Poultry in Sunken Bed, T_5- Floriculture + Fruit Crop on Raised Bed and Fish in Sunken Bed, T_6- Floriculture + Fruit Crop on Raised Bed and Fish in Sunken Bed and T_7- Floriculture + Fruit Crop on Raised Bed and Fish + Poultry in Sunken Bed were implemented with three replications in RBD. Physico-chemical properties of the soil of raised bed and water quality parameters of sunken beds were estimated. Wheat, Indian as well as exotic vegetables, seasonal flowers and fruits were grown in different raised beds (Plate 2.5.1, 2.5.2 and 2.5.3). Six breeds of fish were grown in the sunken beds. Results obtained so far are presented in table 2.5.1. Broccoli, Chinese Cabbage, Pak Choi, Parsley and Swiss chard were grown for seed production. Broccoli and Swiss Chard produced sufficient amount of seed, while Chinese Cabbage and Pak Choi, tried for the first time, produced small amount of seeds.

Plate 2.5.1. Exotic vegetable during *rabi* 2015-16

Plate 2.5.2. Seasonal flowers cultivation during *rabi* 2015-16

Plate 2.5.3. Strawberry cultivation during *rabi* 2015-16

Table 2.5.1. Trial of vegetable, flower and fruit crops during *rabi* 2015-16

Crop	Variety	Yield (kg/ha)	Irrigation (mm)	Rainfall (mm)	TWA (mm)	WUE (kg/ha-mm)
Existing cropping pattern						
Wheat	HD-2967	1600	120	139.5	259.5	6.16
Vegetable crpos						
Coriander	Khushboo	7000	100	219	319	21.94
Spinach	Green Sag	9600	100	219	319	30.09
Fenugreek	Khushboo	14700	100	219	319	46.08
Broccoli	Ludy F1	6600	50	140.1	190.1	34.71
Cauliflower	Lucky	9600	50	140.1	190.1	50.49
Floriculture						
Marigold	Hybrid orange	2555	Nil	140.1	140.1	18.23
Gladiolus (did not respond)	Novalux, White Sea, Advance Red, American Beauty, Her Majesty	–-	Nil	140.1	140.1	– –
Fruit Crop						
Strawberry	**Chandeler**	1265	280 / plot	201.9	481.9	2.62

2.5.2. Effect of Varying Moisture Regimes in Zero-Till Wheat Succeeding Mung Bean and Sorghum

Wheat succeeding mung bean produced significantly higher effective tillers, number of grains/spike, 1000 grain weight and grain yield (4784 kg/ha) than sorghum (4298 kg/ha). The yield and yield parameters did not differ significantly between conventional tillage and zero-tillage in *rabi* but were significantly higher than complete zero (Table 2.5.2). Among the moisture regimes, the yield attributing parameters as well as grain yield of wheat were highest under irrigation at 0.9 IW/CPE and decreased with decrease in the level of moisture regime.

Table 2.5.2. Yield parameters and yield of wheat under different treatments

Treatments	No. of effective tillers per m²	No. of grains per spike	1000 grain weight (g)	Grain yield (kg/ha)
Preceding crops				
Mungbean	328	40.3	37.4	4784
Sorghum	315	38.9	36.2	4298
CD at 5%	5.8	0.23	0.23	325
Tillage practices				
Conventional	327	39.8	37.2	4810
Zero-*rabi*	323	39.7	37.0	4690
Complete zero	315	39.4	36.3	4122
CD at 5%	7.1	0.28	0.28	300
Moisture regimes				
IW/CPE=0.60	314	39.3	36.4	3936
IW/CPE=0.75	324	39.7	37.0	4736
IW/CPE=0.90	327	39.9	37.1	4951
CD at 5%	6.8	0.25	0.26	243

Components of water use and water productivity (WP): Various components of water use towards crop ET *viz.*, soil moisture depletion, effective rainfall, groundwater contribution and irrigation from sowing to 30 DAS, 31 to 75 DAS, 76 to 105 DAS and 106 to maturity of crop were estimated by standard methods (Fig. 2.5.1, 2.5.2). The WP of irrigation and total water use for wheat was higher succeeding mungbean (3.99 and 1.25 kg/m³) than sorghum (3.47 and 1.02 kg/m³). The water productivity of irrigation water under zero tillage in *rabi* was higher than the conventional and zero tillage in both the seasons. Among the moisture regimes, WP was highest with irrigation at IW/CPE of 0.6 (Fig. 2.5.3).

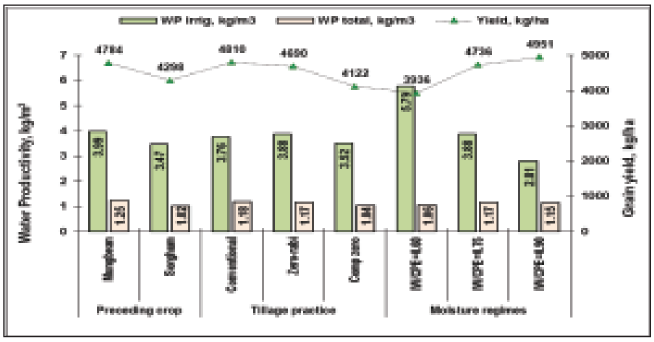


Fig. 2.5.2. Contribution of various water use components in wheat crop under different treatments

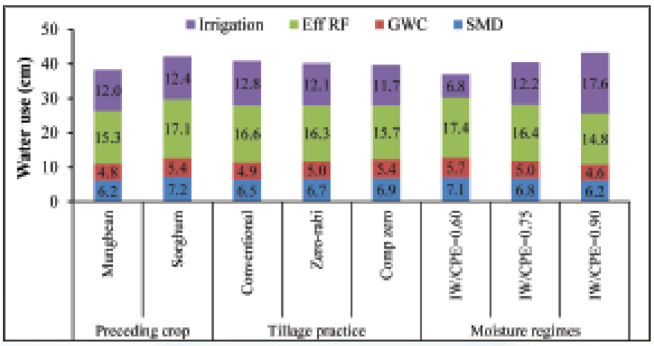


Fig. 2.5.1. Consumptive water use during various wheat crop periods under different treatments

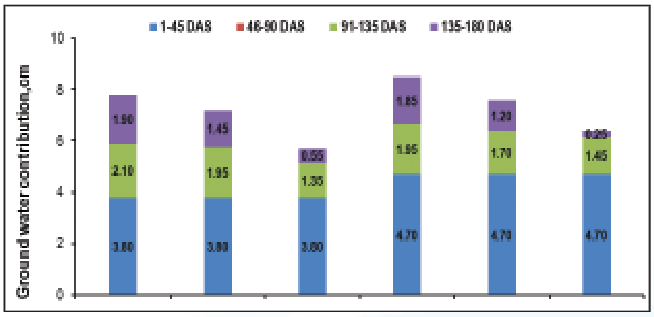


Fig. 2.5.3. Yield and water productivity of wheat under different methods of irrigation and moisture regimes during 2014-15

2.5.3. Irrigation Scheduling in Cotton Cultivars under Semi-Arid Conditions

Cultivar Bio-6588 produced significantly more seed cotton yield than RCH-650 which was higher by 26.5 % (Table 2.5.3). The seed cotton yield was found to be significantly higher with the application of first irrigation at 40 DAS as compared to at 50 DAS under all the corresponding moisture regimes. Irrigation applied IW/CPE=0.90 and 0.75 after first irrigation either at 40 or 50 DAS produced significantly higher seed cotton yield over their corresponding moisture regime of IW/CPE=0.60.

Table 2.5.3. Yield parameters and seed cotton yield of cotton under different treatments

	Treatments	No. of opened bolls per plant	Boll weight (g)	Yield per plant (g)	Seed cotton yield (kg/ha)
Cultivars	Bio-6588	36.3	3.163	115.0	2789
	RCH-650 *(Bt)*	30.1	3.016	90.9	2204
CD at 5%	-	4.3	0.050	14.9	361
Irrigation schedules (irrigation at)	40 DAS+IW/CPE=0.60	33.6	3.062	103.2	2500
	40 DAS+IW/CPE=0.75	35.7	3.120	111.6	2706
	40 DAS+IW/CPE=0.90	35.8	3.135	112.6	2726
	50 DAS+IW/CPE=0.60	30.1	3.015	91.1	2211
	50 DAS+IW/CPE=0.75	31.7	3.092	98.3	2383
	50 DAS+IW/CPE=0.90	32.4	3.112	101.1	2453
CD at 5%	-	1.3	0.023	4.5	111

The contribution from shallow groundwater towards crop ET during 1-45 DAS was lower when first irrigation was applied at 40 DAS than 50 DAS (Fig. 2.5.4). Due to sufficient rains, there was no contribution from groundwater during 46-90 DAS.

At later crop periods (91-180 DAS), it decreased with increase in moisture regimes and mainly depended upon the timings of irrigation. The amount of irrigation water applied under different irrigation schedules is depicted in fig. 2.5.5. An amount of 18.4, 24.0 and 29.4 cm of irrigation water was applied under irrigation schedule of 40 DAS and thereafter at IW/CPE= 0.60, 0.75 and 0.90, respectively. When 1st irrigation was applied at 50 DAS, the respective values of irrigation water applied were 13.1, 18.7 and 24.2 cm.

Water productivity calculated as the seed cotton yield per cubic meter of total water use (ET) and irrigation water use was found to be higher in Bio-6588 (0.407 and 1.309 kg m^3) as compared to RCH-650 cultivar (0.326 and 1.035 kg m^3). This was primarily due to higher seed cotton yield of the former cultivar. Among the irrigation schedules, the WP of total water use was found to be highest i.e., 0.384 kg/m^3 when 1st irrigation was applied at 40 DAS and thereafter at IW/CPE=0.75 as compared to other irrigation schedules. In general, the WP of total water use was higher but the WP of irrigation water was lower when 1st irrigation was applied at 40 DAS as compared to that at 50 DAS. Highest WP of irrigation water (1.687 kg/m^3) was achieved when 1st irrigation was applied

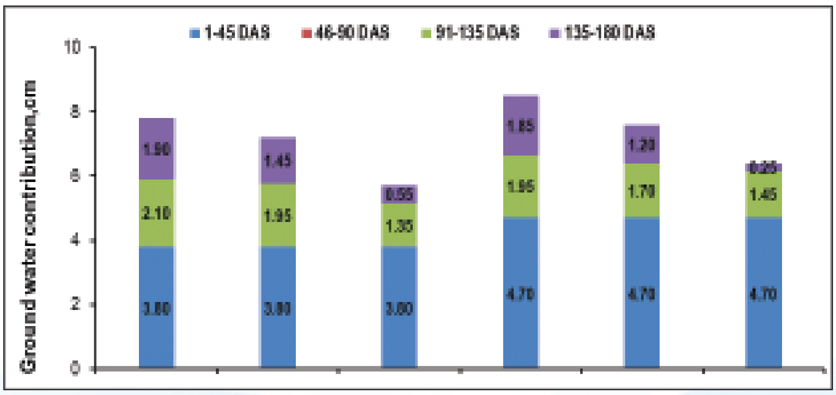


Fig. 2.5.4. Groundwater contribution and amount of irrigation water applied during different periods of cotton under various irrigation schedules

at 50 DAS and thereafter at IW/CPE=0.60 as compared to the other irrigation schedules. WP of irrigation water decreased with increase in moisture regimes from IW/CPE=0.60 to 0.90.

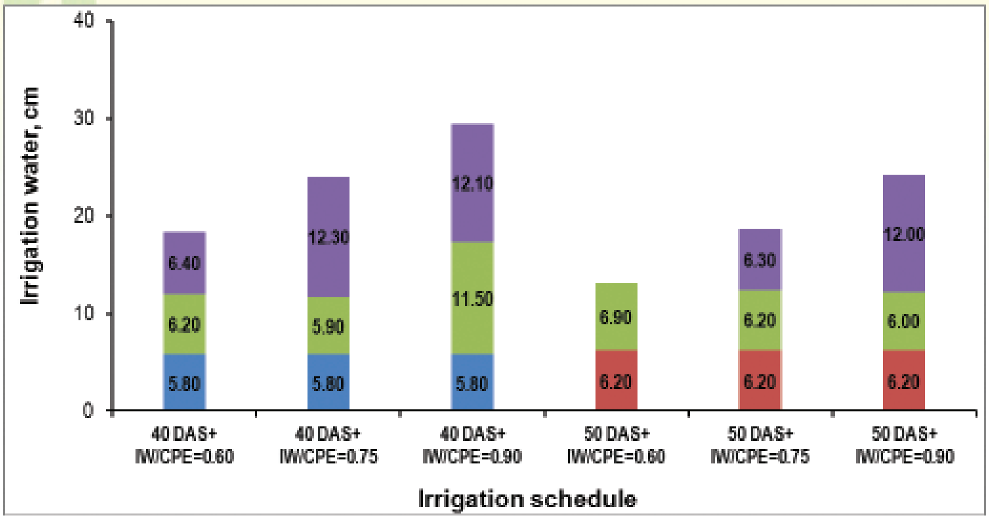


Fig. 2.5.5. Water productivity of total water use (TWP) and irrigation water (IWP) of cotton cultivars under various irrigation schedules

Cultivation of Bio-6588 cultivar provided more net returns (Rs. 51,500 per ha) and B:C (1.68) than RCH-6588 (Table 2.5.4). Irrigation applied at 40 DAS and thereafter at IW/CPE= 0.75 gave higher net return and B:C closely followed by 40 DAS + IW/CPE=0.90. Application of 1st irrigation at 40 DAS provided substantially higher net return and B:C as compared to 1st irrigation at 50 DAS under the corresponding moisture regimes.

Table 2.5.4. Economics in thousand (Rs./ha) of cotton cultivars under different irrigation schedules

	Treatments	Variable cost	Total cost	Gross return	Return/ var.cost	Net return	B:C
Cultivars	Bio-6588	42.3	75.4	126.9	84.6	51.5	1.68
	RCH-650 (*Bt* Cotton)	42.3	75.4	100.3	58.0	24.9	1.33
Irrigation schedules (irrigation at)	40 DAS+IW/CPE=0.60	41.7	74.8	113.7	72.1	39.0	1.52
	40 DAS+IW/CPE=0.75	42.9	76.0	123.1	80.2	47.1	1.62
	40 DAS+IW/CPE=0.90	44.1	77.2	124.0	80.0	46.9	1.61
	50 DAS+IW/CPE=0.60	40.5	73.6	100.6	60.1	27.0	1.37
	50 DAS+IW/CPE=0.75	41.7	74.8	108.4	66.7	33.6	1.45
	50 DAS+IW/CPE=0.90	42.9	76.0	111.6	68.7	35.6	1.47

It may be concluded that under semi-arid conditions and on a sandy loam soil, cultivar Bio-6588 was found better in terms of seed cotton yield, water productivity and net returns. Application of 1st irrigation at 40 DAS and thereafter at IW/CPE=0.90 or 0.75 resulted in higher seed cotton yield, net returns and B:C. The WP of total water use was higher when first irrigation was applied at 40 DAS+IW/CPE=0.75, while the WP of irrigation water under first irrigation at 50 DAS+IW/CPE=0.60.

2.6. Junagadh

Coriander Crop Response to Deficit Soil Moisture in Various Growth Stages under Drip Irrigation System

To assess the response of moisture stress on critical stages of growth and to determine the optimal irrigation schedule for improved water productivity in coriander crop, an experiment was laid out under RBD at the instructional farm of JAU, Junagadh. The pH, EC and texture of the experimental soil is 8.87, 0.4 mmho cm^{-1}, clayey loam, respectively. The field capacity, permanent wilting point, bulk density and infiltration rate were recorded as 30.2 %, 13.5 %, 1.45 g/cc and 1.24 cm/h, respectively. The details of treatments are presented in table 2.6.1.

Table 2.6.1. Details of drip irrigation treatments

Treatments	Irrigation with drip at given PEF during growth stages		
	S_1 (Vegetative stage)	S_2 (Flowering stage)	S_3 (Seed development/ fruiting stage)
T_1	0.4	0.8	0.8
T_2	0.6	0.8	0.8
T_3	0.8	0.4	0.8
T_4	0.8	0.6	0.8
T_5	0.8	0.8	0.4
T_6	0.8	0.8	0.6
T_7	0.8	0.8	0.8
T_8	0.8	0.8	No irrigation
T_9	0.8	No irrigation	No irrigation
T_{10}	Control (Surface flood irrigation @ 0.8 IW/CPE)		

S_1=Vegetative stage (0-55 DAS); S_2=Flowering stage (56-80 DAS); S_3=Seed development/ fruiting stage (81-105 DAS)

Highest grain yield (1785.5 kg/ha), biological yield (3952.7 kg/ha) and water use efficiency (4.04) of coriander crop was obtained under no stress condition during flowering stage and drip irrigation at 0.6 IW/CPE ratio during grain setting stage. There was no significant effect of stage wise stress on harvest index of the crop. Water use efficiency (WUE) was highest (4.04) under no stress condition during development and flowering stage and irrigation at 0.6 IW/CPE ratio at grain setting stage with drip irrigation, which was slightly higher than irrigation @ 0.4 IW CPE during development stage and irrigation @ 0.8 IW/CPE during rest of the crop period. WUE was lowest with flood irrigation method. The quadratic form of the model was found best (R^2 = 0.9) to describe the coriander crop yield response to irrigation (Fig. 2.6.1).

2.7. Kota

2.7.1. Feasibility of Micro Irrigation in Rice in South-east Rajasthan

Advantages of micro irrigation over surface irrigation on water use and yield response of paddy were assessed. Three sprinkler irrigation treatments at 100 % PE (T_1), 125 % PE (T_2) and 150 % PE (T_3) were applied along with one surface irrigation (irrigation after disappearance of ponding water (5 ± 2 cm) (T_4). Table 2.7.1 shows that irrigation at 125 % PE gave significantly gave higher grain yield of rice as compared to other treatments. However, surface irrigation with irrigation applied at 125 % and irrigation at 125 % and 150 % pan evaporation (PE) remained statistically at par with other. Irrigation at 125 % PE gave significantly higher water use efficiency and net return of rice as compared to other treatments. Improvement in WUE due to irrigation was non-significant. However, surface irrigation with irrigation applied at 125 % and irrigation at 125 % and 150% pan evaporation (PE) remained statistically at par with each other.

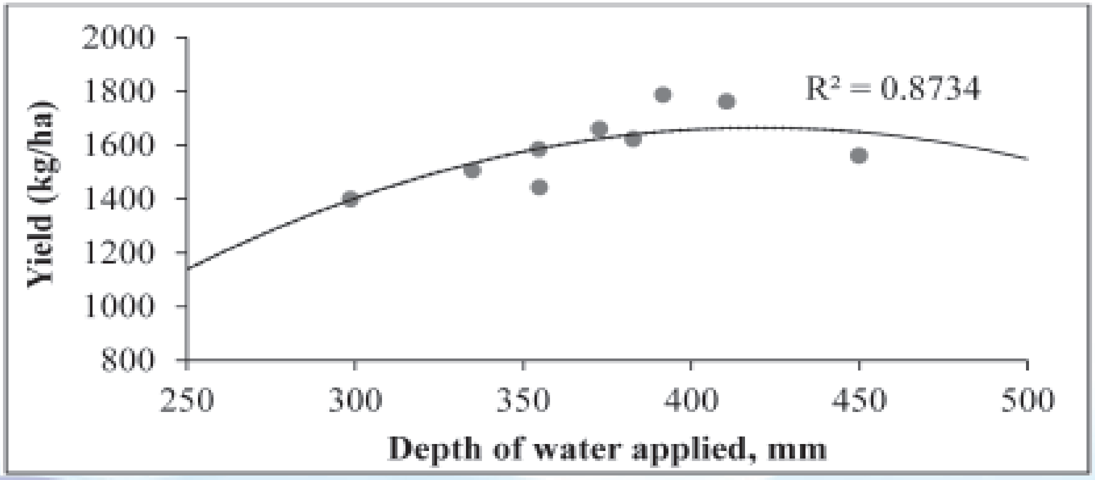


Fig 2.6.1. Functional relationship between yield and depth of water appiled in coriander

Table 2.7.1. Effect of irrigation schedules on water use efficiency and net return of paddy

Treatments	Grain yield (kg/ha)			Straw yield (kg/ha)			Water use efficiency (kg/ha-cm)			Net return (Rs./ha)		
	2014	2015	Pooled	2014	2015	Pooled	2014	2015	Pooled	2014	2015	Pooled
T_1	3450	3471	3461	4461	4439	4450	29.9	36.4	33.2	60476	54635	57556
T_2	3903	3980	3942	5055	5080	5068	31.2	35.8	33.5	71185	65712	68449
T_3	4040	4091	4066	5249	5220	5235	30.0	32.3	31.2	74442	68128	71285
T_4	4147	4205	4176	5396	5380	5388	33.9	36.1	35.0	76979	70632	73806
SEm (±)	61.9	63.5	57.8	81.3	82.0	75.2	-	-	-	1463	1383	1309
CD at 5 %	190.7	195.5	169	250	253	219	NS	NS	NS	4508	4263	3820

2.7.2. Effect of Irrigation Scheduling and Foliar Fertilization on the Productivity of Soybean under Climatic Variability in South-east Rajasthan.

The pooled data of three years revealed that maximum soybean seed yield (1286 kg/ha) obtained under irrigation at flowering and pod development stage where in only one irrigation was applied at pod development stage, because rains was received up to flowering stage. Hence, non-significant difference was observed in the water use efficiency under irrigation regimes. Significantly higher seed yield (1333 kg/ha) was recorded under foliar fertilization 19:19:19 (5 g/l) at 30, 45, 60 and 75 DAS, but it was found at par with foliar fertilization 17:44:00 (5 g/l) at 30, 45, 60 and 75 DAS over rest of foliar fertilization treatments. The water use efficiency was found maximum (23.46 kg/ha-cm) under spray of foliar fertilization 19:19:19 (5 g/l) at 30, 45, 60 and 75 DAS (Table 2.7.2).

Table 2.7.2. Effect of water regimes and foliar fertilization on yield and WUE of Soybean

Treatments	Seed yield (kg/ha)				WUE (kg/ha-cm)			
	2013	2014	2015	Pooled	2013	2014	2015	Pooled
Water regimes								
One irrigation at flowering	1162	1234	1148	1181	23.33	21.53	21.02	21.96
One irrigation at Pod development	1265	1340	1238	1281	22.68	21.17	20.43	21.42
Two irrigation at flowering and pod development	1268	1343	1246	1286	22.72	21.22	20.56	21.50
Rainfed (control)	1160	1232	1142	1178	23.30	21.50	20.92	21.91
SEm ±	19.89	15.22	13.77	14.98	0.364	0.250	0.245	0.263
CD (P=0.05)	63.60	48.69	44.03	43.46	1.163	0.798	0.785	0.763
Foliar fertilization								
Spray of 17:44:00 (5g/l) at 45, 60 and 75 DAS	1236	1311	1203	1250	23.47	21.76	20.89	22.04
Spray of 19:19:19 (5g/l) at 45, 60 and 75 DAS	1244	1322	1216	1261	23.59	21.93	21.11	22.21
Spray of 17:44:00 (5g/l) at 30, 45, 60 and 75 DAS	1277	1365	1258	1300	24.17	22.63	21.84	22.88
Spray of 19:19:19 (5g/l) at 30, 45, 60 and 75 DAS	1309	1403	1286	1333	24.80	23.27	22.33	23.46
Control (RDF)	1003	1036	1006	1015	19.01	17.18	17.50	17.89
SEm ±	13.83	16.66	17.87	14.83	0.265	0.276	0.311	0.261
CD (P=0.05)	39.36	47.42	50.86	41.45	0.755	0.786	0.884	0.729

2.8. Morena

2.8.1. Effect of Irrigation and Sowing Methods on Growth, Yield, Water Productivity and Physicochemical Properties of Pigeonpea - Wheat Cropping System in Alluvial Soils

The study was conducted to study the effect of irrigation and sowing methods on growth, yield water productivity and economics of pigeonpea and wheat. The experiment was carried out in split plot design, where method of sowing (traditional method of sowing, broad bed sowing method, permanent broad bed sowing method and sowing through zero-till seed drill) was main plot and method of irrigation (border strip, drip irrigation and Sub-surface irrigation through porous pipe/inline drippers) was sub-plot. Wheat variety RVW – 4106 followed by pigeonpea variety ICPL – 88039 were grown for the study. Methods of sowing had significant effect on growth and yield contributing characters of wheat (Table 2.8.1).

Wheat

Maximum plant height, number of tillers per plant and grain yield were achieved under broad bed and furrow method of sowing, while maximum length of ear, straw yield and 1000 grain weight were obtained under permanent broad bed furrow method of sowing. The irrigation methods have also significantly increased the growth and yield parameters, grain yield and straw yield of wheat (Table 2.8.1). The maximum number of tiller per plant, length of ear, test weight, grain yield and straw yield were registered under sub-surface irrigation method, except plant height which was noted maximum under drip irrigation method. The lowest values of all the growth and yield contributing characters, grain yield and straw yield were obtained in border strip method of irrigation. The sowing methods and irrigation level significantly affected the net profit, B:C ratio, total water use and water productivity of wheat (Table 2.8.2). The economics analysis of data reveals that maximum gross returns net profit, B:C ratio and water productivity were realised from permanent broad bed and furrow method of sowing. However, total water use was highest under traditional method of sowing. The sub-surface irrigation method recorded maximum gross returns, net returns, B:C ratio and water productivity.

Pigeonpea

The growth and yield components, seed and straw yield of pigeonpea influenced significantly due to sowing methods and irrigation levels (Table 2.8.1). The maximum plant height, number of branches plant^{-1}, test weight, seed yield and straw yield were achieved under permanent broad bed and furrow method of sowing. Values of these parameters were recorded lowest in traditional method of sowing. The plant height, number of branches plant^{-1}, number of pods plant^{-1}, test weight, seed yield and straw yield were obtained maximum under sub-surface irrigation method. All the components were registered lowest in case of boarder strip of irrigation method. The data revealed that highest gross returns, net profit, B:C ratio and water productivitywere observed under permanent broad bed and furrow method of sowing (Table 2.8.2). Under irrigation levels highest gross returns, net profit, B:C ratio and water productivity were observed with sub-surface irrigation method, whereas total water use with boarder strip irrigation method was higher compared to other irrigation methods.

Table 2.8.1 Effect of sowing and irrigation methods on growth and yield of wheat (W) and pigeonpea (P) under pigeonpea-wheat cropping sequence

Treatments	Plant height (cm)		No. of tillers/ plant	Branch-ing/ plant	Length of ear (cm)	No of pod/ plant	1000 grain wt. (g)		Grain yield (t/ha)	Seed yield (t/ha)	Straw yield (t/ha)	
	W	P	W	P	W	P	W	P	W	P	W	P
Sowing methods												
CTSSFD	92.23	156	13.93	12.4	10.14	129	43.16	91.58	4.07	2.08	5.60	5.69
BBF	95.17	164	16.97	15.8	10.70	168	43.75	94.07	4.35	2.43	5.91	6.54
PBBF	95.07	166	16.94	16.0	10.72	164	43.99	94.38	4.33	2.45	5.94	6.68
ZT	92.30	158	14.00	12.2	10.23	134	43.14	92.40	4.21	2.07	5.79	5.57
SEm±	-	10.01	-	3.4	-	388	-	8.3	-	0.34	-	1.00
CD (P=0.05)	0.46	3.33	0.50	1.2	0.34	13.0	0.43	2.8	0.13	0.12	0.13	0.33
Irrigation methods												
BSI	91.88	152	14.00	12.7	10.15	135	42.91	90.05	4.07	1.95	5.64	5.35
DI	94.70	162	15.95	14.7	10.47	153	43.45	94.18	4.28	2.34	5.89	6.39
SSI	94.50	169	16.45	14.9	10.72	159	44.18	95.09	4.38	2.48	5.96	6.78
SEm±	-	25.0	-	3.28	-	56.0	-	5.02	-	0.52	-	1.42
CD (P=0.05)	0.24	8.50	0.25	1.1	0.22	2.52	0.28	0.26	0.12	0.71	0.11	-

CT-Conventional tillage of sowing by seed cum fertilizer drill, BBF- Broad bed and furrow, PBBF-Permanent broad bed and furrow, ZT-Zero tillage sowing, BS-Boarder strip, DI-Drip irrigation, SSI-Sub-surface irrigation

Table 2.8.2. Effect of sowing and irrigation methods on economics and water productivity of wheat and pigeonpea under pigeonpea-wheat cropping sequence

Treatments	Cost of produc-tion (Rs./ha)	Gross income (Rs./ha)		Net return (Rs./ha)		B:C		Total water use (m^3/ha)		Water produc-tivity (kg/m^3)	Water produc-tivity (kg/m^3)
Sowing methods											
	Both crops	W	P	W	P	W	P	W	P	W	P
CTSSFD	36,260	81,430	1,13,290	44,260	77,030	2.19	3.13	31.77	5531	0.128	0.376
BBF	31,840	84,880	1,32,010	53,830	1,00,160	2.63	4.15	30.15	5127	0.144	0.474
PBBF	29,340	86,640	1,33,350	56,050	1,04,020	2.83	4.55	29.53	5033	0.147	0.487
ZT	30,100	84,450	1,12,490	52,500	82,390	2.65	3.74	30.81	5397	0.136	0.384
SEm±	-	320	-	301	-	0.11	-	0.92	270.1	0.008	0.110
CD (P=0.05)	-	120	-	102	-	0.04	-	0.32	90.0	0.003	0.037
Irrigation methods											
BSI	29,690	81,500	1,06,330	48,930	76,640	2.52	3.58	36.47	5415	0.112	0.361
DI	32,830	85,520	1,27,260	52,430	94,430	2.60	3.88	27.57	5268	0.155	0.444
SSI	33,140	87,520	1,35,230	53,620	1,02,090	2.64	4.08	25.69	5133	0.170	0.484
SEm±	-	280	-	178	-	0.08	-	0.66	422	0.005	1.84
CD (P=0.05)	-	100	-	60	-	0.03	—	0.23	141.0	0.002	0.61

2.8.2. Effect of Different Level of Slope and Method of Irrigation on Soybean – Wheat on Growth, Yield and Water Productivity in Alluvial Soil

Wheat

Table 2.8.3 shows that maximum plant height (85.78 cm), tillers per plant (12.65), length of ear (9.13 cm), test weight (38.80 g), grain yield (4.29 t/ha) and straw yield (5.51 t/ha) were achieved with 0.1 % slope level through laser levelling as compared with other treatments. The irrigation through broad bed and furrow method showed best performance in increasing the plant height (85.62 cm), tillers per plant (12.67), length of ears (9.22 cm), 1000 grain weight (38.78 g), grain yield (4.40 t/ha) and straw yield (5.36 t/ha) over boarder strip irrigation method, which was at par with permanent broad bed and furrow irrigation. Such a response with broad bed and furrow method might be ascribed to adequate supply of the moisture to the crop development, favourable induced physiological processes. Mainitaining slope and crop sowing with BBF method are demonstrated in plates 2.8.1 and 2.8.2.

Table 2.8.3. Effect of level of slope and method of irrigation on growth and yield of wheat under soybean-wheat cropping sequence

Treatments	Plant height (cm)	No. of tillers per plant	Length of ear (cm)	1000 grain weight (g)	Grain yield (t/ha)	Straw yield (t/ha)
Levels of slope						
0 % through TL	84.14	11.33	9.02	37.65	4.09	4.98
0 % through LL	85.19	12.45	9.14	38.28	4.28	5.35
0.1 % through LL	85.78	12.65	9.13	38.80	4.29	5.51
0.2 % through LL	85.17	12.38	9.00	38.70	4.18	5.10
SEm±	2.08	1.70	4.63	1.16	0.35	0.49
CD (P=0.05)	0.69	0.57	1.54	0.39	0.12	0.16
Methods of irrigation						
Long BS	84.05	10.81	8.12	37.61	3.84	4.76
BBF	85.62	12.76	9.22	38.78	4.40	5.36
PBBF	85.55	12.66	9.21	38.70	4.39	5.43
SEm±	1.15	1.17	3.41	0.32	0.20	0.37
CD (P=0.05)	0.38	0.39	1.14	0.11	0.07	0.12

TL-Traditional method of levelling, LL-Laser land leveller, BS-Boarder strip, BBBF-Broad bed and furrow, PBBF-Permanent broad bed and furrow

The level of slope and irrigation methods had significant impact on gross return, net profit, B:C ratio, total water use and water productivity as shown in table 2.8.4.

Table 2.8.4. Effect of level of slope and method of irrigation on economics and water productivity of wheat under soybean-wheat cropping sequence

Treatments	Gross income (Rs./ha)	Net return (Rs./ha)	B:C	Total water use (m^3/ha)	Water productivity (kg/m^3)
Levels of slope					
0% through TL	79,020	42,580	2.20	3220	0.127
0% through LL	83,510	47,300	2.34	3168	0.135
0.1% through LL	84,300	49,220	2.43	2696	0.159
0.2% through LL	80,990	45,830	2.37	2548	0.164
SEm±	5520	3550	0.22	244	0.038
CD (P=0.05)	1850	1180	0.07	81	0.013
Methods of irrigation					
Long BS	74,740	33,900	1.84	3257	0.118
BBF	85,620	50,380	2.42	2737	0.167
PBBF	85,510	54,410	2.74	2768	0.162
SEm±	320	230	0.11	101	0.017
CD (P=0.05)	107	80	0.04	34	0.006

TL-Traditional method of levelling, LL-Laser land leveller, BS-Boarder strip, BBBF-Broad bed and furrow, PBBF-Permanent broad bed and furrow

Plate 2.8.1. Slope maintain by laser leveller

Plate 2.8.2. Sowing of crop by BBF

Soybean

Higher plant height (38.8 cm), number of branches per plant (4.9), number of pods per plant (68), number of grains per pod (3.24), test weight (46.2 g) seed yield (1.44 t/ha), and straw yield (2.63 t/ha) were achieved under 0.1 % slope through laser land levellers compared with other method of levelling (Table 2.8.5). Under broad bed and furrow method of irrigation higher plant height (39.3 cm), number of grains per pod (3.22), test weight (46.8 g), seed yield (1.42 t/ha) and straw yield (2.60 t/ha) were observed compared with boarder strip irrigation method (Table 2.8.5). These parameters were at par with conventional broad bed and permanent broad bed and furrow method of irrigation. However, minimum values of these parameters were observed under traditional method of irrigation. Sowing of crop with the help of different methods are shown in plate 2.8.3, 2.8.4 and 2.8.5.

Table 2.8.5. Effect of level of slope and method of irrigation on growth and yield of *kharif* soybean under soybean-wheat cropping sequence

Treatments	Plant height (cm)	No. of branchings per plant	No. of pods per plant	No. of grains pod	1000 grain weight (g)	Grain yield (t/ha)	Straw yield (t/ha)
Levels of slope							
0% through TL	37.4	3.8	56	3.11	45.3	1.24	2.24
0% through LL	38.0	4.7	67	3.20	45.8	1.31	2.40
0.1% through LL	38.8	4.9	68	3.24	46.2	1.44	2.63
0.2% through LL	37.3	4.6	64	3.16	45.9	1.40	2.52
SEm±	1.3	1.00	11.91	0.13	0.89	2.00	0.38
CD (P=0.05)	0.46	0.36	4.0	0.043	0.30	0.66	0.13
Methods of irrigation							
Long BS	35.2	3.8	58	3.10	44.2	1.22	2.21
BBF	39.3	4.8	66	3.22	46.8	1.42	2.60
PBBF	39.2	4.9	67	3.21	46.5	1.41	2.51
SEm±	5.98	1.64	13.4	0.17	3.9	0.31	0.57
CD (P=0.05)	2.00	0.55	4.5	0.06	1.30	0.10	0.19

TL-Traditional method of levelling, LL-Laser land leveller, BS-Boarder strip, BBBF- Broad bed and furrow, PBBF-Permanent broad bed and furrow

The economic analysis indicated that maximum gross returns (Rs. 57,100 per ha), net profit (Rs. 26,780 per ha) B:C ratio (1.88) and water productivity (0.382 kg grain per m^3 water) were recorded higher under 0.1% slope through laser levelling (Table 2.8.6). The net returns (Rs. 28,490 per ha) and B:C ratio (2.04) were obtained higher under permanent broad bed and furrow method of irrigation. The long boarder strip recorded higher total water use and permanent broad bed and furrow method of irrigation achieved maximum water productivity compared with other irrigation methods.

Table 2.8.6. Effect of level of slope and method of irrigation on economics and water productivity of soybean under soybean-wheat cropping sequence

Treatments	Gross income (Rs./ha)	Cost of Production (Rs./ha)	Net return (Rs./ha)	B:C ratio	Total water use (m^3/ha)	Water productivity (kg/m^3)
Levels of slope						
0% through TL	49,120	30,760	18,360	1.60	4150	0.299
0% through LL	51,960	30,650	21,310	1.70	3980	0.329
0.1% through LL	57,100	30,230	26,780	1.88	3770	0.382
0.2% through LL	55,440	30,040	25,390	1.85	3680	0.380
SEm±	-	-	-	-	469	0.082
CD (P=0.05)	-	-	-	-	156.6	0.027
Methods of irrigation						
Long BS	48,340	33,140	15,200	1.46	4210	0.290
BBF	56,280	30,870	25,410	1.82	3800	0.374
PBBF	55,820	27,330	28,490	2.04	3760	0.375
SEm±	-	-	-	-	674	0.127
CD (P=0.05)	-	-	-	-	229	0.042

TL-Traditional method of levelling, LL-Laser land leveller, BS-Boarder strip, BBBF- Broad bed and furrow, PBBF-Permanent broad bed and furrow; Minimum support price @ Rs.3600 per quintal and stover @ in local market Rs.200 per quintal

Plate 2.8.3. Sowing of crop by seed cum fertilizer drill and irrigation through long border strip

Plate 2.8.4. Sowing of crop by broad bed seed cum fertilizer drill and furrow irrigation

Plate 2.8.5. Sowing of crop on permanent broad bed seed cum fertilizer drill and furrow irrigation

2.9. Pusa

2.9.1. Study of the Response of Different Rice Based Cropping System to Water under Upland Condition

A field experiment was laid out in split plot design with five cropping sequences in main plot *viz.*, C_1- Rice(SRI)-Potato-Groundnut, C_2- Rice(SRI)-Potato-Vegetable Cowpea and C_3- Rice(SRI)-Potato-Moong, C_4 - Rice(SRI)-Maize + Potato-Dhaincha and C_5- Rice(SRI)-Maize + Pea(green pod) and three moisture regimes in sub-plot *viz.*, I_1- IW/CPE ratio 0.8, I_2- IW/CPE ratio 1.0 and I_3- IW/CPE ratio 1.2. The experimental soil was sandy loam having bulk density 8.6 g/cc, pH 8.6, EC 0.79 mmhos/cm, OC 0.44%, Olsen-P 11.2 kg/ha, NH_4-AC-K 109 kg/ha, free $CaCO_3$ 26.8% field capacity 22.5% and permanent wilting point 8.2%.

Results revealed that Rice- Maize + Potato- Dhaincha cropping sequence produced significantly higher rice equivalent yield and gross return as compared to Rice-Potato-Cowpea, Rice-Potato-Moong and Rice-Maize + Pea but was at par with Rice-Potato-Groundnut sequence during 2014-15. There was also parity among Rice-Potato-Cowpea, Rice-Potato-Moong and Rice-Maize + Pea sequences. Rice- Maize + Potato- Dhaincha sequence recorded significantly higher net return than Rice-Potato-Cowpea, Rice-Potato-Moong and Rice- Maize + Pea sequences but there was parity in net return with Rice-Potato-Groundnut sequence. Table 2.9.1 shows that B:C ratio was significantly higher with Rice-Maize+ Pea sequence as compared to all other sequences. Significantly higher WUE and water productivity was recorded with Rice- Maize + Potato-Dhaincha sequence as compared to all other sequences. Rice equivalent yield, gross return, net return and B:C ratio were increased significantly from moisture regimes 0.8 to 1.0 IW/CPE ratio but there was non-significant difference between 1.0 and 1.2 ratios. Though there was non- significant difference in WUE and water productivity due to different moisture regimes, the maximum WUE was recorded with 1.0 IW/CPE ratio while water productivity was the maximumwith 1.2 ratio.

Table 2.9.1. Effect of cropping sequence and irrigation on rice yield, B:C ratio, water use efficiency and water productivity

Treatments	Grain yield (t/ha)	B:C	WUE (kg/ha-cm)	Water productivity (Rs./ha-cm)
C_1I_1	28.4	1.77	227.53	2011.83
C_1I_2	29.9	1.91	229.18	2076.71
C_1I_3	31.0	1.99	227.25	2089.02
C_2I_1	23.4	1.58	187.65	1594.54
C_2I_2	24.7	1.73	198.37	1740.53
C_2I_3	25.5	1.79	195.33	1736.19
C_3I_1	24.1	1.63	204.71	1758.40
C_3I_2	25.2	1.71	202.47	1769.74
C_3I_3	25.7	1.76	206.56	1824.91
C_4I_1	28.6	1.87	241.02	2171.37
C_4I_2	30.1	1.99	241.20	2219.32
C_4I_3	30.9	2.06	237.02	2204.33
C_5I_1	25.6	3.29	195.35	2077.76
C_5I_2	26.8	3.43	194.63	2088.47
C_5I_3	27.6	3.48	190.52	2050.67

Source	SEm+	CD at 5 %	CV (%)	SEm+	CD at 5 %	CV (%)	SEm+	CD at 5 %	CV (%)	SEm+	CD at 5 %	CV (%)
Cropping sequence (C)	0.36	1.19	0.41	0.05	0.2	6.4	2.9	9.3	4.0	37.9	123.5	5.8
Irrigation (I)	0.32	0.94	0.46	0.03	0.1	6.0	2.6	NS	4.7	34.3	NS	6.8
C x I	0.71	NS	–	0.07	NS	–	5.70	NS	–	76.68	NS	–

2.9.2. Effect of Moisture Regimes and Levels of Iron on Growth and Yield of Rice under Aerobic Condition

The optimum moisture for growth and yield of aerobic rice was studied and the suitable level of iron for aerobic rice was determined. A field experiment was laid out in split plot design. Three moisture regimes *viz.*, M_1- Irrigation at 10% moisture depletion of field capacity, M_2- Irrigation at 20% moisture depletion of field capacity, M_3- Irrigation at 30% moisture depletion of field capacity in main plot. Four levels of iron *viz.*, I_1- Control, I_2- Basal application of 25 kg $FeSO_4$ + 5 t/ha FYM, I_3- Three foliar application of 1 % $FeSO_4$ at tillering, pre-flowering and flowering stages and I_4- Three foliar application of 2 % $FeSO_4$ at tillering, pre-flowering and flowering stages were in sub-plot. Number of replications for all the treatments in main and sub-plots was three and depth of irrigation was maintained at 3 cm.

Table 2.9.2 shows that maximum grain yield (3.79 t/ha) was recorded with irrigation at 10 % moisture depletion of field capacity (FC) and it was decreased significantly with increase in moisture depletion. There was non-significant difference in grain yield between irrigation at 20 % and 30 % depletion of FC. Significantly higher grain yield was recorded with 3 foliar application of 1 % $FeSO_4$ at tillering, pre-flowering and flowering stages (I_3) as compared to basal application of 25 kg $FeSO_4$ + 5 t/ha FYM (I_2) and control (I_1) but was at par with 3 foliar application of 2 % $FeSO_4$ at tillering, pre flowering and flowering stages (I_4). Water use efficiency was not influenced by different moisture regimes although the highest WUE was recorded with irrigation at 10 % moisture depletion of FC and was decreased with irrigation at increasing %age in moisture depletion of FC. The maximum WUE was recorded with three foliar applications of 2 % $FeSO_4$ at tillering, pre-flowering and flowering stages (I_3) which was significantly superior over basal application of 25 kg $FeSO_4$ + 5 t/ha FYM (I_2) and control (I_1) but was at par with three foliar applications of 1 % $FeSO_4$ at tillering, pre- flowering and flowering stages (I_3).

Table 2.9.2. Effect of moisture regimes and levels of iron on grain yield and water use efficiency of aerobic rice

Treatments		Grain yield (t/ha)			WUE (kg/ha-cm)	
M_1I_1		3.27			50.86	
M_1I_2		3.68			57.36	
M_1I_3		3.88			60.37	
M_1I_4		3.95			61.59	
M_2I_1		2.74			47.02	
M_2I_2		3.13			53.77	
M_2I_3		3.37			57.97	
M_2I_4		3.41			58.51	
M_3I_1		2.33			42.19	
M_3I_2		2.70			48.88	
M_3I_3		2.97			53.73	
M_3I_4		2.98			54.07	
Source	**SEm+**	**CD at 5 %**	**CV (%)**	**SEm+**	**CD at 5 %**	**CV (%)**
Cropping sequence (C)	0.12	0.46	1.09	1.98	NS	11.01
Irrigation (I)	0.07	0.21	0.78	1.17	3.47	7.50
C x I	0.14	0.43	–	2.33	NS	–

2.9.3. Mulching for Improvement of WUE and Crop Productivity of Maize-Maize Cropping System under Calciorthents

The influence of moisture regimes and mulch of grain yield and WUE of maize-maize cropping system was studied. A field experiment was laid out with *rabi* and *kharif* maize grown in a cropping system. Split plot design was adopted with moisture regimes in main plot and mulching treatments in sub-plot. Main plot treatments were I_1- Irrigation with IW:CPE ratio of 0.4, I_2- Irrigation with IW:CPE ratio of 0.6, I_3- Irrigation with IW:CPE ratio of 0.8 and I_4- Irrigation with IW:CPE ratio of 1.0. Sub-plot treatments were M_1- Mulching with sugarcane trash @ 5 t/ha, M_2- Mulching with sugarcane trash @ 10 t/ha, M_3- Mulching with maize stubble @ 5 t/ha, M_4- Mulching with maize stubble @ 10 t/ha and M_5- No mulch. Number of replications for every treatment in main and sub-plot was three. Recommended dose of N:P:K::150:75:50 was applied. It is evident from table 2.9.3 that irrigation levels were not significant on grain yield. Treatments I_2, I_3 and I_4 were at par and significantly increased over I_1. So I_2 is recommended. Mean of M_2 was highest among the other mulching treatments. M_2 is also significant over control and M_1. It is evident from table 2.9.4 that irrigation and their interactions with mulching were non-significant on maize yield. All levels of mulching are at par and significantly increased over the control.

Table 2.9.3. Grain yield (t/ha) of *rabi* and *kharif* maize as influenced by irrigation and mulching treatments

Treatments	I_1 (IW:CPE 0.4)		I_2 (IW:CPE 0.6)		I_3 (IW:CPE 0.8)		I_4 (IW:CPE 1.0)		Mean	
	Rabi maize	*Kharif* maize	*Rabi* maize	*Kharif* maize	*Rabi* maize	*Kharif* maize	*Rabi* maize	*Kharif* maize	*Rabi* maize	*Kharif* maize
M_1: S/C trash @ 5 t/ha	7.75.1	8.2	5.0	8.5	5.0	8.7	5.2	8.3	5.1	-
M_2: S/C trash @ 10 t/ha	7.95.2	8.5	5.3	8.8	5.3	8.9	5.0	8.5	5.2	-
M_3: Maize stubble @ 5 t/ha	7.95.1	8.4	5.1	8.6	5.1	8.8	5.4	8.4	5.2	-
M_4: Maize stubble @ 10 t/ha	8.25.2	8.8	5.3	8.9	5.4	9.1	5.4	8.7	5.3	-
M_5: No mulch	6.84.2	7.4	4.3	7.8	4.5	7.9	5.0	7.5	4.5	-
Mean	**7.75.0**	**8.2**	**5.0**	**8.5**	**5.1**	**8.7**	**5.2**	**–**	**–**	**-**
	SEm±	**SEm±**	**CD (0.05)**	**CD (0.05)**	**CV (%)**	**CV (%)**	–	–	–	–
I	0.13	0.06	0.46	NS	0.62	0.47	–	–	–	–
M	0.15	0.10	0.43	0.30	0.62	0.70	–	–	–	–
I x M	0.3	0.21	NS	NS	–	–	–	–	–	–

Table 2.9.4. WUE (kg/ha-cm) of *rabi* and *kharif* maize as influenced by irrigation and mulch levels

Treatments	I_1 (IW:CPE 0.4)		I_2 (IW:CPE 0.6)		I_3 (IW:CPE 0.8)		I_4 (IW:CPE 1.0)		Mean	
	Rabi maize	*Kharif* maize	*Rabi* maize	*Kharif* maize	*Rabi* maize	*Kharif* maize	*Rabi* maize	*Kharif* maize	*Rabi* maize	*Kharif* maize
M_1: S/C trash @ 5 t/ha	471.2	94.92	366.9	94.66	300.0	93.80	253.30	96.80	347.8	95.05
M_2: S/C trash @ 10 t/ha	486.5	98.06	379.8	98.68	309.8	100.38	261.06	94.68	359.3	97.95
M_3: Maize stubble @ 5 t/ha	484.5	95.86	376.5	95.86	302.6	96.62	255.90	100.75	354.9	97.27
M_4: Maize stubble @ 10 t/ha	505.0	97.74	393.3	99.00	313.8	101.64	265.12	101.09	369.3	99.87
M_5: No mulch	419.6	78.63	332.9	80.21	274.1	83.78	230.91	93.25	314.4	83.97
Mean	**473.3**	**93.05**	**369.9**	**93.68**	**300.1**	**95.24**	**253.3**	**97.32**	**–**	**–**
	SEm±	**SEm±**	**CD (0.05)**	**CD (0.05)**	**CV (%)**	**CV (%)**	**–**	**–**	**–**	**–**
I	6.8	1.15	23.7	NS	7.6	4.70	–	–	–	–
M	6.0	1.93	17.3	5.55	6.0	7.04	–	–	–	–
I x M	12.0	3.86	NS	NS	–	–	–	–	–	–

Grain yield due to I_2 (8.2 t/ha), I_3 (8.5 t/ha) and I_4 (8.7 t/ha) were statistically at par and both were significantly superior to I_1 (7.7 t/ha). The sub-plot treatments (mulching with either S/C trash or maize stubble @ 5 and 10 t/ha) also, significantly influenced the grain yield. Grain yield recorded with S/C trash mulch @ 5 (8.3 t/ha) and 10 t/ha (8.5 t/ha) were statistically at par with each other and likewise, grain yield recorded with maize stubble mulch @ 5 (8.4 t/ha) and 10 t/ha (8.5 t/ha) were at par but all the mulched plots were significantly superior to no mulch plot (7.5 t/ha).

Water use efficiency decreased significantly with each increasing levels of irrigation from I_1 (473.3 kg/ha-cm) to I_4 (253.3 kg/ha-cm). However, due to mulching the data on WUE followed the trends of grain yield and the highest value of 369.3 kg/ha-cm was recorded in sub-plot treatment M_4 (Maize stubble @ 10 t/ha) which was statistically at par with other treatments involving application of mulch except S/C trash @ 5 t/ha and all the mulched plots were significantly superior to M_5 i.e. no mulch (314.4 kg/ha-cm).

2.9.4. Comparative Study of Drip and Surface Irrigation Methods on Potato (*Solanum tuberosum*) crop

A relationship between pressure and emitter discharge was developed and the water requirement and water use efficiency of potato crop was determined. A field experiment was laid out in in

RBD with seven irrigation treatments *viz.*, T_1-Surface irrigation at IW/CPE ratio of 1.0 (control), T_2-Inline drip irrigation at the operating pressure of 0.6 kg/cm^2, T_3-Inline drip irrigation at the operating pressure of 0.8 kg/cm^2, T_4-Inline drip irrigation at the operating pressure of 1.0 kg/cm^2, T_5-Inline drip irrigation at the operating pressure of 1.2 kg/cm^2, T_6-Inline drip irrigation at the operating pressure of 1.4 kg/cm^2 and T_7-Inline drip irrigation at the operating pressure of 1.6 kg/cm^2 with three replication per treatment. Potato variety Kufri Ashoka was taken up as a test crop and recommended dose of fertilizer N:P:K ::150:90:100 kg/ha was applied.

Figure 2.9.1 shows that tuber yield of potato was significantly influenced by operating pressures of inline drip irrigation. The lowest yield of potato was recorded with inline drip irrigation at operating pressure of 0.6 kg/cm^2 (T_2) and significantly increased yield with 1.0, 1.2, 1.4 and 1.6 kg/cm^2 operating pressure. There was non-significant difference in potato tuber yield between surface irrigation at IW/CPE ratio of 1.0 and inline drip irrigation at the operating pressure of 1.0 kg/cm^2 (T_4) and 1.2 kg/cm^2 (T_5). Higher water use efficiency (346.24 kg/ha-mm) obtained in case of inline drip irrigation at the operating pressure of 1.4 kg/cm^2 with less amount of water applied. WUE was decreased with decreasing operating pressure from 1.4 kg/cm^2 to 0.6 kg/cm^2. The lowest WUE was recorded (143.84 kg/ha-mm) with surface irrigation at IW/CPE ratio of 1.0 and more amount of water was applied.

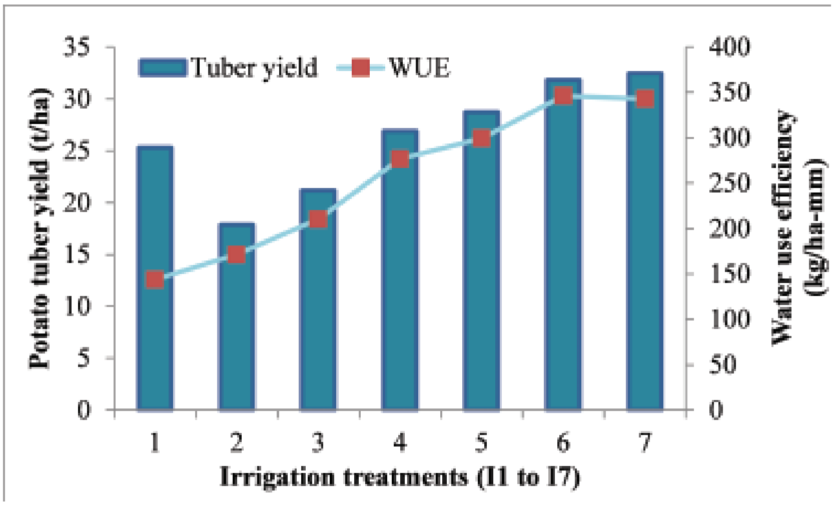


Fig. 2.9.1. Effect of irrigation treatments on tuber yield and water use efficiency (WUE) of potato (q/ha)

2.9.5. Study the Water Requirement of Wheat by Mini Sprinkler Irrigation and LEWA method as Compared with Surface Irrigation

An experiment was conducted in split plot design with three irrigation methods in main plot *viz.*, M_1-Mini sprinkler, M_2- LEWA and M_3- Surface irrigation (control) and three moisture regimes in sub-plot *viz.*, I_1- IW/CPE ratio 0.6, I_2- IW/CPE ratio 0.8 and I_3- IW/CPE ratio 1.0. Table 2.9.5 shows that maximum grain yield of wheat was recorded with irrigation applied at IW/CPE ratio 1.0 and decreased significantly with decreasing IW/CPE ratio from 1.0 to 0.8 and from 0.8 to 0.6. An increase of 34.32 and 23.55 % was observed in WUE in case of mini-sprinkler (M_1) and LEWA (M_2), respectively as compared to surface irrigation (M_3). The higher WUE obtained in case of mini sprinkler irrigated wheat plot was due to higher yield and lesser amount of water applied. WUE was progressively decreased with decreasing IW/CPE from 1.0 to 0.6 ratio.

Table 2.9.5. Effect of irrigation methods and irrigation regimes on grain yield (t/ha) and water use efficiency (kg/ha-mm) of wheat

Irrigation methods	Irrigation regimes							
	I_1		I_2		I_3		Mean	
	Yield	WUE	Yield	WUE	Yield	WUE	Yield	WUE
M_1	3.86	24.49	4.1	19.96	4.44	1801	4.14	20.82
M_2	3.82	21.39	4.09	19.71	4.33	16.34	4.10	19.15
M_3	3.17	17.12	3.76	15.61	4.03	13.77	3.65	15.50
Mean	3.62	21.00	3.98	18.44	4.26	16.04	–	–
Source	SEm+		CD at 5%		CV (%)		–	–
Irrigation methods (M)	0.05	0.25	0.17	0.87	0.51	5.42	–	–
Irrigation regimes (I)	0.06	0.34	0.19	1.00	0.59	6.30	–	–
M x I	1.11	0.58	NS	NS	–	–	–	–

2.10. Sriganganagar

2.10.1. Studies on Irrigation Scheduling in Winter Planted Chilli under Low Tunnels in Cotton Based Drip Irrigation System

A field experiment was conducted on irrigation scheduling in chilli under low tunnels (LT) during three consecutive years from *rabi* 2012-13 to 2014-15 at ARS, Sriganganagar. A Randomised Block Design (RBD) having six irrigation levels *viz.*, 0.6 ET_c (I_1), 0.8 ET_c (I_2), 1.0 ET_c (I_3) and 1.2 ET_c (I_4) through drip (LT), 1.0 ET_c through drip (without LT) and surface irrigation at IW/CPE 1.0 (control) with three replications per treatment was adopted. Considering three years of experimentation, it was observed that the water expense efficiency (WEE) was higher in drip-irrigated plots compared to flood irrigation plots. The mean WEE of 51.1 kg/ha mm recorded under I_1 (0.6 ETc by drip system) was maximum, followed by 48.7 kg/ha-mm under I_2 (0.8 ET_c by drip system) treatment (Table 2.10.1). Drip irrigation at 1.0 ET_c with low tunnel was found optimum irrigation schedule for chilli. It gave 69.85 % higher fruit yield and saved 24.12 % irrigation water over conventional surface irrigation with low tunnel and 101.63 % higher fruit yield of chilli and saved 5.45 % irrigation water over 1.0 ET_c without low tunnel. Comparison of costs and economics regarding chilli production under different drip irrigation treatments and flood irrigation are presented in table 2.10.2.

Table 2.10.1. Effect of different irrigation treatments on expense efficiency (WEE) (kg/ha-mm) and fruit yield (t/ha) of three years of experiment

Irrigation schedules	2012-13		2013-14		2014-15	
	WEE	Fruit yield	WEE	Fruit yield	WEE	Fruit yield
I_1 = 0.6 ET_c through drip (LT)	45.21	27.5	72.091	34.7	35.863	18.7
I_2 = 0.8 ET_c through drip (LT)	39.43	29.7	63.973	36.8	42.640	27.2
I_3 = 1.0 ET_c through drip (LT)	36.37	32.7	65.242	43.7	39.561	29.9
I_4 = 1.2 ET_c through drip (LT)	31.10	32.5	59.660	44.2	37.975	33.1
I_5 = 1.0 ET_c through drip (WLT)	19.17	17.8	23.708	17.2	22.016	17.7
I_6 = Control (Surface irrigation at IW/CPE 1.0)	22.32	22.20	11.184	12.50	29.273	27.9
SEd	-	1.09	-	2.56	-	1.56
CD at 5%	-	2.38	-	5.59	-	3.41

Table 2.10.2. Benefit cost analysis of different irrigation treatments in chilli

Sl. No.	Cost/Economics	Drip Irrigation Schedule (ET_c) 0.6 (LT)	0.8 (LT)	1.0 (LT)	1.2 (LT)	1.0 (WLT)	Flood Irrigation
1	Fixed cost (Rs.)	125000	125000	125000	125000	125000	-
	A. Life (years)	15	15	15	15	15	-
	B. Depreciation (Rs./year)	8333	8333	8333	8333	8333	-
	C. Interest (12%/year)	15000	15000	15000	15000	15000	-
	D. Maintenance ET_c	2500	2500	2500	2500	2500	-
2	Cost of cultivation (Rs./ha)	99000	99000	99000	99000	49000	87000
3	Total cost (Rs./ha)	124833	124833	124833	124833	74833	87000
4	Yield of produce (t/ha)	26.96	31.24	35.43	36.60	17.57	20.86
5	Selling price (Rs./q)	1000	1000	1000	1000	1000	1000
6	Income from produce (Rs.)	269570	312450	354340	365950	175740	208620
7	Water used (mm)	536.9	655.8	775.0	885.8	819.7	1021.4
8	Additional area (ha)	0.474	0.357	0.241	0.132	0.197	-
9	Additional cost (Rs.)	59214	44682	30114	16572	14777	-
10	Total Cost of production (Rs.)	184047	169516	154947	141406	89610	87000
11	Additional Income (Rs.)	127870	111838	85480	48583	34704	0
12	Total Income (Rs.)	397440	424288	439820	414533	210444	208620
13	Net seasonal income (Rs.)	213392	254772	284872	273127	120833	121620
14	B:C	1.16	1.50	1.84	1.93	1.35	1.40
15	Extra cost of treatment (Rs.)	85047	70516	55947	42406	-9389	–
16	Extra income from treatment (Rs.)	188820	215668	231200	205913	1824	–
17	IBCR	2.22	3.06	4.13	4.86	–	–

2.10.2. Studies on response of chilli to fertigation

A field experiment was conducted on fertigation in chilli under low tunnel during three consecutive years from *rabi* 2012-13 to 2014-15 at ARS, Sriganganagar. The fertilizer treatments, 60, 80, 100 and 120 % recommended dose of NPK (70 kg N, 50 kg P_2O_5 and 50 kg K_2O/ha) applied through fertigation as water soluble fertilizers in 9 equal splits at an interval of 13 days were evaluated along with control treatment of flood irrigation with 100% recommended dose (RD) through conventional fertilizers. The pooled data of three years revealed that different fertilizer treatments significantly influenced chilli yield. The highest fruit yield of chilli was recorded with 120 % RD which out yielded rest of the treatments. This treatment increased fruit yield of chilli by 55.4 % over conventional practice. The total water used in this treatment was 742.1 mm as against 1077.3 mm in conventional practice. There was saving of 44.9 % water in comparison to conventional practice, which produced minimum yield among the treatments. The respective WEE was 43.55 and 19.31 kg/ha-mm (Table 2.10.3). The WEE was higher in the drip-irrigated treatments as compared to flood irrigation. The maximum WEE of 47.20 kg/ha mm was recorded under 120% RD in 9 splits. The net seasonal income under 120 % RD drip fertigation treatment was Rs. 194167 as against Rs. 121000 in conventional practice. The respective benefit cost ratio was 1.51 and 1.39 (Table 2.10.4). Thus, 120 % RD (i.e. 84 kg N, 60 kg P_2O_5 and 60 kg K_2O/ha) in nine equal splits at an interval of 13 days was found optimum fertigation schedule for chilli.

Table 2.10.3. Effect of different fertigation treatments on water use and expense efficiency (pooled data)

Fertigation schedule	Effective rainfall (mm)	Irrigation water applied (mm)	Total water use (mm)	WEE (kg/ha-mm)
120 % of RD	152.3	589.8	742.1	43.55
100 % of RD	152.3	589.8	742.1	39.47
80 % of RD	152.3	589.8	742.1	35.29
60 % of RD	152.3	589.8	742.1	31.93
Control (RP)	152.3	925.0	1077.3	19.31

Table 2.10.4. Effect of different fertigation treatments on yield, yield attributes & benefit cost ratio in chilli (pooled data)

Fertigation schedule	Plant population (per plot)	Yield (t/ha)	Fertilizer use efficiency (kg/kg NPK)	B:C
120% of RD	115.11	32.32	158.4	1.51
100% of RD*	115.11	29.10	171.1	1.33
80% of RD	115.78	26.19	192.5	1.17
60% of RD	115.11	23.70	232.3	1.03
Control (RP)	113.11	20.80	122.4	1.39
SEd	1.34	1.44	–	–
CD at 5%	NS	3.0	–	–

*RD = 70 kg N, 50 kg P_2O_5 & 50 kg K_2O/ha

2.11. Shillong

2.11.1. Demonstration on Pea and Capsicum Cultivation in Rice Fallow for Enhancing Water Productivity and Livelihood of Hill Farmers

Capsicum cultivation was also demonstrated in rice fallow land and each selected farmers prepared two plots i.e. pit system and their traditional practice bun system for comparison. Capsicum seed was then sown in a nursery bed as per recommended practices during the month of December. In raised bed system, minimum ploughing was done in the soil and planking was also done to make friable soil bed before transplanting. In pit system, the soil was not ploughed but pits of appropriate depth were being dugged by the farmers. Manures/FYM/vermicompost was also applied as per recommended practices before transplanting. Transplanting was done after about one month from the date of sowing the seeds in both the plots. Two to three weeding and hoeing was done at the initial stage of plant growth (Plate 2.11.1).

a) Farmers preparing the pit and raised beds

b) Capsicum plants in pit and raised bed plots

c) A women farmer harvesting capsicum fruits

Plate 2.11.1. Successful cultivation of capsicum in hills

Impact of the demonstration : The introduction of such technologies after rice has given the farmers, on an average, an extra income of Rs.38,564 from 4600 m^2 area (zero tillage pea) and Rs.43,755 from 2110 m^2 area/- (capsicum cultivation in pit method) and Rs.52,388 from 3575 m^2 area (capsicum cultivation in bun method) to improve their livelihood. The average WUE of capsicum was 17.78 kg/ha-mm; however capsicum grown under pit system recorded a higher WUE (18.13 kg/ha-mm) as compared to bun system (17.43 kg/ha-mm).

2.11.2. Zero Energy Based Water Harvesting (Jalkund) and it's Recycling for High Value Crop under Hilly Condition

The demonstration on low cost micro rainwater harvesting structure and their efficient utilization undertaken at different farmer's field *viz.*, Mawpun village (Plate 2.11.2) and Umeit village (Plate 2.11.3) at Ri-Bhoi District. The harvested water was used for growing vegetable crops; rearing livestock and poultry etc. the technology is getting immense popularity in different states of N.E. hill region.

Fig. 2.11.1. Jalkund at Mawpun village

Plate 2.11.2. Jalkund at Mawpun village

2.12. Rahuri

2.12.1. Development of Deficit Irrigation Practices under Drip for Marigold - *Rabi* Sorghum Crop Sequence for Varied Planting Techniques

Marigold: Yield (17.83 t/ha) of summer marigold was significantly higher when irrigation was applied at 100 % PE than other treatments (Table 2.12.1). Water requirement of summer marigold was highest (70.26 cm) with irrigation at 100 % PE and lowest (28.11 cm) with irrigation at 40 % PE. Water use of summer marigold was highest (505.10 kg/ha-cm) at 40 % PE irrigation and lowest (238.14 kg/ha-cm) at 100 % PE irrigation. Therefore, water saving was highest (61.28 %) at 40 % PE irrigation, whereas least water saved (10.06 %) with irrigation at 100 % PE. Planting methods had no influence on yield of summer marigold flower. Among the planting methods, plant spacing of 60 x 10 cm and lateral spacing of 120 cm recorded highest flower yield (17.13 t/ha), which also consumed maximum water (71.74 cm). Highest water use efficiency (434.30 kg/ha-cm) was obtained with 30-60 x 15 cm planting with 90 cm lateral spacing, with 49.53 % water saving. Summer marigold planted at 30-60 x 15 cm with lateral spacing 90 cm and 40 % PE of irrigation drew net income of Rs.11,42,299 per ha, net profit of Rs.78,853 per cm of water use and water use efficiency of 1113.68 kg/ha-cm.

Sorghum: Grain yield of sorghum was recorded highest (4.33 t/ha) at 90% ET_c whereas fodder yield (14.82 t/ha) was significantly higher at 100% ET_c irrigation than other treatments. Among the planting methods, sorghum planted at 45 x 15 cm at 90 cm lateral spacing recorded significantly higher grain yield of 3.97 t/ha followed by 3.82 t/ha with 45-75 x 10 cm and lateral spacing 120 cm. In case of fodder yield same trend was noticed. Among the irrigation regimes, 100 % ET_c irrigation recorded highest equivalent grain yield of 26.47 t/ha whereas among the planting methods, paired planting of sorghum at 30-60 x 15 cm spacing with lateral spacing of 90 cm recorded significantly highest yield of 23.32 t/ha followed by that (23.20 t/ha) obtained with 45-75 x 10 cm with lateral spacing 120 cm. Total water requirement was also maximum at irrigation regime 100 % ET_c (28.01 cm) and for single row planting (27.91 cm) of sorghum (at 45 x 15 cm and 60 x 10 cm planting with lateral spacing of 90 and 120 cm, respectively). Water use efficiency was higher at 80 % ET_c irrigation (189.78 kg/ha-cm). It was higher (218.81 kg/ha-cm) for 30-60 x 15 cm planting with lateral spacing of 90 cm. In case fodder yield, maximum water use efficiency at 70% ET_c irrigation and 45-75 x 10 cm lateral spacing of 120 cm were 632.25 kg/ha-cm and 690.24 kg/ha-cm, respectively. Water saving was maximum (63.18%) at 70% ET_c irrigation and lowest at 100 % ET_c irrigation (47.91%). Among the planting methods, it was maximum (63.79%) at 30-60 x 15 cm with lateral spacing 90 cm and lowest (48.12%) at 45 x 15 cm with lateral spacing 90 cm and 60 x 10 cm with lateral spacing 120 cm, respectively. Net extra income was higher (Rs.2,40,940 per ha) at I_2S_1, because net profit per cm water use (Rs.22,849 per ha) and water use efficiency (316.93 kg/ha-cm), recorded by same combination. For the economics of *rabi* sorghum-marigold cropping sequence, it was noticed that combination of I_1S_2 recorded net extra income over control (Rs.11,15,228). Net profit per cm water use was Rs.40,918 and water use efficiency was 753.29 kg/ha-cm recorded by I_1S_2.

Recommendation: Summer marigold and *rabi* sorghum (var. Suchitra) may be planted in sequence under drip irrigation at paired row planting of 30-60 x 15 cm with lateral spacing 90 cm and be irrigated at 40 % evaporation (marigold) and 70% ET_c (*rabi* sorghum) at every alternate day in medium deep soils of Western Maharashtra. This will obtain higher yield, water saving, net extra income and water use efficiency of both the crops.

Table 2.12.1. Yield, water applied and water use efficiency for summer marigold

Treatments	Yield (t/ha)				Water saving (%)				Water use efficiency (kg/ha-cm)			
	2012	2013	2014	Pooled	2012	2013	2014	Pooled	2012	2013	2014	Pooled
Irrigation regimes												
I_1- Irrigation at 40 % PE	17.8	13.1	17.0	15.9	54.8	66.4	62.6	61.3	632.1	398.8	727.1	505.1
I_2- Irrigation at 60 % PE	18.4	14.8	17.7	16.9	35.3	49.7	56.1	47.0	433.4	301.1	503.9	361.6
I_3- Irrigation at 80 % PE	17.9	15.4	17.4	16.9	16.8	33.9	25.1	25.3	317.8	235.6	371.6	275.1
I_4- Irrigation at 100 % PE	18.3	16.4	18.8	17.8	7.6	16.1	6.5	10.1	259.2	199.3	322.2	238.1
Planting methods												
S_1: 45 x 15 cm, lateral spacing 90 cm	17.9	14.5	16.8	16.5	16.2	38.3	31.2	28.6	346.6	241.8	391.9	281.8
S_2: 30-60 x 15 cm, lateral spacing 90 cm	18.1	11.4	18.1	17.1	43.9	58.6	46.1	49.5	519.7	376.8	627.7	434.3
S_3: 60 x 10 cm, lateral spacing 120 cm	18.1	15.0	18.4	17.1	16.2	14.4	4.5	11.7	251.5	177.9	308.9	237.9
S_4: 45-75 x10 cm, lateral spacing 120 cm	18.3	15.2	17.5	16.9	35.7	53.6	48.4	45.9	469.7	332.8	544.4	395.8
Control												
S_5: 45 x 15 cm row spacing under surface irrigation (Irrigation at 75 mm CPE at 7.5 cm depth)	12.5	12.5	10.6	11.9	-	-	-	-	121.3	127.7	169.7	141.8

Table 2.12.2. Yield, water applied and water use efficiency of *rabi* sorghum (pooled 2012-2014)

Treatments	Grain weight per ear (g)				Water use efficiency (kg/ha-cm)								Water saving over surface irrigation (%)			
					Grain				Fodder							
	2012	2013	2014	Pooled	2012	2013	2014	Pooled	2012	2013	2014	Pooled	2012	2013	2014	Pooled
A) Irrigation regimes																
I_1: Irrigation at 70 % ET_c	109.3	105.6	103.3	106.1	199.3	182.6	187.0	189.6	483.2	771.0	642.2	632.1	65.2	62.3	62.0	63.2
I_2: Irrigation at 80 % ET_c	111.6	113.6	106.9	110.7	196.8	175.5	197.1	189.8	510.5	716.6	537.3	588.1	60.7	56.9	56.6	58.1
I_3: Irrigation at 90 % ET_c	115.6	114.3	106.7	112.2	196.6	152.8	156.7	168.7	472.5	662.2	498.0	544.3	56.3	51.6	50.6	52.8
I_4: Irrigation at 100 % ET_c	125.3	102.7	103.1	110.4	179.6	145.4	122.3	149.1	473.2	647.7	495.0	538.7	51.8	46.2	45.8	47.9
SE ±	4.8	4.5	2.1	4.1	-	-	-	-	-	-	-	-	-	-	-	-
CD at 5%	NS	NS	NS	NS		-	-	-	-	-	-	-	-	-	-	-
Planting methods																
S_1: 45 x 15 cm, lateral spacing 90 cm	107.3	112.5	105.2	108.3 (106.8)	167.6	133.1	140.0	146.9	351.6	595.3	455.3	467.4	51.78	46.51	46.0	48.1
S_2: 30-60 x 15 cm, lateral spacing 90 cm	115.8	107.8	101.3	105.3 (108.3)	229.8	212.0	214.6	218.8	529.8	822.4	673.1	675.1	65.18	62.33	63.9	63.8
S_3: 60 x 10 cm, lateral spacing 120 cm	125.7	110.5	108.3	112.21 (114.8)	156.5	135.2	131.1	140.9	456.9	600.3	470.9	509.3	51.78	46.51	46.0	48.1
S_4: 45-75 x 10 cm, lateral spacing 120 cm	113.1	105.5	105.1	106.84 (108.0)	239.0	182.3	187.1	202.8	660.6	794.5	615.6	690.2	65.18	59.89	59.6	61.5
SEm±	4.8	5.4	2.7	4.3	-	-	-	-	-	-	-	-	-	-	-	-
CD at 5%	NS	NS	NS	NS	-	-	-	-	-	-	-	-	-	-	-	-
Interaction	NS	NS	NS	NS	-	-	-	-	-	-	-	-	-	-	-	-
Control																
S_5: 45 x 15 cm row spacing under surface irrigation (Irrigation at 75 mm CPE at 7.5 cm depth)	122.0	107.3	115.5	114.9	68.3	64.7	62.3	65.1	166.5	124.4	133.9	141.6	-	-	-	-
Mean	115.5	-	105.0	-	-	-	-	-	-	-	-	-	-	-	-	-

2.13. Parbhani

2.13.1. Design and evaluation of gravity and pressurized irrigation systems

Significantly highest fresh rhizome yield of turmeric was obtained with irrigation at 0.8 PE (2.9 t/ha) and was at par with irrigation at 1 PE (29.1 t/ha) (Table 2.13.1). Lowest irrigation level of 0.6 PE gave lowest fresh rhizome yield (25.9 t/ha). Highest fertigation level of 120 % RDF (240:120:120 NPK kg/ha) gave significantly more fresh rhizome yield (32.6 t/ha) than rest of the lower levels of fertigation. Significantly highest GMR and NMR were noted with irrigation at 0.8 PE than rest of the lower irrigation levels of fertigation, however it was comparable with irrigation at 1 PE in the first year of experimentation. Lowest irrigation level of 0.6 PE recorded the lowest GMR and NMR. Highest level of fertigation i.e. 120% RDF (240:120:120 NPK kg/ha) gave maximum NMR except 100 % RDF (200:100:100 NPK kg/ha). RDF through soil application recorded significantly lowest GMR and NMR. Water use efficiency of 637 kg/ha-cm was observed with irrigation at 0.6 PE and it gradually decreased with increase in irrigation level. Lowest WUE of 345 kg/ha-cm was recorded with irrigation at 1.2 PE.

2.13.2. Response of drip irrigated brinjal crop to different levels of irrigation and fertigation

Table 2.13.2 shows that irrigation level I_3 recorded significantly maximum fruit yield of brinjal i.e. 46.9 t/ha and 43.8 t/ha during 2013-14 and 2014-15, respectively over rest of the irrigation levels. Application of 80 % N through fertigation (F_3) recorded significantly maximum fruit yield of brinjal i.e. 52.9 t/ha and 49.8 t/ha during 2013-14 and 2014-15 respectively. However, treatment F_2 i.e. 100 % N through fertigation was found at par with treatment F_3 during both the years. Interaction effect of irrigation and fertilizer on brinjal fruit yield was found significantly superior in treatment combination I_3F_3 (65.8 t/ha and 66.8 t/ha during 2013-14 and 2014-15 respectively).

However the effect on brinjal fruit yield in treatment combination I_3F_2 was found at par with treatment combination I_3F_3. Application of irrigation at 0.4 PE (I_1) recorded maximum water use efficiency i.e. 139.16 and 91.29 kg/ha-mm which is followed by irrigation treatments I_2 and I_3. Whereas, irrigation treatment I_4 recorded lowest water use efficiency, i.e. 46.57 and 41.69 kg/ha-mm during both the years, respectively (Table 2.13.3).

Table 2.13.1. Turmeric rhizome yield, NMR and water use efficiency as influenced by irrigation and fertigation treatments during 2015-16

Treatments	Rhizome yield (t/ha)	Cost of cultivation (Rs./ha)	NMR (Rs./ha)	Water applied (m^3)	Water use efficiency (kg/ha-cm)
Main plot (Irrigation levels)					
I_1 : Irrigation at 0.6 PE	27.8	126974	230361	4080	637
I_2 : Irrigation at 0.8 PE	35.1	128943	277617	5442	543
I_3 : Irrigation at 1.0 PE	33.3	128723	272337	6798	428
I_4 : Irrigation at 1.2 PE	31.6	128147	258503	8160	345
SE+	1.0	-	5076	-	-
CD	2.9	-	14064	-	-
Sub-plot (Fertigation levels)					
F_1 : RDF through soil application	26.3	112510	205775	6120	378
F_2 : 60 % RDF through drip	29.9	120601	238549	6120	427
F_3 : 80 % RDF through drip	33.1	128420	264830	6120	467
F_4 : 100 % RDF through drip (200:100:100 N, P_2O_5 , K_2O kg/ha)	34.7	135936	284099	6120	499
F_5 : 120 % RDF through drip	35.7	143514	304296	6120	532
SE+	0.9	-	7514	-	-
CD	2.8	-	20795	-	-
I x F	-	-	-	-	-
SE+	1.9	-	11375	-	-
CD	NS	-	NS	-	-
Mean	31.9	128196	259554	6120	461

Table 2.13.2. Brinjal fruit yield as influenced by fertigation and irrigation levels during *rabi* 2013-14 and 2014-15

Treatment	Fruit yield (t/ha)	
	2013-14	2014-15
Fertilizer levels		
F_1: Conventional application of fertilizer		
(100% RDF i.e 100:50:50 NPK)	35.5	33.7
F_2: 100 % RDN through fertigation	49.5	47.1
F_3: 80% RDN through fertigation	52.9	49.9
F_4: 60% RDN through fertigation	35.8	33.6
F_5: 40% RDN through fertigation	27.8	26.7
SE±	1.2	1.2
CD at 5%	3.5	1.5
Irrigation levels		
I_1: 0.4 PE	34.9	33.0
I_2: 0.6 PE	39.9	38.3
I_3: 0.8 PE	46.9	43.8
I_4: 1.0 PE	39.5	37.7
SE±	1.1	1.1
CD at 5%	3.1	3.1
Interaction (I x F)		
SE±	24.49	24.11
CD at 5%	7.1	6.9
GM	4.0	3.8

Table 2.13.3. Comparison of yield, water applied and water use efficiency (WUE) of brinjal influenced irrigation levels during 2013-14 and 2014-15

Irrigation levels	Water applied (mm)		Brinjal yield (t/ha)		WUE (kg/ha-mm)	
	2013-14	2014-15	2013-14	2014-15	2013-14	2014-15
I_1: 0.4 PE	251.26	361.72	34.9	33.0	139.16	91.29
I_2: 0.6 PE	450.04	542.58	39.9	38.3	88.55	70.63
I_3: 0.8 PE	648.82	723.44	46.9	43.8	72.28	60.49
I_4: 1.0 PE	847.60	904.30	39.5	37.7	46.57	41.69

* Rainfall of 146.3 mm (2013-14) and 63.1 mm (2014-15) was received during crop growth period

2.13.3. Water Management in Soybean-Chickpea Cropping System through Sprinkler Method

Soybean: Seed and straw yields of soybean were not significantly influenced by irrigation and fertigation levels. Average soybean seed yield obtained was 1717 and 876 kg/ha during first and second year of experimentation, respectively while average straw yield was 1626 and 1425 kg/ha during first and second year of experimentation respectively (Table 2.13.4).

Chickpea: Significantly higher seed (2973 and 1225 kg/ha) and straw (2840 and 1375 kg/ha) yield were obtained with three sprinkler irrigations at grand growth + flowering + pod formation stage than rest of the irrigation treatments, however the values were comparable with two sprinkler irrigations at flowering + pod formation stages in respect of seed (2860 and 1078 kg/ha) and (2690 and 1348 kg/ha) straw during 2014-15 and 2015-16, respectively (Table 2.13.4). Similarly, three sprinkler irrigations at grand growth + flowering + pod formation stage recorded significantly higher NMR than rest of the irrigation treatments, however it was comparable with two sprinkler irrigations at flowering + pod formation stage during both the years of experimentation. Higher water use efficiency (204 and 62.69 kg/ha-cm) was obtained with sprinkler irrigation at pod formation stage while lower WUE (105 and 33.97 kg/ha-cm) was noted with three surface irrigations at grand growth + flowering + pod formation stage during both the years of experimentation (Table 2.13.4).

Table 2.13.4. Yield of soybean and yield and economics of chickpea as influenced by irrigation treatments

Treatments	Soybean Seed yield (kg/ha)		Chickpea Seed yield (kg/ha)		Chickpea NMR (Rs./ha)		Chickpea WUE (kg/ha-cm)	
	2014-15	2015-16	2014-15	2015-16	2014-15	2015-16	2014-15	2015-16
T_1: Sprinkler irrigation at grand growth stage (GGS)	1650	460.4	2219	646.8	59945	8199	185	56.40
T_2: Sprinkler irrigation at flowering stage (FS)	1760	560.3	2331	728.4	64044	10137	194	60.70
T_3: Sprinkler irrigation at pod formation stage (PFS)	1710	570.1	**2443**	752.3	67927	11001	204	62.69
T_4: Sprinkler irrigation at GGS + FS	1707	567.4	2550	822.7	71927	14305	142	45.71
T_5: Sprinkler irrigation at GGS + PFS	1823	820.3	2650	938.0	74894	18286	147	52.11
T_6: Sprinkler irrigation at FS + FS	1628	823.4	2860	1078.2	82213	24086	159	59.90
T_7: Sprinkler irrigation at GGS + FS + PFS	1721	780.0	2973	1225.1	85994	29467	124	51.05
T_8: Surface (Flood) irrigation at GGS + FS + PFS	1739	596.4	2529	815.4	66557	10053	105	33.97
SE+	81.4	95.5	106.1	54.49	3016	2262	149	52.62
CD at 5%	NS	NS	321.5	165.3	9164	6862	185	56.40
Mean	1717	647.3	2569	875.9	71703	15692	194	60.70

2.14. Gayeshpur

Effects of Irrigation Schedules and Integrated Nitrogen Management on Yield and Water Use Efficiency of Lettuce (Lactuca sativa L.)

Yield and yield attributes of lettuce: The head yield and yield attributes of lettuce were significantly influenced by different irrigation schedules and integrated nitrogen management during the 2014-2015. A perusal of data revealed that irrigation scheduling at IW/CPE 1.0 produced maximum head yield (9.82 t/ha) and yield attributes *viz.*, head diameter (15.4 cm), leaves per plant (15.7 cm) and single head weight (335 g), which was on par with irrigation scheduling at IW/CPE 0.8, but superior to the remaining two irrigation schedules. On the other hand, irrigation at IW/CPE 0.6 registered significantly the lowest head yield and yield contributing parameters. The integrated application of 50% organic N and 50% inorganic N fertilizers recorded maximum head yield (9.78 t/ha), head diameter (14.9 cm), leaves per plant (15.6) and single head weight (326 g) and was superior to the recommended 100% inorganic N fertilizer. Addition of 100% organic N as vermicompost registered the minimum yield contributing parameters and head yield. Pooled values also exhibited the same trend.

Water use and water use efficiency: The relationships of economic yield with water use and water use efficiency at varied irrigation levels are graphically presented in fig. 2.14.1 and 2.14.2. The highest water use (179.95 mm) was found in surface irrigation and the lowest (93.03mm) in irrigation at IW/CPE 0.6. Conversely, the highest water use efficiency (93.59 kg/ha-mm) was recorded with irrigation at IW/CPE 0.6, whereas the lowest (50.42 kg/ha-mm) in the conventional surface irrigation. The interaction effects between irrigation and nitrogen management demonstrated that maximum water use efficiency of 96.59 kg/ha-mm was obtained with irrigation schedule at IW/CPE 0.6 supplemented with 50% inorganic N plus 50% organic N (vermicompost) and minimum of 50.60 kg/ha-mm was recorded with surface irrigation coupled with 100% inorganic N fertilization (Table 2.14.1).

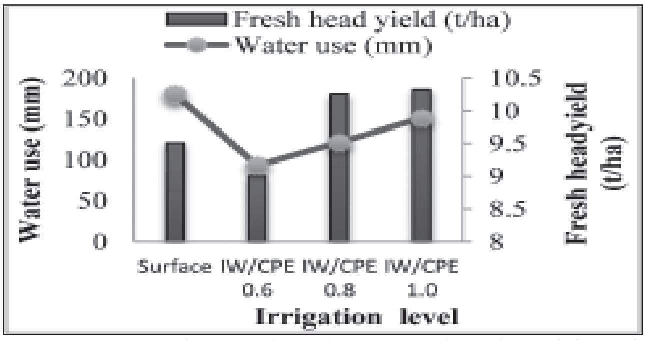


Fig 2.14.1. Relationship between head yield and water use at varying irrigation levels

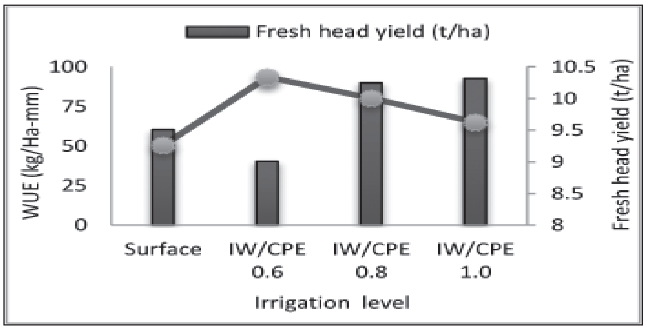


Fig 2.14.2. Relationship between head yield and water use efficiency at varying irrigation levels

The relationship between fresh head yield of lettuce and the amount of plant water use is illustrated in fig. 2.14.3. Coefficient of determination (R^2) value was found to be 0.995 for all the irrigation treatments. Fresh head yield was observed to be maximum of 10.4 t/ha at 140 mm of water use.

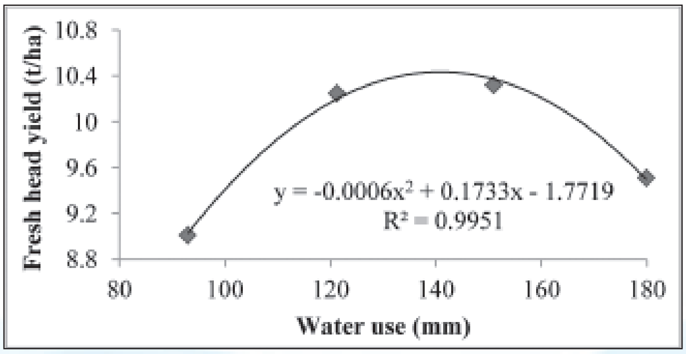


Fig. 2.14.3. Relationship between water use and fresh head yield of lettuce

Table 2.14.1. Interaction effect of irrigation and fertilizer (N) levels on yield attributes and head yield of lettuce plant during 2014-2015

Interaction (I x N)	Head diameter (cm)	No. of leaves per plant	Single head weight (g)	Fresh head yield (t/ha)
I_1 N_1	13.2	14.3	275	9.12
I_1 N_2	13.7	14.7	291	9.36
I_1 N_3	11.5	13.6	262	8.74
I_2 N_1	12.7	13.9	255	8.73
I_2 N_2	13.4	14.4	278	8.98
I_2 N_3	10.8	13.1	241	8.41
I_3 N_1	15.1	15.2	320	9.64
I_3 N_2	16.0	16.6	362	10.35
I_3 N_3	13.6	14.7	293	9.18
I_4 N_1	15.4	15.4	330	9.78
I_4 N_2	16.5	16.7	373	10.43
I_4 N_3	14.3	15.0	302	9.26
SEm±	0.48	0.36	5	0.14
CD (0.05)	1.48	1.17	15	0.43

2.15. Navsari

Effect of Water Application in Different Layers of Soil on Growth and Yield of Drip Irrigated Young Mango Plantation.

During the year under report, mango fruit yield and yield attributes of different treatments were recorded and presented in table 2.15.1. The results revealed that, all the characters affected significantly among the different treatment, except, number of fruits per tree. Significantly, higher yield of mango (61.9 kg/tree) was recorded with treatment T_4 as compared to treatment T_1 (48.7 kg/tree), but it remained at par with treatment T_2 (58.6 kg/tree), T_3 (61.8 kg/tree) and T_5 (59.6 kg/tree). With respect to volume and weight of fruit, similar trend was observed. This was reflected in WUE as T_4 and T_3 recorded higher WUE as compared to remaining treatments.

Table 2.15.1. The yield and yield attributes of young mango as influenced by different treatments

Treatments	No. of fruits per tree	Fruit yield (kg/ tree)	Volume of fruit (ml)	Weight of fruit (g)	Water applied (mm)	WUE (kg/ha-mm)
T_1-Surface drip	273.6	48.7	202.1	214.7	641.7	30.4
T_2-30 cm below ground level through drip	228.3	58.6	229.3	244.7	641.7	36.4
T_3-40 cm below ground level through drip	257.7	61.8	227.4	242.9	641.7	38.5
T_4-50 cm below ground level through drip	270.4	61.9	229.3	246.0	641.7	38.6
T_5-60 cm below ground level through drip	265.8	59.6	227.1	239.7	641.7	37.2
SEm±	33.2	3.31	7.3	237.6	-	-
CD at 5%	NS	9.5	21.0	18.1	-	-
CV (5%)	37.0	17.0	10.0	8.0	-	-

2.16. Jabalpur

Study on Water Productivity in Tribal Area

The present investigation was carried out during *rabi* season of 2014-15 at tribal area of Kundam block in Bichhua and Sanjari villages of district Jabalpur. Survey was conducted with the aim to assess the present cropping system and identify the technology gaps. The improvement there on suggested (Table 2.16.1) and experiments were taken with full package practices. The observations also taken on infiltration characteristics of soil on individual farmer's field with their soil sample analysis, important growth and yield attribute characteristics; yield and quality characters of the experimental crop were recorded at successive growth stages at 30 DAS, 60 DAS, and 90 DAS and subsequently at harvest after threshing of produced and presented in table 2.16.2 and 2.16.3.

Table 2.16.1. Interventions in the existing farmers' practice for cultivating wheat crop

Sl. No.	Particulars	Wheat	
		Farmers' practice	Intervention
1	Farming situation	Flood irrigation	Sprinkler irrigation
2	Variety	Sujata/322	GW-273
3	Time of sowing	October-November	November
4	Method of sowing	Nari/Broadcasting	Line sowing
5	Seed treatment	Without seed treatment	Thirum 3 g/kg of seed
6	Seed rate	200-220 kg/ha	100-120 kg/ha
7	Fertilizer dose	N:P:K (60:20:00)	N:P:K (80:40:20)

Table 2.16.2. Yield attributing characteristics of Bichhua village

Sl. No.	No. of effective tillers per m^2	Grain yield (t/ha)	Harvest index	Depth of water applied (cm)	Water productivity (kg/m^3)
	X7	X13	X15	X16	X17
1	58	3.6	0.50	30	1.22
2	45	3.2	0.49	28	1.14
3	63	4.2	0.64	32	1.32
4	70	2.9	0.32	27	1.09
5	54	3.6	0.55	30	1.19
6	62	3.5	0.56	30	1.18

Table 2.16.3. Yield attributing characteristics of Sanjari village

Sl. No.	No. of effective tillers per m^2	Grain yield (t/ha)	Harvest index	Depth of water applied (cm)	Water productivity (kg/m^3)
	X7	X13	X15	X16	X17
1	41	4.0	0.62	32	1.25
2	35	3.5	0.67	30	1.18
3	39	3.7	0.50	30	1.26
4	41	2.8	0.45	26	1.08
5	35	2.6	0.48	25	1.05
6	64	2.9	0.39	27	1.09
7	48	3.9	0.61	31	1.26
8	41	2.9	0.52	27	1.08
9	46	3.4	0.64	29	1.17
10	48	3.4	0.67	29	1.18
11	38	2.9	0.53	27	1.08
12	40	2.4	0.60	25	0.97

2.17. Belvatagi

2.17.1. Evaluation of Irrigation Levels to Commercial Crops under Pressurized Method (drip) of Irrigation in Intercropping Systems

A field experiment was carried out to study the feasibility of growing chilli with intercrops (onion and cotton; cotton as a relay crop after harvesting onion) under drip with fertigation in Malaprabha Command Area (Plate 2.17.1). Growing onion with drip irrigation @ 1.0 ET_o in raised bed wih paired row (45-120-45 cm) recoreded significantly higher yield (48.83 t/ha) over farmers' practice (Table 2.17.1). Agronomic parameters like plant height and number of leaves, and yield parameters like bulb weight, bulb diameter and volume of bulb were also higher with the above said treatments as compared to farmers'practice. The chilli crop is not fully harvested and cotton is at boll foramtion stage. Results will be reported after the crops are harvested.


General view of drip irrigation


Individual control system


Transplanting of onion on raised bed


Crop at 50 days after transplanting


Crop at 75 days after transplanting (0.8 ET_o)


Crop at 75 days after transplanting (1.0 ET_o)


Cotton sown as relay crop


Onion at harvest, Onion+Chilli, Onion+Chilli+Cotton


Cotton at 20 days old


Chilli at flowering stage

Plate 2.17.1. Drip irrigation in chilli, onion and cotton

Table 2.17.1. Influence of drip irrigation on growth and yield and yield parameters of onion under chilli based intercropping systems in Malaprabha command area

Treatments Main/Sub-vertical strip		Plant height (cm)	No. of leaves	Bulb size diameter (cm)	Bulb weight (10 bulbs) (g)	Bulb volume* (ml)	Onion bulb yield (t/ha)
M_1= 1.0 ET_o	Chilli + Onion + Cotton	39.33	7.63	53.24	440.0	461.33	45.64
	Chilli + Onion	38.21	9.43	54.48	491.0	501.33	48.83
M_2= 0.8 ET_o	Chilli + Onion + Cotton	36.94	8.23	53.96	381.0	419.00	40.80
	Chilli + Onion	39.26	9.10	54.91	428.0	440.67	47.71
M_3= Farmers' method	Chilli + Onion + Cotton	35.94	7.97	49.79	354.3	363.33	33.86
	Chilli + Onion	35.33	8.27	50.27	371.6	364.00	38.77
SEm+	-	1.55	0.32	1.06	12.37	18.06	1.77
CD @ 5 %	-	4.89	0.99	3.36	38.99	56.90	5.58

*Volume of water displaced by 5 bulbs

2.17.2. Evaluation of Irrigation Levels to Different Maize Cropping Systems under Pressurized (drip) Irrigation

Experiment was conducted to evaluate the feasibility of growing maize, wheat, avare and chickpea under drip with fertigation and study the effects of drip with fertigation on growth, yield and nutrient uptake by these crops in Malaprabha Command Area (Plate 2.17.2). Maize was grown in *kharif*, chickpea and wheat were grown during *rabi* with avare as a relay crop. Maize grown under drip at 1.0 ET_o recoreded significantly higher grain yield (9.97 t/ha) and 36.66 % reduction in total water applied over flood irrigation at critical stages (Table 2.17.2). However, maize with 0.8 ET_o under drip was on par with former treatment. If water is stored in farm ponds during pre-mansoon shower, the crop can be grown successfully with limited water supply through drip method.

2.17.3. Studies on Surface and Sub-surface Drip System in Bt Cotton at Various Levels of Irrigation under Vertisols

Water requirement of Bt cotton was determined through surface and sub-surface drip irrigation (Plate 2.17.3). The experiment initiated during *kharif* 2015-16 showed significant increase in WUE for the interaction effects between surface drip and irrigation at 0.6 ET_c (5.46 kg/ha-mm) and subsurface drip and irrigation at 0.6 ET_c (5.45 kg/ha-mm) compared to the control (Table 2.17.3). Water savings with drip irrigation levels I_1, I_2 and I_3 over normal alternatively to alternate furrow (AAF) irrigation were 77.03, 81.04 and 85.11 %, respectively for cotton.

Wetting pattern at 60 mm

General view of experiment with drip line

Avare at emergence in standing maize crop (Relay crop)

General view of *rabi* crops at grand growth

Plate 2.17.2. Drip irrigation in maize, wheat, avare and bengal gram

Table 2.17.2. Influence of pressurized irrigation (drip method) on yield and harvest index of maize in maize based cropping systems in Malaprabha Command Area

Treatments	Grain yield (t/ha)	Straw weight (t/ha)	Harvest index (%)
M_1 = Irrigation to maize @ 1.0 ET_o	9.97	4.18	71
M_2 = Irrigation to maize @ 0.8 ET_o	9.30	4.28	68
M_3 = Irrigation given maize at critical stages	8.10	4.29	65
SEm+	0.30	0.03	1.0
CD @ 5 %	1.04	0.09	4.0

Table 2.17.3. Effects of drip irrigation system and methods of layout on cotton yield, water use efficiency, gross income, net income and B:C ratio during 2015-16

Treatments	Cotton yield (t/ha)	WUE (kg/ha-mm)	Gross income (Rs./ha)	Net income (Rs./ha)	B:C
Irrigation levels					
I_1= 1.0 ET_c	1.97	3.13	88505	46421	2.01
I_2= 0.8 ET_c	1.86	3.70	83807	41723	2.06
I_3= 0.6 ET_c	2.06	5.45**	92570	50486	1.88
SEm+	0.08	0.17	3687	3687	0.093
CD (0.05)	0.25	0.54	11364	11364	0.287
Methods of layout					
M_1= Surface drip system	1.85	3.90	83041	42961	2.017
M_2= Sub-surface drip system	2.08	4.29	93546	49458	1.958
Control / Check					
AAF 0.6 IW/CPE ratio @ 60 mm depth of water	1.79	4.09	88293	41564	1.880
SEm+	0.1	0.28	4437	4437	0.114
CD (0.05)	0.44	0.97	19969	19969	0.511
Interaction effects					
I_1M_1	1.68	2.67	75612	35532	2.22
I_1M_2	2.25	3.58	101398	57310	1.80
I_2M_1	1.80	3.57	80856	40777	2.05
I_2M_2	1.93	3.84	86757	42669	2.08
I_3M_1	2.06	5.46*	92657	52577	1.77
I_3M_2	2.06	5.45*	92483	48394	2.00
Control	1.85	3.12	83257	39128	1.67
SEm+	0.14	0.29	6149	6149	0.16
CD (0.05)	0.42	0.92	18953	18952	0.49

* Significantly superior

Sub-surface drip system

Surface drip system

Irrigation with AAF method

Plate 2.17.3. Cotton crop grown with different irrigation methods

Theme 3

Management of rainwater for judicious use and to develop and evaluate groundwater recharge technologies for augmenting availbality under different hydro-ecological conditions

3.1. Junagadh

Evaluation of Groundwater Recharge Techniques for Junagadh Region

Evaluation of groundwater recharge of on-stream water harvesting structure: Four groundwater recharge techniques namely check dam, recharge basin, groundwater recharge by roof water harvesting and open well recharging were evaluated during last monsoon season (2015). Check dam at Instructional farm, College of Agricultural Engineering and Technology was considered for the evaluation of recharge. The daily water balance of check dam was carried out by analyzing daily rainfall, runoff and evaporation during the monsoon season. The occurrence of annual average runoff from catchment of check dam was estimated to be 15570 cu.m, which occurs at two years return period (Table 3.1.1) and in every two years excess runoff was 2016 cu.m. Thereore, the recharge cum storage capacity was estimated as 13554 cu.m. The water balance sheet and hydrograph was prepared for analysis of daily rainfall, runoff and recharge. Observations show that total recharge was 6897 cu.m, runoff escaped from check dam was 7173 cu.m and total run off from catchment was 8570 cu.m. Structure cost on current rate basis was estimated to be Rs. 95000; so recharge cost wentup to Rs. 0.69 per cu.m of recharge volume for 20 years effective service of structure. Recharge per sq.m of catchment was 0.095 cu.m. Evaporation loss excluding stream flowing period was 233 cu.m and during stream flowing period it was 394 cu.m.

Table 3.1.1. Water balance of check dam on annual events

Annual runoff event	Runoff exceed or equal (m^3)	Storage capacity (m^3)	Recharge (m^3)	Excess runoff (m^3)
1	2	3	4	5
20 years return period	35686	4539	9015	22132
Maximum	122812			109258
Average	15570			2016
Minimum	0			0
Total	–	13554		–

Evaluation of Recharge Basin technique: Recharge basin structure was constructed at Instructional farm. Annual minimum, maximum, average and fifteen years return period of runoff from catchment of recharge basin were determined. Hydrograph was prepared by recording water level in the basin against time for duration for monsoon, staring from the month of June to the end of October. During monsoon season, total 14591 cu.m of runoff volume was generated from catchment area of recharge basin, out of this 6210 cu.m was trapped in the recharge basin and 8381 cu.m was escaped from the basin. Evaporation loss from the basin was estimated to be 54 cu.m; net recharge was 6156 cu.m. During 2015, which was a drought year, cost of recharging was Rs. 0.28 per cu.m for Junagadh region, considering 15 years effective life of the recharge basin. But for 2014, the cost of water recharge was estimated to be Rs. 0.12 per cu.m.

Evaluation of open well recharging: The experiment on open well recharging was carried out at Krushi Gadh Farm of Agronomy Department, Junagadh Agricultural University, Junagadh. The runoff from catchment area of open well recharge structure was estimated and maximum, average, minimum and 15 years return period of runoff were found 1757 mm, 300 mm, 0 mm, 593 mm, respectively. During monsoon season total 6386 cu.m of runoff volume was generated from catchment area of open well recharge structure, out of that 2768 cu.m was recharged in to open well (Fig. 3.1.1) and 3618 cu.m was escaped toward downstream side of filter (Fig. 3.1.2 and 3.1.3). The cost of open well recharge structure was found Rs.57528. The cost of groundwater recharge per liter was determined Rs.0.02 (for one year service of structure). But cost of recharging, considering 15 years effective life of recharge structure is Rs.0.0014 per litre for Junagadh region. Annual runoff event wise costing of groundwater recharge was Rs.0.0001 per litre, Rs.0.0004 per litre and Rs.0.0002 per litre for maximum, average and 15 year return period of runoff, respectively. Filtration results showed that silt retention is low (88%) in the beginning and increased as the season progresses due to 91% silt deposition in upper layer of filter at the end of season. Average filtration efficiency was 90%.

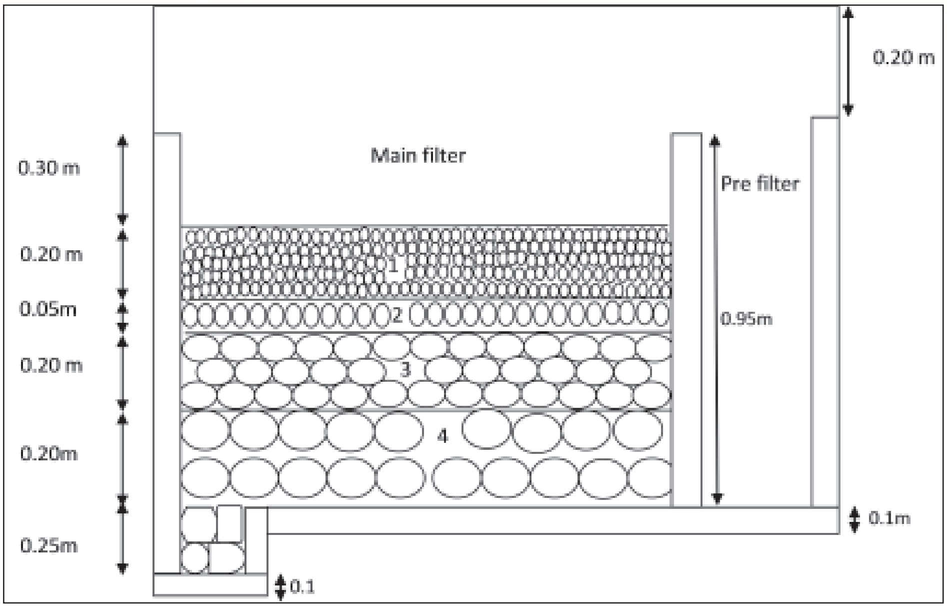


Fig. 3.1.1. Open well recharge structure

Fig 3.1.2. Observation of flow rate through filter

Fig. 3.1.3. Determination of silt in runoff and recharge water

Fig. 3.1.4. Auto distribution system for roof water runoff

The roof water harvesting system installed at CAET, Junagadh Agricultural University was evaluated (Fig. 3.1.4). The nearby tubewells were used for recharging as well as observation wells. Estimated cost of harvesting roof water runoff of storm of 1 to 5 days consecutive maximum rainfall for 10 years return period in sump varies from Rs. 42 to 88 per sq.m of roof. Also estimated runoff for storm of 1 to 5 consecutive days maximum rainfall for 10 years return period varies from 0.19 to 0.39 cu.m per sq.m of roof. Capacity of storage tank in combination with recharge well was found only in case of 1 day maximum rainfall; buffer storage tank of 0.02 cu.m per sq.m of roof is required. The annual average, lowest, highest and 10 years return period of roof water runoff was determined to be 0.62, 0.1, 1.94 and 0.96 cu.m per square meter roof. The safest buffer storage sump in combination of groundwater recharge through tubewell were determined considering 5 consecutive days maximum rainfall, if there is highest rainfall intensity of 10 years return period and time of concentration equal to 20 min. Safest buffer requirement was determined 132 cu.m and per square meter of roof it was 0.173 cu.m. Cost of system per sq. m of roof was found Rs. 44.85. Observations of roof water runoff recharged and collected in the sump were recorded. It was found that, out of 0.54 cu.m per square meter of total roof water runoff, 0.16 cu.m was contributed as groundwater recharge and 0.38 cu.m was collected in to sump. The system cost in combination of groundwater recharge was determined to be Rs.119.26 per square meter of roof area and annual roof water runoff coefficient was determined to be 0.74.

3.2. Ludhiana

Evaluation of Composite Filter for Groundwater Recharge

The study is planned for developing composite filter for recharge of groundwater from runoff water. Four materials have been selected for composite filter *viz.*, brick flakes, gravel, pea gravel and granular activated charcoal. The study is planned for developing composite filter for recharge of groundwater from runoff water. All four materials will be tested for its conductivity. The design of the composite filter has been shown in fig. 3.2.1. For this study, the structure for placing the different filter materials has been fabricated and installed in the field laboratory (Plate 3.2.1). The thickness of the materials in the filter will have different combination. For the first treatment, thickness of the brick flakes layer will be kept as 30 cm and 15 cm gravels, 15 cm pea gravel and 15 cm granular activated charcoal will be used. Before filter structure, alum will be placed at 5 m in the channel. The water quality before and after passing the filter will be tested and silt removal efficiency will be determined along with improvement in runoff quality parameters like TDS, EC, pH, RSC and nitrate. In the second treatment, thickness of the brick flakes layer will be changed from 30 cm to 45 cm keeping other material at same thickness. Before filter structure, alum will be placed at 5 m in the channel. The water quality before and after passing the filter will be tested and silt removal efficiency will be determined along with improvement in runoff quality parameters like TDS, EC, pH, RSC and nitrate. The best combination will be selected and the during monsoon season it will be installed at field. Field study will be conducted for the silt removal and improvement in surface runoff quality. Recharge rate will be monitored after passing surface runoff through the filter. Blockage time of the filter will also be monitored after its regular operation.

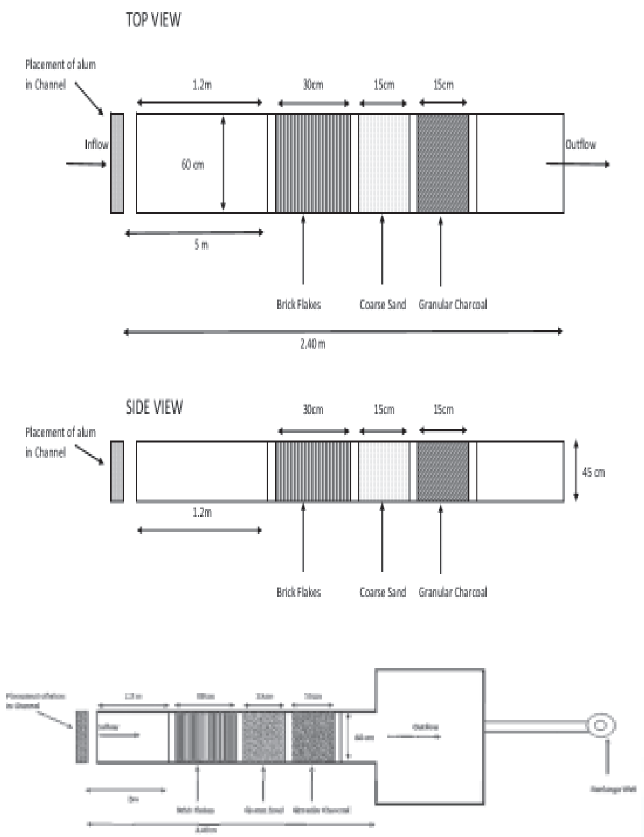


Fig. 3.2.1. Design of composite filter

Plate 3.2.1. Fabrication and installation of composite filter in the field

3.3. Coimbatore

3.3.1. Study on Augmentation of Groundwater Resources by Artificial Recharge Structures and to Identify the Potential Recharge Zone using Remote Sensing and GIS in Selected Watershed of Amaravathi River Basin

The effectiveness of different artificial recharge arrangements for enhancement of recharge and season-wise variability of recharge was studied. The study area of Uppar Odai (4B2A7a2) falls under the catchment area of the Amaravathi river basin. The length of the area is about 18.5 km and encompasses the watershed area of about 79.5 km^2. The river Uppar Odai flows into north east direction and the location map of the area is given in fig. 3.3.1. The highest monthly mean of maximum temperature is around 40.6^{0}C in April and the lowest monthly mean of daily minimum temperature is 22.4^{0}C during January. The monthly potential evapotranspiration varies from as low as 66 mm in November to as high as 130.90 mm in May. The mean annual rainfall of the area is 670 mm. Major part of the study area is having clay loam soil. The pH of the soil ranges from 6.8 to 8.5 and the EC noted from 0.1 to 1.4 dS/m. The depth of soil varies from 12 cm to 23 cm in the study area. The seven thematic layers like Lineament, Drainage density, Soil, Land use/cover, Slope, Geology and Rainfall maps were generated and interpreted in the ArcGIS 9.3 software. The data from the thematic maps can be manipulated and analyzed to obtain the information about recharge pattern.

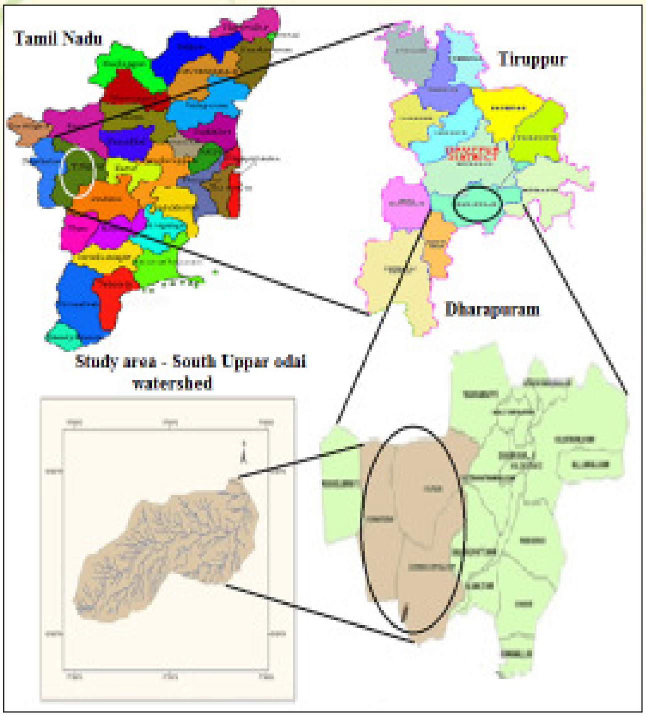


Fig. 3.3.1. Loaction map of Uppar Odai (South)

It was observed from the recharge zone map that moderate zone had the maximum areal extent of 61.7 km^2. It implies that area has moderate potential capacity for recharge of groundwater. The least area of 0.62 km^2 and 1.1 km^2 were found for very poor and very good zones, respectively. The result supports that the hard rock aquifers are fairly heterogeneous as indicated by the variations in lithology, structure and texture within short distances. Based on this finding the artificial recharge structures were to be identified and implemented to augment recharge of groundwater (Fig. 3.3.2).

The suitable locations and area were recommended for construction of water harvesting structures to augment the groundwater recharge.

- In the junction of two first order streams, check dams can be constructed in good and moderate zones. A series of check dams can be constructed to harness the runoff resulting from a rainfall and to recharge at a large scale and in slopes of 0 – 15%.
- Graded bunds can be put in slope areas from 2 to 8% which conserves soil and water of the study area.
- In moderate zones of fallow lands, with a slope of 0 – 10% and clay loam texture or soil with clay content soil suited for structures like farm pond. It stores the surface water which is used as the supplemental irrigation of second cropping.
- In the very good rechargeable zones of agricultural and non-agricultural lands, with a slope of 3 – 5% and sandy soil recharge structures like percolation ponds can be suggested in the II and III order streams where permeability is higher.
- Finally, 5 check dams, 3 percolation ponds and 4 farm ponds are recommended for harvesting the surface water (Fig. 3.3.3).

The resultant map was further crossed with the buffer map of existing structures for locating suitable sites for water harvesting structures. Finally plan for the location of recharge structures was prepared for proper utilization of excess runoff for groundwater recharge.

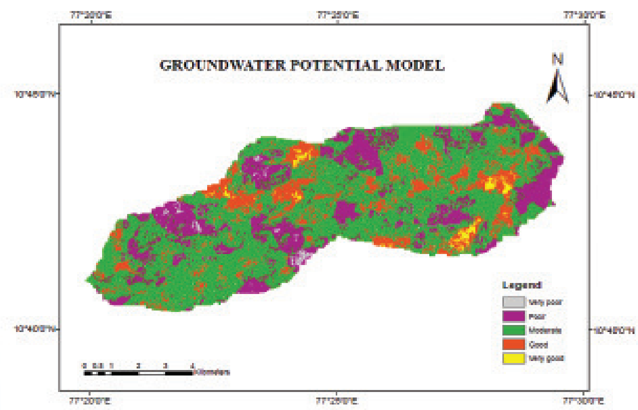


Fig. 3.3.2. Recharge zonation map of Uppar Odai (South)

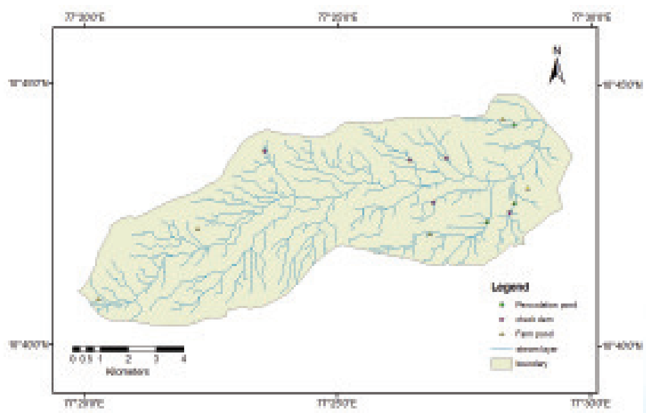


Fig. 3.3.3. Location of water harvesting structures in the Uppar Odai (South)

3.3.2. Enhancing the Water Productivity of Rainfed Crops through Rainwater Harvesting and Recycling

Under the Rainwater Harvesting cum Runoff Management Scheme in Soil Conservation Head, sanction had been granted to adopt suitable techniques, construct suitable structures in ideal locations and formation of farm pond with an aim of harvesting each drop of rainwater, since the importance is highly felt. Since the construction of check dams and formation of farm ponds serve both the vital purposes of gulley controlling and harvest rainwater effectively, formation of farm ponds draw the priority. A farm pond of dimension 53.0 m x 17.0 m x 1.5 m and capacity 1350.0 m^3 was constructed during year 2012 in village Karayepatti, Kongampatti of Madurai district. The bunds were formed around the farm pond to the size as bottom width 3.0 m, top width 1.0 m and height of the bund 1.0 m keeping the bream width as 1.0 m. The inlet and outlet structures were provided for smooth inflow and outflow of water. The catchment area is 14 acres. Based on ten years rainfall data, intensity of rainfall, soil type and slope of the catchment area (16.0 acres), the farm pond at Kongampatti village, Melur Taluk, Madurai district was selected for the study. The annual average rainfall of Melur block is 911.3 mm. During North East Monsoon, there were 3 fillings. The farmer used to cultivate rice crop (VarietyADT-45) by using the farm pond water. With the anticipation of normal distribution of North East Monsoon rainfall the farmer has taken up planting rice (var JCL and NLR) in 5 acres with rainwater. Mini portable sprinkler for lifting water from the farm pond were supplied. Even though there was deficit rainfall (61 % of the normal) the farmer could able to raise paddy and groundnut successfully with mini portable sprinkler irrigation system. Groundnut was sown on 20.11.2014 in one acre and harvested on 20.02.2015. The farmer got paddy 3.9 t/ha and groundnut 1250 kg/ha.

Interventions during the year 2015: Interventions of 2013 and 2014 are presented in Plate 3.3.1. During 2015 experiment, green manure crop sun hemp to enrich the soil fertility and seeds were also supplied. TNAU fine grain rice variety Co-51 was introduced. Technological interventions made to have integrated system to generate more income. In the harvested water fish fingerlings (Rohu, Catla, Mrigal, common carp @ 1000 per tank) were released for more income. In addition to fish farming, poultry farming with country birds also advocated and the excreta of the birds efficiently recycled as feed material for the fingerlings. System of Rice Intensification (SRI) demonstration plot was laid out and the demo plot visited by the nearby farmers of the region.

Benefits realized

- Fresh biomass of 14.2 and 13.56 t/ha, dry biomass of 3.85 and 3.65 t/ha and nitrogen of 116 and 105 kg/ha were added by green manure sunhemp at 40 days after sowing
- Rice variety Co-51 performed well when compared other private fine rice variety, yielded 4.8 t/ha than farmers' practice. The private variety yielded only 4.2 t/ha.
- During northeast monsoon season of this year (2015), there was continuous rainfall of more than 500 mm rainfall with 16 acres catchment area. The farmer was able to harvest around 30000 m^3 of water (in four ponds). With the harvested water, farmer was able to grow eight acres of paddy crop and successfully harvested. The average yield of the paddy was 4.4 t/ha. Even after the harvest paddy crop, more than 2 feet water is available for fishes in three ponds
- The country birds are grown and its voids were used as supplemental feed to the fishes during the season. The famer started with ten hens and one cock initially in July. He maintained 20 birds during the season and the excess birds were sold and farmer realized income of Rs. 10500
- SRI demonstration plot was laid in an area of 0.5 acre. With the demonstration of SRI method of rice cultivation, farmers of that region realized yield of 5560 kg/ha compared to 4650 kg/ha with conventional method (19% yield advantage), in addition to water saving with the SRI method

Construction of rainwater harvesting structure

Successful rice variety JCL: crop at milking stage

Irrigation with mini-sprinker

Plate 3.3.1. Interventions during first year – 2013

3.4. Almora

Effective Utilization of Harvested Water and Storage Dynamics in Runoff Fed LDPE Lined Water Tank

Supplementary irrigation to wheat and dry spell irrigation to soybean crop was provided by the harvested runoff water from upper catchment (1200 m^2) in LDPE lined tank. The mean data (nine years) showed that application of NPK + FYM of both the crops under rainfed as well as supplementary irrigation produced highest yield followed by the 50% NPK + FYM (Table 3.4.1). The similar results were observed in case of WEE, WUE, Gross and net returns. The application of NPK + FYM (Soybean – Wheat rotation in loamy sand soil) gave 7.1 t/ha wheat equivalent yield of both the seasons under rain-fed condition. The yield was higher by 386.3%, 119.8%, 38.7%, 28.9%, 21.2% in comparison to control, NPK + NPK, FYM in *kharif* and NPK in *rabi*, FYM in both the seasons and with 50% NPK + FYM in both the seasons, respectively.

Similarly application of NPK + FYM gave 8.65 t/ha wheat equivalent yield of both the seasons under supplementary irrigation condition and it was 281.1, 86.4, 35.2, 29.1 and 14.1 % higher yield in comparison to control, NPK + NPK, FYM in both season, FYM in *kharif* and NPK in *rabi* and 50% NPK + FYM in both the seasons, respectively. Data analysis revealed that in view of low cost of cultivation and economic returns, application of FYM in *kharif* and NPK in *rabi* was a better treatment. The supplementary irrigation (100 mm) increased the mean wheat yield by 39 to 95% in different years (Table 3.4.1).

It was concluded that FYM + NPK and 50% NPK+FYM application in both the season are better option under sufficient supply of nutrients. But best and economic option was application of FYM in *kharif* and NPK in *rabi* because there was low cost of cultivation but returns were equal under supplementary irrigation in comparison to treatment of 50% NPK+FYM application. Alone application of NPK should not be followed in loamy sand hill soils.

Table 3.4.1. Effect of nutrients and supplementary irrigation on both season mean (2006-2007 to 2014-2015) wheat equivalent yield of wheat-soybean rotation

Treatments	Wheat equivalent yield (t/ha)	WEE (kg/ ha-mm)	WUE (kg/ ha-mm)	Cost of cultivation (Rs./ha)	Gross returns (Rs./ha)	Net returns (Rs./ha)	Economic efficiency Rs./ha/day	Production efficiency (kg/ha/ day)
Rainfed (RF)								
Control	1.46	1.7	2.3	55.0	27.6	-27.4	-70.4	4.0
FYM both season	5.51	6.2	8.9	82.5	96.3	13.8	39.5	15.1
FYM+NPK	7.1	8.0	11.5	92.1	126.5	34.4	94.1	19.4
FYM+50% NPK	5.86	6.6	9.3	87.3	103.6	16.2	45.5	16.1
NPK+NPK	3.23	3.7	5.2	64.7	59.5	-5.1	-7.8	8.8
FYM in *Kharif* +NPK in *rabi*	5.12	5.8	8.2	73.9	89.0	15.2	43.3	14.0
Mean (RF)	4.71	5.3	7.6	75.9	83.7	7.8	24.0	12.9
Supplementary Irrigation (SI)								
Control	2.27	2.3	3.1	57.8	42.5	-15.4	-34.6	6.2
FYM both season	6.40	6.4	8.9	85.2	111.8	26.5	78.0	17.5
FYM+NPK	8.65	8.8	12.0	94.9	154.3	59.3	159.3	23.7
FYM+50% NPK	7.58	7.7	10.6	90.1	136.8	46.6	128.7	20.8
NPK+NPK	4.64	4.7	6.4	67.4	87.2	19.6	59.5	12.7
FYM in *Kharif* + NPK in *rabi*	6.70	6.7	9.2	76.6	120.3	43.6	119.1	18.3
Mean (SI)	6.04	6.1	8.4	78.7	108.8	30.0	85.0	16.5
Overall mean	5.51	5.7	8.0	77.3	96.3	18.9	51.9	14.7
Year (Y)	0.33	–	–	–	5.31	5.31	14.54	0.89
Irrigation (I)	0.15	–	–	–	2.50	2.50	6.85	0.42
YxI	0.46	–	–	–	7.50	7.50	20.56	1.26
Fertilizer (F)	0.27	–	–	–	4.33	4.33	11.87	0.73
YxF	0.80	–	–	–	13.00	13.00	35.60	2.18
IxF	0.38	–	–	–	6.13	6.13	16.78	1.03
YxIxF	1.13	–	–	–	18.38	18.38	50.35	3.09

3.5 Jorhat

3.5.1. Effect of Rainwater Harvesting with Ridge and Furrow on Yield of Sugarcane with Different Methods of Planting

Results of the experiment revealed that different water harvesting techniques significantly influenced the cane yield of sugarcane. The data on growth and yield parameters *viz.*, plant height, cane diameter, cane weight, millable cane and cane yield are presented in table 3.5.1. Ridge mulch by plastic film and furrow with sugarcane trash/weed (H_4) being at par ridge mulch by plastic film and furrow (H_3) recorded significantly higher cane yield than ridge and furrow (H_1) and ridge and furrow with sugarcane trash/weed biomass (H_2). Similar trend was observed in case of cane diameter, single cane weight, millable cane and plant height.

Table 3.5.1. Effect of different treatments on growth, yield attributes and yield of sugarcane

Treatments	Cane length (m)	Cane diameter (cm)	Cane weight (kg)	Millable cane (thousand/ ha)	Cane yield (t/ha)	Total water used (mm)	Field WUE (kg/ha-cm)
Methods of irrigation (M)							
M_1	2.66	2.49	1.17	65.7	75.5	664.2	1136.7
M_2	2.70	2.48	1.14	65.5	73.2	660.6	1108.1
SEm+	0.14	0.05	0.03	1.5	2.6	-	-
CD (5%)	NS	NS	NS	NS	NS	-	-
Water harvesting techniques (H)							
H_1	2.25	2.36	1.07	59.9	61.9	750.3	825.0
H_2	2.32	2.37	1.08	60.4	65.5	703.8	930.7
H_3	3.05	2.59	1.23	69.5	81.3	615.3	1321.3
H_4	3.09	2.65	1.24	72.6	88.7	580.3	1528.5
SEm+	0.20	0.07	0.04	2.1	3.6	-	-
CD (5%)	0.59	0.21	0.13	6.3	10.8	-	-
Control vs. Treatment							
Control (Recommended practice)	1.73	2.44	1.01	57.3	57.9	725.6	798.0
Treatment	2.98	2.61	1.15	65.6	74.3	-	-
SEm+	0.21	0.08	0.05	2.3	3.8	-	-
CD (5%)	0.63	0.22	0.13	6.7	11.5	-	-
Interaction (M x H)	NS	NS	NS	NS	NS	-	-

Water use and water use efficiency (WUE): The data on total water use and water use efficiency of sugarcane are presented in table 3.5.1. Among the water harvesting techniques, the highest amount of water use was recorded under ridge and furrow (750.3 mm). The lowest water use was observed under ridge mulch by plastic film and furrow with sugarcane trash/weed biomass (580.3 mm) followed by ridge mulch by plastic film and furrow (615.3 mm).

The highest water use efficiency (WUE) was observed under plastic film and furrow with sugarcane trash/weed biomass (1528.5 kg/ha-cm) followed by ridge mulch by plastic film and furrow (1321.3 kg/ha-cm). Control i.e. conventional practice recorded the lowest WUE (798.0 kg/ha-cm).

3.5.2. Optimizing Dyke Height for Rainwater Conservation in Rice Field and its Effect on Performance of Relay Crops in Medium Land Situation

Different bund height influenced the number of grains/panicle, grain yield and straw yield of rice significantly (Table 3.5.2). It was observed that bund height of 40 cm being at par with 30 cm recorded significantly higher number of grains/panicle, grain yield and straw yield of rice than 10 and 20 cm high bunds.

Table 3.5.2. Effect of bund height on yield attributes and yield of rice

Treatments	Effective tillers per m^2	Panicle length (cm)	Number of grains per panicle	Test weight (g)	Grain yield (t/ha)	Straw yield (t/ha)
Bund height [H]						
H_1 = 10 cm	165	23..4	190	16.3	47.6	9.04
H_2 = 20 cm	167	23.6	192	16.3	4.84	9.14
H_3 = 30 cm	164	24.0	228	16.4	5.67	10.37
H_4 = 40 cm	155	24.1	232	16.4	5.44	10.05
SEm+	6	0.9	7	0.25	0.17	0.31
CD (P=0.05)	NS	NS	24	NS	0.60	1.06

Water use and water use efficiency (WUE): The data on water and water use efficiency of rice are presented in table 3.5.3. During rice growing season (from transplanting to harvesting) 884.1 mm rainfall was received. Runoff loss was highest under 10 cm bund. However, no runoff loss was observed under 30 and 40 cm bunds. As such, 30 and 40 cm bund recorded the higher water use and WUE than 10 and 20 cm bunds. The highest WUE (59.09 kg/ha-cm) was observed under 30 cm bund. This treatment also recorded the highest rain WUE (64.13 kg/ha-cm).

Table 3.5.3. Effect of bund height on rainwater use from transplanting to harvest

Treatment	Runoff loss (mm)	Soil profile contribution (mm)	Water used (mm)	WUE (kg/ha-cm)	Rainwater use efficiency (kg/ha-cm)
Bund height [H]					
H_1= 10 cm	121.7	141.1	903.5	52.68	53.84
H_2= 20 cm	31.7	97.1	949.5	50.97	54.74
H_3= 30 cm	0	75.4	959.5	59.09	64.13
H_4= 40 cm	0	75.1	959.2	56.71	61.53

During *rabi* season, 40 cm bund recorded the highest water use (179.6 mm) and was closely followed by 30 cm bund (179.0 mm) indicating better residual moisture use by these treatments (Table 3.5.4). Bund height of 10 cm recorded the lowest water use (128.9 mm).

Table 3.5.4. Effect of bund height and relay crops on rice equivalent yield of the rice-relay crop system

Treatment	Rice equivalent yield (t/ha)	Water used (mm)		WUE of the system (kg/ha-cm)
		Rabi crops	Total	
Bund height				
10 cm	5.34	128.9	1032.4	51.8
20 cm	5.47	149.7	1099.2	49.8
30 cm	6.41	179.0	1138.5	56.3
40 cm	6.20	179.6	1138.8	54.4
SEm+	0.18	-	-	-
CD (P=0.05)	0.61	-	-	-
Relay crops				
Lathyrus	5.59	157.3	1100.3	50.8
Linseed	6.60	174.9	1117.9	59.1
Buckwheat	5.38	145.6	1088.6	49.4
SEm+	0.17	-	-	-
CD (P=0.05)	0.51	-	-	-

The highest WUE of the system was observed under 30 cm bund (56.3 kg/ha-cm) (Table 3.5.4). It was followed by 40 cm bund (54.4 kg/ha-cm). Among the cropping systems, rice-linseed cropping system recorded the highest WUE (59.1 kg/ha-cm).

3.5.3. Studies on Water Saving Irrigation via Partial Root Drying (PRD) and Deficit Irrigation on Growth and Yield of Potato

Different irrigation regimes significantly influenced the plant height at 50 days after planting (DAP) and tuber yield whereas number of shoots/plant at 50 DAP were not that influenced. Full irrigation (I_1) recorded significantly higher plant height at 50 DAP than deficit irrigation (I_2) and partial root drying (I_3). Tuber yields of <25 g, 25-50 g, 50-75 g and >75 g and total tuber yield recorded under full irrigation were significantly higher than partial root drying (I_3) which in turn, gave significantly higher tuber yields than deficit irrigation (I_2).

Tuber yields were significantly influenced by different irrigation schedule whereas plant height and number of shoots/plant at 50 DAP was not influenced. Three irrigations at stolonization, tuberization and tuber development stages (S_3) recorded significantly higher tuber yields of <25 g, 25-50 g, 50-75 g and >75 g and total tuber yield than two irrigations at stolonization and tuberization (S_2) and one irrigation at tuberization (S_1). During the crop growing period, 26.9 mm rainfall was received. Corresponding pan evaporation was 155.9 mm. The data on growth and yield of potato are presented in table 3.5.5.

Table 3.5.5. Effect of different treatments on growth and yield of potato

Treatments	At 50 DAP Plant height (cm)	At 50 DAP Number of shoots per plant	Tuber yield (t/ha) <25 g	25-50 g	50-75 g	>75 g	Total
Irrigation regimes							
I_1	39.0	4.5	6.71	6.83	4.05	2.43	20.02
I_2	35.5	4.3	5.06	5.30	3.20	2.08	15.64
I_3	35.6	4.3	5.77	6.02	3.43	2.25	17.47
SEm+	0.9	0.2	0.21	0.22	0.07	0.05	0.5
CD (P=0.05)	2.7	NS	0.61	0.65	0.22	0.15	1.49
Irrigation schedules							
S_1	36.7	4.4	4.89	5.03	2.96	1.81	14.69
S_2	36.9	4.3	5.80	6.08	3.58	2.29	17.75
S_3	36.5	4.4	6.86	7.03	4.14	2.66	20.69
SEm+	0.9	0.2	0.21	0.22	0.07	0.05	0.50
CD (P=0.05)	NS	NS	0.61	0.65	0.22	0.15	1.49
Treatment vs. Control							
Treatment	36.7	4.4	5.85	6.05	3.56	2.25	17.71
Control	31.0	4.1	3.91	4.11	2.35	1.55	11.92
SEm+	1.6	0.4	0.38	0.40	0.14	0.09	0.92
CD (P=0.05)	4.9	NS	1.11	1.19	0.40	0.27	2.72

The data on total water use and WUE of potato are presented in table 3.5.6. It was observed that the amount of irrigation as well as total water used by the crop increased with the increasing levels of irrigation regimes. Among the irrigation regimes, the highest amount of irrigation (1200 m^3) and total water use (2238 m^3) were recorded under full irrigation (I_1). However, it recorded the lowest field water use efficiency (8.95 kg/m^3). The highest field WUE was recorded under partial root drying (PRD) 10.15 kg/m^3 followed by deficit irrigation 9.37 kg/m^3.

Table 3.5.6. Total water used and water use efficiency of potato

Treatments	Total tuber yield (t/ha)	Irrigation water (m^3)	Total water used (m^3)	Field WUE (kg/m^3)
Irrigation regimes				
I_1	20.02	1200	2238	8.95
I_2	15.64	600	1669	9.37
I_3	17.47	600	1722	10.15
Irrigation schedules				
S_1	14.69	400	1511	9.72
S_2	17.75	800	1875	9.47
S_3	20.69	1200	2243	9.22
Control	11.92	0	1134	10.51

Among the irrigation schedule, three irrigation at stolonizaion, tuberization and tuber development (S_3) recorded the highest water use (2243 m^3). It was followed by two irrigations at stolonizaion and tuberization (1875 m^3) and one irrigation at stolonization (1511 m^3). With respect to WUE, the reverse trend was observed. Rainfed crop recorded the lowest water use (1134 m^3) and the highest WUE (10.50 kg/m^3).

3.6. Palampur

3.6.1. Management of Soil Moisture in Summer Crop of Brinjal in High Rainfall Areas of Himachal Pradesh

Mulch sources

Mulch sources had significant effect on brinjal yield, gross returns and WUE during 2014 and on all parameters during 2015. During 2014, the crop planted after application of plastic mulch result in significantly higher brinjal yield and gross returns than crop grown with organic mulch application (7.70 % and 7.67 %) after planting and crop planted without mulching (22.25 and 22.23 %). During 2015, the crop mulched with organic mulch resulted in significantly higher brinjal yield and gross returns than crop planted after application of plastic mulch (12.26 % and 12.32 %) and crop planted without mulching (16.71 and 16.77 %) (Table 3.6.1).

Organic mulch resulted in significantly higher brinjal yield and gross returns (13.51 and 13.53 %) than application of no mulch during 2014. Plastic mulch and no mulch resulted in statistically similar brinjal yield and gross returns during 2015. Mulch sources had no effect on net returns and B:C ratio during 2014. Organic mulch resulted in significantly higher net returns (16.68 and 37.60 %) than application of no mulch and plastic mulch during 2015. Plastic mulch resulted in 15.20 % lower net return than no mulch application during 2015. Plastic mulch also resulted in significantly lower B:C ratio than organic and no mulch (36.54 %), which were at par among themselves during 2015.

During 2014, WUE were significantly higher in crop grown under plastic mulch than crop grown with organic (14.15 %) or no mulch (46.69 %) due to lower water use under plastic mulch than under organic (5.01 %) or no mulch (16.21 %). During 2015 organic mulch resulted in significantly higher WUE than plastic mulch (12.31 % and no mulch (21.37 %) due to 3.69 % lower water use under organic mulch than under no mulch. During 2014, application of organic mulch resulted in significantly higher (28.51 %) WUE than application of no mulch due to 11.79 % lower water use in the former treatment. During 2015 application of plastic mulch resulted in significantly higher (8.06 %) WUE than application of no mulch due to 3.69 % lower water use in the former treatment (Table 3.6.1).

FYM levels: During 2014, FYM levels had significant effect on brinjal yield, gross returns, net returns and WUE. The crop planted after application of FYM @ 10 t/ha resulted in significantly higher yield of brinjal, gross returns, net returns and WUE than crop planted after application of FYM @ 5 t/ha (8.24, 8.21, 10.33 and 7.81 %).

Irrigation levels: Irrigation levels had significant effect on brinjal yield, gross returns, net returns and B:C ratio during both the years. The crop irrigated with 4 cm of water depth resulted in significantly higher brinjal yield, gross returns, net returns and B:C ratio than crop irrigated with 2 cm of water depth during 2014 (11.14 %, 11.19 %, 18.50 % and 21.05 %) and 2015 (5.48 %, 5.48 %, 9.78 % and 10.0 %). Irrigation levels had no effect on WUE during 2014. During 2015, the crop irrigated with 4 cm of water depth resulted in significantly higher WUE (6.64 %) than crop irrigated with 2 cm of water depth due to 1.25 % lower water use and 5.48 % higher brinjal yield by the former treatment (Table 3.6.1).

Brinjal yield: In the crop grown with organic mulch application after planting and without application of mulch, irrigation with 4 cm water depth resulted in significantly higher (20.37 and 21.91 %) brinjal yield than irrigation with 2 cm of water depth. In crop planted after application of plastic mulch, irrigation depth had no effect on brinjal yield. Under irrigation depth of 2 cm, application of plastic mulch resulted in significantly higher yield of brinjal than application of either organic mulch (21.04 %) or no mulch (38.41 %) and application of organic mulch after planting of crop resulted in significantly higher (14.36 %) brinjal yield than application of no mulch. Under irrigation depth of 4 cm, source of mulching had no effect on brinjal yield, however, application of either plastic mulch before planting (8.88 %) or application of organic mulch after planting (12.91 %) resulted in significantly higher yield than no mulching. Brinjal crop resulted in significantly lowest brinjal yield when it is irrigated with 2 cm of water depth under no mulch condition (Table 3.6.1).

Table 3.6.1. Effect of different treatments on productivity, water use and economics of brinjal

Treatments	Brinjal yield (Mg/ha)		TWU (m^3/ha)		WUE (Mg/m^3)		Gross return (Rs./ha)		Net return (Rs./ha)		B:C	
	2014	2015	2014	2015	2014	2015	2014	2015	2014	2015	2014	2015
Mulch sources												
Organic mulch	10.00	9.43	1197 (9)	1567 (10)	8.34	6.02	1,50,000	1,41,438	94,628	86,065	1.71	1.56
Plastic mulch	10.77	8.40	1137 (7)	1567 (10)	9.52	5.36	1,61,500	1,25,925	98,120	62,545	1.55	0.99
No mulch	8.81	8.08	1357 (15)	1627 (13)	6.49	4.96	1,32,125	1,21,125	84,761	73,761	1.79	1.56
CD (P = 0.05)	0.74	0.51	-	-	0.62	0.32	11,100	7,617	NS	7,617	NS	0.15
FYM levels (t/ha)												
Five	9.47	8.45	1230 (10)	1587 (11)	7.81	5.33	1,42,042	1,26,708	87,961	72,628	1.64	1.37
Ten	10.25	8.82	1230 (10)	1587 (11)	8.42	5.56	1,53,708	1,32,283	97,045	75,620	1.73	1.37
CD (P = 0.05)	0.60	NS	-	-	0.51	NS	9,063	NS	9,063	NS	NS	NS
Irrigation levels (cm)												
2	9.34	8.40	1134 (10)	1597 (11)	8.32	5.27	1,40,042	1,26,042	84,670	70,670	1.52	1.30
4	10.38	8.86	1327 (10)	1577 (10)	7.91	5.62	1,55,708	1,32,950	1,00,336	77,578	1.84	1.43
CD (P = 0.05)	0.60	0.41	-	-	NS	0.26	9063	6,219	9,063	6,219	0.16	0.12

*Value in the parenthesis indicate number of irrigations

Water use efficiency: In the crop grown with organic mulch application after planting and without application of mulch, irrigation depth had no effect on water use efficiency. However, in crop planted after application of plastic mulch, irrigation depth of 2 cm resulted in significantly higher (17.98 %) WUE than irrigation depth of 4 cm. Under irrigation depth of 2 cm, application of plastic mulch resulted in significantly higher WUE than application of either organic mulch (25.61 %) or no mulch (59.20 %) and application of organic mulch after planting of crop resulted in significantly higher (26.74 %) WUE than crop planted without mulching. Under irrigation depth of 4 cm, source of mulching had no effect on WUE, however, application of either plastic mulch before planting (34.10 %) or application of organic mulch after planting (30.42 %) resulted in significantly higher yield than no mulching.

Conclusion: The production, economics and water use efficiency of brinjal can be improved by planting the crop after incorporation of FYM @ 5-10 t/ha and mulching the crop with organic material. The crop should be irrigated with 4 cm of water depth.

3.7. Udaipur

3.7.1. Augmentation of Groundwater Resources through Dugout Ponds in Haroti Region of Rajasthan

In Haroti region of Rajasthan namely Bundi, Kota, Baran and Jhalawar district lot of percolation ponds (about 800) were constructed by the Department of Agriculture, Govt. of Rajasthan for augmenting groundwater table and also for providing life saving irrigation to the crop during longer dry spells. The study was continued to standardize the size of the ponds and also to determine recharge rates and volumes as well as irrigation potential increase in the area. The total catchment areas of three selected farm ponds were 4.6, 6.35 and 8.7 ha. Runoff generating capacity of catchment was calculated by SCS curve number method on the basis of ten years data and average rainfall and runoff were estimated as 614.35 mm and 134.12 mm, respectively. The optimum size of the ponds for various catchments was estimated on the basis of runoff yield coming from the catchment area and use of harvested water. The ponds constructed in the area do not have any relationship of runoff and catchment area and in each case; the runoff yield was quite high. The depth capacity curve for all three farm ponds were prepared and presented in fig. 3.7.1. The farm ponds were designed to harvest 50 % of the annual runoff and the details of the optimum size are presented in table 3.7.1.

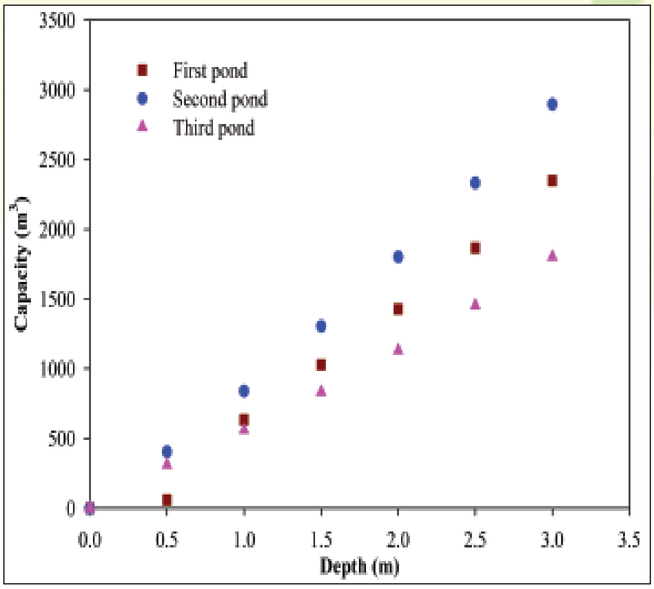


Fig. 3.7.1. Details of depth capacity for first, second and third ponds

A study was conducted to find out percolation through constructed farm pond of size 32 m x 32 m at top and 24 m x 24 m at the bottom with 3 m depth. The minimum recharge rate was found to be 4.32 cm/day during the year 2015 whereas minimum recharge volume was 2256.83 m^3 recorded in 2014.

Table 3.7.1. Optimum size of all three farm ponds

Pond	Catchment area (ha)	Runoff		Existing size of the pond		Optimized size of the 3 m deep and square farm pond		Capacity (m^3)	Side slope (H:V)	
		Generated (m^3)	Designed (m^3)	Top width (m)	Bottom width (m)	Top width (m)	Bottom width (m)		Existing	Recomm-ended (as per soil condition)
1*	4.6	6169.52	3084.76	32.0 x 32.0	24.0 x 24.0	37	28	2350	1.3:1	1.5:1
2	6.35	8516.62	4258.31	41.5 x 28.0	36.0 x 25.0	42	33	2890	1:1	1.5:1
3	8.7	11668.44	5834.22	35.5 x 22.0	27.0 x16.0	49	40	1800	1.5:1	1.5:1

*Monitored pond

Eleven groundwater quality parameters, *viz.*, pH, EC, TDS, Ca, Mg, Na, K, HCO_3, CO_3, Cl, and SO_4 were analyzed to determine their spatial and temporal variations in the study area. The pH of groundwater varied from 7.3 to 8.0 with a mean of 7.64 in pre-monsoon period and 6.9 to 7.8 with a mean of 7.2 in post-monsoon period. The mean concentration of major ions in groundwater is in the following order: cation (meq/l) *viz.*, calcium (6.60)>magnesium (6.53) > sodium (2.94) > potassium (1.48) during pre monsoon period and calcium (5.19)> magnesium (5.11) > sodium (2.71) > potassium (0.45) during post monsoon period and anions (meq/l) *viz.*, bicarbonate (5.69 and 4.56) > chloride (5.73 and 3.72) > sulphate (4.75 and

3.72) > carbonate (3.13 and 1.43) during pre and post monsoon periods, respectively. The suitability of groundwater for irrigation use was evaluated by calculating SAR, Kelly's Ratio (KR), Residual Sodium Carbonate (RSC), Soluble Sodium %age (SSP) and Permeability Index (PI) for pre-and post-monsoon periods. All the samples had SAR less than 10, Kelly's ratio less than 1, RSC less than 1.25 and SSP less than 50 during both pre and post monsoon, suggesting that the groundwater of the study area is suitable for irrigation. On the other hand, the PI values were less than 25 during pre-monsoon for two samples only, which was unsuitable for irrigation. Whereas during post monsoon PI values for all eight samples were more than 25, which was safe for irrigation.

3.7.2. Impact Assessment of Low Cost Groundwater Recharge Structures Constructed in Hard Rock Regions of Southern Rajasthan

To conduct the impact assessment study, depth capacity curves of the low cost water harvesting structures constructed in Girwa block of Udaipur and Kushalgarh block of Banswara, identified last year, had been prepared (Fig. 3.7.2). Groundwater recharge from rainwater harvesting structures situated in hard-rock region of Udaipur district was also assessed.

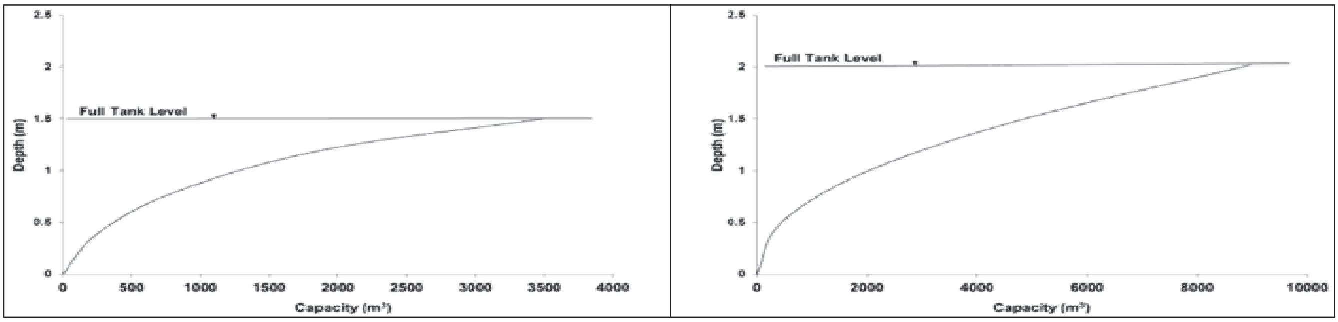


Fig. 3.7.2. Depth-Capacity Curve of (a) Doongri Para (Banswara) and (b) Jhanpa (Girwa) water harvesting structure

Therefore, the results of the study will be mainly applicable to other hard-rock regions of India. The project is important for semi-arid regions of Rajasthan especially for hard-rock areas, which makes it difficult to apply basic hydrologic principles derived for alluvial and unconsolidated geologic formations. Groundwater recharge is one of the vital components of the water cycle and is highly uncertain to be predicted accurately. In hard-rock areas of Rajasthan, cost-effective and feasible methods for artificial groundwater recharging had not yet been identified. Also, studies on evaluating impact of artificial groundwater recharge on improving groundwater quality are rare.

These structures were evaluated in terms of groundwater recharge. Monitoring of stored rainwater

Fig. 3.7.3. Low cost rainwater harvesting-cum-groundwater recharging structure at Doongri para

Fig. 3.7.4. Post-monsoon water table in well near low cost rainwater harvesting-cum-groundwater recharging structure at Doongri para

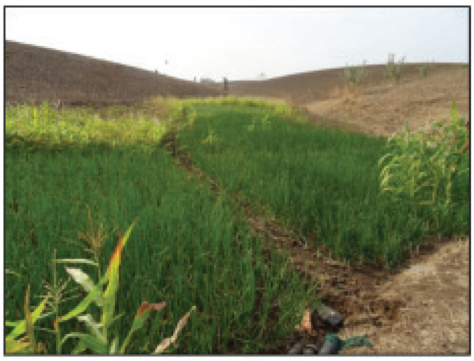


Fig. 3.7.5. Vegetable and horticulture crops grown near low cost rainwater harvesting-cum-groundwater recharging structure at Doongri para

in the structure during monsoon seasons enable to evaluate efficacy of the rainwater harvesting-cum-groundwater recharging structure. A non-recording rain gauge was also installed at the site to measure the rainfall of the area. The water harvesting structure constructed and water level in well in Doongri para village are shown in fig. 3.7.3 and 3.7.4, respectively.

Surface water resources utilization through life saving irrigation: In Doongri Para and Jhanpa villages of the study area, the surface water harvested through low cost rainwater harvesting structure was utilized for providing life saving irrigation the *kharif* crops. The water table monitoring and pond monitoring was carried out to see the effect of these structures on augmentation on groundwater table. Both the structure showed excellent impact on improving the productivity as well as assured crop production by providing life saving irrigation even during longer dry spells and erratic rainfall conditions.

Due to the impact of water harvesting structure constructed in Doongri para, the *kharif* season maize and green gram was grown in the area of 0.45 ha and 0.20 ha respectively. It was possible only because of availability of assured water created through construction of low cost structure. Further, during *rabi* season the wheat and gram crops were taken in the submergence area on residual moisture available through the structure. It was pertinent to point out that due to impact of structure the water table of the well near to structure increases up to 5 m through continues recharging and the available water through recharging was also used for providing irrigation to the *rabi*/vegetable crop like onion, garlic etc. having an area of 0.15 ha (Fig. 3.7.5). The structure showed excellent impact on improving the socio-economic status of the tribal farmers.

3.8. Jabalpur

3.8.1. Assessment of Groundwater Recharge in Jabalpur District Madhya Pradesh

Exact estimation of groundwater recharge is one of the difficult processes in evaluation of groundwater resources as it is almost inevitably subject to large scale of errors. Therefore an attempt was made to understand the spatio-temporal variation in the surface recharge caused due to land use/land cover and hydrological changes in Jabalpur district. Jabalpur district lies within the Narmada river basin with an elevation ranging between 320 to 598 m above mean sea level covering a total area of 5045 km^2. The average minimum and maximum temperature varied from 8.2°C in December/January to 40.5°C in May/June. Average annual precipitation was 1192 mm. Soil in the basin is medium deep black and it is usually clay to loamy in texture. Basin consists of four major soil groups.

Recharge from Water table fluctuation method can be obtained by the given relation: Groundwater Recharge = Water table fluctuation x Specific yield. Specific yield was obtained from long duration pumping tests or from norms for different hydrogeological areas. In situations where specific yield cannot be estimated by other means, the norms given by GEC are adopted. The SWAT model for basin was set up with ArcSWAT version of 2009.93.7b released 9/8/11 using available DEM, stream, soil, landuse, rainfall, temperature and weather generator data. Then the model was simulated from 2008 without any interventions and without any modifications in the calibration parameters. Output (result) obtained from SWAT model was extracted using SWAT plot. After delineation of the watershed using Digital Elevation Model, different base maps *viz.*, land use/land cover map, hydrological response unit map, slope map and drainage map were extracted from the Arc SWAT model.

It was observed from the water budget estimation (Table 3.8.1) of the watershed that the mean annual runoff was 51.5% of the annual precipitation; however the mean annual evapotranspiration was 43 % of the annual rainfall. An estimation of the recharge to the aquifer shows a higher temporal variability with annual values (151-284 mm/year), which corresponds to approximately 12-28% of the annual mean precipitation. This simulated result shows overall good agreement with the independently estimated annual mean groundwater recharge rate of 16.5% using SWAT.

Table 3.8.1. Estimated annual hydrological components of Jabalpur district

Year	Precipitation (mm)	ET (mm)	Runoff (mm)	Recharge (mm)	Recharge as % of precipitation
2006	1037	637.71	492	151.57	14.61
2007	1188	675.12	578	191.72	16.14
2008	1397	598.56	645	177.86	12.73
2009	1583	603.78	862	188.56	11.91
2010	1645	665.55	839	218.06	13.25
2011	1326	609.00	781	254.34	19.18
2012	1870	596.82	986	233.37	12.48
2013	1326	681.21	651	284.82	21.48
2014	2256	686.43	1009	184.11	8.16
2015	1039	687.30	596	175.90	16.93

The groundwater recharge was estimated through water table fluctuation data gathered from a network of 14 observation wells spread over entire study area for the period 2006-2015 from field and Madhya Pradesh State Groundwater Data Center and presented in table 3.8.2. The recharge simulated through SWAT was found to range between minimum of 164.47 mm in Jabalpur block to as high as 258.16 mm in Panagar block, where as the recharge as computed from water fluctuation method ranges between 123.9 mm to 197.00 mm (Table 3.8.2). The variation was within 20 % in all blocks of Jabalpur district except Majholi block. The groundwater recharge was varying from 151.57 mm in the year 2006 to 254.34 mm in the year 2011. While comparing with test method of water fluctuation the results varied from 7.5 to 29.2% (Table 3.8.3). The Groundwater recharge results simulated from SWAT model showed a good agreement with observed values obtained from water fluctuation method. It was revealed from results that total average deviation from observed recharge and simulated recharge varies approximately 15%. It was observed by SWAT that on an average 16.5 % of the rainfall might have joined the groundwater either by direct infiltration or by recharge through various structures such as tanks, reservoirs, check dams, etc.

Table 3.8.2. Groundwater recharge in Jabalpur district using SWAT and WT fluctuations

Block	Recharge WT fluctuation (mm)	Recharge SWAT (mm)	Deviation (%)
Jabalpur	116.45	164.47	29.20
Jabalpur	123.90	170.52	27.34
Jabalpur	154.89	173.47	10.71
Jabalpur	151.82	175.56	13.52
Shahpura	194.94	220.44	11.57
Panagar	233.42	258.16	9.58
Patan	188.65	238.61	20.94
Patan	186.09	223.61	16.78
Kundam	145.12	164.87	11.98
Sihora	210.40	231.99	9.31
Sihora	175.39	209.10	16.12
Sihora	197.00	212.99	7.51
Majholi	128.76	202.33	36.36
Majholi	194.80	238.33	18.26

Table 3.8.3. Temporal variation of groundwater recharge in Jabalpur district

Year	Recharge simulated SWAT (mm)	Recharge through WT fluctuation (mm)	Deviation (%)
2006	151.57	132.47	12.60
2007	191.72	160.04	16.52
2008	177.86	155.13	12.78
2009	188.56	159.45	15.44
2010	218.06	182.84	16.15
2011	254.34	211.15	16.98
2012	233.37	197.21	15.50
2013	242.83	203.23	16.31
2014	184.11	159.91	13.15
2015	175.90	153.97	12.47

Theme 4

Basic studies on soil-plant–water-environment relationship under changing scenarios of irrigation water management

4.1. Pantnagar

4.1.1. Heavy Metals Contamination of Water Resources and Effect of Industrial Effluent on Soil Near Industrial Cluster of Kashipur Town of Uttarakhand State

Contamination of water resources with heavy metals and the effect of industrial effluents on soil near industrial cluster of Kashipur town of Uttarakhand state were studied. The experiment was continued in the same study area reported last year. Five effluent samples were collected from Dhouri Pratha culvert, Sugarcane center site I, Cheema outlet, Multiwal outlet and Kosi bank as well as Kosi river. Groundwater samples were collected near channels (I and II) from Glycol gate no. 1, Dhouri Pratha I, Dhouri Pratha II, Sargam sweets, Punjabi dhaba and Jaishankar tea stall near Channel I and Tea stall at Cheema, Multiwal gate (D.H.P), Petrol pump, Parmanandpur I, Parmanandpur II and Mazar were selected for analysis of heavy metals under the effluence area of channel-II. Soil samples were collected from the agricultural field of University Sugarcane center at Kashipur, which was affected by effluent of channel-I due to seepage and water logging during monsoon season.

The heavy metal content present in the effluent and groundwater of study area is presented in table 4.1.1 and 4.1.2. It was observed that the arsenic content in both the effluents discharged by the industries, groundwater samples and Kosi river was beyond the permissible limit, which was dangerous for human health and crop production. The extent of arsenic content in groundwater is presented in fig. 4.1.1.

Table 4.1.1. Heavy metal present in the effluent

Sl. No.	Heavy metal (mg/l)	Permissible limit in water body	Dhouri Pratha culvert	Sugarcane center site I	Cheema outlet	Multiwal outlet	Kosi bank	Kosi river
1	Arsenic	0.2	18.887	25.102	2.511	29.931	36.103	38.98
2	Copper	3	0.1	0.151	0.122	0.122	0.131	0.108
3	Lead	0.1	0.238	0.244	0.264	0.236	0.231	0.233
4	Zinc	5	0.533	0.403	1.52	0.274	0.68	0.474
5	Nickel	3	0.373	0.284	0.434	0.371	0.383	0.411
6	Cobalt	-	0.133	0.514	0.172	0.353	0.123	0.152
7	Iron	3	5.445	5.86	5.294	5.058	6.66	9.56

It was observed that at all the sites; the concentration of arsenic was above permissible limit. The concentration of arsenic was found to be high at downstream points of observation from effluent channel-Iand near Indian Glycol Ltd. It was found that, effluent channel-I was main cause of increase in toxic level of arsenic in the groundwater of Dhouri Pratha and nearby area of channel-I. As per BIS norms, the permissible limit of concentration of arsenic in the drinking water should be less than 0.05 mg/l. Copper was within permissible limit (3 mg/l) at all the sampling locations of both industrial effluents and groundwater and Kosi river. As copper concentration in the water of Kosi river was well within the tolerance limit, the river water was found suitable for irrigation.

Table 4.1.2. Heavy metal present in the groundwater near effluent Channel I and II

Parameter	Arsenic (mg/l)	Copper (mg/l)	Lead (mg/l)	Zinc (mg/l)	Nickel (mg/l)	Cobalt (mg/l)	Iron (mg/l)
Permissible limit	0.05	0.05-1.5	0.1	5-10	-	-	0.3-1.0
Channel I							
Glycol gate no. 1	18.134	0.089	0.228	0.066	0.284	0.034	7.422
Dhouri Pratha I	21.177	0.061	0.242	0.376	0.212	0.125	17.14
Dhouri Pratha II	13.942	0.095	0.233	0.582	0.334	0.24	3.634
Sangam sweets	10.462	0.045	0.232	0.301	0.209	0.298	4.509
Punjabi Dhaba	7.955	0.053	0.26	0.120	0.398	0.366	4.161
Jaishankar tea stall	6.911	0.057	0.25	0.348	0.408	0.416	5.045
Channel II							
Tea stall at Cheema	4.752	0.066	10.382	0.119	0.410	0.143	3.997
Multiwal gate	25.686	0.049	0.238	0.517	0.192	0.386	4.529
Petrol pump	28.569	0.05	0.224	0.145	0.257	0.367	6.317
Parmanandpur I	30.673	0.067	0.218	0.117	0.320	0.317	4.141
Parmanandpur II	32.993	0.055	0.231	0.597	0.387	0.286	15.07
Mazar	31.77	0.066	0.214	0.613	0.320	0.189	4.079

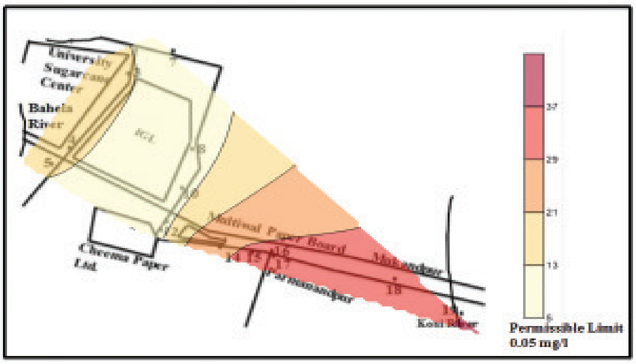


Fig. 4.1.1. Spread of arsenic in groundwater

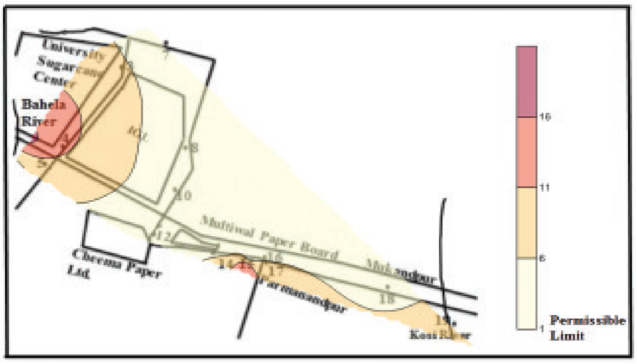


Fig. 4.1.3. Spread of iron in groundwater

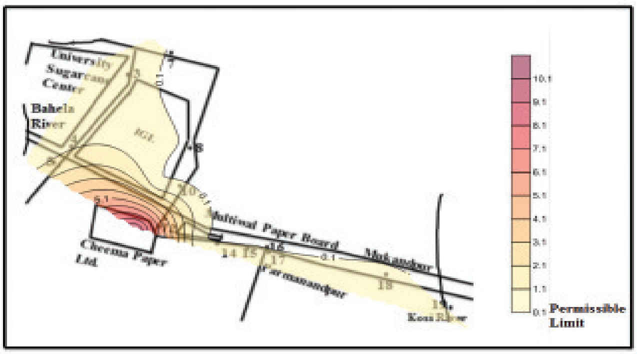


Fig. 4.1.2. Spread of lead in groundwater

Concentration of lead was found more than permissible limit in the effluent of industrial cluster sampling, groundwater samples and Kosi river, which polluted in the surrounding environment and suggested that groundwater and Kosi river water were not fit for irrigation as well as drinking purpose. The high concentration of lead at Tea stall at Cheema might be due to close vicinity of this point to the outlet of the Cheema industry and seepage of effluent from the effluent channel-II into the groundwater. Spread of lead in groundwater is shown in fig. 4.1.2. Zinc concentration in all the samples was found within the permissible limit. The high concentration of zinc content at Dhouri Pratha II and Mazar in both the channels might be due to location of these sampling sites near the channels. Nickel was also present within permissible limit in all the samples of industrial effluents. The high value of nickel concentration at Tea stall at Cheema might be as it was located near cheema industry and also near effluent channel-II.

For Cobalt, higher value at Sugarcane center site I in channel-I indicated towards an additional pollution source between Sugarcane center site I and Dhouri Pratha culvert. The higher concentration of cobalt at Multiwal outlet confirmed that the effluent of Multiwal Board factory was the cause of cobalt concentration in the effluent of the channel-II. The higher concentration of cobalt at Jaishankar tea stall and at Multiwal gate (D.H.P) was located very close to industrial area. Iron was present above the permissible limit in all the samples of industrial effluents, groundwater and Kosi bank. Effluents at these locations would affect the groundwater resources as well as crop production in the area. High concentration of iron in effluent of Kosi bank indicated addition of other pollutants in channel-II. However, iron content in the water of Kosi river was found well within the tolerance limit (50 mg/l) for inland surface water subjected to pollution. It was out of permissible limit (3 mg/l) of drinking water, thereby making the water of Kosi river suitable for irrigation but unsuitable for drinking purpose. Spread of iron in groundwater is shown in fig. 4.1.3.

The physico-chemical characteristics, pH, EC, Cl, Ca, Mg, Na and K estimated are presented in table 4.1.3. The samples collected from different depths indicated that the soil was moderately alkaline. This type of soil would affect plant growth by making phosphorus, iron, copper, zinc, boron and manganese less available to plants. Electrical conductivity below 1000 µS/cm at all three different depths indicated low salt accumulation in the soils. In such soils, moderately alkaline pH will not affect the crops and plants. Low range of calcium (<300 mg/kg) at three different depths would affect plant cell structure as well as strength in the plant. Low levels of magnesium in the soil samples would affect chlorophyll content and enzymatic reaction in different crops growing in the area. Low potassium content in soil may also affect the process of photosynthesis in the crops. From the analysis of sodium, calcium, magnesium, it was observed that exchangeable sodium %age was below 15. Chloride content in soil was observed within medium range (10-20 mg/kg) for plant growth.

It may be concluded from the study that high concentrations of arsenic, lead and iron were found in the groundwater of nearby area of industrial cluster at several locations. This can cause several diseases in human body such as slight increase in blood pressure, cardiac arrest, skin, bladder and lungs cancer. It may also affect crop growth in terms of shrink of root, stem, chlorosis, turning of young leaves into white and necrotic which can be resulted into decrease in grain yield.

4.1.2. Development of Water Production Function for Different Crops under Tarai Conditions of Uttarakhand

The experiment was conducted to develop an optimum crop plan with given water supply and yield target, so that it may assist in developing sustainable water resources utilization plan for crop rotation. The experiment was conducted with 36 lysimeters associated with 30, 60 and 90 cm water table depths. Crop rotation was carried out with rice cv. Pant Dhan-12 during *kharif* season of 2015, yellow mustard cv. Pant Yellow Sarson-1 during *rabi* season 2014-15 and cowpea cv. Pant Lobia-1 during summer season of 2015. For rice, 7.5 cm irrigation was given after every three days after disappearance of ponded water. For mustard, six irrigation treatments based on IW:CPE ratios were applied using flood and sprinkler methods. Cowpea was grown with three irrigation treatments using flood and sprinkler methods.

The average yield of rice was 4.41 t/ha, obtained with an average water requirement of 683.53 mm and 6.51 kg/ha-mm WUE. There was well distribution of rainfall from June to October 2015 which helped rice to grow well.

Yellow Mustard: The total water use by the yellow mustard crop was highest (651.5 mm) at IW:CPE 0.5 by flood method under 30 cm water table depth (Table 4.1.4). More water was required to maintain shallow water table depth as compared to deep water table depths of 60 and 90 cm. This trend was common irrespective of irrigation methods and irrigation schedules. Among water table depths, 30 cm water table required 422 mm of water and the amount decreased by 22.1% and 47.4% for 60 and 90 cm water table depths (Table 4.1.4). The total crop water use also varied in similar fashion. Mustard yield was highest when water table was maintained at 30 cm and decreased by 109 and 387 kg/ha at 60 and 90 cm water table depths, respectively. Among the water

Table 4.1.3. Physico-chemical properties of soil samples of agricultural field

Soil parameters	Characteristics	Location	Depth		
			0-5 cm	50 cm	100 cm
pH	Slightly acidic (6.1-6.5)	F3	7.3	8.5	7.9
	Neutral (6.6-7.3)	G3	8.1	8.4	8.6
	Moderately alkaline (7.4-8.4)	H2	8.4	8.4	8.2
		Avg.	**7.9**	**8.4**	**8.2**
EC	Low (<1000 µs/cm)	F3	160	120	110
	Medium (1000-2500 µs/cm)	G3	160	100	80
	High (>2500 µs/cm)	H2	250	170	170
		Avg.	**190**	**130**	**120**
Cl	Low (5-10 mg/kg)	F3	9.94	11.36	12.78
	Medium (10-20 mg/kg)	G3	9.94	11.36	12.78
	High (20-50 mg/kg)	H2	19.88	15.62	14.2
		Avg.	**13.3**	**12.8**	**13.3**
Ca	Low (<300 mg/kg)	F3	105.81	57.71	52.71
		G3	115.23	80.16	86.08
	Normal (>300 mg/kg)	H2	57.71	64.12	105
		Avg.	**92.9**	**67.3**	**81.3**
Mg	Low (<120 mg/kg)	F3	19.46	18.03	19.12
		G3	22.02	13.62	15.38
	Normal (>120 mg/kg)	H2	82.44	33.64	48.75
		Avg.	**41.3**	**21.8**	**27.8**
Na	ESP <15 (saline soil)	F3	9	5	4
		G3	6	3	2
	ESP >15 (alkaline or saline-alkaline soil)	H2	18	12	14
		Avg.	**11**	**6.7**	**6.7**
K	Low (<108 mg/kg)	F3	12	3	5
	Medium (108-280 mg/kg)	G3	19	4	6
	High (>280 mg/kg)	H2	14	13	19
		Avg.	**15**	**6.7**	**10**

table depths, WUE was highest at 60 cm. Sprinkler method of irrigation was superior to flood method for seed yield and WUE. Total water use and groundwater contribution were however, also higher in sprinkler method. The mean grain yield was decreased as the irrigation frequency was increased (Table 4.1.4). It was the maximum at IW:CPE 0.50 (971 kg/ha) and lower at IW:CPE 1.00 (860 kg/ha). The WUE was comparable between IW:CPE ratio 0.50 and 0.75 but was the lowest at 1.00 (1.74 kg/ha-mm).

Table 4.1.4. Water use parameters of yellow mustard under different treatments during *rabi* season 2014-15

Treatments	Groundwater contribution (mm)	Total water use (mm)	Seed yield (kg/ha)	Water use efficiency (kg/ha-mm)
Water table depths (cm)				
30	422.0	573.4	1072	1.88
60	328.6	480.0	963	2.02
90	222.2	373.6	685	1.83
Irrigation methods				
Flood	320.5	460.1	797	1.74
Sprinkler	328.1	491.1	1016	2.08
Irrigation schedules				
IW:CPE 0.50	358.0	486.0	971	1.99
IW:CPE 0.75	300.8	443.8	889	2.00
IW:CPE 1.00	314.0	597.0	860	1.74

Data on interactive effect of various factors tested (Table 4.1.5), shows that at all the irrigation schedules and methods, seed yield and WUE were higher with 30 cm water table depth. In sprinkler method, the yield was higher at all the levels of irrigation application. WUE also showed similar results, except with 60 cm water table depth and IW:CPE 0.75. The reduction in seed yield with increase in water table depth was more in flood method as compared to sprinkler method. Frequent irrigation in sprinkler method might have maintained better moisture regime in the top zone of the soil and therefore produced higher seed yield. But WUE was in the order of 60 cm>30 cm> 90 cm. Sprinkler method of irrigation had higher WUE than flood method in almost all the irrigation schedules and water table depths.

Table 4.1.5. Seed yield (kg/ha) and water use efficiency (kg/ha-mm) of yellow mustard under different treatments in lysimeters

Water table depth (cm)	IW : CPE 0.50		IW : CPE 0.75		IW : CPE 1.00	
	Flood	Sprinkler	Flood	Sprinkler	Flood	Sprinkler
Seed yield						
30	1086	1325	781	1212	981	1046
60	981	1124	846	1087	791	947
90	486	821	568	840	657	740
Water use efficiency						
30	1.67	2.41	1.72	2.13	1.65	1.69
60	1.87	2.48	2.16	2.00	1.68	1.92
90	1.33	2.21	1.85	2.12	1.74	1.75

The research findings indicate that sprinkler irrigation method recorded higher seed yield and WUE of yellow mustard than flood irrigation. Shallow water table depth (30 cm) was more suitable for this crop. Even at deeper water table depths, sprinkler method was superior over flood method. IW:CPE ratio 0.50 (2 irrigations) along with 73.3 mm rainfall was adequate to produce good seed yield of yellow mustard.

Cowpea: The number of irrigations required at 100, 150 and 200 mm CPE were 6, 4 and 3, respectively during the entire summer season. To maintain groundwater table at 30 cm, highest 1328.4 mm water was needed in 200 mm CPE schedule with flood method. However, it was 1308.6 mm under sprinkler method when irrigation was scheduled at 100 mm CPE (Table 4.1.6).

Interaction effects of different factors showed that WUE of 1.10 kg/ha-mm was maximum under 60 cm water table where six irrigations were scheduled by flood method based on 100 mm CPE, which was near at par in the same treatment under sprinkler method of irrigation (Table 4.8.3). The WUE was lowest (0.70 kg/ha-mm) under 30 cm water table where three irrigations were given based on 200 mm CPE. The maximum seed yield of 1408.2 kg/ha was obtained under 60 cm water table where 6 irrigations were given based on 100 mm CPE by flood method followed by 1356 kg/ha under same treatment receiving same number of irrigations by sprinkler method. However, grain yield of 789.2 kg/ha was obtained under 90 cm water table where 3 irrigation were given based on 200 mm CPE by sprinkler method followed by 850.6 kg/ha under same treatment receiving same number of irrigations by flood method (Table 4.1.6).

Table 4.1.6. Water use, grain yield and water use efficiency (WUE) of cowpea

Irrigation treatment and Water table depth	Groundwater contribution (mm)	Total water applied (mm)*	Total water use (mm)	Seed yield (kg/ha)	WUE (kg/ha-mm)
100 mm CPE, Flood					
30 cm	1254.4	258.3	1512.7	1264	0.84
60 cm	1026.8	258.3	1285.1	1408	1.10
90 cm	865.4	258.3	1123.7	1026	0.91
100 mm CPE, Sprinkler					
30 cm	1308.6	198.3	1506.9	1135	0.75
60 cm	1146.6	198.3	1344.9	1356	1.01
90 cm	946.2	198.3	1144.5	985	0.86
150 mm CPE, Flood					
30 cm	1279.6	198.3	1477.9	1125	0.76
60 cm	1078.6	198.3	1276.9	1248	0.98
90 cm	906.3	198.3	1104.6	863	0.78
150 mm CPE, Sprinkler					
30 cm	1206.8	158.3	1365.1	1311	0.96
60 cm	990.5	158.3	1148.8	1213	1.06
90 cm	876.5	158.3	1034.8	927	0.90
200 mm CPE, Flood					
30 cm	1328.4	168.3	1496.7	1048	0.70
60 cm	1121.6	168.3	1289.9	1247	0.97
90 cm	926.4	168.3	1094.7	851	0.78
200 mm CPE, Sprinkler					
30 cm	1287.6	138.3	1425.9	1048	0.74
60 cm	1046.3	138.3	1184.6	1127	0.95
90 cm	904.6	138.3	1042.9	789	0.76

* (Irrigation + Rainfall)

In summer season, limited irrigation depth (3 cm) produced better grain yield than sprinkler (2 cm). Due to less irrigation depth, sprinkler method had slightly higher WUE (0.89 kg/ha-mm) than flood method (0.87 kg/ha-mm). Irrigation application at 150 mm CPE was optimum as it had comparable grain yield and WUE with 100 mm CPE, but required less irrigation water.

Table 4.1.7 shows that seed yield of cowpea was comparable at 30 and 60 cm water table depths, but considerably lower at 90 cm depth (907 kg/ha). The groundwater contribution and total crop water use was the maximum at 30 cm water table depth but had the lowest WUE (0.79 kg/ha-mm). Limited irrigation as flood method produced comparable yield to sprinkler method of irrigation. Irrigation to cowpea may be applied at 150 mm CPE value. Seed yield and water use efficiency of cowpea under different treatments in lysimeters is shown in table 4.1.8.

Table 4.1.7. Seed yield and water use parameters of cowpea cv. Pant Lobia-1 during 2015

Treatments	Groundwater contribution (mm)	Total water use (mm)	Seed yield (kg/ha)	Water use efficiency (kg/ha-mm)
Water table depths (cm)				
30	1277.6	1464.2	1156	0.79
60	1068.4	1255.0	1267	1.01
90	904.2	1090.9	907	0.83
Irrigation methods				
Flood	1087.5	1295.8	1120	0.87
Sprinkler	1079.3	1244.3	1099	0.89
Irrigation schedules				
100 mm CPE	1091.3	1319.6	1196	0.91
150 mm CPE	1056.4	1234.7	1115	0.91
200 mm CPE	1102.5	1255.8	1018	0.81

Table 4.1.8. Seed yield (kg/ha) and water use efficiency (kg/ha-mm) of cowpea under different treatments in lysimeters

Water table depth (cm)	IW : CPE 0.50		IW : CPE 0.75		IW : CPE 1.00	
	Flood	Sprinkler	Flood	Sprinkler	Flood	Sprinkler
Seed yield						
30	1264	1135	1125	1311	1048	1048
60	1408	1356	1248	1214	1247	1127
90	1026	985	863	927	851	789
Water use efficiency						
30	0.84	0.75	0.76	0.96	0.70	0.74
60	1.10	1.01	0.98	1.06	0.97	0.95
90	0.91	0.86	0.78	0.90	0.78	0.76

4.1.3. Determination of Crop Coefficients for Mustard and Cowpea

Evapotranspiration and crop coefficient (K_c) are the key to irrigation management decision. Values of crop coefficients for yellow mustard cv. Pant Yellow Sarson-1 and for cowpea cv. Pant Lobia-1 were computed based on ET_p (Jensen-Haise method, 1963) and crop ET (determined by lysimeters) for three consecutive years 2012-13, 2013-14 and 2014-15 are presented in table 4.1.9. The average K_c for Pant Yellow Serson-1 is 0.61 ranging from 0.18 at sowing time to 1.22 at stage of flowering and pod formation stage. Kc values increased till 11th week and decreased thereafter K_c values for Pant Lobia-1 ranged from 0.23 at sowing time to 1.46 at pod formation stage, with an average value of 0.88.

Table 4.1.9. Crop coefficients (K_c) for yellow mustard cv. Pant Yellow Sarson-1 and for cowpea cv. Pant Lobia-1 at Pantnagar

Weeks after sowing	Yellow mustard	Cowpea
1	0.18	0.23
2	0.40	0.54
3	0.58	0.56
4	0.60	0.67
5	0.68	0.77
6	0.70	0.78
7	0.52	0.86
8	0.77	0.80
9	0.87	0.99
10	0.74	1.04
11	1.22	1.46
12	0.80	1.32
13	0.60	1.00
14	0.52	0.82
15	0.42	0.71
16	0.36	0.55
17	0.39	-
Mean	**0.61**	**0.88**

4.2. Ludhiana

4.2.1. Estimation of Carbon Emissions for Groundwater Pumping in Central and Southwest Punjab

Carbon emission for groundwater pumping in Central and southwest Punjab was estimated using Geoinformatics.

Central Punjab

Punjab has 98% of the net area sown as irrigated. The irrigated areas from canals and tubewells in the state are 28% and 72% of the total area, respectively. This has led to overexploitation of groundwater resources through energized tubewells numbered at 13.83 lakh in the state. Up to 1995, average fall of water table in Punjab was about 23 cm per year, which during the next 6 years (1997-2003) increased to 53 cm per year and was about 51.5 cm per year during 1998 to 2006. A study was planned to understand the variation in carbon emissions due to groundwater pumping in central Punjab using geoinformatics under four zones, namely UB-III, BD-III, SC-III and BM-III. A choropleth maps of tubewell density were prepared, the maps of groundwater draft, energy consumption and carbon emissions were prepared in GIS. The groundwater draft during monsoon season is presented in fig. 4.2.1.

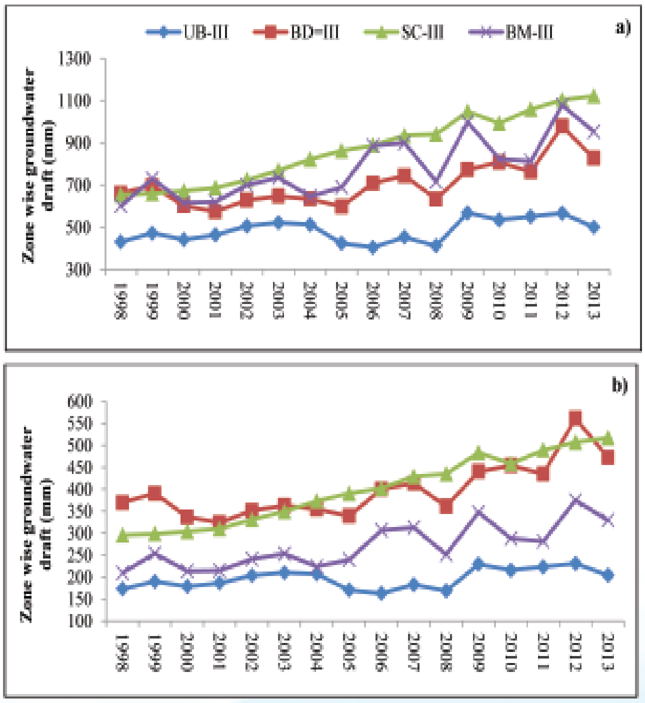


Fig. 4.2.1. Monsoon (a) non-monsoon (b) season groundwater draft (mm) in different zones

Increase in groundwater draft and water table depth resulted in increase of energy requirement in agricultural sector over the years. The overall energy required for groundwater pumping in central Punjab was 3074.5 MkWh in 1998 which increased to 7919.6 MkWh (90%) in 2013 (Fig. 4.2.2). Of this, energy requirement during monsoon season varied from 2098.5-5379.7 MkWh and non-monsoon energy requirement varied from 976.0- 2540.0 MkWh during the study period.

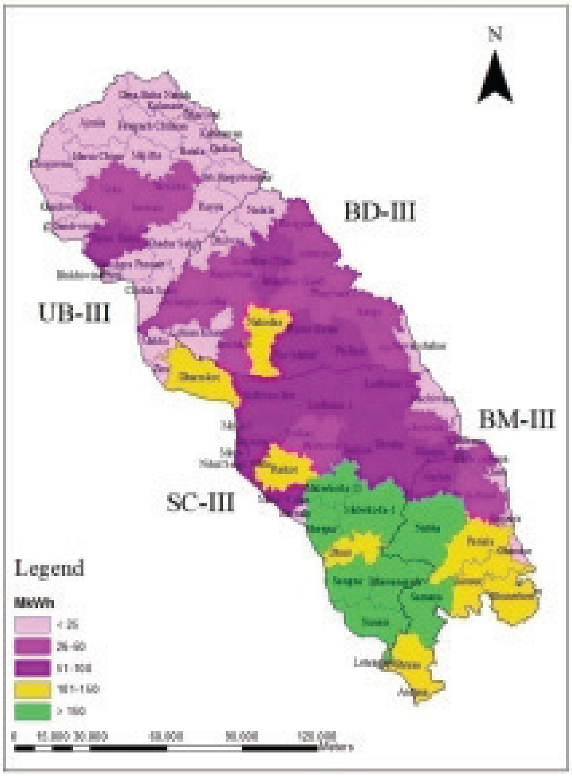


Fig. 4.2.2. Change map of energy requirement in central Punjab from 1998-2013

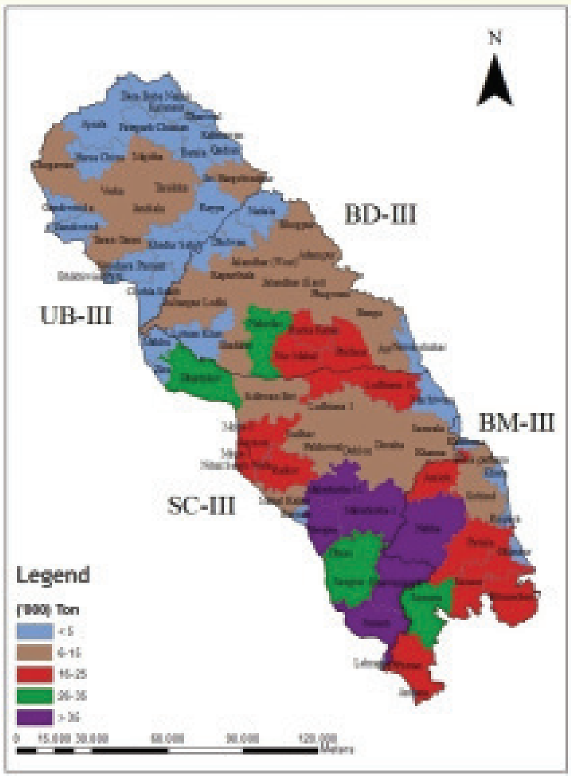


Fig. 4.2.3. Change map of C-emission in central Punjab from 1998-2013

Amongst the four zones, UB-III had the lowest and SC-III had highest contribution to C-emissions (Fig. 4.2.3). However, BM-III region followed fluctuating trend from 2003 to 2013. In UB-III, C-emissions increased from 57 ('000) to 150 ('000) tonnes, whereas in SC-III the C-emissions increased from 143.6 ('000) to 660 ('000) tonnes. Similarly, the increase in C-emissions in BD-III and BM-III was from 100 ('000) to 276 ('000) tonnes and from 65 ('000) to 264 ('000) tonnes, respectively during the study period. Overall UB-III, BD-III, BM-III and SC-III witnessed 162%, 176%, 304% and 360% increase in C-emissions, respectively.

South-west Punjab

The spatio-temporal variation in energy consumption due to groundwater pumping in southwest Punjab (Zone I and II) was quantified and emission rate with groundwater levels were correlated. Electrical pumpset density per 1000 ha in southwest Punjab was 301 in 1998 and increased to 659 in 2014 for zone-I and was 92 in 1998 and this increased to 184 in 2014 for zone II during the study period. The groundwater draft was highest in zone-I during the monsoon season and non-monsoon period. This can be attributed to high tubewell density in zone-I. In zone-II, monsoon groundwater draft increased from 11597 to 20760 ha-m during the study period. Time series analysis of water table revealed that in zone-I and zone-II, the water table depth declined from 9.8-25.1 m to 5.3-9.1 m, respectively during the study period. The overall energy required for groundwater pumping in southwest Punjab was 1158 MkWh in 1998, which increased to 5216 MkWh (90%) in 2014. The temporal analysis of energy requirement has been presented in fig. 4.2.4.

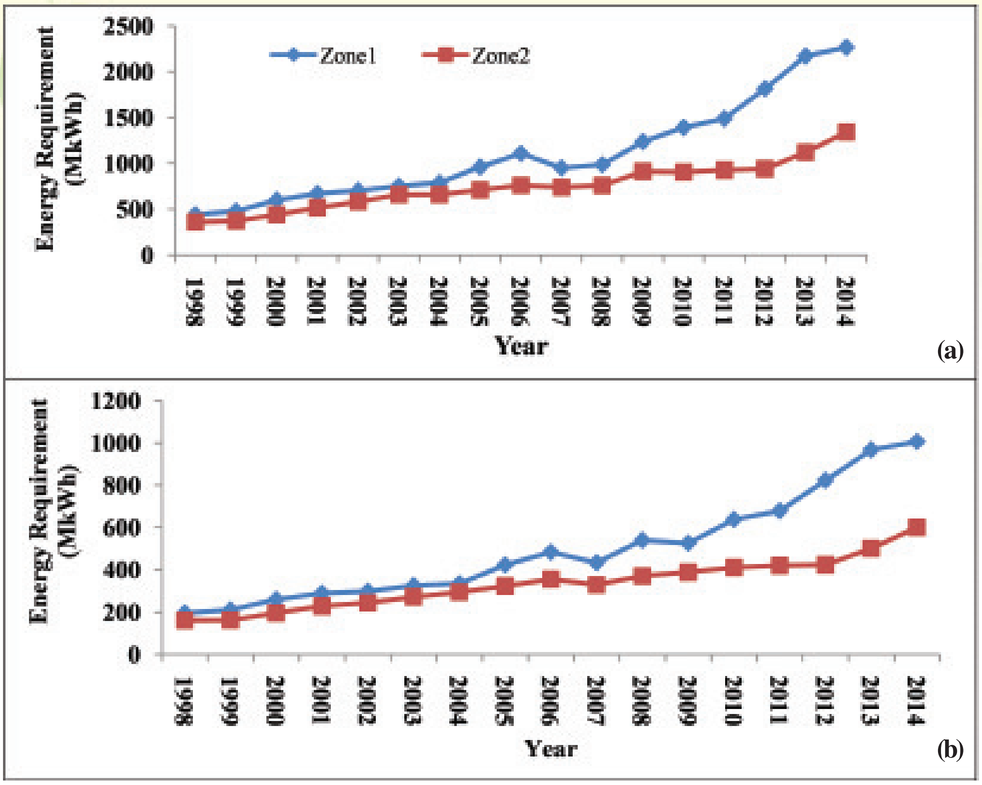


Fig. 4.2.4. Zone-wise energy requirement (MkWh) during (a) monsoon and (b) non-monsoon seasons

The overall C-emissions of southwest Punjab had increased from 94.4 ('000) to 536.0 ('000) tonnes from 1998 to 2014. Of this, C-emissions from electrical tubewells ranged from 90.9-530.0 ('000) tonnes and diesel tubewells ranged from 3.4-3.9 ('000) tonnes during the study period. Blocks namely Barnala, Sangrur, Sherpur and Sunam of zone-I witnessed a change of more than 35 ('000) tonnes in C-emissions from 1998 to 2014. The rate of C-emissions with every metre decline in groundwater table was computed for two zones (Fig. 4.2.5 and 4.2.6).

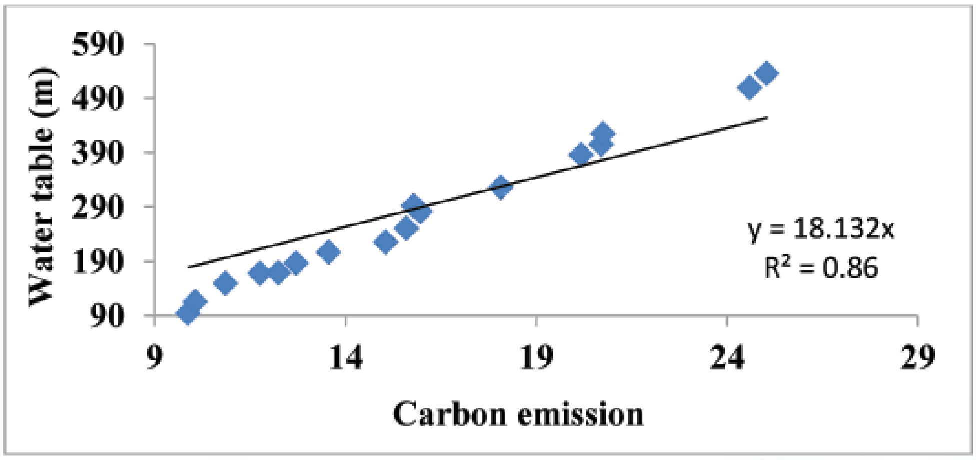


Fig. 4.2.5. Relationship between carbon emissions ('000 tonnes) and water table in zone-I of southwest Punjab

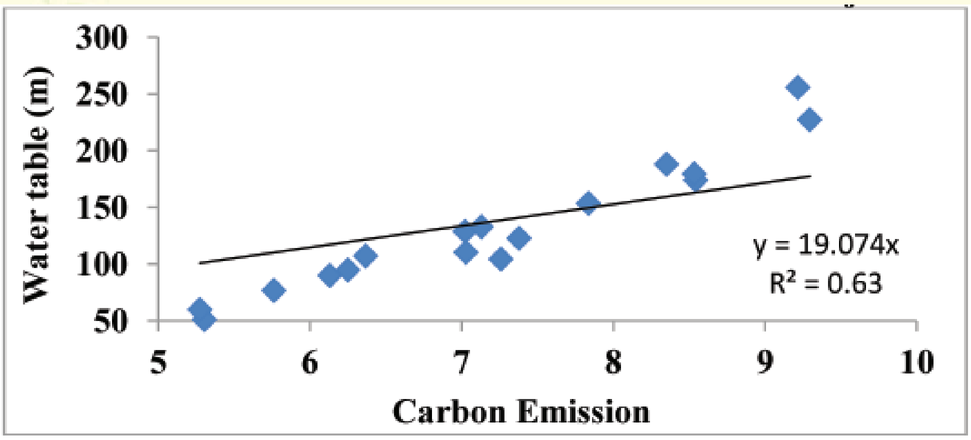


Fig. 4.2.6. Relationship between carbon emissions ('000 tonnes) and water table in zone-II of southwest Punjab

4.2.2. Development of Low Cost Nano Filter for Removal of Arsenic from Groundwater

An acrylic sheet box of height 70 cm, width 20 cm and thickness 12 cm was used for fabrication of filter. The filter is divided into three parts i.e. reservoir tank, material container and filtered storage tank as shown in fig. 4.2.7. The dimension of reservoir tank and filtered storage tank is 20×20×12 cm. It can store water upto 4.8 litres. The dimension of material container is 30×20×12 cm.

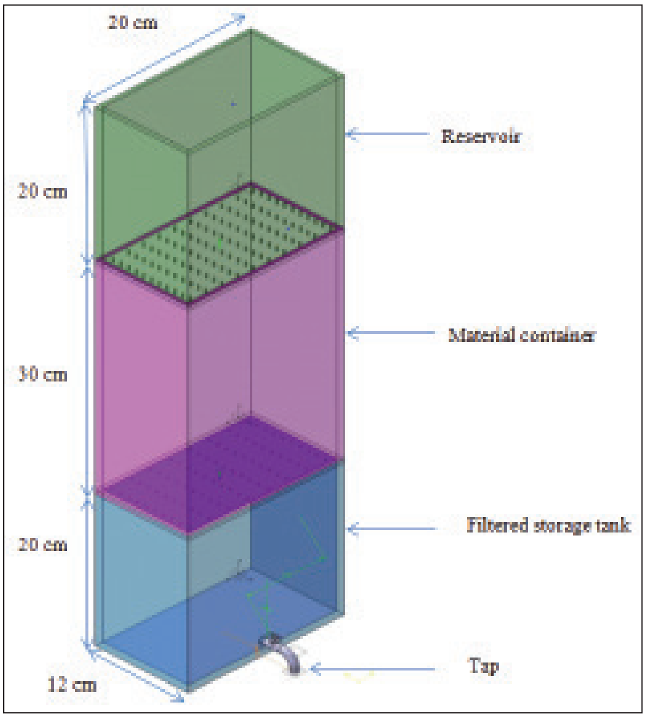


Fig. 4.2.7(a). Schematic diagram of developed filter

Fig. 4.2.7(b). Uncoated sand filled in material container

A lab study was conducted for the removal for As(III) through the uncoated sand and charcoal at different thickness 5, 7.5 and 10 cm and at different flow rates of 1, 2, 4 and 7 l/h for adsorption time of 30, 120 and 240 minutes respectively. The initial and final concentration of As(III) after passing through the filter media remained same i. e. As(III) was not removed by uncoated sand and charcoal. The effect of adsorption time, thickness and flow rate on As(III) removal efficiency was studied and presented in fig. 4.2.8 and 4.2.9. It is observed that at a particular thickness of filter media (IOCS) as the flow rate increases, the As(III) removal efficiency decreases. As the thickness of filter media (IOCS) was increased from 5 to 10 cm, there was relatively more improvement in As(III) removal efficiency at flow rate of 1 l/h for adsorption time of 120 minutes.

So it was concluded that the maximum As(III) removal efficiency was 100 % for initial concentration of 0.25 and 0.10 mg/l respectively for thickness of filter media (IOCS) 10 cm at flow rate of 1 l/h for adsorption time of 120 minutes.

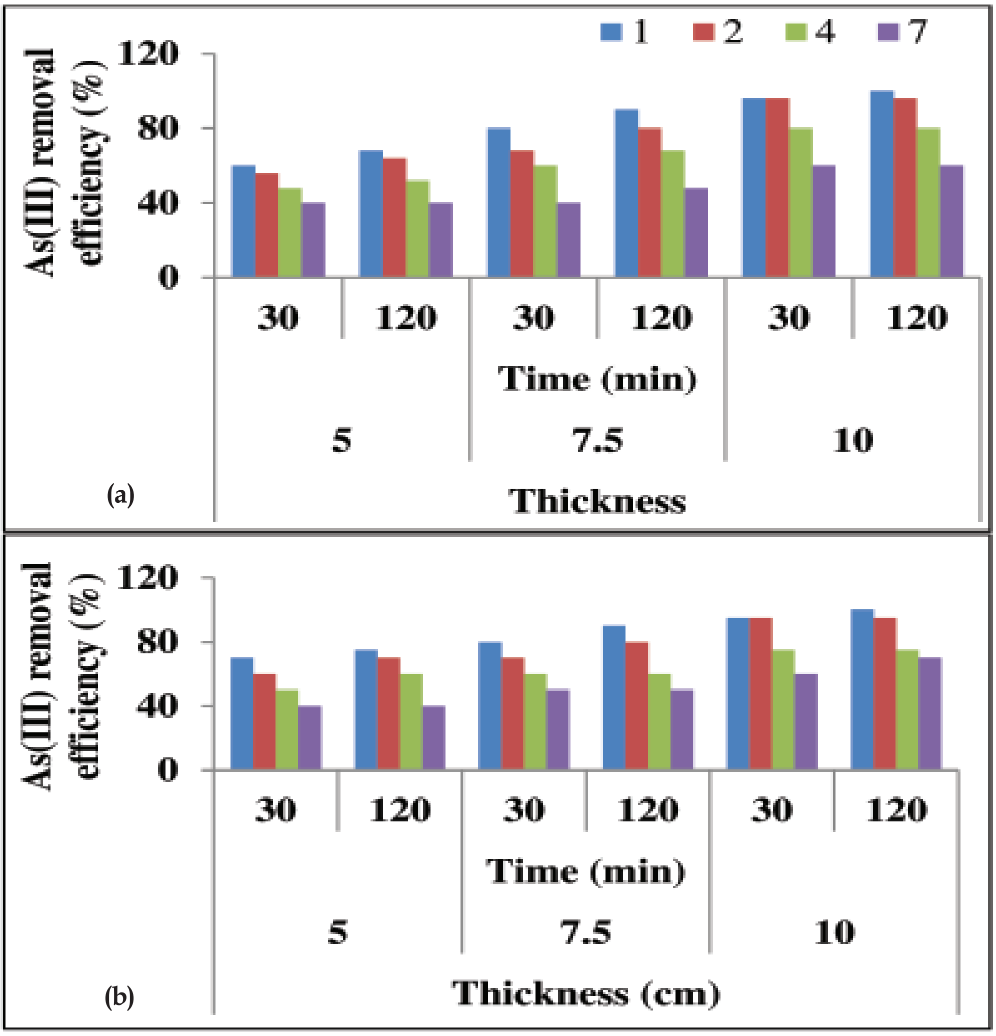


Fig. 4.2.8. Effect of adsorption time, thickness and flow rate (1, 2, 4 and 7 l/h) on As (III) removal efficiency for initial concentration (a) 0.25 mg/l and (b) 0.10 mg/l

As(III) contaminated groundwater sample was taken near Buddha Nullah in village Wallipur, Ludhiana having initial concentration of As(III) as 0.08 mg/l. The groundwater sample was passed through filter having thickness of filter media as 10 cm at flow rate of 1 l/h for adsorption time of 30 and 120 minutes. The results revealed that final concentration of As(III) was 0.005 and 0.0 mg/l at flow rate of 1 l/h for adsorption time of 30 and 120 minutes respectively which was less than maximum permissible limit of

0.01 mg/l. So it was concluded from the results that for As(III) concentrations less than 0.10 mg/l, thickness of filter media (IOCS) may be taken as 10 cm with a flow rate of 1 l/h and adsorption time 30 minutes. When As(III) contaminated groundwater was passed through iron oxide coated sand, initial and final MPN was 11. Similarly, when As(III) contaminated groundwater was passed through IOCS (thickness of filter media 10 cm) and charcoal (thickness of filter media 20 cm) final MPN observed was zero. So it can be concluded that charcoal helps to remove bacteria from groundwater and filtered water can be used for drinking purposes. Batch study results showed that iron oxide-coated sand (IOCS) can be effectively used to achieve a low level of As(III) in drinking water.

4.2.3. Evaluation of Cropping System Model for Estimation of Groundwater Use

An attempt has been made to simulate the water balance in rice using cropping system model and to develop relationships between the model parameters and the groundwater level. A field experiment was conducted during *kharif* season of 2014 on sandy loam (Typic Ustochrept) soil at research farm of Punjab Agricultural University, Ludhiana. There were 6 treatments, which were replicated three times in 18 plots of size 6×4 m^2 in a split-plot design. The treatments included: three dates of transplanting – June 6 (D_1), June 21 (D_2) and July 5 (D_3); one cultivars – PR121 (V) and two irrigation regimes – 2 day drainage (I_1) and tensiometer based (I_2). The meteorological data (daily maximum and minimum temperatures, rainfall, pan evaporation, sunshine hours, morning and evening relative humidity) was collected from the meteorological observatory of the Punjab Agricultural University, Ludhiana located at a distance of 100 m from the experimental field during the crop growing season (June to October). The experimental scale (0-15 cm) has pH = 6.67, EC = 0.23 dS m^{-1}, OC = 0.26 %, NH_4-N = 12.84 ppm, NO_3-N = 25.67 ppm, P = 44 kg ha^{-1}, K = 117.6 kg ha^{-1}, bulk density = 1.52 g cm^{-3}, K_{sat} = 0.04 cm h^{-1}, CEC = 9.91 meq/100 g, sandy loam texture and aggregate stability (MWD) = 0.25 mm. Rice yields and attributes in different treatments as influenced by transplanting date and irrigation regime are presented in table 4.2.1.

Table 4.2.1. Effects of transplanting date and irrigation regime on rice yield and yield attribute

Date	Irrigation	1000 grain weight (g)	Filled grain (%)	Grain loop (cm)	Yield (kg/ha)
D1	2 day drainage	25.9	89.8	21.3	5863.7
	Tensiometer	26.2	87.7	21.8	5923.2
D2	2 day drainage	28.9	89.7	21.8	6703.1
	Tensiometer	28.5	90.7	21.5	7884.6
D3	2 day drainage	28.2	93.5	21.2	5119.4
	Tensiometer	29.1	92.6	20.4	5902.6

Water balance in cropped soil is estimated by the equation

$$P + I = R + D + ÄS + ET \qquad (1)$$

where, P, I, R, D, ÄS and ET are precipitation, irrigation, runoff, drainage, change in soil water storage and evapotranspiration, respectively. The already calibrated and validated DSSAT model (Vashisht et al., 2013) was evaluated during 2014–15. Simulated grain yield matched reasonably with the observed yield of rice (Fig. 4.2.9) with RMSE = 0.09, ME = 0.99 and R^2 = 0.96.

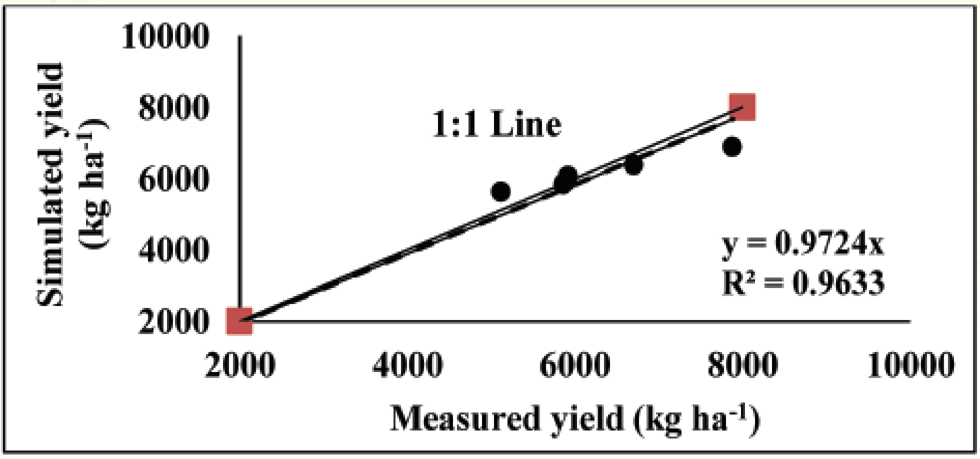


Fig. 4.2.9. Simulated and observed grain yields of rice under different treatments

The water use efficiency (WUE) was affected by different dates of sowing and irrigation treatments. The water use efficiency was maximum in treatment combination of D_2T_2 and minimum in D_3T_1 (Fig. 4.2.10).

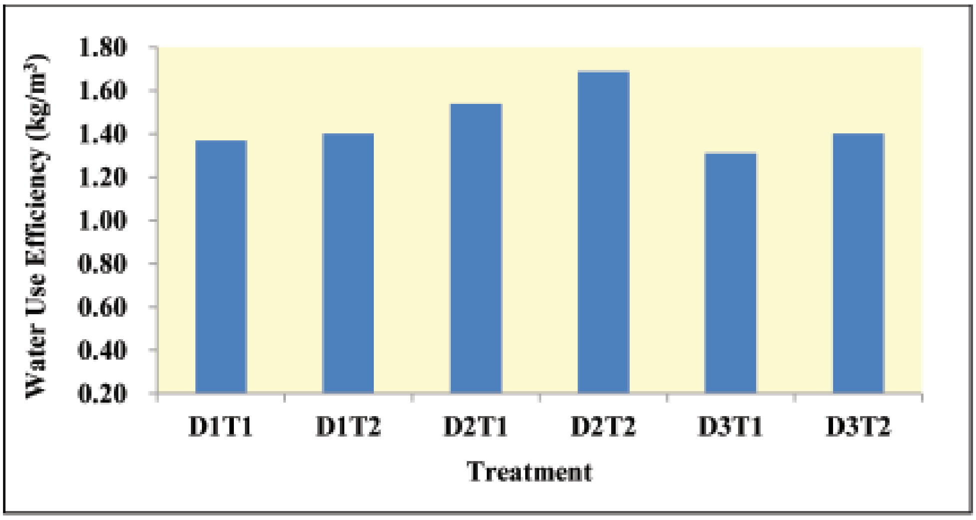


Fig. 4.2.10. Water use efficiency as influenced by different treatments

4.3. Coimbatore

4.3.1. Evaluation of Alternate Wetting and Drying Irrigation (AWDI) in Transplanted Rice in Western Zone of Tamil Nadu

An experiment was laid out in RBD to standardize the safe AWDI for transplanted rice in western zone of Tamil Nadu and to optimize the water productivity under AWDI. A PVC pipe of length 40 cm and diameter 15 cm with perforations on all sides was used. When ponded water dropped to 10, 15, 20 cm below the ground level, irrigation was given (Plate 4.3.1, 4.3.2 and 4.3.3).The irrigation water applied, effective rainfall and total water used were recorded under different irrigation treatments. Total water use was higher (1622.7 mm) under the current recommended farmers' practice of irrigation to 5 cm depth one day after disappearance of ponded water (T_8), while irrigation after 20 cm DPW from transplanting to 10 days prior to harvest (T_3) consumed lowest (972.7 mm) quantity of water (Table 4.3.1).

Table 4.3.1. Effect of treatments on water use and water use efficiency for second crop

Treatments*	Irrigation water applied (mm)	Effective rainfall (mm)	Total water used (mm)	Grain yield (kg/ha)	WUE (kg/ha-mm)	B:C
T_1	1150	272.7	1422.7	6772	4.76	2.68
T_2	750	272.7	1022.7	6529	6.38	2.43
T_3	700	272.7	972.7	6190	6.36	2.39
T_4	1020	272.7	1292.7	6878	5.32	2.75
T_5	1200	272.7	1472.7	6296	4.28	2.42
T_6	950	272.7	1222.7	6508	5.32	2.58
T_7	1100	272.7	1372.7	6825	4.97	2.68
T_8	1350	272.7	1622.7	5820	3.59	2.21

*T1 - Irrigation after 10 cm drop of ponded water (DPW) (from ground level) from (seven days after) transplanting to 10 days prior to harvest

T2 - Irrigation after 15 cm DPW from seven days after transplanting to 10 days prior to harvest

T3 - Irrigation after 20 cm DPW from seven days after transplanting to 10 days prior to harvest

T4 - Irrigation after 15 cm DPW upto maximum tillering stage (30-35 DAT) and 10 cm DPW upto 10 days prior to harvest

T5 - Irrigation after 15 cm DPW upto maximum tillering stage (30-35 DAT) and continuous submergence upto 10 days prior to harvest

T6 - Irrigation after 15 cm DPW upto panicle initiation stage (45-50 DAT) and 10 cm DPW upto 10 days prior to harvest

T7 - Irrigation after 15 cm DPW upto panicle initiation stage (45-50 DAT) and continuous submergence upto 10 days prior to harvest.

T8 - Farmers' practice – Irrigation to 5 cm depth one day after disappearance of ponded water

The grain yield and straw yield per plot were significantly not influenced among the various irrigation treatments. However, increased grain (21.7 kg/plot) and straw yield (32.3 kg/plot) were recorded in Irrigation after 15 cm DPW up to maximum tillering stage (30-35 DAT) and afterwards irrigation after 10 cm DPW up to 10 days prior to harvest. The lowest grain (18.3 kg/plot) and straw yield (22.7 kg/plot) were recorded in farmers' practice of irrigation to 5 cm depth one day after disappearance of ponded water.

Plate 4.3.1. Field water tube fixed in the experimental plot

Plate 4.3.2. Water level found inside the field water tube

Plate 4.3.3. DPW measurement inside the field water tube during irrigation

4.3.2. Studies on Alternate Wetting and Drying Irrigation Regimes Management through Field Water Tube Device in Rice in Western Zone of Tamil Nadu

The feasibility and efficiency of field water tube for alternate wetting and drying irrigation regime management in rice was studied to optimize water use for higher yield. A field experiment was laid out in split plot design. Main plot treatments were: I_1 - Safe Alternate Wetting and Drying (SAWD) irrigation after 15 cm DPW (from ground level) up to maximum tillering stage (50-55 DAT) and continuous submergence up to 10 days prior to harvest, I_2 - SAWD irrigation after 15 cm DPW up to panicle initiation (70-75 DAT) stage and continuous submergence up to 10 days prior to harvest and I_3- Maintain 2.5 cm of water up to 7 DAT and cyclic submergence throughout the crop period (Conventional irrigation). Sub-plot treatments include N_1- Farm Yard Manure @ 12.5 t/ha, N_2 - Vermicompost @ 5 t/ha, N_3- FYM @ 6.25 t/ha + Green manure (Sesbania aculeata) @ 6.25 t/ha and N_4 - Vermicompost @ 2.5 t/ha + Green manure (Sesbania aculeata) @ 6.25 t/ha with three replications. Rice variety Improved White Ponni was planted with spacing 20 cm x 15 cm.

Irrigation regimes and organic sources of nutrients had a profound influence on the grain yield of rice. Safe AWDI after 15 cm DPW up to panicle initiation and continuous submergence up to 10 days prior to harvest (I_2) recorded higher grain yield of 4364 kg/ha which was followed by safe AWDI after 15 cm DPW upto maximum tillering and continuous submergence upto 10 days prior to harvest (I_1). The lowest grain yield was recorded in conventional irrigation (I_3) with 4002 kg/ha. And application of vermicompost @ 2.5 t/ha + green manure @ 6.25 t/ha (M_4) registered higher grain yield of 4535 kg/ha and was superior to all other treatments.

Interaction effect between the treatments was significant (Table 4.3.2). At all irrigation regimes, vermicompost @ 2.5 t/ha + green manure @ 6.25 t/ha (M_4) was found to be better and at all organic sources of nutrients, irrigation at safe AWD after 15 cm DPW upto panicle initiation and continuous submergence up to 10 days prior to harvest (I_2) accounted for producing higher grain yields. Among the treatment combinations, I_2M_4 registered the higher grain yield of 4685 kg/ha and it was at par with I_1M_4 which recorded 4519 kg/ha. Interaction effect between the treatments was found significant. In all irrigation regimes, application of vermicompost @ 2.5 t/ha + green manure @ 6.25 t/ha (M_4) were obtained higher straw yield. At all organic sources of nutrients, I_2 had registered higher straw yield. Among the treatment combinations, I_2M_4 resulted in higher straw yield of 7163 kg/ha. The increased yield might be due to increased DMP, productive tillers, uptake of nutrients and source to sink conversion which resulted in higher grain yield. The higher straw yield registered in safe AWDI after 15 cm DPW upto panicle initiation stage and continuous submergence upto 10 days prior to harvest might be due to adequate moisture availability throughout the crop growth.

The irrigation treatments also showed considerable variation in WUE. Higher WUE of 4.13 kg/ha-mm was noticed under safe AWDI after 15 cm DPW upto panicle initiation and continuous submergence upto 10 days prior to harvest (I_2) followed by safe AWDI after 15 cm DPW upto maximum tillering and continuous submergence upto 10 days prior to harvest (I_1) with WUEof 3.59 kg/ha-mm. Lower WUE (3.3 kg/ha-mm) was observed under the conventional irrigation practice where 2.5 cm of water was maintained up to 7 DAT and cyclic submergence throughout the crop period (I_3).

The combination of irrigation and organic sources of nutrients showed the significant variation on water productivity in rice under organic farming. In irrigation regimes, higher water productivity (2521 l/kg) was found in safe AWDI after 15 cm DPW upto panicle initiation and continuous submergence upto 10 days prior to harvest (I_2). Conventional irrigation (I_3) recorded lower water productivity (3044 l/kg). The consumptive water use depends mostly on irrigation frequency and the quantity of water used by the crop. Water input (Irrigation plus effective rainfall) varied between 1057 to 1213 mm among the different irrigation regimes. The increased consumptive use of water registered in conventional practice of irrigation i.e. maintain 2.5 cm of water up to 7 DAT and cyclic submergence throughout the crop period was mainly due to more frequent irrigations with increased daily evapotranspiration. Lesser consumptive use of water was observed in safe AWDI after 15 cm DPW upto panicle initiation and continuous submergence upto 10 days prior to harvest was due to lesser number of irrigations and increased dry cycles with reduced evapotranspiration. Higher water productivity recorded by providing safe AWDI after 15 cm DPW upto panicle initiation stage and continuous submergence upto 10 days prior to harvest. This

Table 4.3.2. Effect of irrigation regimes and organic sources of nutrients on grain yield (kg/ha), straw yield (kg/ha), water use efficiency (kg/ha-mm) and water productivity (l/kg)

Treatment interaction	Grain yield	Straw yield	Water use efficiency	Water productivity	B:C
I_1M_1	3679	5759	3.22	3107	2.12
I_1M_2	3824	6079	3.35	2989	1.81
I_1M_3	4393	6780	3.84	2602	2.49
I_1M_4	4519	6929	3.95	2529	2.50
I_2M_1	3947	6187	3.73	2678	2.28
I_2M_2	4341	6497	4.11	2794	2.04
I_2M_3	4485	6804	4.24	2357	2.54
I_2M_4	4685	7163	4.43	2256	2.59
I_3M_1	3660	5553	3.02	3314	2.13
I_3M_2	3901	5901	3.22	3109	1.85
I_3M_3	4048	6432	3.34	2997	2.32
I_3M_4	4400	6871	3.63	2757	2.45

might be due to increasing ratio of grain yield to total water input levels of irrigation.

Gross return and net return was markedly influenced by irrigation and organic sources of nutrients practices.Combination of safe AWDI after 15 cm DPW upto panicle initiation and continuous submergence upto 10 days prior to harvest with application of vermicompost @ 2.5 t/ha + green manure @ 6.25 t/ha (I_2M_4) had recorded the highest gross return of Rs.88,957 per ha and net income of Rs.54,593 per ha with B:C ratio of 2.59. Safe AWDI after 15 cm DPW upto panicle initiation and continuous submergence upto 10 days prior to harvest with application of FYM @ 6.25 t/ha + green manure @ 6.25 t/ha (I_2M_3) registered second higher gross return of Rs.85,090 per ha and net return Rs.51,576 per ha with B:C ratio of 2.54. Conventional irrigation practice i.e. application of vermicompost @ 5 t/ha (I_3M_2) fetched lowest gross income Rs.73,988 per ha, net income Rs.33,924 per ha and B:C ratio 1.85. The increased net return and benefit cost ratio due to higher yield, followed by safe AWDI after 15 cm DPW upto panicle initiation and continuous submergence upto 10 days prior to harvest with application of FYM @ 6.25 t/ha + green manure @ 6.25 t/ha fetched the next higher net return and B:C due to reduced cost of cultivation.

4.4. Chalakudy

Soil Nutrient Dynamics under Varying Moisture Regimes in Banana

During the first year experiment (2012) with banana under drip irrigation, application of P at 75% and K at 125% of recommended dose of fertilizer was beneficial for growth and yield parameters of banana.The second year crop was sown in November 2014. In this crop, all fertilizer treatments performed uniformly. The study showed that P at 75% and K at 125% of RDF helped in increasing yield. It was also observed that higher level of K (125%) always performed better at all the three levels of P.

Among different methods of irrigation, basin irrigation resulted in significantly higher yield than drip irrigation (Table 4.4.1). This suggests that water requirement for banana is very high and saving water may negatively affect the yield. Banana being a succulent water loving plant, responds well to irrigation. But water being a limited resource, its efficient use is inevitable. Drip irrigation at 75% pan evaporation could save irrigation water and increased water use efficiency (Table 4.4.1).

With the study on soil nutrient dynamics under varying moisture regimes in banana it was found that has shown that application of T4 increased yield to an extent of 17.5% over the present recommendation. The results suggest that the recommendation of P_2O_5 could be reduced to 86 gm/plant instead of the present 115 g/plant (Table 4.4.2).

Table 4.4.1. Effect of irrigation methods and fertilizer levels on yield (kg/plant) of banana

Fertilizer levels	Irrigation methods		Mean
	Basin	Drip at 75% PE	
NPK-100-100-100	8.890	7.680	8.285
NPK-100-100-125	9.323	8.683	9.003
NPK-100-75-100	9.273	8.237	8.755
NPK-100-75-125	9.593	8.183	8.888
NPK-100-50-100	8.633	7.460	8.047
NPK-100-50-125	9.067	7.697	8.382
Mean	9.130	7.990	-

CD (0.05) for Factor A = 0.160; CD for Factor B = 0.277; CD for AxB = 0.391; CV = 2.699

Table 4.4.2. Effect of irrigation methods and fertilizer levels on P content (g/plant) in soil after harvest

Fertilizer levels	Irrigation methods		Mean
	Basin	Drip at 75% PE	
NPK-100-100-100	131.367	121.977	126.672
NPK-100-100-125	127.832	91.062	109.447
NPK-100-75-100	128.235	100.969	114.602
NPK-100-75-125	117.217	85.931	101.574
NPK-100-50-100	120.180	71.552	95.866
NPK-100-50-125	86.425	73.178	79.802
Mean	118.543	90.778	-

CD (5%) for A=4.43; B=7.67; AxB=10.84

4.5. Gayeshpur

4.5.1. Integrated Management of Irrigation Water and Fertilizers for Wheat Crop

The experiment was conducted to examine the integrated effect of fertilizer levels and irrigation schedule on yield and WUE of wheat. Grain yield and nutrient uptake of wheat were significantly influenced by irrigation and fertilizer levels. Among the three irrigation treatments (Table 4.5.1), grain yield was highest (3344 kg/ha) with irrigation at 20% MAD of ASM. Grain yield was relatively higher in high frequency irrigation than in low frequency irrigation, which resulted in drastic reduction in yield owing to increasing water stress condition regardless of fertilizer levels. On the other hand, grain yield was increased with incremental increase in fertilizer application and the highest yield was obtained with fertilizer level of 160:80:80. Increasing fertilizers doses also had greater impact on grain yield augmentation even in water stress conditions. Reduction in yield was greater between irrigation at 40% and 60% MAD of ASM than between irrigation at 20% and 40% MAD of ASM at all the fertilizer treatments. Maximum grain yield of 4087 kg/ha was received from irrigation at 20% MAD of ASM with 160:80:80 kg/ha of $N:P_2O_5:K_2O$ fertilization.

The uptake of NPK nutrients almost followed the same trends as in grain yield. Among the irrigation treatments, maximum nutrients uptake of 89.3, 23.3 and 72.8 kg for N, P and K per hectare had taken place with highest irrigation frequency at 20% MAD of ASM, which also resulted in highest yield (3344 kg/ha) among the treatments. Among the fertilizer treatments, nutrient uptake was highest with fertilization level of 160:80:80, followed by lower levels of fertilizations.

Table 4.5.1. Effect of irrigation and fertilizer levels on the grain yield, water use and water use efficiency of wheat during 2014-2015

Treatments	Grain yield (kg/ha)	Water use efficiency (kg/ha-mm)	Nutrient uptake (kg/ha)		
			N	P	K
Irrigation schedules (ASMD)					
I_1 - Irrigation at 20%	3344	5.50	89.3	23.3	72.8
I_2 - Irrigation at 40%	3182	7.62	81.5	22.1	68.6
I_3 - Irrigation at 60%	2830	10.52	70.9	19.8	63.5
CD at 5%	214	-	5.1	4.8	4.9
Fertilizer levels (kg/ha $N:P_2O_5:K_2O$)					
F_0 - 0:0:0 (control)	1780	4.49	47.4	12.8	39.8
F_1 - 80:40:40	3220	8.13	76.5	19.4	69.6
F_2 - 120:60:60	3611	9.11	93.7	24.7	78.7
F_3 - 160:80:80	3863	9.80	97.8	26.1	82.3
CD at 5%	282	-	6.7	4.3	5.1

Water use and water use efficiency by wheat crop varied with the levels of water and fertilizers application (Table 4.5.2). The total water use was found maximum (608.52 mm) was with irrigation scheduled at 20% MAD of ASM and minimum (268.87 mm) with irrigation at 60% MAD of ASM. Water use efficiency (10.52 kg/ha-mm) was highest with irrigation at 60% MAD of ASM, and lowest (5.50 kg/ha-mm) with irrigation at 20% MAD of ASM. Gradual increase of fertilizer input showed consistent increase in yield and WUE of wheat, irrespective of the levels of irrigation. Apparently, water use efficiency was higher where the frequency of irrigation was lowest, that is 60% MAD of ASW. Apparently, water use efficiency appeared to be higher where less irrigation and highest level of fertilizers (160:80:80 kg/ha $N:P_2O_5:K_2O$) applied and the level of fertilizer was highest, that is 160:80:80 kg/ha applied.

Table 4.5.2. Components of soil water balance, water use and water use efficiency of wheat under different irrigation schedules and fertilizer levels during 2014-2015

Treatment interaction	Profile contribution (mm)	Irrigation (mm)	Rainfall (mm)	Total water use* (mm)	Grain yield (kg/ha)	WUE (kg/ha-mm)
I_1F_0	15.95	550	24.2	610.15	1963	3.22
I_1F_1	10.85	550	24.2	605.05	3432	5.67
I_1F_2	12.98	550	24.2	607.18	3896	6.42
I_1F_3	17.49	550	24.2	611.69	4087	6.68
I_2F_0	20.91	350	24.2	415.11	1786	4.30
I_2F_1	23.28	350	24.2	417.48	3285	7.87
I_2F_2	27.20	350	24.2	421.4	3722	8.83
I_2F_3	19.98	350	24.2	414.18	3934	9.50
I_3F_0	23.26	200	24.2	267.46	1592	5.95
I_3F_1	27.18	200	24.2	271.38	2943	10.84
I_3F_2	22.25	200	24.2	266.45	3216	12.07
I_3F_3	25.98	200	24.2	270.18	3568	13.21

* including a common irrigation of 20 mm for seedling emergence

4.6. Jorhat

Greywater - Characterization and Influence on Soil Properties

The relatively clean wastewater from baths, sinks, washing machines, and other kitchen appliances, commonly known as greywater. In Assam, about 24340 lakh litres of greywater is wasted per day.

The experiment was planned to characterize the quality of greywater to find wayouts for reuse of the water for productive purposes. Greywater was characterized by analytically measuring selected wastewater constituents like on total nitrogen, nitrate (NO_3^-), ammonium (NH_4^+), orthophosphate, total suspended solids (TSS), alkalinity, chloride (Cl^-), Biochemical Oxygen Demand (BOD), dissolved oxygen (DO), pH and EC as per standard protocol (Table 4.6.1). Potential effects of different soil depths, loading rates, and differences in soil type on soil properties are being evaluated with the help of column study.

Table 4.6.1. Constituents of greywater

Constituent	Nov'14	Dec'14	Jan'15	Feb'15	Mar'15	Apr'15	May'15	Jun'15	Jul'15	Aug'15
DO (mg/l)	1.2	2.2	3	1.7	2.8	3	4.4	4.1	4.8	5
BOD (mg/l)	89	103	115	98	88	69	74	68	57	60
	Nov'14	Dec'14	Jan'15	Feb'15	Mar'15	Apr'15	May'15	Jun'15	Jul'15	Aug'15
TKN (mg/l)	14	24	26	21	18	14	14.2	13.1	12	11
NO_3-N (mg/l)	3	5	8	5	3	0	0	0	0	0
NH_4-N (mg/l)	5	9	10	12	8	6	5	7	5	4
	Nov'14	Dec'14	Jan'15	Feb'15	Mar'15	Apr'15	May'15	Jun'15	Jul'15	Aug'15
Alkalinity (mg/l)	89	102	98	112	97	74	79	69	48	52
TSS (mg/l)	31	47	56	51	48	32	30	19	15	12
Cl (mg/l)	132	147	144	131	108	100	87	68	72	59
EC (mS/cm)	1.841	1.913	2.019	1.859	1.898	1.125	1.059	0.958	0.989	1.001
	Nov'14	Dec'14	Jan'15	Feb'15	Mar'15	Apr'15	May'15	Jun'15	Jul'15	Aug'15
pH	6.6	6.5	6.5	6.7	6.9	7.2	7.4	7.5	7.4	7.4
PO_4-P (mg/l)	0.9	1.1	1.4	1.4	1.2	1.1	0.8	0	0	0

4.7. Navsari

4.7.1. Feasibility of Drip Irrigation in Summer Paddy

Results revealed that both the individual effects i.e., variety and drip lateral spacing as well as their interactiib effects were found to be significant on grain yield of paddy. Table 4.7.1 shows that GNR-3 (V_1) recorded significantly higher grain yield compared to NAUR-1 (V_2). Among the three lateral spacing treatments, treatment of L_1 (40 cm) was significantly superior over wider lateral spacing treatment i.e., L_2 (60 cm) and L_3 (80 cm). Treatment V_1L_1 (GNR-3 on closer lateral spacing at 40 cm) out-yielded rest of the treatments by recording significant higher grain yield of paddy (4823 kg/ha). Control-1 vs. treatment was significant whereas, control-2 vs. treatment was not significant for grain yield. This implies that variety GNR-3 performed better under flood irrigation as compared to drip. Method of irrigation did not statistically alter the grain yield of NAUR-1. Only control-1 vs. rest analysis was found to be significant on grain yield of paddy. Here, GNR-3 on closer lateral spacing (V_1L_1) recorded significantly higher grain yield of paddy as compared to flood irrigated GNR-3 (control-1).

Table 4.7.1. Grain yield (kg/ha) of summer paddy as influenced by different treatments

Treatment/ Variety	Spacing			Mean (V)
	L_1 (80 ls)	L_2 (60 ls)	L_3 (40 ls)	
V_1 – GNR-3	1570	2469	4823	2954
V_2 – NAUR-1	785	1211	2783	1593
Mean (S)	1178	1840	3803	2274
Control-1 (GNR-3) mean	2975	Control-2 (NAUR-2) mean	2031	–
Source	**V**	**S**	**V x S**	**–**
SEm±	102.6	83.8	145.2	–
CD @ 5%	297.0	242.0	419.3	–
-	**Control-1 vs. Rest**	**Control-2 vs. Rest**	**Control-1 vs. Treatment mean**	**Control-2 vs. Treatment mean**
SEm±	131.25	112.4	171.85	147.13
CD @ 5%	377.0	NS	494.0	NS
CV %	12.9	–	–	–

4.7.2. Drainage Demonstrations on Farmers' Fields in UKC

Since the completion of Indo-Dutch Network project in 2003, about 68 farmers have installed CSSD/OSSD system (Total-140.86 ha) covering about 69.59, 28.57 and 42.70 ha area with drain spacing of 30-40, 40-50 and 50-60 m, respectively in Surat, Bharuch, Tapi and Navsari district of South Gujarat under technical guidance of this unit. The cost of the system was borne by the farmers. These farmers are cultivating array of crops in CSSD/OSSD installed fields. On overall basis, they have reported about 15-40 % increase in crop yields from 2003 to 2015 (Table 4.7.2). Apart from yield increase, they also experienced early vapsa conditions in fields which facilitate timely interculturing and thereby minimize weeds and disease infestation in the crops. After this reporting year, only technical guidance about drainage technologies will be given to the farmers by experts of this unit.

Table 4.7.2. Details of SSD demonstrations completed on farmers' fields

Sl. No.	District	Drain spacing (m)	No. of farmers	Crops taken	Area covered (ha)			Increased yield over pre-drainage yield (%)
					CSSD	OSSD	Total	
1	Surat	30-40	22	S'cane Cotton	50.34	-	50.34	28.45
	Bharuch		4	S'cane Cotton	12.10	-	12.10	20-25
	Navsari		2	S'cane	-	-	-	-
				Banana Mango	-	-	-	-
				Vegetables Rose	5.40	-	5.40	30.35
	Tapi		1	Sugarcane	1.75	-	1.75	-
	Sub-total	**-**	**29**	**-**	**69.59**	**-**	**69.59**	-
2	Surat	40-50	19	S'cane	-	-	-	-
				Cotton Wheat	-	-	-	-
				Vetetable	25.47	1.50	26.97	15-40
	Bharuch		-	-	-	-	-	-
	Navsari		1	S'cane	-	-	-	-
				Vegetables	-	-	-	-
				Rose	1.60	-	1.60	30-40
	Sub-total	**-**	**20**	**-**	**22.07**	**1.50**	**28.57**	-
3	Surat	50-60	12	S'cane Cotton	-	-	-	-
				Wheat Mango	-	-	-	-
				Vegetable	-	-	-	-
				Sapota	20.40	2.0	22.40	20-50
	Bharuch		5	S'cane	7.80	10	17.80	30-40
	Navsari		2	Mango	-	-	-	-
				Sapota	2.50	-	2.50	15-20
	Sub-total	**-**	**19**	**-**	**30.70**	**12.0**	**42.70**	-
	Gross total	**-**	**68**	**-**	**127.36**	**13.50**	**140.86**	-

4.7.3 Study on Pit Method of Planting in Sugarcane under Drip Irrigation

The results of second ratoon crop of sugarcane experiment presented in table 4.7.3. The results revealed that sugarcane yield was significantly affected by the individual effects of pit diameter (D) and pit spacing (S) as well as their interaction effect. Treatment D_2 (142 t/ha) registered significantly higher yield as compared to treatment D_3 (132 t/ha), but remained at par with treatment D_1 (132.0 t/ha). Among the three spacings, yield with treatment S_2 (137 t/ha) and S_3 (129 t/ha) remained at par with each other.

Interaction effects of pit diameter and pit spacing (D x S) was significant on cane yield. The values of cane yield was significantly higher in D_2S_2 (151 t/ha) treatment as compared to rest of the treatment combinations, but it was statistically at par with treatment combination D_2S_1 (140 t/ha). With respect to control vs. rest analysis, the effect was significant; higher cane yield was registered with treatment mean than control.

Table 4.7.3. Second ratoon yield of sugarcane as influenced by different treatments

Treatments	Pit diameter (cm)			
Pit spacing (m)	D_1 (45 cm)	D_2 (60 cm)	D_3 (75 cm)	Mean
S_1 (1.5 x 1.5 m)	132	140	100	124
S_2 (1.75 x 1.75 m)	133	151	128	137
S_3 (2.1 x 2.1 m)	132	135	128	129
Mean	132	142	116	130
Control	115	-	-	-
		Sources		
Statistics	**S**	**D**	**S x D**	**Cont vs. Rest**
SEm±	3.0	3.0	5.2	1.65
CD at 5%	8.8	8.8	15.2	4.77
CV (%)	9.10	–	–	–
Total water applied	936.0 mm	–	–	–

4.8. Parbhani

Effect of Mulching and Drip Irrigation on Growth and Yield of Watermelon

The experiment was conducted I) to determine the water requirement of watermelon under mulching with drip irrigation and II) to study the effect of various mulches on growth and yield of watermelon. Watermelon yield is affected by different irrigation levels (Table 4.8.1). Irrigation at 0.6 PE (I_1) recorded lowest yield i.e. 7.59 t/ha whereas highest yield i.e. 9.65 t/ha was recorded when irrigation was applied at 0.8 PE. The application of irrigation at 1.0 PE recorded 9.47 t/ha watermelon yield during 2013-14. Similarly, during 2014-15 lowest yield i.e. 21.70 t/ha recorded when irrigation applied at 0.6 PE (I_1) whereas highest yield i.e. 29.01 t/ha was recorded when irrigation was applied at 1.0 PE. The application of irrigation at 0.8 PE recorded 27.87 t/ha watermelon yield. Results of the analysis of yield data further revealed that treatment I_2 (0.8 PE) and I_3 (1.0 PE) recorded significantly higher yield over treatment I_1. However yield recorded in treatment I_3 (1.0 PE) was found to be at par with treatment I_2 during 2013-14 and 2014-15. Maximum watermelon yield obtained in treatment I_2 and I_3 during 2013-14 and 2014-15, respectively.

Black polythene mulch (thickness = 30 micron), transparent polythene mulch (thickness = 30 micron) and soybean straw mulch (5 t/ha) were used to study the effect of different mulches on yield of watermelon. Yield data recorded under different mulches indicated that black polythene mulch recorded maximum yield i.e. 12.16 and 31.85 t/ha which was followed by transparent polythene mulch and soybean straw mulch, respectively during 2013-14 and 2014-15 (Table 4.8.1). Lowest yield i.e. 6.25 and 20.35 t/ha were recorded from the unmulched plot (M_4), respectively during 2013-14 and 2014-15. It is thus concluded that black polythene mulch gave significantly higher yield over rest of the treatments.

From table 4.8.1, it is revealed that treatment combination I_3M_1 recorded significantly higher yield over the treatment combinations I_1M_2, I_1M_3, I_1M_4, I_2M_3, I_2M_4, I_3M_2, I_3M_3 and I_3M_4. However yield recorded from treatment combination I_1M_1, I_2M_1, I_2M_2 were found to be at par with that of treatment combination I_3M_1. It is thus revealed that effect of interaction of irrigation and mulching was found in case of black polythene mulch and in transparent polythene mulch with irrigation treatment I_2 during 2013-14.

Effect of irrigation levels and mulches on water use efficiency: Table 4.8.1 shows that maximum water use

Table 4.8.1. Yield, water use and economics of watermelon under different irrigation levels and mulches and their interaction effects on yield during 2013-14 and 2014-15

Treatments	Watermelon yield (t/ha)		Water use efficiency (kg/ha–mm)		NMR (Rs./ha)	B:C
	2013-14	2014-15	2013-14	2014-15	2014-15	2014-15
Irrigation levels						
I_1 - Irrigation at 0.6 PE	7.59	21.70	29.50	54.38	45646	1.53
I_2 - Irrigation at 0.8 PE	9.65	27.87	28.14	52.46	81616	1.95
I_3 - Irrigation at 1.0 PE	9.47	29.09	22.08	43.81	86333	1.97
SE +	0.30	1.12	-	-	6764	-
CD at 5%	0.90	3.34	-	-	20292	-
Mulches						
M_1 - Black polythene mulch with drip	12.16	31.85	-	-	98758	2.06
M_2 - Transparent polythene mulch with drip	9.64	28.27	-	-	76124	1.84
M_3 - Soybean straw mulch with drip	7.55	24.42	-	-	61839	1.73
M_4 - Control (drip)	6.25	20.35	-	-	48069	1.64
SE +	0.35	1.18	-	-	6885	-
CD at 5%	1.02	3.50	-	-	20459	-
Interaction effects						
I_1M_1	11.51	-	44.76	62.45	-	-
I_1M_2	7.22	-	28.06	57.81	-	-
I_1M_3	6.28	-	24.4	52.22	-	-
I_1M_4	5.35	-	20.79	45.01	-	-
I_2M_1	11.74	-	34.24	65.32	-	-
I_2M_2	12.16	-	35.46	57.25	-	-
I_2M_3	8.38	-	24.44	47.13	-	-
I_2M_4	6.32	-	18.42	40.2	-	-
I_3M_1	**13.23**	-	30.87	54.08	-	-
I_3M_2	9.55	-	22.28	47.18	-	-
I_3M_3	8.00	-	18.66	41.23	-	-
I_3M_4	7.08	-	16.52	32.71	-	-
SE +	0.60	-	-	-	98798	-
CD at 5%	1.77	-	-	-	NS	-

efficiencies i.e. 29.50 and 54.38 kg/ha–mm were observed in treatment I_1 followed by treatments I_2 and I_3 during 2013-14 and 2014-15, respectively. The result shows that I_2 could be recommended to growers to save water under limited water conditions while taking the risk of lowered yield. Further, the interaction effects of irrigation levels and mulches show that that maximum water use efficiency was obtained in treatment combination I_1M_1 followed by I_2M_2, during 2013-14 whereas the maximum water use efficiency was obtained in treatment combination I_2M_1 followed by I_1M_1, during 2014-15.

Economics: Data furnished in table 4.8.1 revealed that application of irrigation through drip at 1.0 PE recorded significantly higher GMR (Rs. 1,74,555 per ha) and NMR (Rs. 86,333 per ha) than that obtained through 0.6 PE; however it was comparable with 0.8 PE in respect of both GMR (Rs. 167203 per ha) and NMR (Rs. 81616 per ha) during 2015. Similarly, higher B:C ratio was obtained in irrigation level 1.0 PE followed by 0.8 PE. With regards to mulches, significantly maximum GMR (Rs. 1,91,076 per ha) and NMR (Rs. 98,758 per ha) were noticed with black polythene mulch (M_1) as compared to rest of the mulches during 2015. Similarly, higher B:C ratio was obtained with black polythene mulch followed by transparent polythene mulch.

4.9. Udaipur

Characterization and Utilization of Wastewater in Vegetable Growing Areas of Haroti Region of Rajasthan

For characterization of wastewater in Haroti region, eight sites were selected in Bundi, nine each in Kota, Baran and Jhalawar districts, where wastewater is being used for irrigating vegetable crops. The major vegetable crops grown with the wastewater irrigation in the region are: cauliflower, cabbage, spinach, brinjal, radish, carrot, garlic, potato, coriander in winter season and onion, cucumber, ridge gourd, bottle gourd, okra, cluster bean, bitter gourd, pumpkin, brinjal and chillies in summer season but at some places at Bundi and Kota, this water is also being used for irrigating cereal crops, mustard and fodder crops especially oats, lucern (rijka) and berseem. The chemical characteristics of the samples collected are presented in table 4.9.1.

Table 4.9.1. Quality of wastewater in Haroti region during 2015-16

Location code	EC (dS/m)	pH	TDS (ppm)	Heavy metals (meq/l)							
				Fe	Mn	Cu	Zn	Cd	Pb	Cr	Ni
B-1	1.74	7.1	1080	0.070	0.048	0.043	0.084	0.009	0.055	0.099	0.011
B-2	2.50	6.8	1580	0.170	0.045	0.092	0.188	0.010	0.086	0.153	0.070
B-3	2.10	6.8	1310	0.149	0.151	0.093	0.168	0.008	0.069	0.130	0.076
B-4	1.99	7.0	1250	0.081	0.055	0.059	0.120	0.003	0.077	0.099	0.071
B-5	1.81	7.0	1150	0.095	0.040	0.065	0.129	0.008	0.060	0.081	0.008
B-6	2.10	6.7	1320	0.145	0.039	0.082	0.156	0.003	0.091	0.092	0.079
B-7	2.10	6.6	1370	0.150	0.159	0.093	0.180	0.007	0.095	0.113	0.100
B-8	1.99	6.5	1280	0.147	0.134	0.077	0.164	0.003	0.085	0.087	0.082
K-1	1.56	6.9	976	0.097	0.101	0.082	0.165	0.002	0.093	0.076	0.087
K-2	2.90	6.8	1810	0.199	0.208	0.182	0.355	0.515	1.135	0.589	0.701
K-3	2.30	6.5	1460	0.176	0.190	0.094	0.202	0.006	0.063	0.092	0.100
K-4	2.20	6.8	1370	0.160	0.172	0.100	0.202	0.716	0.120	0.129	0.399
K-5	2.80	6.8	1750	0.172	0.190	0.107	0.205	0.002	0.062	0.076	0.144
K-6	2.80	6.6	1740	0.156	0.170	0.097	0.197	0.311	0.067	0.061	0.073
K-7	2.90	6.6	1850	0.183	0.171	0.112	0.206	0.008	0.099	0.091	0.098
K-8	3.20	6.6	2030	0.191	0.198	0.163	0.241	0.003	0.046	0.051	0.059
K-9	2.20	6.9	1360	0.179	0.192	0.120	0.217	0.651	0.074	0.057	0.061

A-1	0.70	7.1	443	0.056	0.047	0.044	0.091	0.012	0.024	0.022	0.004
A-2	0.91	6.9	576	0.059	0.040	0.049	0.101	0.065	0.050	0.039	0.002
A-3	0.64	7.0	410	0.042	0.050	0.044	0.101	0.076	0.036	0.039	0.050
A-4	0.85	7.0	546	0.072	0.033	0.058	0.104	0.003	0.056	0.055	0.036
A-5	0.80	7.1	512	0.069	0.042	0.073	0.118	0.049	0.057	0.061	0.008
A-6	1.94	6.8	1210	0.089	0.047	0.069	0.135	0.117	0.100	0.102	0.009
A-7	2.20	7.0	1380	0.102	0.034	0.080	0.147	0.137	0.127	0.118	0.014
A-8	1.72	7.0	1070	0.100	0.050	0.069	0.129	0.078	0.080	0.101	0.006
A-9	1.74	6.8	1050	0.084	0.045	0.076	0.151	0.056	0.089	0.088	0.003
J-1	0.80	7.3	503	0.068	0.034	0.072	0.084	0.046	0.045	0.045	0.012
J-2	0.77	7.3	488	0.074	0.045	0.052	0.085	0.049	0.054	0.041	0.006
J-3	0.67	7.2	418	0.084	0.038	0.073	0.126	0.059	0.040	0.027	0.012
J-4	0.71	7.2	451	0.056	0.023	0.052	0.099	0.065	0.054	0.013	0.004
J-5	0.85	7.2	529	0.066	0.044	0.062	0.121	0.059	0.073	0.028	0.007
J-6	0.69	7.1	434	0.081	0.048	0.059	0.110	0.069	0.058	0.039	0.009
J-7	1.27	6.9	808	0.101	0.049	0.083	0.154	0.151	0.129	0.101	0.015
J-8	0.91	7.1	555	0.085	0.050	0.075	0.140	0.072	0.081	0.073	0.007

Four most polluted sites (B-2, K-2, A-7 and J-7) were selected (one site in each city) for sampling from Bundi, Kota, Anta and Jhalawar cities where common vegetable crops spinach, cabbage, cauliflower and garlic crops were grown. The edible parts of vegetable crops comprising leaves or fruits were collected randomly from the most polluted sites *viz.*, cabbage, cauliflower, spinach leaves and garlic cloves. The heavy metals *viz.*, iron, manganese, copper, zinc, cadmium, lead, chromium and nickel in the edible parts of the vegetableswere estimated using standard methods (Table 4.9.2). The maximum permitted level (MPL) of the heavy metals in edible parts of vegetables as provided by by WHO (1996) are 425, 500, 10, 100, 0.02 and 2.0 mg/kg for Fe, Mn, Cu, Zn, Cd and Pb, respectively. The wastewater of Bundi and Kota cities are found to have much more metallic concentrations to cause their accumulation in the wastewater irrigated vegetable crops to the toxic levels due to muddling/mixing of industrial and domestic wastewater together. The wastewater quality of Anta (Baran) and Jhalawar cities are good enough to reuse in irrigating the vegetable crops with a very little extent of heavy metal problems. Hence, the planning and development of safe agricultural farming systems for reuse of wastewater for irrigation in urban and peri urban areas in Haroti region of Rajasthan is essential.

Table 4.9.2. Heavy metal accumulation (mg/kg) in common vegetable crops at most polluted sites in Bundi and Kota during 2015-16 experiment

Crop	Metal	B-2 site of Bundi	K-2 site of Kota	A-7 site of Anta	J-7 site of Jhalawar
Spinach	Fe	351.24	415.32	336.75	323.49
	Mn	163.18	180.24	125.22	131.45
	Cu	14.68	20.69	9.19	8.65
	Zn	98.71	111.23	78.56	61.13
	Cd	0.08	0.14	0.04	0.05
	Pb	0.14	2.28	0.23	0.22
	Cr	1.45	3.02	1.51	1.30
	Ni	2.40	2.78	0.91	0.54
Cabbage	Fe	97.14	132.09	94.34	96.13
	Mn	149.68	164.02	160.12	144.24
	Cu	14.60	21.19	6.34	8.45
	Zn	85.72	111.36	92.12	56.98
	Cd	0.06	0.08	0.03	0.02
	Pb	0.13	1.78	0.12	0.74
	Cr	0.97	1.36	1.22	1.04
	Ni	1.22	2.98	1.15	1.34
Cauliflower	Fe	93.47	111.69	90.62	78.76
	Mn	132.68	174.57	123.44	111.54
	Cu	12.12	17.89	7.90	8.34
	Zn	73.18	93.23	75.38	82.57
	Cd	0.07	0.12	0.01	0.01
	Pb	0.12	0.60	0.11	0.12
	Cr	0.85	1.41	0.67	0.44
	Ni	1.02	2.19	0.98	0.91
Garlic	Fe	343.54	441.33	311.14	340.25
	Mn	75.33	91.90	58.44	81.91
	Cu	12.58	16.67	9.88	7.22
	Zn	60.44	132.68	44.48	70.11
	Cd	0.12	0.17	0.02	0.01
	Pb	1.07	1.50	1.11	1.22
	Cr	1.59	2.09	1.12	1.14
	Ni	1.44	1.61	1.22	1.84

4.10. Almora

Effect of Tillage and Irrigation on Rice-Wheat Rotation

Wheat: Grain yield of wheat was higher (45.6 t/ha) in zero tillage compared to that with conventional tillage (4.32 t/ha). During the crop season, 281 mm rainfall was received (effective rainfall = 221.5 mm). The highest grain yield (4.71 t/ha) was recorded with four irrigation scheduled at pre-sowing + CRI + flowering + grain filling followed with three and two irrigations. Higher profile moisture depletion was recorded in conventional tillage in comparison to zero tillage (Table 4.10.1).

Table 4.10.1. Grain yield and water use of wheat as influenced by tillage and irrigation levels

Treatments	Grain yield (t/ha)	PMC (+)	Irrigation (mm)	WE (mm)	WEE (kg/ha/ mm)	WUE (kg/ha/ mm)	Gross returns ('000) (Rs./ha)	Gross returns per mm applied water (Rs./ha)	Net returns ('000) (Rs./ha)	Net returns applied water (Rs./ha)
Tillage										
Zero	4.56	-77.9	125.0	483.9	9.5	10.8	93.25	953.2	58.05	597.1
Conventional	4.32	-92.6	125.0	498.6	8.7	9.9	88.62	911.3	44.95	466.9
CD (P=0.05)	NS	–	–	–	NS	NS	NS	NS	10.17	118.95
Irrigation										
Pre-sowing (PS)	4.36	-101.2	50.0	432.2	10.1	11.7	88.14	1762.9	51.3	1026.5
PS+CRI	4.20	-86.1	100.0	467.1	9.0	10.3	86.78	867.8	48.2	482.2
PS+CRI+ Flowering	4.48	-85.2	150.0	516.2	8.7	9.8	92.49	616.6	52.2	347.9
PS+CRI+ Flowering+GF	4.71	-68.5	200.0	549.5	8.6	9.6	96.33	481.6	54.3	271.4
CD (P=0.05)	NS	–	–	–	0.75	0.86	6.54	63.39	NS	63.4

The water expense efficiency (WEE), water use efficiency (WUE), gross returns, net returns and net returns per mm applied water were higher in zero tilled plots in comparison to conventionally tilled plots. The higher WEE (10.1 kg/ha-mm) and WUE (11.7 kg/ha-m) was observed with one irrigation and two irrigation applied at pre-sowing stage (Table 4.10.1).

Rice: Grain yield and water use in table 4.10.2. There was no difference in rice grain yield between zero tillage and conventional tillage. The rice grain yield was very poor due to low rainfall with very poor distribution delayed sowing.

Table 4.10.2. Grain yield and water use of rice under tillage and irrigation

Treatments	Grain yield (t/ha)	PMC (+)	Irrigation (mm)	WE (mm)	WEE (kg/ha /mm)	WUE (kg/ha /mm)	Gross returns ('000) (Rs./ha)	Gross returns per mm applied water (Rs./ha)	Net returns ('000) (Rs./ha)	Net returns per mm applied water (Rs./ha)
Tillage										
Zero	1.63	-75.5	125	624.7	2.57	3.0	33.3	309.7	-11.0	-141.4
Conventional	1.69	-90	125	639.2	2.60	3.0	34.9	319.6	-15.3	-193.2
CD (P=0.05)	NS	-	-	-	NS	NS	NS	NS	NS	NS
Irrigation										
Pre-sowing (PS)	0.99	-103.5	50	577.7	1.72	2.0	23.6	472.4	-21.0	-420.4
PS+tillereing	1.50	-84.0	100	608.2	2.46	2.9	31.3	313.1	-15.1	-151.0
PS+tillering+PI	1.95	-74.4	150	648.6	3.00	3.5	39.0	259.7	-9.2	-61.5
PS+tillering+PI+GF	2.19	-69.1	200	693.3	3.15	3.6	42.7	213.4	-7.3	-36.4
CD (P=0.05)	0.23	-	-	-	0.37	0.43	4.32	33.42	4.33	76.87

Higher grain yield (2.19 t/ha) was recorded with four irrigations in comparison to the lower levels of irrigation. Like wheat, in rice as well, the profile moisture use was more in the conventional tillage than zero tillage. The gross returns increases with number of irrigation but gross returns per mm applied water decreased with increasing level of irrigation. The net returns and net returns per mm applied water were negative due to low rainfall and dry spells resulted in poor yield.

4.11. Faizabad

Effect of Different Land Configuration and Moisture Regimes on Herb and Oil Yield of Mentha

Mentha oil is a source of foreign currency. Its production potential mainly depends on better water and fertilizer management practices. The study was taken because the crop is suffering due to continuous and heavy rains (pre- and post-monsoon), technology for this crop. The study is conducted to find out appropriate land configuration and suitable moisture regime for mentha planting to determine the oil yield, water use efficiency and economic feasibility of different treatments. A split plot design was adopted with land configurations M_1- Flat bed planting at 45 x 20 cm, M_2-Ridge planting at 45 x 20 cm, M_3-Raised bed planting (two paired row on bed of 70 cm and furrow 20 cm), M_4-Raised bed planting (3 rows on bed of 100 cm and furrow 35 cm) as main plot treatments, and moisture regimes I_1-Irrigation 0.6 IW/CPE, I_2-Irrigation 0.8 IW/CPE, I_3-Irrigation 1.0 IW/CPE and I_4-Irrigation 1.2 IW/CPE as sub-plot treatments. Every treatment had three replications.

Results showed that land configuration has significant effect on herb and oil yields of mentha (Table 4.11.1). Raised bed planting of mentha in paired row on 70 cm bed and 20 cm furrow (M_3) gave the significantly higher yields of herb (17.77 t/ha) and oil (130.96 l/ha) over other land configuration treatments. M_3 also recorded highest WUE (45.69 kg/ha-mm) followed by ridge planting method. The irrigation level 1.2 IW/CPE gave the maximum herb yield (18.11 t/ha) and oil yield (128.04 l/ha), which was significantly higher over other levels of irrigation (0.6 and 0.8 IW/CPE) except 1.0 IW/CPE irrigation level. But WUE was highest (48.43 kg/ha-mm) in 0.60 IW/CPE moisture regime followed by 0.8, 1.0 and 1.2 IW/CPE moisture regimes.

Table 4.11.1. Effect of land configuration and moisture regimes on herb and oil yield of mentha

Treatments	Herb yield (t/ha)	Oil yield (l/ha)	WUE (kg/ha-mm)
A. Land configuration (Main plot)			
M_1-Flat bed planting	13.21	85.10	33.97
M_2-Ridge planting	16.43	121.90	42.34
M_3-Raised bed planting (two paired row on 70 cm bed and 20 cm furrow)	17.77	130.96	45.69
M_4-Raised bed planting (three rows on bed of 100 cm and furrow 35 cm)	15.01	115.50	38.59
CD at 5%	0.73	5.95	-
B. Moisture regimes (Sub-plot)			
I_1-Irrigation 0.6 IW/CPE	12.11	94.43	48.43
I_2-Irrigation 0.8 IW/CPE	16.02	115.95	45.77
I_3-Irrigation 1.0 IW/CPE	17.30	124.04	38.43
I_4-Irrigation 1.2 IW/CPE	18.11	128.04	36.23
CD at 5%	0.95	7.30	-

4.12. Dapoli

4.12.1. Enhancing Mango Yield through Irrigations at Critical Stages during Fruit Development

The treatments were incorporated during February 2015. Fixed amount of water was applied weekly to the plants as per the treatments (T_1 to T_4) mentioned in table 4.12.1 *viz.*, 300, 600, 900 and 1200 litres per plant, respectively at different critical stages of plant. Water was applied @ 100 litres per week per plant. The results indicate that the maximum yield (27.50 kg/plant) was reported in T_4 while the lowest yield (12.25 kg/plant) was reported in control.

Mango yield can be significantly increased due to irrigation in different growth stages of fruit development. The yield significantly increased and was highest (27.50 kg/plant) when irrigation was delivered up 80 days from peanut stage of mango (Table 4.12.1). This indicated that mango may require water up to 80 days from peanut size of mango to increase the yield.

Table 4.12.1. Water applied to mango crop under treatments

Treatments	Total water applied (l/plant)	Yield (kg/plant)
T_1- Water application from peanut stage up to 20 days	300	21.50
T_2- Water application from peanut stage up to 40 days	600	22.88
T_3- Water application from peanut stage up to 60 days	900	25.75
T_4- Water application from peanut stage to 80 days	1200	27.50
T_5- Control (No irrigation)	No irrigation	12.25
SE+	-	0.76
CD at 5%	-	2.33

4.13. Jammu

4.13.1. Performance Evaluation of System of Rice Intensification (SRI) over Scientific Management Practices (SMP) for Basmati Rice at Jammu

The experiment was conducted with split plot design with establishment methods as main plot and fertility regimes in sub-plots (Table 4.13.1). The yields obtained with different methods were 2.41, 2.51, and 2.87 t/ha with S_1, S_2 and S_3, respectively. Irrigation water applied for S_1 - 1150 mm, for S_2 - 1620 mm and for S_3 - 1720 mm. The water expense efficiency (WEE) with S_1, S_2, and S_3 was 1.49, 1.20 and 1.38 kg/ha-mm, respectively with B:C ratio being 1.27 (Table 4.13.2).

Table 4.13.1. Treatment taken in split plot design

Establishment methods (Main plots)	Fertility regimes (Sub-plots)
• S_1 = SRI (AI) (Aerobic irrigation-to moist the soil & periodic operation on cono-weeder)	• F_1 = (100% N through FYM) • F_2 = (100% N through green manuring
• S_2 = SRI (3 DADPW with 7 cm irrigation)	• S_3 = Conventional transplanting
• F3 = (100% N through green manuring (continuous submergence of 7 cm water)	• F4 = Recommended dose (40 kg N, 20 kg P_2O_5, 10 kg K_2O)

Table 4.13.2. Effect of planting methods and different manures to supplement nitrogen on water expense efficiency of basmati rice (cv. Basmati-370)

Treatments	Grain yield (q/ha)	Rainfall received (mm)	Effective Rainfall (mm)	Irrigation applied (mm)	Total applied water (mm)	WEE (kg/ha-mm)
Establishment methods						
S_1	2.41	639.8	464.8	1150	1614.8	1.49
S_2	2.51	639.8	464.8	1620	2084.8	1.20
S_3	2.87	470.8	357.4	1720	2077.4	1.38
SEm±	0.06	–	–	–	–	–
CD (0.05)	0.20	–	–	–	–	–
Fertility regimes						
F_1	2.44	583.4	289.0	1496.7	1925.66	1.27
F_2	2.67	583.4	289.0	1496.7	1925.66	1.38
F_3	2.60	583.4	289.0	1496.7	1925.66	1.35
F_4	2.68	583.4	289.0	1496.7	1925.66	1.39
SEm±	0.05	–	–	–	–	–
CD (0.05)	0.16	–	–	–	–	–

CD (0.05) for S x F is NS

4.14. Palampur

4.14.1. Studies on Soil–Plant Water Dynamics under Protected Conditions in Relation to Drip Based Irrigation and Fertigation Scheduling on Cucumber

Effects of varying drip irrigation levels and NPK fertigation were studied under protected environment to evaluate water and nutrient use efficiencies of cucumber. Irrigation scheduling was followed at 40% CPE and 80% CPE; fertigation scheduling was followed at 50 % RDF (25 % applied as basal and 75 % through fertigation in 5 splits at fortnightly interval), 100 % RDF (25 % applied as basal and 75 % through fertigation in 7 splits at 10 day interval), 150 % RDF (25 % applied as basal and 75 % through fertigation in 10 splits at 7 day interval), 200 % RDF (25 % applied as basal and 75 % through fertigation in 20 splits at 3 day interval), 200 % RDF (50 % through conventional fertilization and 50 % through fertigation in 7 splits at 10 days interval). For control treatment, conventional fertilizers urea, single super phosphate and muriate of potash and drip irrigation (at 100 % CPE) were applied. Farmers' practice included FYM 1 kg and IFFCO 10 g per m along with 2 g/l of 19:19:19 at 15 days intervals; drip irrigation was applied daily at the rate of 2 l/ m^2. Effects of the treatments of experiment and farmers' practice on yield, water use and economics are shown in table 4.14.1. Irrigation at 80% CPE resulted in 11.22 and 17.40 % higher cucumber yield and 18.63 and 9.79% higher B:C ratio in 2014 and 2015, respectively. Application of 200% RDF resulted in 33.94 and 33.93% (significant) higher marketable yield of cucumber, 33.45 and 33.44 % higher B: C ratio and 33.95 and 65.40 % higher water use efficiency during 2014 and 2015, respectively. During both the years, control plot resulted in significantly lower marketable yield (16.32 and 18.36 %). Farmers' practice had 52.94 and 55.05 % higher water use than fertigation during 2014 and 2015, respectively. Fertigation resulted in 34.50 and 57.16 % higher WUE and 13.45 and 17.89 % higher B:C ratio than farmers' practice in 2014 and 2015, respectively.

Table 4.14.2 shows the interaction effects between irrigation and fertigation scheduling on cucumber yield. Application of 200 % RDF and drip irrigation at 0.8 CPE resulted in significantly higher cucumber yield among other interaction effects. Thus it is concluded that under protected condition, cucumber crop should be irrigated at 0.8 CPE and fertigated with 200 % RDF to obtain higher productivity and B:C ratio.

Table 4.14.2. Interaction effect of fertigation scheduling and irrigation scheduling on marketable yield (kg/m) of cucumber

Fertigation scheduling	Irrigation scheduling			
	2014		2015	
	0.4 CPE	0.8 CPE	0.4 CPE	0.8 CPE
50% RDF	4.03	4.07	4.11	4.17
100 % RDF	5.00	6.13	4.60	6.08
150 % RDF	5.73	6.42	5.92	7.88
200 % RDF	4.90	5.17	5.96	6.00
200 % RDF (50 % conventional and 50 % fertigation)	6.87	7.97	6.59	9.09
CD (P = 0.05)	0.33		0.47	

Table 4.14.1. Effect of different treatments on productivity, water use and economics of cucumber under protected conditions

Treatments	Marketable yield (kg/m^2)		TWU (m^3/m^2)		WUE (kg/m^3)		B:C	
	2014	2015	2014	2015	2014	2015	2014	2015
Irrigation scheduling								
0.4 CPE	3.92	4.14	0.068	0.072	57.65	57.50	1.61	1.94
0.8 CPE	4.36	4.86	0.136	0.146	32.06	33.29	1.91	2.13
CD (P = 0.05)	0.43	0.51	-	-	-	-	-	-
Fertigation scheduling								
50 % RDF	4.05	4.15	0.102	0.109	39.71	38.07	2.12	2.17
100 % RDF	5.54	4.74	0.102	0.109	54.31	43.49	2.96	2.53
150 % RDF	6.08	5.89	0.102	0.109	59.61	54.04	3.05	2.95
200 % RDF	5.03	6.04	0.102	0.109	49.31	55.41	2.14	2.57
200 % RDF (50 % conventional and 50 % fertigation)	7.42	7.84	0.102	0.109	72.75	71.93	3.95	4.17
CD (P = 0.05)	0.68	0.86	-	-	-	-	-	-
Control vs. Others								
Control	4.87	5.01	0.156	0.169	31.22	29.64	4.84	4.72
Others	5.82	5.93	0.102	0.109	57.06	54.40	2.88	2.94
CD (P = 0.05)	0.71	0.84	-	-	-	-	-	-
Farmers' practice vs. Fertigation								
Farmers' practice	5.63	5.83	0.156	0.169	36.09	34.50	2.38	2.46
Fertigation	5.62	5.91	0.102	0.109	55.10	54.22	2.75	2.90
CD (P = 0.05)	NS	NS	-	-	-	-	-	-

4.15. Powarkheda

4.15.1. Response of Irrigation Scheduling under Different Methods of Sowing of Rice in Deep Vertisols

The experiment was conducted to test suitability of different methods under deep black soil, evolve suitable water management practices under different sowing method and determine water requirement of rice under different sowing method. A factorial RBD design was adopted including sowing methods, direct seeded (M_1), lehi method (M_2) and transplanting (M_3) and irrigation scheduling, irrigation at 1 DADPW (I_1) and continuous submergence (I_2) for variety Pusa Sugandha-4.

Table 4.15.1. Mean grain yield and monetary returns of rice under different treatments

Treatments	Grain yield (kg/ha)			Cost of cultivation (Rs./ha)	Gross income (Rs./ha)	Net monetary (Rs./ha)	B:C
	2014-15	2015-16	Mean				
Direct seeded							
DS 1 DADPW	3249	3285	3267	59957	98010	38053	1.63
DS Submergence	2884	3278	3081	61957	92430	30473	1.49
Lehi method							
Lehi 1 DADPW	2848	3584	3216	58258	96480	38222	1.66
Lehi Submergence	2827	3292	3060	60258	91800	31542	1.52
Transplanting							
T.P. 1 DADPW	2598	4813	3706	64963	111180	46217	1.71
T.P. Submergence	2618	4146	3382	66963	101460	34497	1.52
SEm±	114.6	226.8	-	-	-	-	-
CD at 5%	361.0	784.8	-	-	-	-	-
CV (%)	7.22	5.46	-	-	-	-	-

Market price: Rice Rs.3000 per quintal

Results show that grain yield of Pusa Sugandha 4 was maximum (4813 kg/ha) under transplanting with irrigation at 1 DADPW which was at par with the yield (4146 kg/ha) under transplanting with submergence (Table 4.15.1). Highest water use efficiency (41.03 kg/ha-cm) was recorded under transplanting with irrigation at 1 DADPW. Growth and vigour of the crop under direct seeded and lehi methods were adversely affected under scanty rainfall and hot dry weather conditions resulting in lower seed yields. On the basis of 2014-15 and 2015-16 data, mean the net monetary returns of Rs.46217 per ha and benefit-cost ratio of 1.71 were also higher under the same treatment (Table 4.15.1).

4.15.2. Effect of Land Configuration on Productivity of Wheat Based Crop Sequence

The experiment was carried out to find out i) suitable cropping sequence for command area, ii) the effect of sowing methods on drainage, plant stand, crop growth and yield of sorghum, sesame and soybean and iii) work out irrigation requirement under different planting system. Sorghum, sesame and soybean were sown in *kharif* season wheat was sown in *rabi* season. Different sowing methods for wheat, FIRBS - Irrigation at 1.0 IW/CPE ratio with 7.5 cm depth (4 irrigation) and conventional - Irrigation at 1.0 IW/CPE ratio with 7.5 cm depth (4 irrigation) were applied. For sorghum, seasame and soybean BBF – Broad bed furrow (BBF) 180/30 cm and conventional – Normal planting were applied. Results revealed that broad furrow sowing of sorghum gave considerably higher sorghum yield as compared to conventional sowing (Table 4.15.2). Wheat yields under conventional method and FIRBS did not differ significantly. On the basis of three years data, wheat–sorghum sequence proved superior with maximum wheat yield (7269 kg/ha), net monetary returns (Rs. 46783 per ha) and B:C ratio 1.75 as compared to other cropping sequences (Table 4.15.3).

Table 4.15.2. Pooled yield (kg/ha) and WUE of *kharif* crops and *rabi* under different sowing methods

Sl. No.	Treatments	Grain/Seed yield (kg/ha)				Mean SEY (kg/ha)	WUE (kg/ ha-cm)
		2011-12	2012-13	2014-15	Mean		
	***Kharif* crops**						
1	Sorghum in BBF	4389	2857	3333	3526	3526	47.39
2	Sorghum in Conv.	3727	2057	3105	2963	2963	39.19
3	Sesame in BBF	539	091	363	0331	1765	5.72
4	Sesame in Conv.	469	069	267	0268	1429	4.59
5	Soybean in BBF	278	832	447	0519	1038	11.83
6	Soybean in Conv.	294	664	409	0456	912	9.92
	SEm±	-	-	-	-	144.14	-
	CD at 5%	-	-	-	-	321.1	-
	CV (%)	-	-	-	-	9.10	-
	***Rabi* crops**						
1	FIRBS sowing	4852	3908	3762	4174	-	-
2	Conventional sowing	4108	3711	4440	4086	-	-
	SEm±	83.9	65.0	172.7	82.03	-	-
	CD at 5%	361.1	NS	NS	NS	-	-

Table 4.15.3. Wheat equivalent yield (kg/ha) and economics of different crop sequence (pooled data for 3 years)

Sl. No.	Treatments (Crop sequence)	Wheat equivalent yield (kg/ha)	Net monetary returns (Rs./ha)	B:C
1	Wheat – Sorghum	7269	46783	1.75
2	Wheat – Sesame	5155	14525	1.23
3	Wheat – Soybean	5265	12623	1.19

4.16. Bathinda

Optimizing Irrigation and Nitrogen in Capsicum in Relation to Mulching

A field experiment was carried out to find out the optimum level of irrigation and nitrogen application on yield and water productivity of hybrid capsicum var. Indra under mulching. Split split plot design was adopted with treatments mulching (no mulch and straw mulch @ 6 t/ha), irrigation levels (IW/CPE = 0.6, IW/CPE = 0.9 and IW/CPE = 1.2) and nitrogen levels (100, 125 and 150 kg N/ha) with three replication per treatment.

The rice straw mulch application @ 6 t/ha significantly increased capsicum yield. Application of nitrogen significantly increased the capsicum yield up to 125 kg/ha and 150 kg/ha under mulch and no mulch condition, respectively (Table 4.16.1). Application of irrigation at IW/CPPE= 1.2 has shown significant effect of capsicum yield. Water expense efficiency was higher under mulch application than no mulch conditions (Table 4.16.1). Application of 125 kg N/ha along with straw mulch @ 6 t/ha and 150 kg N/ha without mulch at irrigation level of IW/CPE = 1.2 is recommended to obtain higher capsicum yield and maximize water productivity. The outcome of this research will facilitate in enhancing the yield of capsicum with mulch in combination with optimum irrigation and nitrogen thus improving the economic returns of the farmers.

Table 4.16.1. Yield (kg/ha) of capsicum as influenced by nitrogen and irrigation levels under varying mulch condition (pooled mean 2011-2014)

Irrigation levels	Nitrogen levels									Mean	
	N_1			N_2			N_3				
No mulch											
	Yield	WEE	B:C	Yield	WEE	B:C	Yield	WEE	B:C	Yield	WEE
I_1	7052	118.1	0.81	7488	124.4	0.91	7824	132.9	0.99	7455	125
I_2	8122	108.7	1.07	8808	114.3	1.24	9162	121.4	1.32	8697	115
I_3	9008	95.9	1.28	9724	102.6	1.45	10450	110.5	1.63	9727	103
Mean	8061	107.6		8673	113.8		9145	121.6		8626	114
With mulch											
I_1	7802	133.5	1.10	8744	145.8	1.34	9319	158.4	1.48	8622	146
I_2	9692	130.9	1.59	10258	139	1.73	10440	142.2	1.76	10130	137
I_3	10597	113.4	1.81	11196	119.1	1.96	11631	123.6	2.06	11141	119
Mean	9364	125.9	-	10066	134.6	-	10463	141.4	-	9964	134

CD (5%) for yield: Nitrogen = 468, Irrigation=366, Mulch= 263

4.17. Jabalpur

Assessment of Water Use Efficiency as Affected due to Climate Change

Earth's temperature has increased by 0.74°C during the last century (1906 to 2005) due to increase in greenhouse gases through anthropogenic emissions. This temperature may rise from 1.8–4.0°C by the turn of 21st century resulting in an anticipated instability in food, feed and fibre production. Besides this, it will reduce crop duration, vary pest populations, hasten mineralization in soils, increase rate of evapotranspiration (ET) and crop yield. Due to increase in ET, there will be more soil warming with reduced availability of soil moisture to crops or reduction in water use efficiency. This may increase the demand for crop water than the present scenario. An attempt has been made to assess the variation in water use efficiency of major *rabi* and *kharif* crops planted in Kymore Plateau and Satpura hill zone due to climate change in central Madhya Pradesh.

The trends of different climatic parameters as well as water availability periods were estimated on annual, month-wise, season wise and week wise through aridity index and moisture index. In addition, variation in water use efficiency of different crops of *kharif*, *rabi* and *zaid* season over the last 30 years at Jabalpur were also taken into account. The trend of different weather elements like maximum temperature, minimum temperature, average temperature, relative humidity in the morning, relative humidity in the evening, average relative humidity, wind velocity, sunshine hours, rainfall and ET_o for the three seasons over the period of last 30 years at Jabalpur are presented in table 4.17.1 and 4.17.2. These trends are presented to know the variation that shows positive (P) and negative (N) trends. Among the three seasons, ET_o was highest in zaid and lowest in *rabi* season over the three decades (1984-2013).

Table 4.17.1. Trend of weather elements during *rabi* season

Year	T_{max} (°C)	T_{min} (°C)	RH_{max} (%)	RH_{min} (%)	Wind speed (km/h)	Rainfall (mm)	Sunshine hours	ET_o (mm)
1984-1988	27.19	11.84	89.67	40.85	2.46	153.50	8.01	398
1989-1993	27.85	11.69	86.13	36.31	2.32	37.22	8.27	407
1994-1998	27.11	12.27	89.00	42.51	1.42	156.94	7.68	372
1999-2003	27.80	12.12	88.78	38.19	1.66	85.62	7.91	385
2004-2008	27.41	11.88	89.80	37.43	1.98	83.66	7.95	391
2009-2013	27.88	11.42	88.68	38.29	2.62	82.24	7.71	408
Normal	27.54	11.87	88.68	38.93	2.08	99.86	7.92	393
Trend	P	N	P	N	P	N	N	P

Table 4.17.2. Trend of weather elements during *zaid* season

Year	T_{max} (°C)	T_{min} (°C)	RH_{max} (%)	RH_{min} (%)	Wind speed (km/h)	Rainfall (mm)	Sunshine hours	ET_o (mm)
1984-1988	38.04	20.72	52.97	18.13	4.61	33.80	9.09	500
1989-1993	37.43	20.53	52.87	19.78	4.60	35.72	8.74	486
1994-1998	36.87	20.62	57.57	23.01	3.48	41.78	8.72	453
1999-2003	37.58	21.05	52.49	18.50	3.83	27.74	8.59	463
2004-2008	37.34	20.67	56.01	20.10	4.52	48.16	8.65	483
2009-2013	38.19	19.70	53.98	18.24	4.99	16.88	8.45	500
Normal	37.58	20.55	54.31	19.63	4.34	34.01	8.70	481
Trend	P	N	P	N	P	N	N	P

Aridity index was estimated as the ratio of precipitation (P) to potential evapotranspiration (PET) (Fig. 4.17.1). Moisture index is a measure of the water balance of an area in terms of gains from precipitation (P) and losses from potential evapotranspiration. Positive values of the ratio mean that the precipitation is excessive, deficient with negative values. Aratio of zero means that water supply is equal to water needs. Moisture index was estimated (Fig. 4.17.1) as described by Thornthwaite (1955) using the relationship,

$$I_m = 100\left(\frac{P}{PET} - 1\right)$$

where, I_m = moisture index, P = precipitation and PET = potential evapotranspiration. Weekly aridity index and moisture index is presented in table 4.17.3, with reported weeks having different climate types.

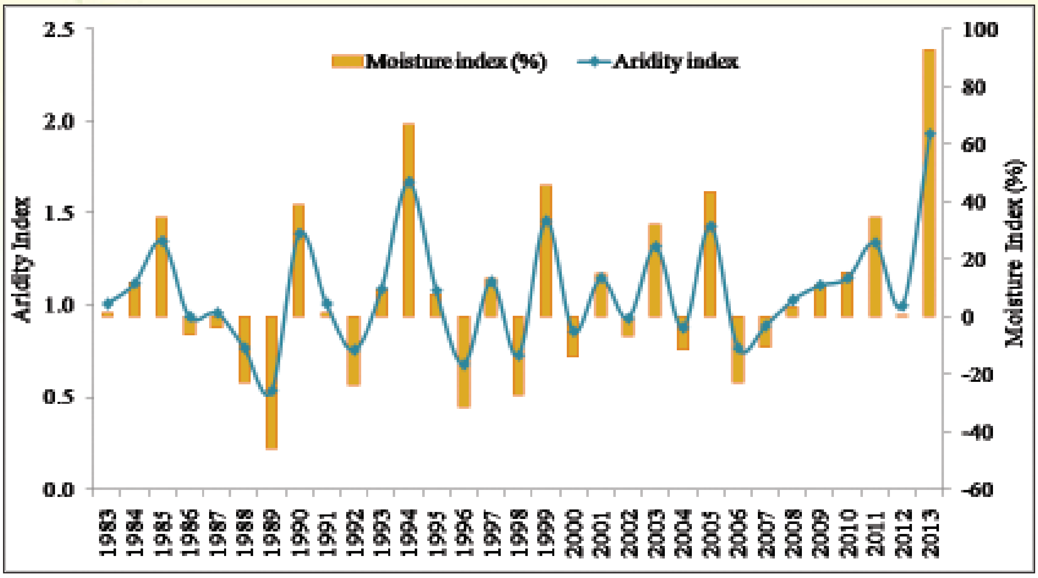


Fig. 4.17.1. Year-wise variation of aridity and moisture indices of Jabalpur region

Table 4.17.3. Week wise aridity and moisture indices for Jabalpur region

Climate type	Weeks
Aridity Index	
Humid	24th -39th
Sub humid	6th , 40th
Semi arid	1st, 2nd, 4th, 5th, 7th, 9th, 10th, 11th, 23rd, 41st, 42nd, 46th, 49th, 52nd
Arid	3rd, 8th, 12th, 13th, 14th, 16th, 18th, 20th, 21st, 22nd, 43rd, 44th, 45th, 47th, 48th,50th,51st
Hyper arid	15th, 17th, 19th
Moisture Index	
Per humid	26th -38th
Humid	25th
Moist sub humid	39th
Dry sub humid	24th
Semi arid	1st, 2nd,6th,7th,23rd,40th,42nd
Arid	3rd-5th,8th-22nd,41st,43rd-52nd

Crop water use efficiency of four major crops of the region, *viz*., paddy and soybean in *kharif* and wheat and gram in *rabi* was estimated. Following is the crop growing period and the crop coefficient values of the crops as per Standard Meteorological Week (SMW) (Fig. 4.17.2). It was observed that normal values of water use efficiency of soybean, paddy, wheat and gram were 0.288, 0.200, 0.730 and 0.473 kg/m^3, respectively. The respective rates of increment in water use efficiency of soybean, paddy, wheat and gram were 24, 33, 33 and 25 % during 1983 to 2012 for Jabalpur region.

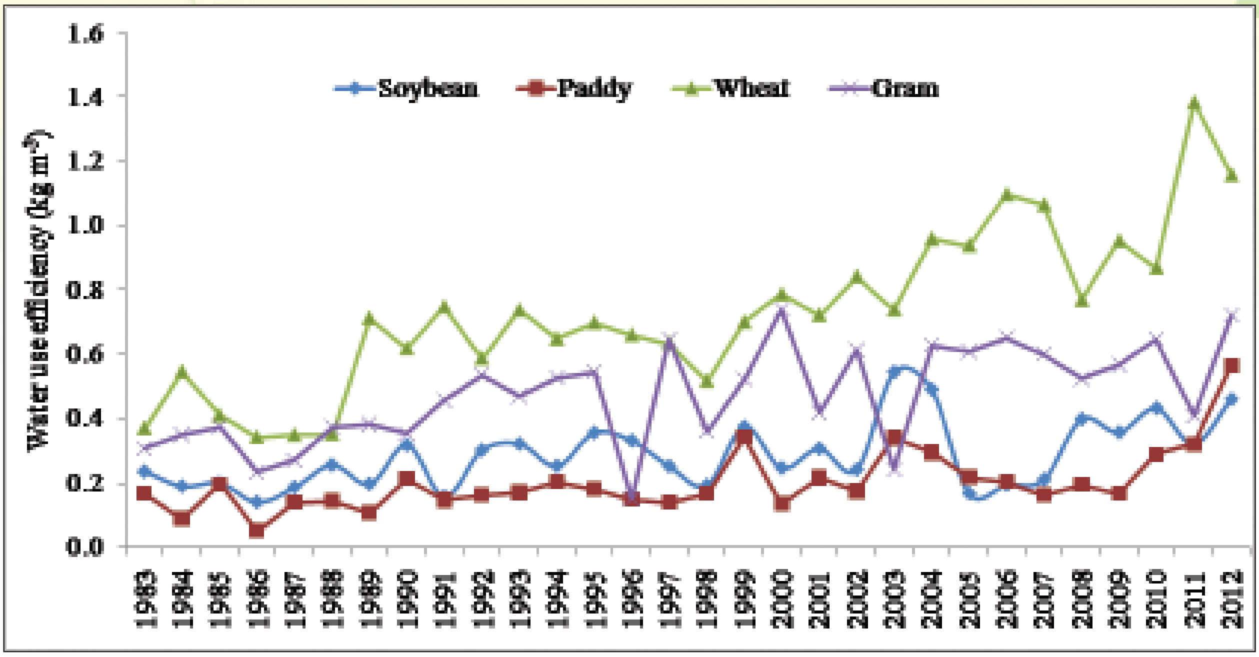


Fig. 4.17.2. Water use efficiency of four crops

4.18. Belvatagi

4.18.1. Studies on Site-Specific Nutrient Management (SSNM) for Maize-Chickpea Sequence and Integrated Nutrient Management in Sunflower-Chickpea under Varied Levels of Irrigation

Maize-Chickpea

SSNM system was assessed in the cropping sequence to maintain soil fertility and improve economic status of the farming community. Results in table 4.18.1 indicate that among the targeted yield levels, significant increase in yield of *kharif* maize over target yields of 8 and 10 t/ha could be possible during 2014 and pooled data. However, yields were close to the targeted yields of 12 t/ha and 14 t/ha (11.76 t/ha and 13.05 t/ha) during 2014. Net return, B:C and WUE were also significantly higher at 14 t/ha target over 8 and 10 t/ha targets. Chickpea crop grown after maize recorded non-significant change in pooled yield with varied levels of irrigation. However, the different levels of fertilizers applied to chickpea showed significantly higher pooled yield (1.79 t/ha), net return (Rs. 43,362 per ha) B:C ratio (4.47) and WUE (8.23 kg/ha-mm) for treatment T_4 compared to those for T_1. The maize-chickpea cropping system had significantly higher total net returns of Rs. 98,302 and Rs. 1,81,947 during 2013 and 2014, respectively for T_4 compared to other targeted yield levels. Therefore, in Malaprabha Command Area, the cropping system of maize in *kharif* followed by chickpea in *rabi* season seems to be more profitable, if the farmers adopt this concept.

Sunflower-Chickpea

Table 4.18.2 shows that sunflower crop receiving irrigation level at 0.6 IW/CPE recorded significantly higher yield, gross income, net income, B:C during 2013. However, such significance was not observed during 2014 and in pooled analysis. Among different nutrient combinations, RPP recorded significantly higher yield during both the years and in pooled analysis (2.1 t/ha). The former treatment also recorded higher net returns (Rs.50,519), B:C ratio (3.73) and WUE (5.97) in pooled analysis. The interaction effect between irrigation and nutrient level showed that treatment RPP with 0.6 IW/CPE recorded significantly higher grain yield (2.15 t/ha), net returns (Rs. 50,683). The higher B:C ratio (3.94) and WUE (6.37 kg/ha-mm) was observed with irrigating at critical stages with RPP treatment combinations. In the whole cropping system, application of irrigation at 0.6 IW/CPE with RPP for both crops (sunflower during *kharif*followed by chickpea during *rabi*season) recorded higher net returns of Rs. 1,01,196 and Rs. 1,02,493 during the consecutive years. This type of cropping system also exists in the Malaprabha Command Area. The best treatments can be adopted by farmers to get higher yield and income.

4.18.2. Studies on Various Irrigation and Micronutrient and Boron Levels on Maize and Iron Levels on Sunflower under Malaprabha Command Area

Maize in maize-chickpea cropping system

The interaction effects between irrigation and boron levels (Table 4.18.3) showed that, irrigating the crop at 0.8 IW/CPE along with foliar application of 0.5% $FeSO_4$ and 0.5% $ZnSO_4$ with borax @ 0.1% at 30 and 45 DAS recorded higher yield (92.5 q/ha), net return (Rs. 74,008), B:C ratio (3.92) and WUE (19.48) over rest of the treatments. But, it was at par with all the treatments receiving boron either through soil or leaves. During *rabi* season, it was observed that chickpea grown as succeeding crop after maize with treatment T_5 recorded significantly higher yield (1924 kg/ha), net returns (Rs. 46,196), B:C ratio (4.21) and WUE (10.22) compared to other treatments. Growing maize in *Kharif* by irrigating at 0.8 IW/CPE with Granubor (boron) @ 6 kg/ha followed by growing chickpea with 0.6 IW/CPE recorded significantly higher gross returns of Rs. 1.47.718 with net returns of Rs.1.08.668 during 2013 and Rs.1,17,265 during 2014. This system seems to be more remunerative to the farmers of Malaprabha command area.

Sunflower

The two years pooled data indicated that fertilizer levels had significantly increased grain yield (1.93 t/ha), 4.79 t/ha and WUE (6.35 kg/ha-mm) with the application RPP +25 kg $FeSO_4$/ha+0.75% $FeSO_4$ spray (30 DAS) + 0.5% lime as compared to rest of treatments. Average amount of water saved in two years was 18.23% with irrigation at critical stage of crop. Pooled data indicated that significantly higher gross return, net return and B:C ratio found with irrigation @ 0.8 IW/CPE compared to that in critical stages of the crop (Table 4.18.4).

4.18.3. Studies on Irrigation Levels to Different *Rabi*Crops under Late *Rabi*/ Early Summer Situations in Malaprabha Command Area

The experiment was conducted to find out suitable *rabi*crops and enhance their water productiveity in late *rabi*/ early summer after harvest of maize. Table 4.18.5 showed that application of water @ 0.8 IW/CPE recorded higher yield as compared to that with 0.6 IW/CPE. Among the different pulses, bengal gram recorded higher yield during Ist forenoon (FN) of December comapred to other crops. The yield levels went on decreasing with delay in sowing (Dec IInd FN and Jan Ist FN). The performances of greengram and cowpea were better in Dec IInd FN and Jan Ist FN compared to chickpea.

4.18.4. Studies on Effect of Irrigation Levels and INM in Bt Cotton under Vertisols

Experiment was to study the effect of irrigation levels and INM in Bt cotton in clay texture soil with pH 8.45, organic carbon 0.51% and EC 0.29 dS/m. The initial available NPK of the soil were 141.20, 16.00 and 523.60 kg/ha, respectively. During 2014-15 (Table 4.18.6), among the irrigation levels, I_1 recorded significantly higher kapas yield (1.73 t/ha), dry matter (5.04 t/ha), and nitrogen (100.13 kg/ha), phosphorus (25.89 kg/ha) and potassium (118.92 kg/ha), iron (479.32 g/ha), zinc (326.59 g/ha), boron (202.63 g/ha) uptake, net return and B:C ratio compared to I_3. Among the INM levels, F_3 recorded significantly higher yield (1.48 t/ha), WUE (3.23 kg/ha-mm), and nitrogen (160.90 kg/ha), phosphorus (41.17 kg/ha) and potassium (184.19 kg/ha), iron (752.52 g/ha), zinc (440.76 g/ha), boron (202.63 g/ha) uptake, net return and B:C ratio. Among interactions, higher kapas (1.91 t/ha) and seed (1.39 t/ha) yield were recorded with I_1F_3. There is non-significant difference in interaction of irrigation levels and INM levels for nutrient uptake, net return and B:C ratio.

Table 4.18.1. Grain yield, water use efficicency (WUE) and economics of maize and chickpea from pooled data of 2013 and 2014 experiments for irrigation levels (0.6 and 0.8 IW/CPE) and total net return from maize-chickpea cropping system

Treatments	Grain yield (t/ha)		WUE (kg/ha-mm)		Net return (Rs./ha)		B:C		Total NR (cropping sequence) (Rs./ha)	
	Maize	Chickpea	Maize	Chickpea	Maize	Chickpea	Maize	Chickpea	2013	2014
T_1: Targeted yield of 8 t/ha	8.73	1.42	19.86	6.54	81116	32182	3.84	3.55	85525	135695
T_2: Targeted yield of 10 t/ha	9.73	1.62	21.78	7.48	89565	37546	3.95	4.08	90461	155476
T_3: Targeted yield of 12 t/ha	10.1	1.74	22.64	7.98	93256	41525	3.92	4.26	93205	167269
T_4: Targeted yield of 14 t/ha	10.98	1.79	24.47	8.23	101593	43362	3.98	4.47	98302	181947
Sources	CD*	CD	CD	CD	CD	CD	CD	CD	-	-
Main plot (I)	NS	NS	2.21	NS	NS	1735	NS	0.12	-	-
Sub-plot (T)	6.6	71.3	1.42	0.73	5565	5787	0.22	0.69	-	-
I x T	9.4	19	3.25	0.91	7871	96	0.31	0.94	-	-

*CD at 5%

Table 4.18.2. Grain yield, water use efficicency (WUE) and economics of sunflower and chickpea from pooled data of 2013 and 2014 experiments for irrigation levels (0.6 IW/CPE and critical growth stages) and total net return from sunflower-chickpea cropping system

Treatments	Grain yield (t/ha)		WUE (kg/ha-mm)		Net return (Rs/ha)		B:C		Total net returns (cropping sequence) (Rs/ha)	
	Sunflower	Chickpea	Sunflower	Chickpea	Sunflower	Chickpea	Sunflower	Chickpea	2013	2014
N_1 = 75% N through organics	14.4	1.76	3.94	8.56	34424	39786	3.63	3.44	68346	77485
N_2 = 100% N through organics	15.7	1.84	4.31	8.94	34985	41543	3.15	3.69	74624	79375
N_3 = 100% inorganics	18.7	2.00	5.15	9.73	42596	44977	3.58	3.86	85364	91242
N_4 = (50% organics + 50% inorganics)	17.8	1.91	4.86	9.26	43317	45079	3.88	3.97	93994	92008
N_5 = RPP (RDF + FYM)	21.0	2.09	5.79	10.14	50519	48343	3.73	4.21	101196	102493
Sources	CD*	CD	CD	CD	CD	CD	CD	CD	-	-
Main plot (I)	NS	NS	0.71	0.17	8,070	3159	0.53	0.08	-	-
Sub-plot (T)	1.4	134	1.03	0.71	6,797	3283	0.37	0.21	-	-
I x T	2.0	22	1.34	0.87	9,613	69	0.52	0.31	-	-

*CD at 5%

Table 4.18.3. Grain yield, WUE and economics of maize and chickpea as influenced by irrigation and boron levels in cropping sequence and their interaction during 2013 and 2014 and pooled

Treatments	Grain yield (t/ha)				WUE (kg/ha-mm)				Net return (Rs./ha)				B:C				Total net return for cropping sequence (Rs./ha)			
	Maize		Chickpea		Maize		Chickpea		Maize		Chickpea		Maize		Chickpea		2013		2014	
	0.8 IW/CPE	Ctitical stages	0.8 IW/CPE	Ctitical stages	0.8 IW/CPE	Ctitical stages	0.8 IW/CPE	Ctitical stages	0.8 IW/CPE	Ctitical stages	0.8 IW/CPE	Ctitical stages	0.8 IW/CPE	Ctitical stages	0.8 IW/CPE	Ctitical stages	0.8 IW/CPE	Ctitical stages	0.8 IW/CPE	Ctitical stages
N_1 : RDF (N, P, K, Zn, Fe & FYM)	7.96	75.9	1.529	1.702	16.7	19.34	8.49	9.45	58,987	57,050	31939	35981	3.41	3.37	3.37	3.51	82,848	85,150	97242	98779
N_2:RDF (N, P, K, Zn, Fe & FYM) +2 kg/ha Granubor	8.21	81.4	1.556	1.84	16.93	19.73	8.64	10.21	60,487	59,375	34942	40599	3.45	3.45	3.58	3.79	86,187	88,235	99911	104323
N_3:RDF (N, P, K, Zn, Fe & FYM) +4 kg/ha Granubor	8.16	85.8	1.754	1.819	17.51	20.14	9.74	10.1	61,459	60,910	39349	41828	3.48	3.5	3.74	3.98	94,319	91,250	102418	106956
N_4:RDF (N, P, K, Zn, Fe & FYM) +6 kg/ha Granubor	8.63	88	1.591	1.61	19.48	20.52	8.86	8.94	64,076	62,334	41351	44952	3.55	3.52	3.84	4.1	90,896	89,154	105561	108764
N_5:N_1 + foliar spray of 0.5% ZnSO4+0.5% FeSO4 + 0.1% Borax twice at 30 and 45 DAYS	9.25	88.5	1.978	1.87	17.4	19.7	10.06	10.39	74,008	63,798	42552	46196	3.92	3.57	4.17	4.26	1,08,668	97,140	117265	111916
Source	**SEm+**	**CD***	**SEm+**	**CD**	**SEm+**	**CD**	**SEm+**	**CD**	**SEm+**	**CD**	**SEm+**	**CD**	**SEm+**	**CD**	**SEm+**	**CD**	-	-	-	-
Main Plot (I)	2.2	NS	20	121.4	0.73	NS	0.21	0.64	4,120	NS	14	83	0.17	NS	0.01	0.08	-	-	-	-
Sub Plot (F)	2.6	7.8	40	118.8	0.87	2.54	0.24	0.73	4,930	14,779	637	1911	0.2	0.6	0.07	0.21	-	-	-	-
I x F	3.9	11.7	4	12	1.31	3.9	0.22	0.67	6,972	20,901	8	23	0.28	0.85	0.1	0.31	-	-	-	-

*CD at 5%

Table 4.18.4. Pooled grain yield, water use efficicency (WUE) and economics of sunflower as influenced by irrigation and iron levels and their interaction in two years of experiment

Treatments	Grain yield (t/ha)		WUE (kg/ha-mm)		Net return (Rs./ha)		B:C	
	I_1=0.8 IW/CPE	I_2= Critical Stage	I_1= 0.8 IW/CPE	I_2 = Critical Stage	I_1=0.8 IW/CPE	I_2= Critical Stage	I_1= 0.8 IW/CPE	I_2 = Critical Stage
F_1: RPP (Recommended NPK (90:90:60) + 100 kg gypsum + 10 kg $ZnSO_4$ + 8 t/ha FYM + 0.5% borax spray at ray floret stage)	1.61	1.58	4.93	6.08	26045	26271	2.99	3.17
F_2: RPP + 10 kg/ha $FeSO_4$	1.67	1.66	5.10	5.89	26735	27606	2.94	3.14
F_3: RPP + 25 kg/ha $FeSO_4$	1.76	1.70	5.37	6.05	27855	27341	2.88	2.99
F_4: RPP + 0.5 % $FeSO_4$ spray (30 DAS) + 0.25% lime	1.68	1.66	5.11	6.01	26430	27266	2.86	3.06
F_5: RPP + 0.75 % $FeSO_4$ spray (30 DAS) + 0.5% lime	1.69	1.66	5.16	5.98	26466	25811	2.81	2.79
F_6: RPP + 10 kg/ha $FeSO_4$ + 0.5 % $FeSO_4$ spray (30 DAS) + 0.25% lime	1.81	1.79	5.51	6.38	28960	29938	2.94	3.17
F_7: RPP + 25 kg/ha $FeSO_4$ + 0.5 % $FeSO_4$ spray (30 DAS + 0.25% lime)	1.93	1.80	5.88	6.8	31363	31710	2.93	3.08
F_8: RPP + 10 kg/ha $FeSO_4$ + 0.75 % $FeSO_4$ spray (30 DAS) + 0.5% lime	1.83	1.81	5.57	6.62	29633	29701	2.90	3.07
F_9: RPP + 25 kg/ha $FeSO_4$ + 0.75 % $FeSO_4$ spray (30 DAS) + 0.5% lime	1.94	1.91	5.92	6.77	31236	31291	2.89	3.03
Sources	**SEm+**	**CD***	**SEm+**	**CD**	**SEm+**	**CD**	**SEm+**	**CD**
Main plot (I)	0.02	NS	0.030	0.180	308.6	NS	0.021	0.128
Sub-plot (N)	0.02	0.06	0.061	0.176	249.6	719.2	0.024	0.069
I x N	0.03	NS	0.087	NS	453.9	NS	0.038	0.110

* CD at 5% level of significance

Table 4.18.5. Grain yield (kg/ha) and WUE (kg/ha-mm) of different *rabi* crops as influenced by irrigation levels and sowing dates in Malaprabha command area

Treatments		Sub-plot: Dates of planting							
		Dec I[st] FN		Dec II[nd] FN		Jan I[st] FN		Mean	
Main plot: Irrigation levels	Sub-sub plot: Crops	Yield	WUE	Yield	WUE	Yield	WUE	Yield	WUE
0.6 IW/CPE	**Bengal gram**	1168	6.26	565	3.14	489	2.72	740.6	4.04
	Green gram	739	3.96	987	5.48	847	4.71	857.7	4.72
	Cowpea	342	1.83	528	2.94	270	1.50	380.0	2.09
	Mean	749.7	4.02	523.3	3.85	535.3	2.98	659.4	3.61
0.8 IW/CPE	**Bengal gram**	1523	8.16	784	4.35	416	2.31	907.7	4.84
	Green gram	804	3.42	943	5.24	842	4.67	863.0	4.44
	Cowpea	604	3.35	429	2.38	270	1.50	434.3	3.38
	Mean	977	4.97	718.6	3.99	509.3	2.82	735.0	4.22
Sources		**Crop yield**		**WUE**		-			
		SEm±	CD @ 5%	SEm±	CD @ 5%	-			
Irrigation levels (I)		12.9	NS	0.07	0.4	-			
Sowing dates (S)		50.7	165.3	0.27	0.89	-			
Cropping systems (C)		25.6	74.7	0.14	0.41	-			
I x S x C		62.7	182.9	0.34	0.99	-			

Table 4.18.6. Effect of irrigation and INM levels on yield (t/ha), water use efficiency (kg/ha-mm) and economics of *Bt* cotton during 2014-15

Treatments		Kapas (lint+seed) yield	Water use efficiency (kg/ha-mm)	Net returns (Rs./ha)	B:C
Main plot: Irrigation levels					
I_1 –	0.8 IW/CPE ratio	1.73	2.85	57753.2	3.12
I_2 –	0.6 IW/CPE ratio	1.65	2.76	54100.8	3.00
I_3 –	Critical stages	1.52	3.12	47460.0	2.75
	S.Em+	0.02	0.04	948.7	0.06
	CD (0.05)	0.08	0.15	3724.9	0.22
	CV (%)	0.5	-	-	-
Sub-plot: INM levels					
F_1 –	100 % RDF + FYM @ 10 t/ha	1.69	3.01	54929.6	2.96
F_2 –	100 % RDF + FYM @ 10 t/ha + one row of sunhemp in between two rows of *Bt* cotton	1.73	3.08	56927.7	3.03

F_3	100% RDF + FYM @ 10 t/ha + one row of sunhemp in between two rows of *Bt* cotton + $ZnSO_4.7H_2O$ @ 25 kg/ha + $FeSO_4.5H_2O$ @ 25 kg/ha + Borax @ 5 kg/ha	1.81	3.23	60684.3	3.16
F_4	75% RDF + FYM @ 10 t/ha + Rhizobium (2 g/kg seed) + one row of sunhemp in between two rows of *Bt* cotton + $ZnSO_4.7H_2O$ @ 25 kg/ha + $FeSO_4.5H_2O$ @ 25 kg/ha + Borax @ 5 kg/ha + maize stalk 10 t/ha	1.48	2.65	46656.5	2.86
F_5	50% RDF + FYM @ 10 t/ha + Rhizobium (2 g/kg seed) + one row of sunhemp in between two rows of *Bt* cotton + $ZnSO_4.7H_2O$ @ 25 kg/ha + $FeSO_4.5H_2O$ @ 25 kg/ha + Borax @ 5 kg/ha + maize stalks @ 10t/ha	1.46	2.60	46324.3	2.79
	SEm+	0.03	0.04	1208.3	0.05
	CD (0.05)	0.07	0.13	3526.7	0.13
	CV (%)	0.45	-	-	-
	Interactions (Irrigation level x INM level)				
	I_1F_1	1.84	3.03	61807.7	3.19
	I_1F_2	1.85	3.06	62591.7	3.22
	I_1F_3	1.91	3.15	65270.3	3.31
	I_1F_4	1.54	2.54	49409.3	3.00
	I_1F_5	1.52	2.51	46987.0	2.90
	I_2F_1	1.75	2.92	57564.0	3.05
	I_2F_2	1.80	3.01	60193.7	3.14
	I_2F_3	1.83	3.05	61369.7	3.18
	I_2F_4	1.47	2.46	46374.3	2.83
	I_2F_5	1.42	2.38	45002.3	2.79
	I_3F_1	1.50	3.07	45417.0	2.63
	I_3F_2	1.55	3.18	47997.7	2.72
	I_3F_3	1.70	3.49	55413.0	2.99
	I_3F_4	1.44	2.96	44185.7	2.75
	I_3F_5	1.43	2.93	44284.0	2.68
	SEm+	0.04	0.08	2092.8	0.08
	CD (0.05)	0.13	NS	NS	NS

4.19.1. Chiplima

4.19.1. Evaluation of Different Integrated Weed Management Practices under Modified Water Regimes in SRI

Among weed management methods, number of tillers was significantly higher in W_2, whereas number of panicles per plant, length of panicle, number of filled grains per panicle and yield were significantly higher in W_4. The variation in test weight was non-significant among the weed management practices. The irrigation levels affected the weed population and at saturation the weed count and its dry weight was found to be significantly higher than rest two irrigation levels (Table 4.19.1). Among different weed management methods, application of pre and post emergence weedcides suppressed the germination of the broad leaves and sedges. The best weed management method was achieved by application of both pre-and post-emergence weedicide in treatment W_4. The pooled mean of two years indicates that application of 5 cm standing water on the day before the weeding operation (I_1) obtained significantly highest grain yield of 5.62 t/ha. Integrated weed management method of W_4 (Application of one pre- and post-emergence herbicide i.e., Pretilachlor and Oxadiargyl) recorded significantly highest grain yield of 5.50 t/ha.

4.19.2. Effects of Water Regimes and Crop Geometry on Yield and Water Productivity in Maize – Greengram Intercropping System

Most remunerative *rabi* cereal and most widely adopted *rabi* pulse of the zone, maize and greengram were taken up to intensify land use through intercropping. Results (Table 4.19.2) showed that all yield attributes were favourably influenced by irrigation treatment at 0.80 IW/CPE followed by 0.90 IW/CPE which was at par with 0.70 IW/CPE. Maize intercropped with greengram in ratio 2:2 gave the highest maize equivalent yield and B:C ratio.

4.19.3. Optimising Irrigation Scheduling and Nutrient Management for Onion and Toria

The present study was undertaken to find out a suitable dose of sulphur for onion and toria, fix irrigation schedules and study quality parameters of onion. From the results (Table 4.19.3), it is evident that application of 40 kg/ha S along with irrigation at 1.2 IW:CPE can produce economically higher bulb yield in onion. The crop had highest water use efficiency with irrigation at 0.8 IW:CPE. For toria, application of 45 kg/ha S along with irrigation at 0.6 IW:CPE can produce economically higher seed yield. Highest water use efficiency was observed with irrigation scheduling at 0.6 IW:CPE.

4.19.4. Irrigation and Micronutrient Interaction Study in Aerobic Rice

The experiment was carried out to develop package and practices of aerobic rice cultivation. Aerobic rice variety CR Dhan 200 produced significantly highest grain yield at RDF (80-40-40) with 5 kg/ha Zn + 0.2 % B as foliar spray (2 nos.) with irrigation after 3 rainless days. Highest water use efficiency was observed when less water was applied (Table 4.19.4).

Table 4.19.1. Effect of irrigation and methods of weed control on yield and yield attributes in SRI

Treatments	No. of tillers per plant		No. of panicles per plant		Length of panicle		No. of filled grains per panicle		Test weight (g)		Yield (t/ha)	
	2014	2015	2014	2015	2014	2015	2014	2015	2014	2015	2014	2015
Water regimes												
I_1:2′′ standing water from the day of weeding operation	45	42.15	38	35.08	17	15.42	72	74	21.87	21.53	5.72	5.52
I_2:1′′ standing water from the day of weeding operation	44	40.33	31	31.13	16	16.21	66	64	21.95	21.61	5.06	5.21
I_3:at saturation	41	38.28	21	25.35	14	15.44	58	62	21.64	21.38	4.48	4.64
SEm±	NS	NS	2.89	2.43	NS	0.92	NS	2.76	NS	0.43	0.31	0.21
CD	NS	NS	8.67	7.31	NS	NS	NS	8.51	NS	NS	0.94	0.59
Weed management methods												
W_1:Weeding by Mandwa weeder at an interval of 7 days	24.25	38.66	16.79	20.33	10.83	13.32	50.08	53.66	21.5	21.32	4.64	4.93
W_2:Application of pre-emergence herbicide + use of Mandwa weeder after 20-30 days at an interval of 7 days	54.5	52.85	20.54	20.11	14.03	14.11	60.23	58.95	21.76	21.73	5.00	4.87
W_3:Weeding by Mandwa weeder at an interval of 7 days up to 20 days + application of post-emergence herbicide	38.25	35.22	25.25	25.15	17	17.5	68.6	69.1	22.2	22.11	5.24	5.38
W_4:Application of one pre- + one post-emergence herbicide	48.75	49.66	30.83	29.82	20.33	19.95	69.21	69.81	21.84	21.98	5.45	5.56
SEm±	1.83	1.63	0.95	0.61	0.53	0.48	4.51	3.26	NS	0.51	0.35	0.28
CD (at 5%)	5.29	4.96	2.74	1.89	1.54	1.44	13.09	9.85	NS	NS	1.01	0.87

Table 4.19.2. Effect of intercropping and irrigation regimes on growth and yield attributes of maize and greengram

Treatments	Yield (t/ha)				Maize equivalent yield (t/ha)		Land-equivalent ratio		B:C		WUE (kg/ha-mm)
	Maize	Maize	Green-gram	Green-gram							
	2014	2015	2014	2015	2014	2015	2014	2015	2014	2015	
Main plot: Irrigation level											
0.70 IW/CPE	3.34	3.51	0.16	0.19	3.97	4.11	-	-	1.98	1.81	8.08
0.80 IW/CPE	3.60	3.67	0.21	0.21	4.40	4.46	-	-	2.25	2.13	7.97
0.90 IW/CPE	3.36	3.22	0.20	0.20	4.10	3.98	-	-	2.11	1.94	6.46
1.00 IW/CPE	2.79	2.92	0.16	0.18	3.38	3.60	-	-	1.66	1.52	4.89
SEm±	0.03	0.02	0.01	0.01	0.04	0.08	-	-	-	-	-
CD (P=0.05)	0.09	0.06	0.03	0.02	0.13	0.24	-	-	-	-	-
Sub-plot: Crop geometry											
Maize (Sole crop)	4.17	4.67	0.00	0.00	4.17	4.67	1.00	1.00	1.94	1.89	-
M:G (1:1)	3.92	4.00	0.22	0.24	4.74	4.93	1.56	1.69	1.99	2.21	-
M:G (1:2)	3.36	3.72	0.22	0.21	4.17	4.51	1.42	1.52	1.96	2.01	-
M:G (2:1)	4.01	4.10	0.12	0.19	4.50	4.79	1.32	1.52	1.94	2.01	-
M:G (2:2)	4.13	4.41	0.20	0.20	4.87	5.17	1.56	1.53	2.28	2.33	-
Greengram (Sole crop)	0.00	0.00	0.36	0.29	1.33	1.10	1.00	1.00	1.88	1.76	-
SEm±	0.02	0.02	0.01	0.01	0.04	0.04	-	-	-	-	-
CD (P=0.05)	0.07	0.04	0.02	0.02	0.10	0.12	-	-	-	-	-

Table 4.19.3. Effect of irrigation and sulphur levels on yield and water use efficiency in onion and toria

Treatments	Bulb (onion) / Seed (toria) yield (t/ha)		Water requirement* (cm)		Water use efficiency (kg/ha-cm)	
	2013-14	2014-15	2013-14	2014-15	2013-14	2014-15
Onion						
Irrigation scheduling						
I_1: 0.8 IW/CPE	17.00	18.03	60	60	283.2	300.4
I_2: 1.0 IW/CPE	18.32	18.83	65	65	280.9	289.6
I_3: 1.2 IW/CPE	19.41	19.32	70	70	277.3	276.0
CD (5%)	1.80	0.90	-	-	-	-
Sulphur levels						
S_1:20 kg/ha S	17.07	18.04	-	-	-	-
S_2:40 kg/ha S	19.25	19.58	-	-	-	-
S_3:60 kg/ha S	18.11	18.56	-	-	-	-
CD (5%)	0.95	0.89	-	-	-	-

Toria						
Irrigation scheduling						
I_1: 0.6 IW/CPE	0.49	0.58	15	15	32.7	38.5
I_2: 0.8 IW/CPE	0.52	0.61	20	20	26.0	30.3
I_3: 1.0 IW/CPE	0.54	0.61	25	25	21.7	24.5
CD (5%)	NS	NS	-	-	-	-
Sulphur levels						
S_1: 30 kg/ha S	0.49	0.57	-	-	-	-
S_2: 45 kg/ha S	0.57	0.62	-	-	-	-
S_3: 60 kg/ha S	0.50	0.60	-	-	-	-
CD (5%)	0.33	0.21	-	-	-	-

* For onion- nursery bed irrigation (30 cm)

Table 4.19.4. Effect of irrigation and micronutrient levels on yield and water use efficiency in aerobic rice

Treatments	Grain yield (t/ha)	Water requirement (cm)	Water use efficiency (kg/ha-cm)
Irrigation scheduling			
I_1: Irrigation after 3 rainless days	4.05	80.98	50.01
I_2: Irrigation after 5 rainless days	3.91	67.05	58.35
I_3: Irrigation after 7 rainless days	3.78	56.67	66.70
I_4: Rainfed condition	3.20	50.53	63.32
CD (P = 0.05)	0.24	-	-
Micronutrient levels			
N_1:RDF (80-40-40)	3.03	61.10	49.59
N_2: RDF (80-40-40) + 5 kg/ha Zn + 0.2 % B as foliar spray (2 nos.)	4.27	61.10	69.88
N_3: RDF (80-40-40) + 5 kg/ha Zn	3.79	61.10	62.03
N_4: RDF (80-40-40) + 2.5 kg/ha Zn + 0.2 % B as foliar spray (2 nos.)	4.12	61.10	67.43
N_5: RDF (80-40-40) + 2.5 kg/ha Zn	3.70	61.10	60.56
N_6: RDF (80-40-40) + 0.2% B as foliar spray (2 nos.)	3.64	61.10	59.57
CD (P = 0.05)	0.17	-	-

Theme 5

To evolve management strategies for conjunctive use of surface and groundwater resources for sustainable crop production

5.1. Faizabad

5.1.1. Conjunctive Use of Surface and Groundwater at Middle of Distributory for Optimum Production

An attempt was made to use both canal and tubewell water for irrigation, in contrast to farmers' practice, with a goal to save irrigation water while maintaining productivity of wheat crop in the middle end of Chandpur distributory command area. Seven locations of Chandpur distributory were chosen for the study. Treatments applied were T_1- Farmers own practice i.e. 10-12 cm water by flooding/field to field irrigation as and when canal water was available and T_2- Improved water management practices i.e. 6 cm water through canal as well as groundwater provided at critical stages of crops (3 irrigations one each at crown root initiation (CRI), late jointing and milking stage). Observations from the experiment indicated that conjunctive use of water with improved irrigation practice of 6 cm water at critical growth stages of wheat by check basin (5x10 m^2) produced significantly higher grain yield (4212.86 kg/ha) of wheat as compared to farmers' practices (3232.14 kg/ha), in which 10 cm water was applied twice by flooding and field to field method. The increase in yield was recorded as 30.34% in case of improved irrigation practice over farmers' practice. Water expense efficiency (WEE) was also found significantly higher (41.59%) with improved irrigation practice in comparison to farmers' practice (Table 5.1.1).

Table 5.1.1. Effect of conjunctive use of surface and groundwater on productivity and WEE of wheat at middle end of distributory during 2014-15

Treatment	No. of Irrigations			Effective rainfall (cm)	Total water applied (cm)	Grain yield (kg/ha)	WEE (kg/ha-cm)
	Canal	Tubewell	Total				
T_1 (Farmers' practice)							
Field 1	2	-	2	-	20	3110	123.46
Field 2	2	-	2	-	20	3350	132.99
Field 3	2	-	2	-	20	3375	133.98
Field 4	2	-	2	-	20	3100	123.06
Field 5	2	-	2	-	20	3150	125.05
Field 6	2	-	2	-	20	3390	134.58
Field 7	2	-	2	-	20	3150	125.05
Mean	**-**	**-**	**-**	**-**	**-**	**3232.14**	**128.31**
T_2 (Improved practice)							
Field 8	2	1	3	-	18	4350	187.58
Field 9	2	1	3	-	18	4100	176.80
Field 10	2	1	3	-	18	4010	172.92
Field 11	2	1	3	-	18	4250	183.27
Field 12	2	1	3	-	18	4260	183.70
Field 13	2	1	3	-	18	4250	178.96
Field 14	2	1	3	-	18	4370	188.44
Mean	**-**	**-**	**-**	**-**	**18**	**4212.86**	**181.67**

Increase in yield and WEE (%) w.r.t. T_1 - 30.34 and 41.59

Plate 5.1.1. Multiple use of water through integrated farming system in canal command

5.1.2. Multiple use of Water Through Integrated Farming System at Head of the Chandpur Distributory

The experiment was conducted to i) develop village ponds for water harvesting, ii) efficiently use the harvested water for fish culture and duckery, iii) efficiently use the harvested canal and tubewell water for different cropping systems and iv) to study the economics of integrated farming system. Ponds owned by two farmers at Kail (tail end) and Daulatpur (middle) minors were selected for the study. The treatments were I) Conventional farming system consisting of cropping system Rice-Wheat+Rai, and II) Integrated farming system consisting of (A) cropping systems (Rice-Gram+Rai (4:1), Rice-Pea+Rai (2:2), Rice-Wheat+Rai (9:1)), (B) Pisiculture+Duckery and (C) irrigation levels for paddy (1-3 DADPW), wheat (3 irrigations at CRI, late jointing and milking stage) and pulse (2 irrigations (pre-flowering and pod formation). The study was conducted from 2012 to 2015. Integrated farming system was followed by the four farmers who grew gram, wheat and pea along with rai as intercrop during *rabi* season 2012-15. The crops were irrigated with canal and pond water. The crops were sown in the month of November every year. Rice was planted during *kharif* 2012-15 and three/four irrigations were given from canal and shallow tubewell. No irrigation was given from pond water. Results obtained from integrated farming are presented in table 5.1.2.

Table 5.1.2. Grain yield and economics of different cropping systemsunder multiple use of water through integrated farming in canal command (2012-15)

Cropping system	Area (ha)	Yield (kg/plot)			Cost of cultivation (Rs./ha)	Gross return (Rs./ha)	Net return (Rs./ha)	B:C
		Kharif	*Rabi*					
			Main crop	Inter crop				
Conventional practice								
i) Rice–Wheat + Rai	1.0	4331	3749	366	48250	125638	77388	1.60
Integrated cropping system								
i) Rice-Gram + Rai (4:1)	0.25	1201	359	178	11700	36804	25104	
ii) Rice-Pea + Rai (2:2)	0.25	1227	268	212	11200	30685	19485	
iii) Rice-Wheat + Rai (9:1)	0.25	1209	1067	112	12750	35713	22963	2.40
Pisiculture + Duckery	0.25	Fish - 531 kg			10000	53100	42100	
		Eggs – 3336 kg			4200	16680	9700	
Total	**1.0**	**-**	**-**	**-**	**50850**	**172982**	**122132**	

Market price of produce: Rice – Rs.13.50 per kg, Wheat – Rs.14.50 per kg, Rai – Rs.35 per kg, Gram – Rs.40 per kg, Pea – Rs.25 per kg, Fish - Rs.100 per kg and Duck egg- Rs.60 per dozen

Experimental results indicated that integrated farming system (Plate 5.1.1) accrued the net return of Rs.1,22,132.00 per hectare per year which was 57.80% higher than that of conventional cropping system (Rs.77388 per hectare year). The benefit cost ratio under the system was estimated as 2.40 against 1.60 for conventional cropping system. The system proved beneficial to the farmers. It was concluded that integrated cropping system with pisiculture and duckery was highly productive, remunerative and most water efficient system through multiple use of water under canal command. Multiple use of water through integrated cropping system with pisiculture and duckery was recommended to get maximum harvest and earn maximum net return with higher water use efficiency under canal command.

5.2. Bilaspur

Effect of Value Added Water and Integrated Nutrient Management on Growth and Yield of Rice-Wheat Crop Sequence under Conjunctive Use Condition

Dairy surface water produced higher rice grain yield (3.66 t/ha) and straw yield (4.84 t/ha) followed by Dairy surface water + Tubewell water (34.07 and 4.72 t/ha) in the year 2015 (Table 5.2.1). Similarly, under different nutrient management 100% RDF gave significantly higher yield (3.68 t/ha) than 75% RDF and 75% RDF + Brown manure but at par with 75% RDF + Green manure (3.67 t/ha) and 75% RDF + BGA (3.60 t/ha). Higher net return Rs.32605 was found under Dairy surface water followed by Dairy surface water + Tubewell water with Rs.28897 per ha.

Table 5.2.1. Growth, yield attributing characters of paddy as influenced by different treatments

Treatment	Plant height (cm)	Tillers per m^2	1000 grain wt. (g)	Length of panicle (cm)	No. of grains/ panicle	Grain yield (t/ha)	Straw yield (t/ha)	Benefit Cost ratio
Main plot								
W_1	82.05	410.00	24.33	22.52	89.52	3.66	4.48	1.24
W_2	78.37	364.26	23.55	21.86	70.17	3.17	4.47	0.95
W_3	80.33	383.20	23.97	21.93	78.82	3.41	4.72	1.10
CD (5%)	NS	5.00	NS	NS	1.98	NS	NS	1.22
Sub-plot								
F_1	78.78	378.44	23.99	22.19	79.31	3.68	4.85	1.10
F_2	78.79	364.00	23.80	22.00	77.48	3.33	4.64	1.20
F_3	84.32	447.11	24.19	22.59	84.00	3.67	4.78	0.73
F_4	77.64	347.44	23.76	21.42	74.37	2.78	4.26	1.23
F_5	81.82	392.11	24.04	22.32	82.35	3.60	4.84	-
CD (5%)	NS	29.87	NS	NS	NS	0.31	0.30	-
CV (%)	8.37	9.97	6.24	9.98	9.62	0.90	0.77	-

W1 = Dairy surface water
W2 = Tubewell water
W3 = Dairy surface water + Tubewell water
F1 = 100% RDF
F2 = 75% RDF
F3 = 75% RDF + Green manure
F4 = 75% RDF + Brown manure
F5 = 75% RDF + BGA

The grain and straw yield under different sources of water were not significant. However, the treatment W_1 produced higher grain yield (3.65 t/ha) and straw yield (4.83 t/ha) followed by W_3 grain yield was 3.41 t/ha and straw yield 4.72 t/ha. Similarly under different nutrient management F_1 gave significantly higher yield (3.61 t/ha) than F_2 and F_4 but at par with F_3 (3.68 t/ha) and F_5 (3.6 t/ha). Similarly, straw yield was significantly in F_1 (4.85 t/ha) than F_4 but at par with F_2, F_3 and F_5. Higher net return Rs.32605 was found under W_1 followed by W_3 Rs.28897 per ha. Under different nutrient management F_1, F_3 and F_5 gave higher net return Rs.32520, 32257, and 32103 respectively.

5.3. Jammu

5.3.1. Modeling for Planning the Conjunctive Use of Water at Basin Level within the Canal Commands of Jammu

An experiment was planned to enhance water productivity by utilization of stored rainwater and groundwater for supplemental irrigation in Ranbir canal command area (tail end); and further explore feasibility of such conjunctive uses of water in other command areas. More than 13,000 ha of farmers' land falls under this command where rice-wheat cropping sequence was mostly practiced. The experiment aims at bridging the gap between present yield (2.3 to 2.5 t/ha) to potential yield (3.3 t/ha) of rice variety Basmati-370 during *kharif* season. The first step towards this was water budgeting for quantification of blue and green water available was pre-requisite for planning the conjunctive use. Further, wheat crop was also affected due to deficit irrigation duting *rabi* season. But due to climate aberrations excess rainfall was recorded during *rabi* 2014-15. Therefore, land geometry may be improved through agro techniques and conjunctive use of water may be planned to improve water productivity of rice-wheat sequence in the area.

The study area was digitized and variability of slope in the command is presented in contour map (Fig. 5.3.1). Water budgeting of basmati rice within Jammu canal command was done during *kharif* 2015 (Table 5.3.1). Irrigation water supply (ha-m) of each distributary is estimated during *kharif* 2015 on the basis of designed discharge and command area of the identified distributaries (Table 5.3.2)

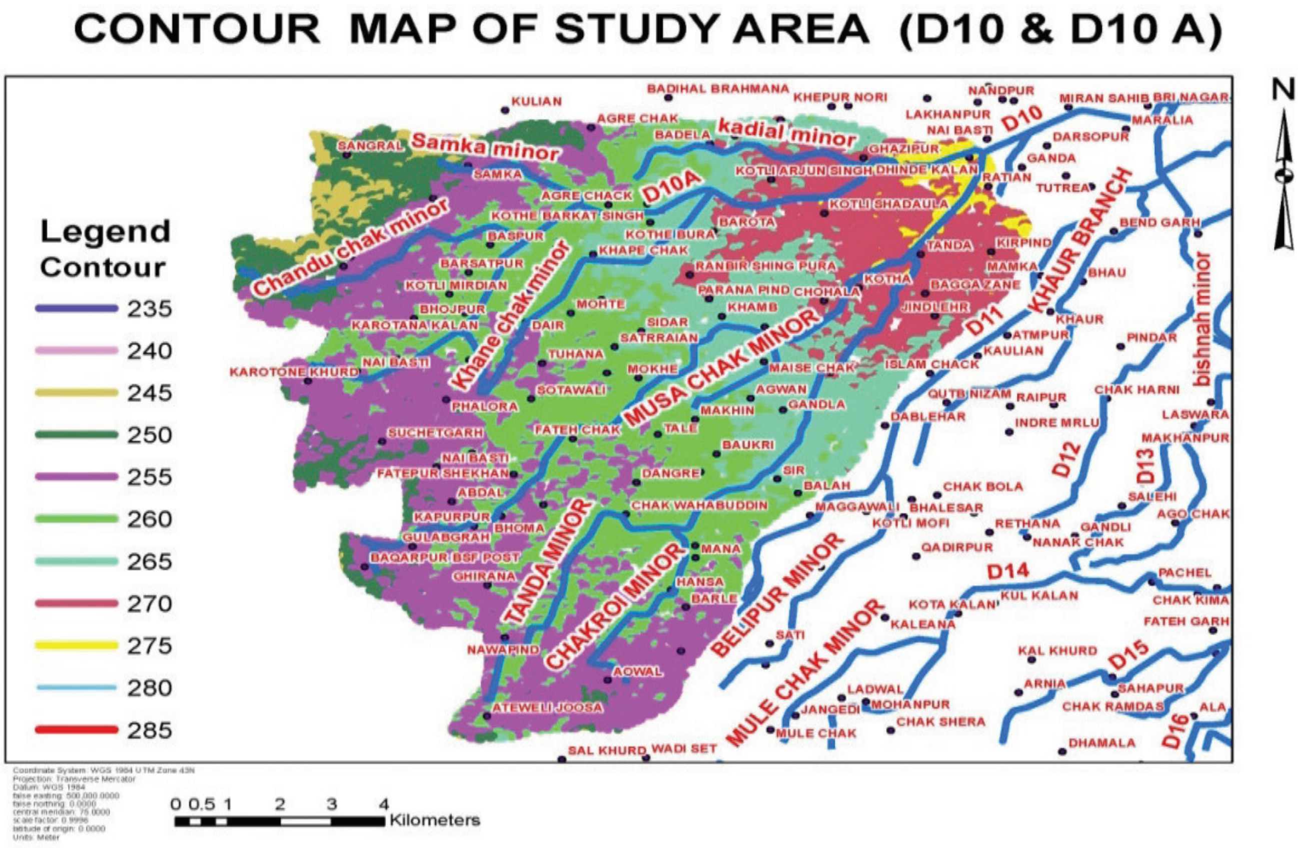


Fig. 5.3.1. Contour map of Ranbir canal command area

Table 5.3.1. Water budgeting of basmati rice within Jammu canal command (*Kharif* 2015)

Month	J	F	M	A	M	JU	JL	A	S	O	N	D
ET_o (mm/ day)	0.7	1.0	1.51	3.5	7.2	9.8	5.0	4.4	5.0	2.6	2.0	1.0
Duration of growth stages	-	-	-	-	-	-	Initial stage (31d)	Crop Dev. Stage (31d)	Mid season stage (30d)	Late season stage (31d)	Matu-rity stage (21d)	-
K_c values at GS	-	-	-	-	-	-	0.7	1.0	1.15	1.15	0.8	-
K_c value for the month	-	-	-	-	-	-	0.7	1.0	1.15	1.15	0.8	-
PET_c (mm/ day)	-	-	-	-	-	-	3.5	4.4	5.75	2.99	1.60	-
PET_c / month	-	-	-	-	-	-	108.5	136.4	172.5	92.69	33.6	-
Evapo-ration during LP (mm)	-	-	-	-	-	150	-	-	-	-	-	-
Percola-tion/ month (mm)	-	-	-	-	-	-	-	-	-	-	-	-
Rainfall (mm/ month)	17.20	116.5	334.8	149.2	18.7	96.6	368.1	318.8	115.5	21.9	14.2	28.4
Effective rainfall (mm/ month)	4.32	74.0	248.6	100.2	5.2	69.7	161.8	156.8	94.1	8.9	–	–
Irrigation require-ments and applied (mm/ month)	-	-	-	-	-	80.3	0.0	20.2	82.6	83.80	29.8	-

Month	J	F	M	A	M	JU	JL	A	S	O	N	D
AET_c = PET_c (mm)	-	-	-	-	-	150	108.5	136.4	172.5	92.69	33.6	-
Water loss to the atmosphere (mm)	693.7	-	-	-	-	-	-	-	-	-	-	-
Yield (t/ha)	2.5	-	-	-	-	-	-	-	-	-	-	-
Green & Blue water foot print (m^3/t)	2774.8	-	-	-	-	-	-	-	-	-	-	-
Total water needed (m^3/kg)	2.7	-	-	-	-	-	-	-	-	-	-	-

Table 5.3.2. Irrigation water supply during *kharif* 2015

Identification of canal network	Designed command area (ha)	Name of village with predominant cropping pattern	Designed discharge (cumec)	Estimated blue water at 7 days interval over crop period of 155 days (ha-m)	Estimated blue water available within for command at 40% efficiency (ha-m)
*MI_1 (D-10)	60	Kotlishah Dowla, Tanda Minor (Rice-Wheat)	0.04	10.4	4.2
**MA_2 (D-10)	3760	Ratian head to Kapoorpur (Rice-Wheat)	2.46	637.6	255.0
MI_3 (D-10)	240	Musachak minor (Rice-Wheat)	0.17	44.0	17.6
MA_4 (D-10)	2530.8	Main Tanda minor (Rice-Wheat)	2.69	697.3	278.9
MI_5 (D-10)	924.8	Chakroi minor (Rice-Wheat)	0.65	168.5	67.4
MA_6 (D-10A)	1000	Katyal minor (Rice-Wheat)	0.70	181.4	72.5

MI_7 (D-10A)	40	Badyal-A (Rice-Wheat)	0.02	5.2	2.0
MI_8 (D-10A)	34	Badyal-B (Rice-Wheat)	0.02	5.2	2.0
MA_9 (D-10A)	2896	Ratian head to Koratana (Rice-Wheat)	2.83	733.5	293.4
MI_{10} (D-10A)	100	SKUAST channel (Rice-Wheat)	0.07	18.1	7.2
MI_{11} (D-10A)	600	Khanna chak minor (Rice-Wheat)	0.42	108.8	43.5
MI_{12} (D-10A)	270	Samka minor (Rice-Wheat)	0.25	64.8	25.9
MI_{13} (D-10A)	920	Chandu chak minor (Rice-Wheat)	0.65	168.5	67.4
Total Area	13375.6				1137
AET of rice (mm)	**Command area (ha)**	**WR (ha-m)**	**ER (mm)**	**Green water (ha-m)**	**Blue water (ha-m)**
694	13375	9282	412	5510	1137

*MI minor; **MA major

Results obtained so far are as follows:

- Water requirement in the command area was 9282 ha-m
- Green water available in the command area was 5510 ha-m
- Blue water available in the command area was 1137 ha-m
- Total water available in the command area was 6647 ha-m
- Water deficit in the canal command with respect to rice cultivation was 2635 ha-m
- The deficit in water supply was the triggered for low productivity of rice
- It required the water saving intervention to promote the water productivity of rice across the command area
- Two water saving technologies *viz.*, Integrated Nutrient Management along with 3 DADPW and SRI technology were the most promising water saving technologies which could be transferred to the farmers' field

5.4. Bhavanisagar and Coimbatore

5.4.1. Conjunctive Use of Groundwater and Canal Water in the Command Area-Lower Bhavani Project

The current challenges in a canal command area are inequitable water availability at head vs. tail, access to surface water and groundwater, saline groundwater in tail-end villages and threat of waterlogging and crop losses. A suitable plan was adopted for controlling the problem of rising water levels by adopting the technique of conjunctive use of surface and groundwater, and proper drainage during supply period. Village-wise plans for development of groundwater resource in conjunction with surface water were prepared. The sustainability of the present irrigation pattern with respect to conjunctive use of water resources was tested with suggestions for improvement. The total ayacut area of the selected distributory is 3960.82 ha, covering six revenue villages in Gobichettipalayam taluk of Erode district. The command area is divided into two halves i.e. odd turn and even turns sluice command of equal extent. The ayacut area under odd turn is 2011.55 ha and even turn is 1949.27 ha. Villages benefited by canal water in the selected distributory (Kugulur distributory) are vettaikarankoil, Pachimalai, Kullampalayam, Udaiyampalayam, Polavakalipalayam, Vellampalayam, Bommanaiyankanpalayam, Kulavikaradu, Andipalayam, Odadurai, Thalaikombupudur, Kugulur. Three wells each in head, middle and tail end reaches of the selected distributary of both odd turn and even turn sluice command were identified in the odd turn and even turn, respectively. Totally 18 wells (9 wells in odd turn and 9 wells in even turn) were selected for the study purpose. It was observed that when water was released from the canal, areas adjoining to the distributory of the study area (upto 50 m length) were facing drainage problem. This problem existed in head reach farmers' field only.

Water was drained by providing field channel at suitable grade and conveyed to the interiorly located storage depression. No salinity problem was noticed in the selected distributory. Water was released for irrigation from canal for odd turn sluice command from January to April 2015 and August to December 2015. When water was released for odd turn sluice command, the farmers at head reaches mostly irrigated with canal water and some of the farmers irrigated with well water. The case was reversed in tail reaches (more irrigation from well and less irrigation from canal) because the tail end farmers were not getting canal water sufficiently (Fig. 5.4.1 and 5.4.2). More than 75 % of the farmers having open wells were also having borewells (one or two) so that they can give irrigation to annual crops during summer. Among them nearly 60 % of farmers pumped out water from bore wells in to open wells / surface level tanks and gave irrigation to fields by pumping water from open wells/diverting water from surface level tanks. The reason was the low yield from bore wells which cannot be directly let in to the fields. In the even turn sluice command, water was not released for irrigation from canal during the year 2015. Hence all the farmers used groundwater only for irrigation. When water was released from the canal farmers irrigated their fields through canal water only. During the absence of canal water supply, well water was used for irrigation. After canal water is released, they used groundwater in conjunction with canal water. Farmers who are at the head of the sluice used more of canal water whereas at the tail reach of sluice, farmers used comparatively more of groundwater since the availability at tail reach was less compared to head reach. During water release period farmers who installed drip system at their fields used only groundwater.

Depth of water level from ground surface in the study area varied between 3 and 10 feet below ground level during pre-monsoon and depth of water level varied between 5 and 50 feet below ground surface during post-monsoon. During the northeast monsoon depth to water level in the study area was at zero and it continued till February. Then water level in the well started to decline. Depth to water level varied from 1 to 30 feet during summer (March to May) and southwest monsoon (June to September) (Fig. 5.4.3). It was observed that the situation differed in the tail end. Though water was released in the canal during odd turn, depth to water level in the tail end wells was observed to be more than 25 feet (Fig. 5.4.4).

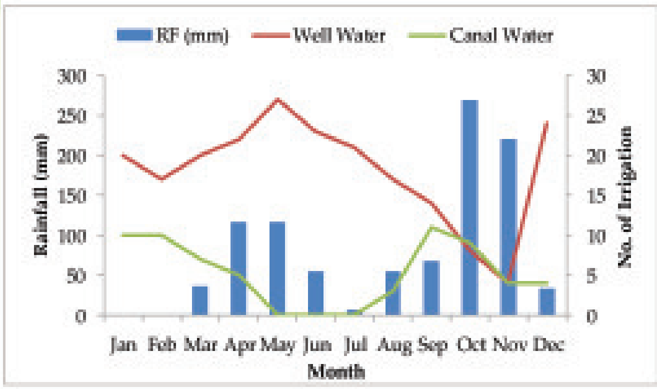


Fig. 5.4.1. Utilization of well water and canal water for odd turn sluice command

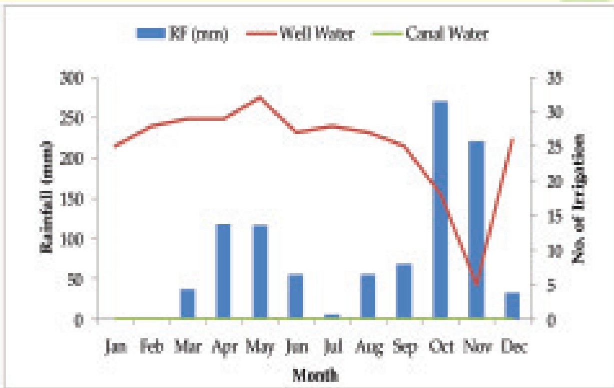


Fig. 5.4.2. Utilization of well water and canal water for even turn sluice command

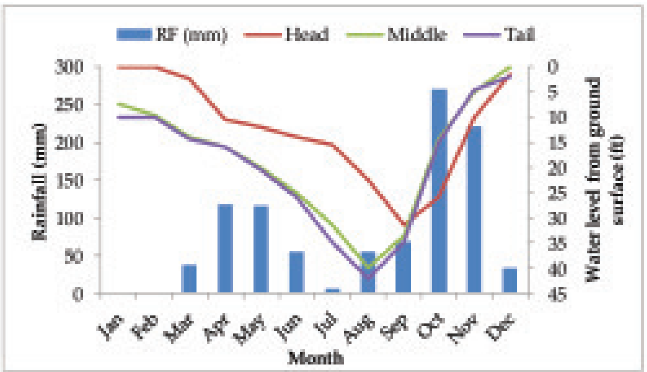


Fig. 5.4.3. Water level fluctuations for odd turn sluice command

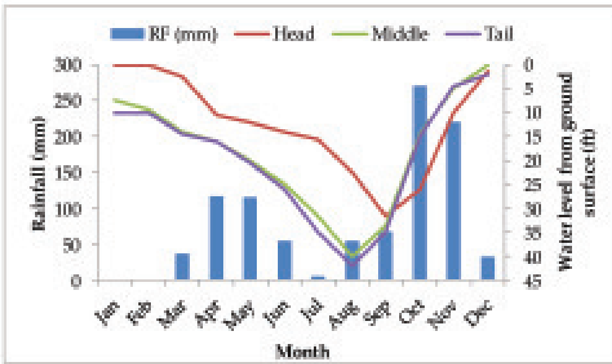


Fig. 5.4.4. Water level fluctuations for even turn sluice command

5.5. Udaipur

5.5.1. Development of Optimal Allocation Plan for Conjunctive Use of Water in Jaisamand Command

The study in Jaisamand command area (Fig. 5.5.1) was undertaken with the objective to bring more area under cultivation or to increase production per unit area of available land and water resources. It is important to optimize the available land and water resources for achieving maximum production. The existing cropping pattern in Jaisamand command area remained same since inception of the canal network. There was need to utilize resources at maximum economic efficiency. Looking to the need of the area the study on development of conjunctive use planning for optimal allocation of surface and groundwater for optimal production in Jaisamand command area had been conducted. The salient features of the canal system are shown in table 5.5.1.

Fig. 5.5.1. Jaisamand command area map

The estimation of rainwater, surface water and groundwater of the canal area was carried out after collecting pertinent data of the rainfall, water table fluctuations and discharge of the canal. The availability of surface runoff has been estimated using SCS curve number method. The daily rainfall data of last 10 years were collected and analyzed to find out the runoff potential in the command area. The water table monitoring was carried out for the selected 19 wells of the command area and total recharge volume was estimated using water table fluctuation technique. The availability of canal water was estimated using the data collected through discharge and duration of the canal running days. The discharge of the RMC and LMC was 7.56 and 1.53 cumec whereas; the average canal running days were only 25.

The total availability of water from three different sources was estimated for their optimal allocation during *kharif* and *rabi* crops, details of which are presented in table 5.5.1. Monthly net crop water requirements were estimated using CROPWAT (FAO, 1992 Model) (Table 5.5.2). In Jaisamand command area general crops like maize, soybean, moong, wheat, mustard etc. are grown. The total cropped area is 30250 ha in *kharif* and *rabi* season. The total production obtained was 62468.25 tonnes with investment of Rs. 778.86 million and net benefit obtained was Rs. 412.56 million.

Table 5.5.1. Water availability estimated under rainwater, surface water and groundwater

Sl. No.	Particulars	Water availability (ha-m)
1	Rainwater availability through surface runoff	1203.2
2	Groundwater availability through recharging	844.8
3	Canal water availability	1963.44
	Total	**4011.44**

Table 5.5.2. Monthly water requirement of crops (mm)

Month	Maize	Soybean	Greengram	Wheat	Mustard	Gram	Barley
January	-	-	-	111.17	11.16	55.17	98.61
February	-	-	-	113.17	-	-	57.37
March	-	-	-	25.59	-	-	-
April	-	-	-	-	-	-	-
May	-	-	-	-	-	-	-
June	-	-	-	-	-	-	-
July	138.17	99.59	85.80	-	-	-	-
August	173.57	152.54	147.55	-	-	-	-
September	192.03	171.28	129.34	-	-	-	-
October	31.11	30.29	-	-	58.03	60.49	-
November	-	-	-	50.57	105.94	96.13	36.41
December	-	-	-	90.86	93.04	95.07	75.23
Total	**534.89**	**453.71**	**362.69**	**391.36**	**268.17**	**306.86**	**267.62**

5.6. Rahuri

5.6.1. Effect of Polluted Groundwater Due to Sugar Factory Effluent on Yield of Wheat Crop and Soil Properties

A field experiment was conducted with wheat var. Trimbak (NIAW-301) as test crop. Randomized block design with five treatments and four replications. The treatments were T_1- Irrigation with polluted groundwater due to sugar factory effluent, T_2- Irrigation with normal well water, T_3- One irrigation with normal well water followed by two irrigations with polluted groundwater due to sugar factory effluent, T_4- One irrigation with polluted groundwater due to sugar factory effluent by two irrigations with normal well water and T_5- Alternate irrigation- one irrigation with polluted groundwater due to sugar factory effluent and other by normal well water.

Water samples from low, medium and highly polluted wells and their chemical analysis are presented in table 5.6.1 and fig. 5.6.1. Wheat yield affected by the presence of heavy metals in groundwater is presented in table 5.6.2. Comparison of accumulation of heavy metals in wheat grains is shown in fig. 5.6.2.

Table 5.6.1. Water quality parameters in high polluted groundwater (LPGW), medium polluted groundwater (MPGW), low polluted groundwater (LPGW) and normal well water (NWW)

Parameter	NWW	HPGW	MPGW	LPGW
pH	7.23	7.84	7.69	7.36
EC, dS/m	0.54	7.02	1.57	0.65
SAR	0.74	12.51	7.84	5.38
Irrigation Class	C_2S_1	C_4S_2	C_3S_1	C_2S_1
Total Dissolved Salts (TDS), mg/l	364.8	5952.0	1523.2	620.80
Calcium, meq/l	6.70	12.15	11.00	16.45
Magnesium, meq/l	3.20	14.80	13.65	24.2
Sodium, meq/l	2.30	40.11	28.63	27.17
Potassium, meq/l	2.40	3.95	8.56	5.35
Carbonate, meq/l	–-	–-	–-	-
Bicarbonate, meq/l	1.70	8.90	5.85	5.8
Chloride, meq/l	4.50	21.26	10.10	4.9
Sulphate, meq/l	4.20	–-	–-	9.71

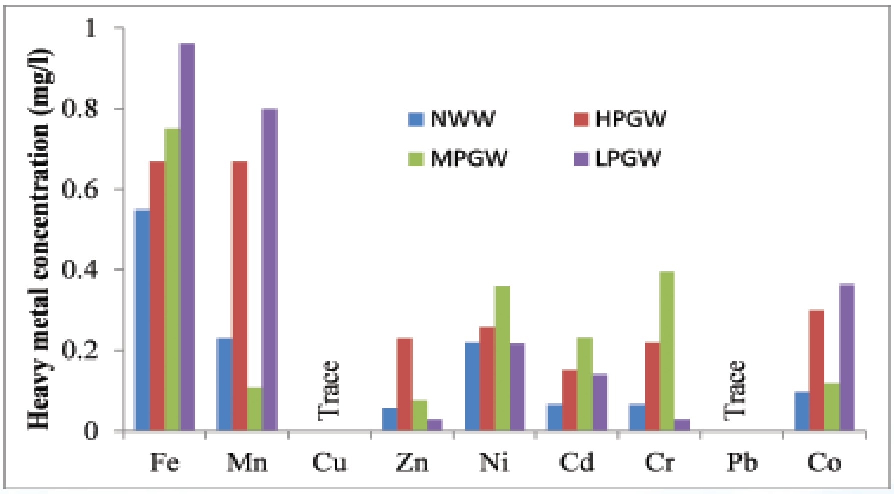


Fig. 5.6.1. Heavy metal concentration in normal well water (NWW), high polluted groundwater (HPGW), medium polluted groundwater (MPGW) and low polluted groundwater (LPGW)

Table 5.6.2. Pooled yield of wheat (2012 to 2015) as influenced by irrigation with low polluted groundwater (LPGW), medium polluted groundwater (MPGW) and high polluted groundwater (HPGW)

Treatments	Grain yield (t/ha)		
	LPGW	MPGW	HPGW
T_1	2.24	2.39	2.03
T_2	2.56	2.76	2.45
T_3	2.40	2.56	2.14
T_4	2.50	2.69	2.24
T_5	2.43	2.61	2.20
SE±	0.06	0.06	0.04
CD at 5%	0.18	0.20	0.14

Recommendation

High polluted water with irrigation class (C_4S_2, EC> 2.25 dS/m, 10<SAR<17) is not recommeneded for wheat production.

In medium deep soil, to obtain maximum yield of wheat crop with medium polluted water of class C_3S_1 (0.75<EC<2.25, SAR<10), wheat crop be irrigated in the sequence of irrigation of one medium polluted water followed by two irrigations of normal water.

In medium deep soil, to obtain maximum yield of wheat crop with low polluted water of class C_2S_1 (0.25<EC<0.75, SAR<10), wheat crop be irrigated in the sequence of one irrigation of low polluted water followed by two irrigations of normal water.

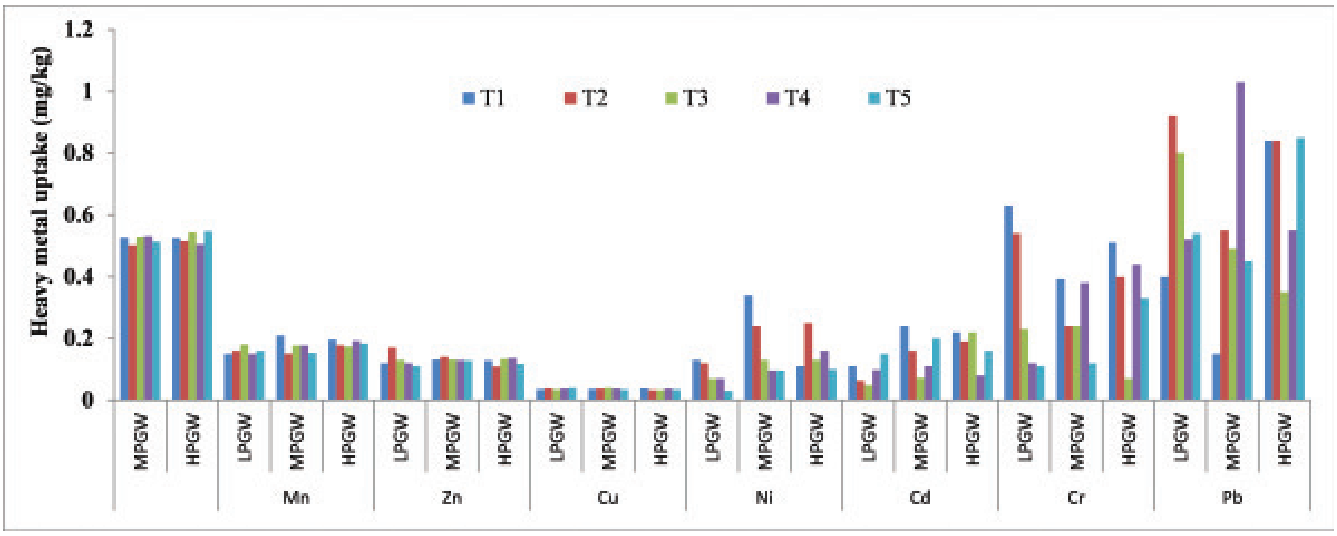
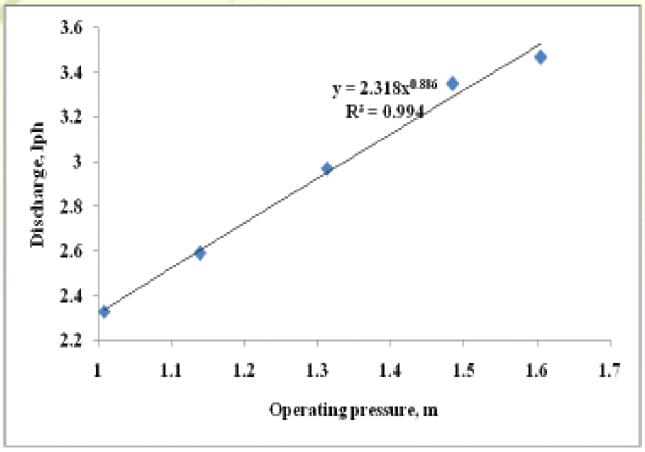


Fig. 5.6.2. Average accumulation of heavy metals in wheat grains (2012-13 to 2014-15)

The flow rate through the emitters and micro-tubes and the pressure developed due to water level (head) in farm pond were measured to develop the pressure discharge relationship. The pressure discharge relationship was developed by plotting discharge against the operating pressure. The results of discharge and pressure developed due to different water levels in farm pond are presented in fig. 5.6.3. The emission uniformity of emitters and micro-tubes were measured and calculated by adopting the standard procedure. Two laterals of lengths 10 m and 15 m and depths of water in farm pond 2.70 and 2.27 m were used for this purpose.

Results showed that emission uniformity of the emitter system was 90.34 % and 91.91 % at 2.70 m and 2.27 m depths of water in farm pond, respectively for 10 m lateral length (Table 5.6.3). For 15 m lateral length, emission uniformity of the emitter system was 91.01% and 87.32 % at the same consecutive depths of water in farm pond (Table 5.6.3). It was also observed that emission uniformity of the micro-tube system was 91.38 % and 89.59 % at 2.70 m and 2.27 m depths of water in farm pond for 10 m lateral length. For 15 m lateral length, emission uniformity of the micro-tube system was found 91.88 % and 87.92 % at the same consecutive depths of water in farm pond.



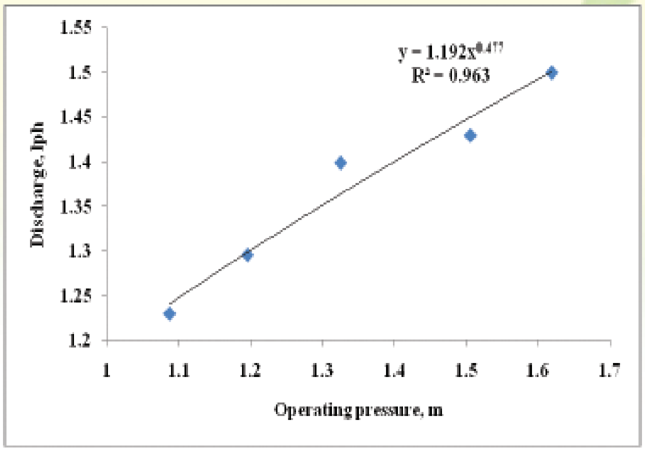


Fig. 5.6.3. Pressure-discharge relationship for emitter (left) and micro-tube (right)

Table 5.6.3. Emission uniformity of emitter and micro-tube system at 10 m and 15 m lateral lengths

Sl. No.	Depth of water in farm pond (m)	Length of lateral with emitter (m)	Pressure (kg/cm²)	Mean emission uniformity (%)
Emitters (Turbo key)				
1	2.70	10	0.1508	90.34
2	2.70	15	0.1508	91.01
3	2.27	10	0.1127	91.91
4	2.27	15	0.1127	87.32
Micro-tube				
1	2.70	10	0.1492	91.38
2	2.70	15	0.1492	91.88
3	2.27	10	0.1024	89.59
4	2.27	15	0.1024	87.92

5.7. Bathinda

5.7.1. Evaluation of Drip Irrigation System in Vegetable Crops using Brackish Water

The experiment was conducted to study the feasibility of drip irrigation system throughout the year for cropping system of vegetables [Cucumber (Feb to May) - Bottlegourd (June to Oct) - Cauliflower (Nov to Feb)]. Randomised block design was adopted using D_1 - Canal water (CW), D_2 - Canal water:Tubewell water (1CW:1TW), D_3 (1CW:2TW), D_4 - 1CW:3TW and D_5 – TW with three replications per treatment. Quality of tubewell water was estimated: RSC = 6.3-6.4 meq/l, EC = 2.1-2.3 dS/m. Dripper discharge was 2.4 l/h.

Results of different quality of water on yield and water expense efficiency (WEE) of cauliflower (Plate. 5.7.1), cucumber and bottle gourd are shown in Table 5.7.1. Results revealed that yield of cauliflower, cucumber and bottle gourd was highest with canal water treatment and was significantly higher than that of other treatments except 1CW:1TW treatment for cauliflower and bottle gourd. Maximum WEE was in CW treatment followed by 1 CW:1 TW and lowest in TW treatment for all the crops.

Table 5.7.1. Effect of different qualities of water on yield, yield attributing characteristics and water expense efficiency of cauliflower, cucumber and bottle gourd

Treatments	Cauliflower		Cucumber		Bottle gourd	
	Curd yield (t/ha)	WEE (t/ha-cm)	Yield (t/ha)	WEE (t/ha-cm)	Yield (t/ha)	WEE (t/ha-cm)
CW	20.65	0.99	13.3	0.27	41.46	0.9
1 CW:1 TW	19.44	0.96	9.76	0.20	37.62	0.32
1 CW:2 TW	18.80	0.92	8.04	0.17	36.67	0.80
1 CW:3 TW	18.51	0.92	7.21	0.15	34.31	0.76
TW	18.06	0.90	6.73	0.14	33.64	0.74
CD @ 5%	1.64	-	1.26	-	4.93	-

CW = Canal water; TW = Tubewell water; 1, 2, 3 - proportion of tubewell water

5.7.2. Growth and Yield Response of *Bt* Cotton to Water Quality and Fertigation Levels under Drip System

Effect of water quality and fertigation on seed cotton yield and water expense efficiency of drip irrigated *Bt* cotton was studied (Plate. 5.7.2). A field experiment was conducted with split plot design with fertigation levels (F_1 = 60% of RDN, F_2 = 80% of RDN and F_3 = 100% of RDN) as main plot treatments and irrigation water quality (Canal water (CWg), Irrigation with CWg till germination and subsequent irrigation with poor quality tubewell water (CW_g- TW) and CW_g/TW (alternate)) as sub-plot treatments, with three replications per treatment. Crop geometry was paired row with 55-80-55 cm spacing. Dripper discharge was 2.4 l/h. Irrigation was applied based upon Penman-Monteith method. Rainfall during crop season was 36.86 cm. Irrigaion water applied to every treatment is 19.2 cm.

The effect of irrigation water quality and fertigation levels on different growth and water use parameters are given in table 5.7.2. The data shows that seed cotton yield recorded significantly higher values when canal irrigation or alternate irrigation with canal and tubewell water applied than with tubewell water alone. On an average, the observed seed cotton yield was 2143.6 kg/ha with canal water followed by 2007.3 kg/ha with alternate irrigation of canal and tubewell water and 1644.4 kg/ha with tubewell water alone. Similar trends were observed for other growth parameters i.e. number of bolls per plant and number of sympods per plant. Among different fertigation schedules, seed cotton yield was at par when 80% and 100% of recommended dose of fertilizer was applied. Both treatments had significantly higher yield than the treatment in which 60% of recommended dose of fertilizer was applied. The WEE was highest with canal water and lowest with tubewell water treatments.

Table 5.7.2. Irrigation water applied, profile water use, water expense efficiency (WEE), yield and yield attributing parameters of cotton with poor quality water in different methods of irrigation

Fertigation levels	Profile water use (cm)	Water expense (cm)	Yield (kg/ha)	WEE (kg/ha-cm)	Plant height (cm)	No. of bolls per plant	Sympods per plant
			F_1 = 60% of RDN				
CW	2.63	58.7	1826.7	31.1	113.5	37.1	29.4
CW_g - TW	1.46	57.5	1504.0	26.1	99.7	31.1	26.0
CW/TW	2.01	58.1	1718.0	29.6	107.8	35.1	27.7
Mean	-	-	1682.9	-	107.0	34.4	27.7
			F_2 = 80% of RDN				
CW	2.93	59.0	2193.3	37.2	118.3	45.1	34.2
CW_g - TW	1.72	57.8	1657.3	28.7	103.0	33.9	28.4
CW/TW	2.33	58.4	2012.0	34.5	109.0	41.5	32.1
Mean	-	-	1954.2	-	110.1	40.2	31.6
			F_3 = 100% of RDN				
CW	2.86	58.9	2410.7	40.9	121.5	49.2	36.9
CW_g - TW	1.85	57.9	1772.0	30.6	112.7	36.4	30.9
CW/TW	2.45	58.5	2292.0	39.2	114.1	46.3	34.7
Mean	-	-	2158.2	-	116.1	44.0	34.2
			Overall average				
CW	-	-	2143.6	-	117.8	43.8	33.5
CW_g - TW	-	-	1644.4	-	105.1	33.8	28.4
CW/TW	-	-	2007.3	-	110.3	41.0	31.5
Fertigation level (CD 5%)	-	-	251.6	-	NS	6.07	4.77
Water quality (CD 5%)	-	-	202.3	-	8.9	5.57	2.24
Interaction	-	-	NS	-	NS	NS	NS

Plate 5.7.1. Drip irrigated cauliflower

Plate 5.7.2. Drip irrigated cotton

5.7.3. Evaluation of Furrow Irrigation System with Poor Quality Water in Wheat-Cotton Cropping Sequence

Field experiment was done to study the effects of poor water quality on growth and yield of cotton and wheat. The effect of the water on soil properties in cotton-wheat cropping sequence was also analysed. The experiment was laid out in split plot design with irrigation water [CW; poor quality TW water; pre-sowing irrigation (Rauni) with CW and subsequent irrigations with TW water (CWpsi + TW)] in main plot and irrigation methods [check basin irrigation (CB), each furrow irrigation (EF and alternate furrow irrigation (AF)] in sub-plots. Rainfall received during the crop season was 14.4 cm.

The effect of irrigation water on water use parameters is given in table 5.7.3. The irrigation to each furrow (EF) and alternate furrow (AF) saved 26.7 and 46.7% of irrigation water applied as compared to flat (check basin, CB) method of irrigation on an average basis.The amount of irrigation water applied and total water use was in the order of check basin irrigation method>each furrow irrigation>alternate furrow irrigation. The overall seed cotton yield was highest in each furrow irrigation method. The highest WEE was recorded in each furrow method of irrigation irrespective of water quality,except in TW irrigation. The tubewell water irrigation decreased the seed cotton yield in flat (check basin) method of irrigation.On an average basis,tubewell water irrigation alone yielded 646 kg/ha seed cotton yield as compared to758 kg/ha with rauni with canal water followed by all other irrigations with tubewell water and 902 kg/ha with canal water irrigation alone.

Table 5.7.3. Irrigation water applied, profile water use, water expense, yield water expense efficiency and yield attributing parameters of wheat with different source of water and irrigation methods

Irrigation methods	Irrigation water applied (cm)	Profile water use (cm)	Water expense (cm)	Grain yield (kg/ha)	Water expense efficiency (kg/ha-cm)	Plant height (cm)	No. of tillers per metre row
			Canal water				
CB	30.0	7.1	51.5	4397	85.4	92.9	121.2
EF	22.0	9.0	45.4	4010	88.4	95.2	113.0
AF	16.0	13.0	43.4	3342	77.1	89.3	104.1
Mean	22.7	9.7	46.7	3916	83.6	92.4	112.8
			Tubewell water				
CB	30.0	9.3	53.7	4095	76.2	92.3	114.7
EF	22.0	10.0	46.4	3715	80.0	93.3	109.5
AF	16.0	12.1	42.5	3248	76.5	90.3	103.0
Mean	22.7	10.5	47.5	3686	77.6	92.0	109.0
			Pre-sowing irrigation with canal water and all other irrigation with tubewell water				
CB	30.0	9.8	54.2	4223	78.0	91.1	118.8
EF	22.0	10.4	46.8	3990	85.3	94.2	112.4
AF	16.0	11.7	42.1	3310	78.6	90.0	104.0
Mean	22.7	10.6	47.7	3841	80.6	91.8	111.7
			Overall average				
CB	30.0	13.7	53.1	4238	79.9	92.1	118.2
EF	22.0	11.6	46.2	3905	84.6	94.2	111.6
AF	16.0	10.6	42.7	3300	77.4	89.9	103.7
			CD (5%)				
Irrigation water	-	-	-	NS	-	NS	NS
Irrigation method	-	-	-	236	-	1.9	5.9
Interaction	-	-	-	NS	-	NS	NS

5.7.4. Effect of Quality of Water on Growth, Yield and Quality of Potato under Varying Mulch Conditions

Field experiment was conducted to study the effect of different qualities of water on potato yield and water productivity under mulching and to study the effect of quality of water on soil properties as well. Randomised Block design with treatments T_1 = No mulch under canal water (CW), T_2 = No mulch under tubewell water (TW), T_3 = No mulch under CW/TW (alternate irrigation), T_4 = Straw mulch under canal water (CW), T_5 = Straw mulch under tubewell water (TW), T_6 = Straw mulch under CW /TW (alternate irrigation), T_7 = Plastic mulch under canal water (CW), T_8 = Plastic mulch under tubewell water (TW), T_9 = Plastic under CW /TW (alternate irrigation), Straw mulch @ 6 t/ha, Plastic sheet (50 micron, black), each with 3 replications were adopted during the study period 2008 – 2014. In the physico-chemical characteristics of soil (0-15 cm), soil texture was found to be Loamy Sand with pH, EC, $CaCO_3$, OC, 8.31, 0.16 dS/m, 4.45%, 0.21% respectively. Also, the available P was 13.5 kg/ha and available K was 334 kg/ha. While composition of tubewell water EC, Na^+, Ca^{+2} + Mg^{+2}, CO_3^{-2}, HCO_3, RSC, SAR was 2.20 dS/m, 20.87 meq/l, 1.64 meq/l, 2.4 meq/l, 5.68 meq/l, 6.44 meq/l, 23.05, respectively.

Results showed that alternating the application of tubewell water (saline sodic) with canal water significantly enhanced the marketable potato tuber yield to the tune of 30.9 % than only tubewell water application (Table 5.7.4). Alternate use of CW and TW under straw mulch and plastic mulch increased the tuber yield by 18.8% and 31.7% over no mulch. Mulch application significantly increased the tuber yield. The application of straw and polythene mulch improved the tuber yield by 21.4 and 33.3 % respectively, over no mulch regardless of quality of water. However, polythene mulch proved to be superior compared with straw mulch by 9.8 %. Mulch application decreases pH and ESP of the surface layer of the soil under TW and CW/TW treatments. Organic carbon status of the soil improved with the application of straw mulch. Effect of mulching and irrigation water quality on biochemical composition of potato is shown in table 5.7.5.

It may be recommended that cyclic use of saline sodic water and canal water with or without mulch was recommended to obtain higher marketable potato tuber yield and to maintain soil health. The outcome of this research will help in judicious use of poor quality groundwater inconjunction with good quality canal water in potato without affecting the economic returns ofthe growers along with minimal effect on soil quality.

Table 5.7.4. Plant growth, tuber yield and water expense efficiency (WEE) of potato with poor quality water under varying mulch conditions (Pooled mean of five years)

Irrigation methods	Marketable tuber yield (t/ha)	WEE (kg/ha-cm)	Plant height (cm)	No. of haulms per plant	B:C
CW M_0	13.94	269.93	27.66	3.52	1.31
TW M_0	9.47	183.44	24.42	2.85	0.88
CW/TW M_0	12.58	139.62	26.30	3.22	1.18
CW M_S	17.10	331.55	30.50	4.09	1.54
TW M_S	11.67	221.53	25.98	3.11	1.04
CW/TW M_S	14.94	281.86	29.12	3.59	1.34
CW M_P	18.88	357.06	33.10	4.41	1.47
TW M_P	12.54	239.96	28.98	3.61	0.97
CW/TW M_P	16.56	318.07	31.72	4.35	1.28
CD (5%)	2.17	–	5.08	0.59	–

Table 5.7.5. Effect of mulching and irrigation water quality on biochemical composition of potato

Biochemical character	Type of mulch	Irrigation water quality			Mean
		CW	TW	CW/TW	
Dry matter (%)	No Mulch	14.10	14.57	14.18	14.28
	Straw Mulch	14.73	16.99	15.61	15.78
	Plastic Mulch	16.11	17.14	16.41	16.55
	Mean	14.98	16.23	15.40	-
	CD (5%) for M = 0.86 and WQ = 0.78				
Total sugars (% dry weight)	No Mulch	2.90	3.23	3.18	3.10
	Straw Mulch	3.32	3.43	3.38	3.38
	Plastic Mulch	2.78	2.94	2.90	2.87
	Mean	3.00	3.20	3.15	-
Reducing sugars (% dry weight)	No Mulch	1.83	1.46	1.66	1.65
	Straw Mulch	1.85	1.48	1.74	1.69
	Plastic Mulch	1.82	1.41	1.72	1.65
	Mean	1.83	1.45	1.71	-
Starch (% dry weight)	No Mulch	15.02	13.88	14.16	14.28
	Straw Mulch	15.62	14.94	15.36	15.31
	Plastic Mulch	15.11	14.14	14.59	14.61
	Mean	15.37	14.54	14.98	-
	CD (5%) for M = 0.36				
Ascorbic acid (mg/100g)	No Mulch	14.65	13.07	13.50	13.74
	Straw Mulch	15.70	15.12	15.20	15.34
	Plastic Mulch	15.72	14.00	14.25	14.66
	Mean	15.36	14.06	14.32	-
	CD (5%) for WQ = 0.58				

5.7.5. Screening of Wheat Cultivars Under Varying Saline Sodic Irrigation Water Conditions

The study was done to select suitable wheat cultivars under varying saline sodic irrigation water environments. Field experiment was carried out with split plot design with water quality in main plot and wheat cultivars in sub-plot. Water sources were canal water and tubewell water. Quality of tubewell was analysed as shown in Table 5.7.6. Five wheat cultivars included in the study were V1: PBW-343, V2: DBW-17, V3: KRL-19, V4: PBW-590 and V5: PBW-550. Number of replication for each treatment was three.

Table 5.7.6. Tubewell water quality

	Location	Catagory	EC (μmhos/cm)	RSC (meq/l)
1.	PAU, Regional Station, Bathinda	High RSC (5-8meq/l) + Medium EC (2000-4000 μmhos/cm)	2150	6.0
2.	Vill. Gehri Buttar	High RSC (5-8meq/l) + Low EC (< 2000 μmhos/cm)	1550	5.5

The effects of quality of irrigation water on yield and other parameters of different wheat cultivars at Regional Station, Bathinda are given in table 5.7.7. The quality of water had no significant effect on grain yield of different wheat cultivars, however, various wheat cultivars showed significant difference with respect to grain yield, number of tillers per meter row length and height among themselves. Significantly maximum yield and number of primary tillers and were recorded under PBW 343 and PBW-550 than other varieties. The mean profile water use under canal and tubewell water was 2.87 and 2.18 cm, respectively. The overall WEE of PBW 343 and PBW-550 was higher than remaining cultivars.

The effects of quality of irrigation water on yield and other parameters of different wheat cultivars at village Gehri Buttar are given in table 5.7.8. The quality of water had non-significant effect on grain yield of different wheat cultivars. The mean grain yield of wheat was higher under canal water than tubewell water alone application. The wheat cultivars PBW 550 and PBW 343 gave significantly higher grain yield than other varieties under canal water as well as tubewell water. However, the wheat cultivars *viz.*, PBW-343, and PBW-550 performed better than all the varieties under tubewell water. The water use efficiency was also highest under canal water than tubewell water alone application.

Table 5.7.7. Yield, irrigation water applied, profile water use, water expense, water expense efficiency and yield attributes of wheat at Regional Station, Bathinda

Variety	Irrigation water applied (cm)	Profile water use (cm)	Water expense (cm)	Grain yield (kg/ha)	Water expense efficiency (kg/ha-cm)	Plant height (cm)	No. of primary tillers
Canal water							
V_1	30	4.01	46.35	3954	85.3	88.3	104.1
V_2	30	1.02	43.36	3354	77.4	82.2	90.7
V_3	30	2.80	45.14	3445	76.3	80.3	94.7
V_4	30	3.64	45.98	3204	69.7	85.3	91.2
V_5	30	4.38	46.72	3907	83.6	87.4	96.0
Mean	30	2.87	45.2	3572	77.2	84.7	95.3
Tubewell water							
V_1	30	2.48	44.82	3635	81.1	86.8	102.0
V_2	30	2.78	45.12	3221	71.4	83.3	88.5
V_3	30	1.37	43.71	3142	71.9	85.1	90.9
V_4	30	2.08	44.42	3076	69.3	81.7	88.1
V_5	30	2.80	45.14	3645	80.7	85.1	94.5
Mean	30	2.18	44.5	3344	73.4	84.4	92.8

Overall average							
V_1	30	3.25	45.59	3795	83.2	87.5	103.0
V_2	30	1.90	44.24	3286	74.4	82.8	89.6
V_3	30	2.09	44.43	3294	74.1	82.7	92.8
V_4	30	2.86	45.20	3140	69.5	83.5	89.7
V_5	30	3.59	45.93	3776	82.2	86.3	95.3
CD (5%)							
A (Water)	-	-	-	NS	-	NS	NS
B (Variety)	-	-	-	323	-	3.2	8.38
A x B	-	-	-	NS	-	NS	NS

Table 5.7.8. Yield, yield attributes and water use efficiency (WUE) of wheat at village Gehri Buttar, district, Bathinda

Variety	No. of tillers per metre row length	Spike length (cm)	Grain yield (kg/ha)	WUE (kg/ha-cm)
Canal water				
V_1	102.2	8.83	3651	121.7
V_2	97.6	8.80	3346	111.5
V_3	98.3	9.20	3177	105.9
V_4	91.6	8.77	3078	102.6
V_5	100.7	9.60	4089	136.3
Mean	98.1		3468	115.6
Tubewell water				
V_1	101.1	8.93	3497	116.6
V_2	95.2	8.90	3267	108.9
V_3	95.1	9.70	2826	94.2
V_4	87.1	9.27	2772	92.4
V_5	99.0	9.03	4098	136.6
Mean	**95.5**		**3292**	**109.7**
Overall average				
V_1	101.7	8.88	3574	119.1
V_2	96.4	8.85	3307	110.2
V_3	96.7	9.45	3002	100.1
V_4	89.3	9.02	2925	97.5
V_5	99.8	9.32	4094	136.5
CD (5%)				
A (Water)	NS	NS	NS	-
B (Variety)	5.35	NS	335	-
A x B	NS	NS	NS	-

5.7.6 *In Situ* Evaluation of Water Purifier for Irrigation Purpose in South-West Punjab

Field experiment was carried out to study the performance of water purifier under different water qualities (saline, sodic and saline-sodic). Randomised Block Design having 4 replications on wheat (HD 2967) – Raya (PBR-91) – Cotton (NCS 855 BG II) crops varieties with treatments T_1 = Canal water (CW), T_2= Tubewell water (TW), T_3 = Purified tubewell water (PTW), T_4 = Purified tubewell water / tubewell water (PTW/TW) were used alternately. The irrigation water applied (IWA) for wheat, raya, cotton was 30 cm, 22.5 cm and 30 cm, respectively. Different water quality parameters of tubewell water before and after treatment are given in table 5.7.9.

Table 5.7.9. Analysis of untreated and treated tubewell water samples

Treatments	Water quality parameters(*meq/l)					EC	Remarks
	$*CO_3^{-2}$	$*HCO_3^-$	$*Cl^-$ Mg^{+2}	$*Ca^{+2}$	*RSC	(µmhos/cm)	
Untreated (Tubewell water)	Nil	8.1	3.3	2.1	6.0	2200	-
Treated (using water purifier)	Nil	8.2	3.4	2.1	6.1	2150	No change in water quality

Table 5.7.10. Profile water use (PWU), yield, water expense efficiency (WEE) of wheat, raya and cotton as influenced by different treatments

Treatments	PWU (cm)			Yield (kg/ha)			WEE (kg/ha-cm)		
	Wheat	Raya	Cotton	Wheat	Raya	Cotton	Wheat	Raya	Cotton
T_1	2.13	5.07	0.89	5168	2107	1889	111.1	50.2	28.5
T_2	1.74	5.65	-2.49	4926	2075	881	106.8	48.8	14.0
T_3	5.97	6.09	-4.02	4881	2164	1145	96.9	50.3	18.7
T_4	4.22	6.31	-3.08	4887	2150	1123	100.5	49.8	18.0
CD (5%)	-	-	-	NS	NS	304	-	-	-

The effect of different qualities of water on grain yield of wheat, raya and cotton with other water expense components are given in table 5.7.10. Application of varying qualities of irrigation water didn't affect the grain yield of wheat significantly. It suggests that during the initial years of application of poor quality tubewell water alone didn't lower wheat yield in light textured soils. The WEE was lowest in PTW treatment. While in raya, different qualities of irrigation water had non-significant effect on its yield. (Table 5.7.10). The WEE was lowest where irrigations of purified tubewell water alone were applied. However, in case of cotton (*kharif*), application of tubewell water alone, purified tubewell water alone and purified tubewell water/tubewell water (alternately) produced statistically similar seed cotton yield which was significantly lower than canal water alone (Table 5.7.10). In other words, the seed cotton yield was maximum in treatment T_1 and significantly differed than T_2, T_3 and T_4 treatments. The WEE was maximum under canal water treatment.

5.7.7. To Study the Growth and Water Use of Tree Species under Different Saline Sodic Water Environments

The experiment with three tree species Poplar, Eucalyptus and Burma dek was conducted in Randomized Block Design. Five different qualities of water taken as treatments were Canal water (CW), Saline sodic tubewell (TW) water, CW:TW (alternately), 2 CW:1TW and 1 CW : 2 TW, each with three replications. Seven trees were planted per plot, with dates of plantation for Dek: 23/08/2010, Eucalyptus: 08/09/2010 and Poplar: 27/01/2011. Number of irrigations applied from Nov. 2014-Oct. 2015 for Dek, Poplar and Eucalyptus were 9, 12 and 14, respectively with irrigation water depth 2.8 cm. The saline sodic tubewell water had RSC = 6.4 meq/L and EC = 2400 µ mhos/cm.

Results show that growth parameters (height and girth) taken in November, 2015 differ significantly for dek and poplar with the water treatments (Table 5.7.11). In case of dek, maximum height was found with canal water, which was significantly higher than irrigation with TW and 2 TW:1CW. The lowest height of dek was recorded under tubewell water alone. Among the treatments, height of poplar trees with canal water irrigation was significantly higher than TW and 2 TW:1CW treatments. The girth of poplar trees was similar for CW, CW:TW and 2CW:1TW treatments, but were significantly higher than the TW and 2 TW:1CW treatments. The data in table 5.7.12 indicates that water expense under different tree species was lowest in canal water followed by 2CW:1TW treatment.

Table 5.7.11. Height and girth of dek, eucalyptus and poplar under different qualities of water during November 2015

Treatments	Dek		Eucalyptus		Poplar	
	Height (m)	Girth (cm)	Height (m)	Girth (cm)	Height (m)	Girth (cm)
CW	12.93	52.9	21.76	67.6	13.15	47.2
TW	9.60	40.9	20.13	61.5	10.88	38.4
CW:TW	11.26	48.1	21.02	64.9	12.32	43.7
2CW:1TW	12.26	50.7	21.64	66.3	12.89	45.8
2TW:1CW	10.71	44.0	20.46	62.4	11.21	41.3
CD (5%)	1.57	4.6	NS	NS	1.64	3.9

Table 5.7.12. Irrigation water applied (IWA), profile water use (PWU) and water expense (WE) in different tree species

Treatments	IWA (cm)	PWU (cm)	Rainfall (cm)	WE (cm)
		Dek		
CW	25.2	4.69	53.89	83.78
TW	25.2	8.36	53.89	87.45
CW:TW	25.2	7.1	53.89	86.19
2CW:1TW	25.2	5.44	53.89	84.53
2TW:1CW	25.2	8.05	53.89	87.14
		Eucalyptus		
CW	39.2	7.23	53.89	100.32
TW	39.2	9.41	53.89	102.5
CW:TW	39.2	8.89	53.89	101.98
2CW:1TW	39.2	7.75	53.89	100.84
2TW:1CW	39.2	8.98	53.89	102.07
		Poplar		
CW	33.6	4.23	53.89	91.72
TW	33.6	7.49	53.89	94.98
CW:TW	33.6	6.86	53.89	94.35
2CW:1TW	33.6	5.67	53.89	93.16
2TW:1CW	33.6	6.03	53.89	93.52

5.8. Jabalpur

Comparative Study on Performance of Water User Associations (WUA)

Performance assessment of a command area has been focused on internal processes of irrigation systems. The type of performance measures chosen depends on the purpose of the performance assessment activity. It was useful to consider an irrigation system in the context of nested systems to describe different types and uses of performance indicators. Many internal process indicators related to assess performance of any irrigation system were analyzed.The area selected for the present study was command area under three WUAs at their locations in Madhya Pradesh. They are Bijori WUA in Jabalpur district, Bauchhar WUA in Narsinghpur district and Govindgarh WUA in Rewa district (Fig. 5.8.1). Bijori and Bauchhar WUAs are a part of Left Bank Canal of Rani Awanti bai Sagar Irrigation Project and Govindgarh WUA was under Govindgarh tank.The major crops grown in the area during *rabi* season are wheat, gram, lentil, pea, arhar and some vegetables crops and in *kharif* season the main crop is paddy.

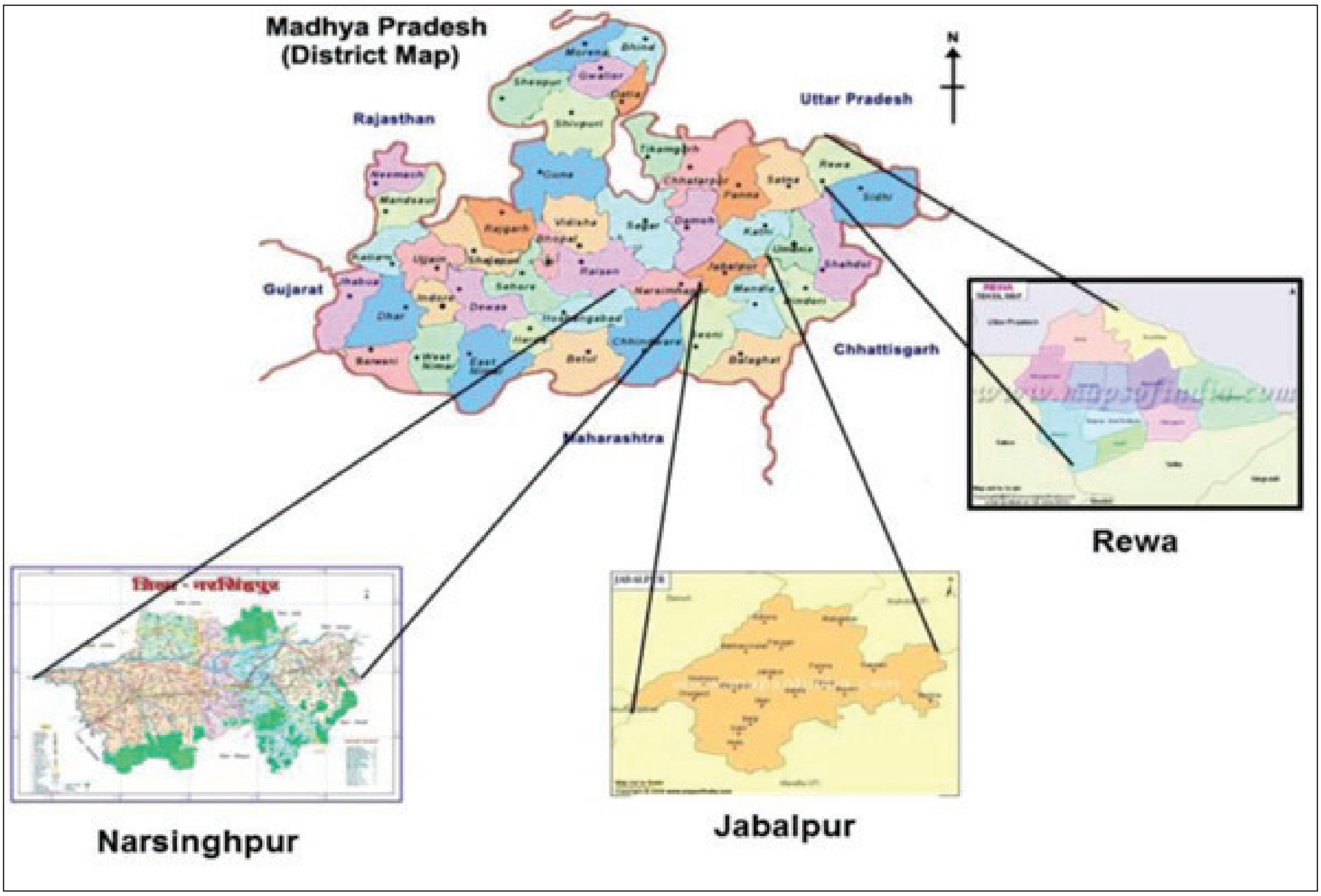


Fig. 5.8.1. Location map of study area in Madhya Pradesh

Daily records of supply head in main canal were obtained from the Water Resources Department, Government of Madhya Pradesh. Based on cross sectional area, slope and outlet conditions, the discharge delivered to the command area was estimated. Operating hours of selected minor and the schedule of operation of the main canal during the irrigation season were observed to estimate the volume of water delivered to study area. Location of different fields, water courses, field channels, area irrigated and sources of irrigation water were also obtained from the records of the local irrigation authorities. Table 5.8.1 presents the area under irrigation in different WUAs.

Table 5.8.1. Irrigation in command areas

Sl. No.	Description	Name of the WUA		
		Bijori	Bauchhar	Govindgarh
1	Gross command area (ha)	2082	1531	1840
2	Canal irrigated area (ha)	889	110	1120
3	Tubewell irrigated area (ha)	960	190	362

Asymmetrical factorial design with 3 replications was used for the experiment with four groups of farmers' category namely marginal, small, medium and large and three reaches namely head, middle and tail reach. In this experiment input values were water productivity of wheat at 3 different reaches of four categories of farmers at all three Water User Association. There were nine minor having length from 1.2 km to 3.21 km. Total number of farmers were 2268. Distribution of these farmers were in marginal (0 - 1 ha), small (1 - 2 ha), medium (2 - 4 ha) and large (> 4 ha) category is presented in fig. 5.8.2. Nine farmers in each category distributed in head, middle and tail end of command, were selected randomly for the study. In Bijori, Govindgarh and Bauchhar WUA, total number of farmers were 1150, 844 and 274, respectively. The distribution of number of farmers is presented in fig. 5.8.2.

Total survey area was highest in large category followed by medium, small and marginal in all the WUAs. %age of total number of farmers covered three WUAs in different categories was highest in Bauchhar WUA because it has total number of farmers less as compared to other WUAs. The details regarding the area of cross section, depth of flow and velocity in minors and field channel obtained from the measurement along with the location. Bottom width of minors was 0.3 and side slope were 1:1.1 to 1:1.5, depth of flow change varied from 0.11 to 0.43 m. accordingly velocity was recorded as 0.27 to 1.15 m/s in various minors. Water productivity of wheat crop in different reaches was estimated for four categories of farmers under different reaches and presented in table 5.8.2. In all the WUAs, water productivity of medium category was found significantly higher than the other categories. In Bijori WUA, maximum water productivity was found in middle reach of medium category (0.854) and minimum in head reach of marginal category (0.407). In Govindgarh WUA, maximum water productivity was found in tail reach of medium category (2.089) and minimum in head reach of marginal category (0.612). In Bauchhar WUA, maximum water productivity was found in middle reach of medium category (1.556 kg/m^3) and minimum in head reach of marginal category (0.472 kg/m^3). It was observed that the mean water productivity was significantly highest in Govindgarh WUA in tail reach of medium farmer category and lowest in Bijori WUA in head reach of marginal farmer.

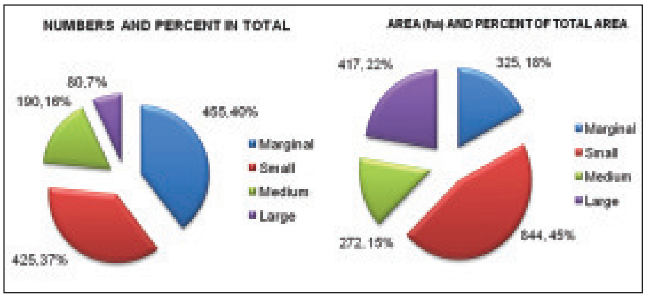


Fig. 5.8.2(a). Distribution of land holdings in Bijori WUA

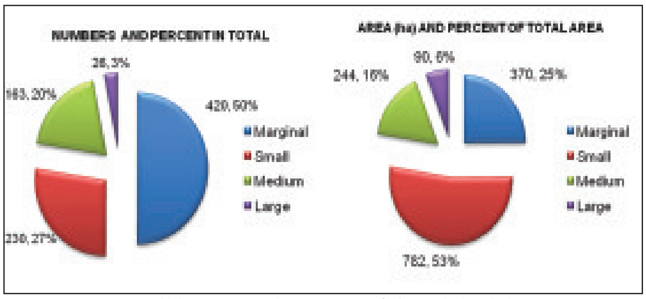


Fig. 5.8.2(b). Distribution of land holdings in Govindgarh WUA

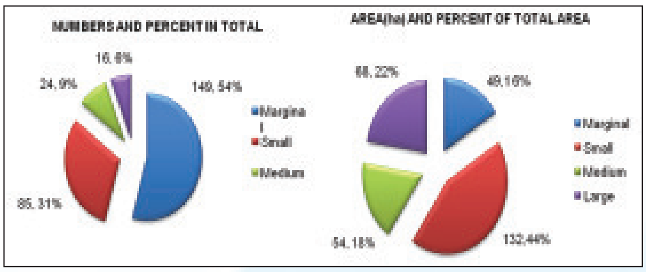


Fig. 5.8.2(c). Distribution of land holdings in Bauchhar WUA

Table 5.8.2. Mean water productivity of wheat (kg/m^3)

		Water productivity of Bijori	Water productivity of Govindgarh	Water productivity of Bauchhar
Category	Marginal	0.590	0.759	0.845
	Small	0.550	1.274	0.835
	Medium	0.699	1.564	1.210
	Large	0.559	1.508	1.076
	SE d	0.13	0.21	0.23
	CD	0.06	0.10	0.11
Reach	Head	0.524	0.991	0.612
	Middle	0.652	1.341	1.063
	Tail	0.623	1.495	1.300
	SE d	0.05	0.09	0.10
	CD	0.11	0.18	0.20
Category x Reach				
Marginal	Head	0.407	0.612	0.472
Small	Head	0.445	1.069	0.674
Medium	Head	0.641	1.351	0.623
Large	Head	0.605	0.933	0.679
Marginal	Middle	0.595	0.960	0.683
Small	Middle	0.568	1.623	0.880
Medium	Middle	0.854	1.252	1.556
Large	Middle	0.591	1.530	1.132
Marginal	Tail	0.769	0.704	1.379
Small	Tail	0.638	1.128	0.952
Medium	Tail	0.603	2.089	1.451
Large	Tail	0.482	2.061	1.417
-	SE d	0.11	0.18	0.19
-	CD	0.22	0.37	0.40

5.9. Chiplima

Feasibility Study on Multiuse of Water in Chronically Waterlogged Ecosystem in Hirakud Command

An intervention was undertaken to convert a chronic waterlogged ecosystem of Hirakud Command (Plate 5.9.1) into productive land. The entire area was put under land configuration through trench formation, pond excavation and development of field plots to grow water chestnut, fish and lowland rice, respectively. Pond and field bunds were used to grow banana and vegetables, respectively. From *kharif* 2001 to 2015 there was gradual decline in the crop yield, which might be due to deterioration of soil health. In order to improve the soil health, intervention was undertaken by growing rice with rice mill waste (RMW) and gypsum. Performances of different crop components are shown in table 5.9.1.

The uncultivated chronically waterlogged areas located in the bottom reach of terraced topographic situation of irrigated command could be utilized properly with suitable land configuration (Plate 5.9.2). The technology was suitable for all chronically waterlogged ecosystems. Chronically waterlogged areas can be very productive by digging trenches with 2 m width and 0.75 m depth in 8.60% area and a farm pond (1.5 m depth) in 4.0% area developed elevated plots (42.72% area) with bunds (1.5 m width) in 41.25% area and having drainage channel (3.4% area) in one side. It was possible to raise different crops along with rearing of fishes with multiple use of water. Growing water chestnut in trenches, okra, ridge gourd, beans, cowpea and radish on trench bunds was successful in increasing the profitability of the system with enhanced water productivity. During 2014, with all interventions the rice equivalent yield was 5.86 q/ha and total gross income was Rs.70,369 from one hectare of configured land.

Table 5.9.1. Yields of different crop components and their monetary values per hectare of configured waterlogged area in one year

Crop components	Yield (kg/ha)		Total (kg/ha)	Unit price (Rs.)	Total income (Rs.)	Rice equivalent yield (t/ha)
	Rabi 2014-15	*Kharif* 2015				
Rice	2911	1956	4867	12	58,404	4.87
Fish	12	30	42	80	3,360	0.28
Water chestnut	35	-	35	15	525	0.04
Cowpea	115	22	137	10	1,370	0.11
Bean	82	20	102	10	1,020	0.09
Raddish	200	60	260	5	1,300	0.11
Okra	35	150	185	10	1,850	0.15
Ridge gourd	22	128	150	10	1,500	0.13
Banana (bunch)	8	5	13	80	1,040	0.09
Total	**-**	**-**	**-**	**-**	**70,369**	**5.87**

Technology Assessed, Refined and Transferred

RICE

Bilaspur

- Delaying irrigation up to 3 to 5 days after subsidence of ponded water could be considered to be the best water regime for paddy in clay-loam to clay soil as about 40-60% of irrigation water could be saved without any loss in yield in comparison to continuous submergence (± 5 cm ponded water).
- Rice cultivation under SRI system produced higher grain yield and high net return with provision of combination of irrigation 3DADPW and interculture tools-Ambika paddy weeded (2 times).
- In rice bunded field, soybean could be successfully grown with depth of drainage channel 30 cm at a distance of 6 m strip in clay loam soil in the region.

Hisar

- Zero tillage was adopted on about 65,000 ha area by about 20000 farmers in Karnal, Kaithal, Kurukshetra, Ambala and Jhajjar districts in rice-wheat system under Resource conservation technology.

Jammu

- In light textured soils of command area, by adopting the SRI practice, the irrigation was applied with 40 mm depth upon the appearance of hair-line cracking during vegetative phase for Basmati-370 rice. 12 days old seedling was transplanted with a spacing of SRI was 25 cm x 25 cm. This saved irrigation water from conventional method (1720 mm) to SRI (1150 mm) i.e. the extent of 33%; while as the reduction in yield from 2.87 to 2.41 t/ha (16%) as compared to traditional continuous ponding of 70 mm water practiced by farmers. This acted as an alternate management practice for water scarce reaches of the canal command. The B:C ratio was 1.27.

Jorhat

- In case of autumn rice, recommended irrigation practice i.e. 5 cm irrigation 3 DADPW (days after disappearance of ponded water) saves about 30% irrigation water over the existing farmer's practice i.e. continuous submergence. Thus, the farmers can increase their area under irrigation to an extent of 30% with the same irrigation water.

Kota

- Irrigation were applied at critical stages of rice i.e. CRI, late tillering, flowering and milk stages using the border strip method (5m x 50m) with cut off ratio of 80%. This method saved 16 cm water and also gave 8.7 and 8.5% higher yield in LMC and RMC area respectively than wild flooding practice of farmers.

Navsari

- The results revealed that both the individual effects i.e., variety and drip lateral spacing as well as their interactive effects were found to be significant on grain yield of paddy. Between the two varieties tested, GNR-3 recorded significantly higher grain yield as compared to NAUR-1. Among the three lateral spacing treatment, treatment of L_1 = 40 cm found significantly superior over wider lateral spacing treatment i.e., L_2 = 60 cm and L_3 = 80 cm. Treatment combination GNR-3 on closer lateral spacing at 40 cm out yielded rest of the treatments by recording significantly higher grain yield of paddy.

Powerkheda

- The on farm trials conducted at five locations in Khojanpur, Fefartal and Palashdoh villages during the kharif 2015 demonstrated that the average seed yield of paddy under the SRI was maximum (4520 kg/ha) which was 4% more than the yield of transplanting method with 1 DADPW (4346 kg/ha) and 8.2% more than the yield under continuous submergence. The net return of Rs.70637 per ha, B:C ratio 2 and WEE of 86.10 kg/ha-cm was highest under SRI.
- The seed yield of rice variety *Pusa Sugandha 4* was found to be the maximum (4813 kg/ha) under transplanting with irrigation at 1 DADPW which was at par to the yield (4146 kg/ha) under transplanting with submergence. The highest water use efficiency (41.03 kg/ha-cm) was recorded under transplanting with irrigation at 1 DADPW. The net monetary returns of Rs.46217 per ha and B:C ratio of 1.71 were also high under the same treatment.

Shillong

- Puddled transplanted (6015 kg/ha) and unpuddled transplanted (5715 kg/ha) rice recorded higher yield as compared to other tillage practices with an increase of 29.2% in yield as compared to unpuddled wet seeded rice. Also, the seed yield (2.75%) and water use efficiency (2.86%) of succeeding lentil were higher under zero tillage and straw mulching respectively compared to that without mulch.

WHEAT

Bilaspur

- Sprinkler irrigation up to vegetative stage with surface irrigation afterwards, produced higher grain yield of wheat with lower water expense and maximum net return as compared to border strip method of irrigation.
- Higher yield of wheat was obtained with high WEE and net returns by providing 5 irrigations and fertilizer dose of 100:60:40, kg/ha under late sown conditions in Chhattisgarh plain.

Hisar

- In most of the areas in western and southern regions underlain with brackish groundwater, conjunctive use of brackish water and canal water practice was adopted and followed by the farmers along with mini-sprinkler irrigation method in wheat.

Jammu

- During rabi 2011-12 and 2012-13, revealed that irrigation (40 mm) at CRI stage, followed by scheduling of 40 mm irrigation at net CPE of 40 mm (i.e. IW/CPE 1.00) emerged as the best irrigation practice for wheat (cv. Ankur Mangesh) in light textured soils. Zero-tillage method of establishment (yield 4.7 t/ha) more than that of conventional method of wheat sowing (yield 4.4 t/ha) wherein 100% recommended dose of nitrogen was applied coupled with maintenance of 1.0 IW/CPE ratio. The WEF (Water Expense Efficiency) was 14.28 kg/ha-mm. The B:C ratio was evaluated as 2.89:1.
- The yield of wheat (*cv. Raj-3077*) was in the range of 33 t/ha with irrigation application at IW/CPE of 1.0 resulting in water expense efficiency of 11.5 kg/ha-mm under different establishment methods comprising of conventional, FIRBS (dimension includes 37 cm bed width, 30 cm furrow width, and height 15 cm) and zero-tillage.

Pantnagar

- In heavy soils having poor drainage with low moisture loss pattern wheat sowing on raised beds offset the adverse effect of excess moisture up to some extent compared to flat sowing (farmers' practice). It provided higher grain yield and net return over flat sowing.

Powerkheda

- The on-farm trials conducted at five locations in Palashdoh, Khojanpur and Fefartal villages of Hoshangabad District during rabi season 2014 –15 that the average seed yield of wheat under zero tillage sowing (4556 kg/ha) was 4.1% more than that obtained under conventional method (4378 kg/ha). The net returns of Rs.38014 ha and B:C ratio 2.3 obtained were higher under zero tillage. The data indicated that WUE (151.87 kg/ha-cm) under zero tillage was considerably more than that under conventional practice (116.75 kg/ha-cm).

Pusa

- The water requirement of wheat by mini-sprinkler irrigation and LEWA method as compared with surface irrigation revealed that the lowest grain yield of wheat was recorded with surface method of irrigation and significantly higher grain yield was recorded with mini-sprinkler and LEWA system of irrigation.
- Maximum grain yield of wheat was recorded with irrigation applied at 1.0 IW/CPE and decreased significantly with decreasing IW/CPE ratio from 1.0 to 0.6.
- Water use efficiencies achieved in wheat crop were 20.31, 18.73, and 15.12 kg/ha-mm with mini-sprinkler, LEWA and surface irrigation method, respectively. WUE increased by 34.33 and 23.88% with mini-sprinkler and LEWA, respectively as compared to surface irrigation.
- Maximum grain yield of wheat was recorded with irrigation level receiving 5 irrigations at 20, 40, 60, 80 and 100 DAS which was significantly superior over irrigation level receiving 3 irrigations at 20, 50 and 80 DAS and receiving 3 to 4 irrigations based on IW/CPE ratio of 1.0 but was statistically at par with irrigation levels of receiving 4 irrigations at 20, 40, 70 and 90 DAS.

MAIZE AND SOYABEAN

Bilaspur

- The IW/CPE ratio 1.0 with 200 kg/ha N was adopted for maize which gave higher grain yield with higher water expense efficiency.

Jammu

- For maize (cv. GS-2) highest yield of 3.32 t/ha was obtained when four irrigations were applied, one each at pre-sowing, knee height stage, tassling and silking followed by 3.17 t/ha when three irrigations were given at pre-sowing, knee height stage and tassling. Highest WUE of 3.87 kg/ha-mm was obtained when the crop was irrigated thrice, once each at pre-sowing, knee height stage and tassling followed by 3.85 kg/ha-mm when two irrigations (pre-sowing & knee height stage) were applied and 3.76 kg/ha-mm when four irrigations were applied (pre-sowing, knee height stage, tassling and silking). The B:C ratio 1.06 was achieved when the crop was sown in lines followed 0.77 and 0.55 when crop ridge sown or dibbled, respectively. Highest B:C of 2.08 was obtained with four irrigations, one each at pre-sowing, knee height stage, tassling and silking followed by a ratio of 1.98 when three irrigations were given at pre-sowing, knee height stage and tassling.

Shillong

- Zero tillage resulted in higher maize equivalent yield (MEY) (5821 kg/ha) as compared to conventional tillage. Among the intercropping system / residue management treatments, the MEY was higher under Maize + Groundnut Paired Row (residue retention) which was 35.2 % more as compared to sole maize and the yield of succeeding toria was also found to be higher under Maize + Groundnut Paired Row (residue removal) which was 20.4 % higher as compared to Sole Maize.
- Maize and succeeding mustard grown under zero tillage had significantly higher grain yield which was 7.6 % and 2.3 % higher as compared to when grown under conventional tillage. Whereas among the residue management practices, the grain yield of maize (6758 kg/ha) and seed yield of mustard (848.3 kg/ha) was highest under maize stalk cover + poultry manure + Ambrosia @ 5 t/ha, which was 32.2% and 15.8% increase in the yield as compared to control.
- Maize intercropped with ash gourd was found to be the best system for the terrace condition of mid altitude of Meghalaya for soil moisture conservation and yield of maize. The yield obtained was 17.4% higher as compared to control.

Kota

- Soybean+maize intercropping system (4:2) gave higher soybean equivalent yield (20.1%) with one irrigation at pod development stage by border strip method as compared to sole soybean (farmers' practice).
- Maximum soybean seed yield (1286 kg/ha) obtained under irrigation at flowering and pod development stage. Significantly higher seed yield (1333 kg/ha) and water use efficiency (23.46 kg/ha-cm) were recorded under foliar fertilization spray of 19:19:19 (5 g/l) at 30, 45, 60 and 75 DAS over rest of the foliar fertilization treatments.

Powerkheda

- The seed yield with flatbed sowing of maize (3042 kg/ha) was slightly more than that under ridge-furrow (2951 kg/ha) and broad bed furrow (2827 kg/ha). Application of 125% NPK (150:75:50 kg/ha) gave maximum seed yield of 3335 kg/ha but it showed parity with the yield (3023 kg/ha) with 100% NPK (120:60:40 kg/ha). The seed yield (2461 kg/ha) under 75% NPK (90:45:30 kg/ha) was reduced significantly.

PULSES AND OILSEEDS

Bilaspur

- The IW/CPE ratio 0.8 (or four irrigations 25, 54, 82 and 102 days after sowing) gave higher rabi sunflower yield with higher water expense efficiency.
- The IW/CPE ratio 0.9 (or 8-9 irrigations) was recommended for summer groundnut which gave higher yield with high water expense efficiency.
- Brinjal (var. Mukta Keshi) showed better growth and green fruiting with irrigation at 0.8 IW/CPE (about 7 irrigations at an interval of 20-25 days) with application of 200 kg/ha N in sandy loam soil.
- The crop coefficient of sunflower (var. Jwalamukhi) for Agro-climatic zone-Chhattisgarh plain has been worked out as 0.32-1.02 with seasonal value of 0.69. The crop matured in 128 days with measured crop evapotranspiration of 25.76 cm.
- The crop coefficient of lentil (var. K-75) for Agro-climatic zone-Chhattisgarh plain has been found in the range of 0.31-0.95 with seasonal value of 0.65. The crop matured in 109 days with measured crop evapotranspiration of 16.17 cm and estimated potential evapotranspiration of 22.95 cm.

Coimbatore

- Operation Research Project on improved water management practices in LBP (Lower Bhavani Project) led to water saving in improved water management practice over farmers' practice of raising groundnut range from 24 -31% in head, middle and tail reaches of the canal. Also, the WUE increased from 3.82 to 4.12 kg/ha-mm in head, middle and tail reaches, respectively. The yield increased to the tune of 14 to 17% in all the reaches compared to the farmers' practice.

Jorhat

- In Assam, fallow area was adopted under different rabi crops after the rice harvest. Rapeseed, an important oilseed crop, was thus cultivated under irrigated condition. The yield increased by about 27% by providing only one irrigation during the time of flowering.

SUGARCANE

Bilaspur

- The drip irrigation at 80% PE with paired row planting 60 cm for sugarcane (var. CO-1305) gave maximum yield with increase in yield by 24.8% and 43.3%, respectively and water saving over traditional surface irrigation.

Jorhat

- Growing sugarcane especially for chewing purpose drew the attention of the farmers because of the market demand. *In situ* rainwater harvesting technique like ridge mulch by plastic film and furrow with sugarcane trash/weed or only plastic mulching in ridge area increased the yield of sugarcane. Under irrigated condition, sugarcane yield increased about 30.6% through irrigation one each during April, October and November.

Navsari

- Sugarcane yield was significantly higher in 60 cm pit diameter with pit spacing of 1.75 x 1.75 m treatment as compared to rest of the treatment combinations, but it was statistically at par with treatment combination 60 cm pit diameter with pit spacing of 1.5 x 1.5 m. With respect to control vs. rest analysis, the effect was significant, higher cane yield was registered with treatments mean than control.

VEGETABLES

Bilaspur

- Use of sprinkler irrigation increased yield of onion and potato by 26% and 18%, and 42% and 36% over surface irrigation, respectively.
- The drip irrigation (alternate day) at 0.6 PE with Boron @ 2.0 kg/ha gives maximum tomato (var. Pusa Ruby) yield with B:C ratio of 1.8 while comparing other drip irrigation treatments (irrigation at 1.0, 0.8 and 0.4 PE) and increased 74% yield and 45.45% saving of water over traditional surface (alternate furrow) irrigation.

Jorhat

- In Assam, crops like tomato and brinjal are grown extensively during rabi. The irrigation practices followed were unscientific i.e. frequently applied with unmeasured depth. As evident from the experiments, proper adoption of irrigation practices to these crops helped in considerable increase of production recording about 100% for tomato, 26.6% for brinjal over the farmers' practice. Apart from increase in yield, irrigation water could be saved to the tune of 33.3%.
- Garlic and onion are remunerative spice crops of Assam. Maintenance of optimum soil moisture through drip irrigation at 1.0 PE increased bulb yield of garlic and onion. The rise occurred was about 50-54.9% more yield over the rainfed system (farmer's practice).

Palampur

- Brinjal crop when irrigated with gravity fed drip irrigation system and fertigated twice a month with 75% of the recommended NPK, saved 47.96% irrigation water and increased WUE along with maximizing the production.
- Onion crop was irrigated at 3 days interval with cumulative PE of 0.6% and fertigated with 100 % of recommended N with locally prepared liquid manure which was enriched with 1 % liquid biofertilizer (E100) for better production and economics.
- The production, economics and WUE (Water Use Efficiency) of brinjal improved by planting the crop after incorporation of FYM @ 5-10 t/ha and mulching the crop with organic material. The crop was irrigated with 4 cm of water depth.
- For higher productivity and B:C ratio, cucumber crop was irrigated at 0.8 CPE and fertigated with 200% RDF (50% through conventional and 50% through fertigation in 7 splits at 10 days interval).

Shillong

- Drip irrigation + black polythene had significant influence on the growth and yield of tomato under terrace land situation. There was an increase in fruit yield up to 34.6% tomato compared to other treatments.

Sriganganagar

- Drip irrigation at 1.0 ET_c under low tunnels was found optimum irrigation schedule for chilli. It gave 69.8% higher fruit yield and saved 24.1% irrigation water over conventional surface irrigation with low tunnel and 101.6% higher fruit yield and saved 5.4% irrigation water over 1.0 ET_c without low tunnel.
- The 120% recommended dose (i.e. 84 kg N, 60 kg P_2O_5 & 60 kg K_2O per ha) of fertilizers in 9 equal splits each at an interval of 13 days through water soluble fertilizers was found optimum fertigation schedule for chilli. It gave 55.4% higher fruit yield of chilli over conventional practice. The total water used in this treatment was 742.1 mm against 1077.3 mm in conventional practice. There was 44.9% water saving in comparison to conventional practice. The WEE under 120% RD through drip fertigation and conventional practice was 43.55 and 19.31 kg/ha-mm, respectively. The net seasonal income under 120% RD drip fertigation treatment was Rs.194167 as against Rs.121000 in conventional practice. The respective B:C ratios were 1.51 and 1.39.

HORTICULTURAL CROPS

Bilaspur

- The higher yield of banana was recorded under drip at 80% PE with 43.62% increase in yield and 27.63% water saving compared to those with surface irrigation. When compared with the mulch, 20.3% more water saving was observed.
- Buch (*Acorus Calamus*) recorded higher rhizome yield with high net return with a spacing of 30x20 cm. The crop consumes 288 cm water in its cropping period of 10-11 months when irrigation provided after 1 DADPW. Buch can be well adopted in waterlogged areas.

Jorhat

- Assam lemon is a specialized high value crop for the state. Being shallow rooted crop, drainage was an important aspect. A drainage water system through pipe made from split bamboo with mineral envelop was found to be superior. The same pipe was then utilized for irrigation during winter season.

Navsari

- From the pooled results, it was concluded that for getting higher fruit yield of banana, water soluble fertilizer, *viz.*, urea, 12:16:00 and 13:00:45 showed its superiority. But economically used fertilizer *viz.*, urea, orthophospheric acid and muriate of potash recorded higher net return values over water soluble fertilizer. In case of levels of fertilizer, crop fertilized with 80% RDF and applied twice in a week proved beneficial.
- Significantly, higher yield of mango (61.9 kg/tree) was recorded with 50 cm below ground level through drip treatment as compared to surface drip treatment (48.7 kg/tree), but it remained at par with 30 cm below ground level through drip treatment (58.6 kg/tree), 40 cm below ground level through drip (61.8 kg/tree) and 60 cm below ground level through drip (59.6 kg/tree). With respect to volume and weight of fruit, similar trends were observed.

Rahuri

- The yield (17.83 t/ha) of summer marigold was significantly highest when irrigation at 100% PE next in order of sequence was 80% PE 16.91 t/ha.
- Water requirement of summer marigold was higher at 100% PE of irrigation 70.26 cm and lowest was at 40% PE irrigation 28.11 cm.
- Water use of summer marigold was higher 505.10 kg/ha-cm at 40% PE irrigation and lowest was at 100% PE irrigation 238.14 kg/ha-cm. Water saving was highest (61.28%) at 40% PE irrigation and lowest (10.06%) at 100% PE of irrigation.
- Among the planting methods of marigold, maximum water requirement was required at 60 x 10 cm planting with lateral spacing 120 cm (71.74 cm). Water use efficiency (434.3 kg/ha-cm) and water saving (49.5%) were highest at 30-60 x 15 cm planting with 90 cm lateral spacing.
- The net extra income, net profit and water use efficiency obtained by planting summer marigold at 30-60 x 15 cm with lateral spacing 90 cm and 40% PE of irrigation were Rs.11,42,299 per ha, Rs.78,853 per cm of water use and 1113.68 kg/ha-cm, respectively.

OTHER CROPS

Navsari

- Summer cluster bean variety G.G.2 in black soils of South Gujarat were irrigated at 0.6 IW/CPE ratio and fertilized with 20:40:00 NPK kg/ha with urea and Single Super Phosphate in order to fetch higher yield with higher net returns.

Powerkheda

- The results of on farm trial at Tangna and Matapura villages under rainfed condition during kharif 2015 revealed that average seed yield of sorghum was 2390 kg/ha. The traditional crop of soybean at farmers' field failed due to moisture stress during the crop season. Thus, sorghum appeared to be a suitable alternative to soybean under rainfed condition.
- In wheat based crop sequence, broad furrow sowing of sorghum gave considerably higher sorghum equivalent yield (SEY) of 3526 kg/ha compared to that under conventional sowing (2963 kg/ha). The SEY with sesame and soybean was substantially lower due to very low productivity. Wheat – sorghum sequence proved superior with maximum wheat equivalent yield (7269 kg/ha), net monetary returns (Rs.46783 per ha) and B:C ratio 1.75.

Rahuri

- The grain yield of sorghum was recorded highest 4.33 t/ha at 90% ET_c whereas fodder yield was significantly higher 14.82 t/ha at 100% ET_c irrigation.
- Among the planting methods sorghum planted at 45 x 15 cm at 90 cm lateral spacing recorded significantly higher sorghum grain yield of 3.97 t/ha next in order of sequence was 45-75 x 10 cm with lateral spacing 120 cm 3.82 t/ha. Same trend was noticed in case of fodder yield.
- In case of sorghum grain equivalent yield it was noticed that among the irrigation regimes, 100% ET_c irrigation recorded highest grain equivalent yield 2.65 t/ha whereas in case of planting method, paired planting of sorghum 30-60 x 15 cm with lateral spacing 90 cm recorded significantly highest yield 2.33 t/ha second in order of sequence was 45-75 x 10 cm with lateral spacing 120 cm 2.32 t/ha.
- Total water requirement was maximum at 100% ET_c of irrigation regime 28.01 cm. Among the planting methods it was highest (27.91 cm) on single row planting of sorghum i.e. at 45 x 15 cm and 60 x 10 cm planting with lateral spacing of 90 and 120 cm, respectively.
- Among the irrigation regimes, water use efficiency was higher at 80% ET_c irrigation 189.78 kg/ha-cm. In case of planting methods it was higher at 30-60 x 15 cm with lateral spacing of 90 cm 218.81 kg/ha-cm.
- In case fodder yield maximum water use efficiency was at 70% ET_c irrigation 632.25 kg/ha-cm and in case of planting methods it was higher at 45-75 x 10 cm lateral spacing of 120 cm 690.24 kg/ha-cm.
- Among the irrigation regimes maximum water saving (63.18%) was at 70% ET_c irrigation and lowest (47.91%) was at 100% ET_c irrigation whereas among the planting methods it was maximum (63.79%) at 30-60 x 15 cm with lateral spacing 90 cm whereas lowest (48.12%) was at 45 x 15 cm with lateral spacing 90 cm and 60 x 10 cm with lateral spacing 120 cm, respectively.

Shillong

- Zero tillage for both kharif and rabi crops resulted in higher grain yield as compared to conventional tillage. Significantly higher grain yield of rice (17.2%) and succeeding rabi crops pea (16.4%), mustard (34.6%) and buckwheat (27.4%) were recorded under zero tillage for both crops. Water use efficiency was also significantly higher for the crops compared to that with conventional tillage.
- Turmeric grown under terrace condition with FYM + straw mulching recorded significantly higher yield (25250 kg/ha) as compared to other treatments. There was an increase of 55.6% of yield under FYM @ 5 t/ha + mulching @ 5 t/ha compared to control.

Jammu

- Laser leveling improved grain yield of rice-wheat sequence by 1 t/ha. Water use efficiency was increased from 9.78 kg/ha-cm in farmer levelled field to 11.57 kg/ha-mm in laser levelled field. from 9.78 kg/ha-mm farmer leveled field to 11.57 kg/ha-mm in laser leveled fields. The increased yield level in laser levelled plots was due to overall improvement in water application efficiency by 4%, water distribution efficiency by 13% and water storage efficiency by 9%.

Morena

- The chickpea crop was taken under broad bed furrow (BFF) irrigation method and boarder strip as farmers' practices. Improved variety JG-130 was sown with other recommended practices. BFF irrigation increased seed yield by 76.3%, gross returns by Rs.23200 per ha and net returns by Rs.23840 per ha when compared with boarder strip practices adopted by farmers.

Tribal Sub Plan

Bilaspur

- Feeder dug out farm pond at village Tilliya (Polmi) for storage of water were constructed at the tribal dominated village Polmi Tilliya, Kerajhariya and Kartali (Block - Pali, District – Korba).
- The villagers were able to successfully conserve water after the construction of sump well near the backwater of Khutaghat dam and construction of check dam at Kerajharia and Kartali village.
- The benefits procured were: creation of secured irrigation infrastructure in tribal dominated area, increased cropping intensity, increased crop productivity, increased technical skill with upliftment of socio-economic status of the tribes.

Chiplima

- In Chetanpada, a tribal village, five bore wells with electrification and submersible pump and sprinkler set converting rice fallow to a three vegetable cropping system in an area of seven acres was implemented in order to provide with a reliable water resource for crop cultivation.
- In Mendelipali, year round vegetable production including installation of low cost shed net house with micro sprinkler for off-season nursery raising was deployed. This resulted in availability of water and infrastructure to grow crops during off-season.
- In Kadelpal, low cost steel wells in the stream were constructed, now the farmers use diesel pumps to safely lift water. Due to provision of conveyance pipes water is delivered to the crops. No conveyance losses have occurred in this process.

Dapoli

- About 320 m^3 rainwater was harvested in the remote and hilly lands where farmers always face water scarcity problem because of the implementation of 'Jalkund' Technology. Around 80 'Jalkund' were constructed in different villages, through which total 40 tribal farmers were benefitted. Four hundred mango grafts and 450 cashew grafts were distributed to the farmers. Mango and cashew grafts were planted on 4 ha and 4.5 ha area, respectively as a demonstration and were irrigated through harvested rainwater. At present, there is about 80% success of the plantation in this hilly area.
- During field visit to the tribal fields, the abandoned wells were converted into small farm ponds with HDPE plastic lining called as 'Sunken dyke'. This is now used for harvesting rain water for subsequent irrigation to the rabi crop for individual/group of tribal farmers in Thane and Palghar district of Konkan region of Maharashtra.
- Five farmers were selected and HDPE plastic paper (500 micron) was distributed for lining to the 'Sunken dyke' with the help of which the farmers are storing rain water.
- Due to the implementation of plastic lined temporary check dams at Jawhar Taluka, a water source is been created for sustainable livelihood to tribal farmers with reference to agricultural production and livestock so as to enhance economic status and check migration of the villagers.
- Plastic lined check dams (Bandhara) named as "Konkan Vijay Bhandara" were constructed where the tribal farmers now take vegetables and irrigate them with the stored water in Bandharas. Farmers in Jawhar taluka of Palghar district have also been profited due to this intervention since 5 acres of land has come under vegetable cultivation with irrigation.

Rahuri

- Yield increase in wheat variety NIAW-34 and Tapovan with recommended practice plot were 16.60% and 19.50%, respectively over farmers' practice. The WUE in recommended practice plots ranged from 70.28 to 71.94 kg/ha-cm, which is higher than farmers' practice.
- Yield increase in chickpea was 16.31% in recommended practice plot as compared to that in control plot. The WUE was 117.50 kg/ha-cm in recommended practice plot which was higher than the farmers' practice (82.29 kg/ha-cm).

Parbhani

- Through sprinkler irrigation, almost 53 farmers thus availed benefits such as the 30-40% water saving. Operation of sprinkler irrigation saved time, labour and energy. Water applied is uniform all over the area, including the undulating topography.
- The farmers were able to apply protective irrigations to soybean, red gram, turmeric and cotton in kharif season. This resulted in vigorous growth of the crop and higher yields although there was scanty rainfall (480 mm) in 2014 with long dry spell during entire monsoon season.
- With implementation of seed-cum-ferti drill, about ninety farmers have experienced that sowing of *kharif* crops like soybean and pigeonpea with the help of seed-cum-ferti drill was very easy and handy as compared to their traditional implements. Most of the farmers have also performed the harrowing operation with this implement after making necessary adjustments. They even noticed that seed and fertilizers were placed at proper depth due to this implement hence yielded a uniform germination and vigorous growth of crop.
- The farmers were also enable to carry out the intercultural operation like hoeing in soybean, pigeonpea, cotton and other crops with the help of seed-cum-ferti drill after making necessary adjustments in the implement with the provided blade harrow.
- With the use of the seed of improved varieties of soybean, about one hundred seventy seven farmers experienced uniform germination and good vigour of the crop. The soybean yield of improved varieties ranged from 1500 to 2700 kg/ha against 250 to 700 kg/ha of traditional varieties. Also, the performance of MAUS-81 was better than JS-93-05.

Pusa

- The tribal village - Katraw, Gram Panchayat-Jamunia, Block-Gaunaha, Distt.-West Champaran was selected for the on farm water management activities. The work plan included about seven thousand farmers who will be benefited after construction of the check dam/ diversion structure with sluice gate on a natural stream (Budhia Nadi) at Nawkatti (Jamunia) because most of water is wasted. A further 3-way diversion structure with sluice gate would be constructed in the next phase (from December, 2015).

Palampur

- A progressive increase in marketable yield of cucumber was recorded with increase in fertigation scheduling from 50% to 150% during two years. The result is obtained from a study conducted on soil–plant-water dynamics under protected conditions in relation to drip based irrigation and fertigation scheduling on cucumber at each level of irrigation scheduling.
- Application of 200% RDF resulted in significantly higher marketable yield of cucumber than that obtained at any other levels of fertigation under irrigation schedule of 0.4 CPE as well as under irrigation schedule of 0.8 CPE. The yield obtained was 7.97 and 9.09 kg/ m^2 compared to all other combinations of fertigation and irrigation scheduling (Table 1).

Table 1. Interaction effect of fertigation scheduling and irrigation scheduling on marketable yield (kg/m^2) of cucumber

Fertigation scheduling	Irrigation scheduling			
	2014		2015	
	0.4 CPE	0.8 CPE	0.4 CPE	0.8 CPE
50% RDF	4.03	4.07	4.11	4.17
100% RDF	5.00	6.13	4.60	6.08
150% RDF	5.73	6.42	5.92	7.88
200% RDF	4.90	5.17	5.96	6.00
200% RDF (50% conventional & 50% fertigation)	6.87	7.97	6.59	9.09
CD (P = 0.05)	0.33		0.47	

- Under protected condition, for higher productivity and B:C ratio, cucumber crop should be irrigated at 0.8 CPE and fertigated with 200 % RDF (50 % through conventional and 50 % through fertigation in 7 splits at 10 days interval).
- **Irrigation scheduling:** During 2014 and 2015, drip irrigation of cucumber (under protected condition) at cumulative potential evaporation of 0.8 resulted in significantly higher (11.22 and 17.40 %) yield than drip irrigation at 0.4 CPE. During both the years, drip irrigation at 0.8 CPE resulted in 18.63 and 9.79% higher B:C ratio and 44.39 and 4.84% lower water use efficiency due to 100% higher water use than drip irrigation at 0.4 CPE.
- **In Fertigation scheduling:** Application of 200% RDF resulted in 33.94% and 33.93% higher marketable yield, 33.45% and 33.44% higher B:C ratio and 33.95% and 65.40% higher water use efficiency than that obtained by application of 100 % RDF (25 % applied as basal and 75 % through fertigation in 7 splits at 10 day interval) during both the years of experiment.
- In control vs. various other treatments, control plot resulted in significantly lower marketable yield (16.32 & 18.36 %) than that obtained in other treatment. During 2014 and 2015, control plot resulted in 68.06 and 60.54 % higher B:C ratio and 45.29 and 45.50 % lower water use efficiency due to 52.94 and 55.05 % lower total water use compared to other treatments.
- Under protected condition, for higher productivity and B:C ratio, cucumber crop should be irrigated at 0.8 CPE and fertigated with 200 % RDF (50 % through conventional and 50 % through fertigation in 7 splits at 10 days interval).

Powerkheda

- Under the Water Resource Development, a Stop Dam was constructed on the rainy season Nala near the fields of Jasman Akhandi, Jhandu Chouhan, Premlal and few more fields situated 200 m away from Golandoh village. The dam length was 50 m, main board height was 4.5 m, water storage capacity was 1.85 ha m and number of beneficiaries were more than 15. The benefits availed by the farmers includes availability of irrigation water in about 10 - 12 ha area and recharging of groundwater which improved water level in open wells in the villages.
- Similar Stop Dam with varying specifications were constructed which added benefits such as availability of irrigation water in about 2.0 ha area, recharging of groundwater, and land development leveling of about 1 acre land.
- A Water Harvest Tank was constructed on the field of Shri Ramcharan S/O, Radhelal Chouhan, Village - Tangna, Block - Kesla, Hoshangabad (March 2016). The tank specifications were: Tank area - 0.40 ha, Average depth - 2.0 m, Water storage - 0.80 ha m and Number of beneficiaries – 5. A water harvest structure and field leveling (WHSL) was also constructed on the field of Shri Santosh Mohabe, Village - Tangna, Block - Kesla, Hoshangabad (March 2016). The specifications were: Length of bund - 35 m, Bund height - 2.0 m and Field leveling - 0.4 ha availing benefits like life saving irrigation water availability for 1.5 ha, land improvement i.e. leveling in 0.4 ha and groundwater recharging.
- The crop diversification with sesame, sorghum and maize was taken as intervention. The seeds of improved varieties of these crops were provided to the farmers as detailed in table 2.

Results revealed that all the three crops suited well under the given farming situation of the adopted village but the adverse weather conditions like low rainfall, long dry spell at every stage and cessation of rains at the end of August 2015 adversely affected crop growth and yields. However, the average grain yield harvested for sorghum was 2.05 t, 1.60 t for maize and 0.55 t for sesame.

Table 2. Details of intervention

Sl. No.	Crop	Variety	No. of farmers	Total area (ha)	Seed for demonstration (kg)
1.	Sesame	Weston 11	20	8.0	2.0
2.	Sorghum	NJH - 40 (Ratna)	20	8.0	6.0
3.	Maize	DKC 7074 (Hybrid)	23	8.0	8.0

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STAFF POSITION OF AICRP ON IRRIGATION WATER MANAGEMENT AS ON 31.12.2015

Designation	Almora	Bilaspur	Bathinda + Ludhiana
Chief Scientist	Dr. S.C. Pandey	Dr. A.K. Sahu	Dr. Rajan Aggarwal
Agronomist	Dr. Sher Singh	Dr. A.K. Swarnkar	Vacant
Soil Physicist	Dr. S.C. Pandey	Sh. P.K. Keshri	Dr. A.S. Sidhu
Agril Engineer	Vacant	Dr. Devesh Pandey	Dr. Sudhir Thaman
Jr. Agronomist	Dr. D. Mohanta	Dr. Geet Sharma	Dr. (Mrs.) A. Kaur
			Dr. K.S. Sekhon
			Er. Amina Raheja
			Dr. (Mrs.) S. Kaur
			Dr. Sanjay Satpute
	Chalakudy	**Belvatagi**	**Chiplima**
Chief Scientist	Dr. Mini Abraham	Dr. Gopal V. Dasar	Dr. A.K. Mohanty
Agronomist	Dr. Anitha S.	Dr. G.B. Shashidhar	Dr. (Mrs.) S. Mohapatra
Soil Physicist	Smt. Aswathi Gopinath	Dr. S.S. Gundlur	Dr. P.K. Samant
Agril Engineer	Smt. E.B. Gilsha Bai	Sri J.K. Neelakanth	Dr. N. Panigrahi
Jr. Agronomist	Dr. Deepa Thomas	Dr. S.P. Halagalimath	Dr. B.R. Nayak
	TNAU (Bhavanisagar + Madurai + Coimbatore)	**Dapoli**	**Faizabad**
Chief Scientist	Dr. V.K. Duraiswamy	Dr. R.T. Thokal	Vacant
Agronomist	Dr. S.K. Natarajan	Dr. (Smt.) R.S. Patil	Vacant
Soil Physicist	Dr. S. Thenmozhi	Dr. K.P. Vaidya	Vacant
Agril Engineer	Dr. M. Manikanandan	Dr. B.L. Ayare	Dr. R.C. Tiwari
Jr. Agronomist	Dr. J. Bhuvaneswari	Dr. T.N. Thorat	Dr. B.N. Singh
Chief Scientist	Dr. T. Ragavan		
Agronomist	Vacant		
Soil Physicist	Dr. A. Rathinasamy		
Agril Engineer	Dr. M. Rajeswari		
Jr. Agronomist	Dr. N.K. Sathiyamoorthy		
Asst. Prof.	Dr. A. Raviraj		
Asst. Prof.	Dr. A. Valliammai		
Asst. Prof.	Dr. D. Jayanti		
	Jorhat	**Gayeshpur**	**Kota**
Chief Scientist	Dr. R.K. Thakuria	Dr. S.K. Patra	Dr. Pratap Singh
Agronomist	Dr. K. Pathak	Dr. B. Biswas	Dr. H.P. Meena
Soil Physicist	Dr. B.K. Medhi	Dr. K. Bhatacharya	Dr. N.N. Sharma
Agril Engineer	Dr. P. Baruah	Er. S. Saha	Er. I.N. Mathur
Jr. Agronomist	Dr. A. Sharma	Mr. R. Poddar	Dr. R.S. Narolia

	Hisar	Jammu	Powarkheda
Chief Scientist	Vacant	Dr. A.K. Raina	Dr. N. K. Seth
Agronomist	Dr. A.S. Dhindwal	Dr. B.R. Bazaya	Dr. P.B. Sharma
Soil Physicist	Dr. V.K. Phogat	Dr. Abhijit Samanta	Dr. P.S. Kulhare
Agril Engineer	Vacant	Er. N.K. Gupta	Vacant
Jr. Agronomist	Vacant	Dr. Vijay Bharti	Dr. Vinod Kumar

	Morena	Pusa	Navsari
Chief Scientist	Dr. Y.P. Singh	Vacant	Vacant
Agronomist	Vacant	Dr. Vinod Kumar	Dr. V.P. Usadadiya
Soil Physicist	Vacant	Dr. Mukesh Kumar	Dr. J.M. Patel
Agril Engineer	Er. S.K. Tiwari	Dr. S.P. Gupta	Er. N.G. Savani
Jr. Agronomist	Vacant	Dr. Rajan Kumar	Dr. R.B. Patel
Jr. Soil Chemistry		Dr. A.K. Singh	
Jr. Agril. Engineer		Dr. Ravish Chandra	

	Palampur	Parbhani	Pantnagar (WM + GWU)
Chief Scientist	Er. R.K. Gupta	Dr. A.S. Kadale(I/C)	Dr. Subhash Chandra
Agronomist	Dr. Kapil Saroch	Dr. G.D. Gadade	Vacant
Soil Physicist	Dr. Naveen Datt	Dr. U.N. Karad	Dr. H.S. Kushwaha
Agril Engineer	Dr. S.K. Sharma (Soils)	Dr. A.S. Kadale	Dr. Vinod Kumar
Jr. Agronomist	Vacant	Dr. G.D. Gadade	Dr. Gurvinder Singh
			Dr. H.C. Sharma
			Dr. Yogendra Kumar
			Dr. Harish Chandra
			Mr. U.C. Lohani

	Sriganganagar	Rahuri (WM + GWU)	Shillong
Chief Scientist	Vacant	Dr. M.B. Dhonde	Dr. D.J. Rajkhowa
Agronomist	Dr. R.P.S. Chauhan	Dr. J.B. Shinde	Vacant
Soil Physicist	Dr. B.S. Yadav	Dr. B.D. Bhakare	Dr. U.S. Saikia
Agril Engineer	Vacant	Vacant	Vacant
Jr. Agronomist	Vacant	Dr. S.S. Tuwar	Vacant
		Dr. S.D. Dahiwalkar	
		Er. S.A. Kadam	
		Er. K.G. Powar	
		Sri E.K. Kadam	

	Junagadh	Udaipur
Res. Engineer	Dr. H.D. Rank	Dr. P.K. Singh
Asst. Professor	Er. P.B. Vekaria	Dr. K.K. Yadav
Asst. Professor	Vacant	Dr. Manjeet Singh

Revised Budget Estimate (RE) of AICRP on Irrigation Water Management

Head-wise allocation of budget (ICAR share) for each centre under AICRP on Irrigation Water Management based on Revised Estimate for the year 2015-16

(Rs. in lakh)

Sl. No.	Name of the Centre	Grant-in-aid Salary	Grant-in-aid General	Grant-in-aid Capital	Total NTSP	Total TSPT	Total TSP & NTSP=RE
1	VPKAS, Almora	0	5	0	5	0	5
2	PAU, Ludhina (Bathinda & Ludhiana)	130	15	0	145	0	145
3	UAS, Belvatagi	80	6	0	86	0	86
4	TNAU, Coimbatore (Madurai, Bhavanisagar & Coimbatore)	230	26	0	256	0	256
5	IGKVV, Raipur (Bilaspur & Raipur)	110	10	0	120	0	120
6	KAU, Chalakudy	70	7	0	77	0	77
7	OUAT, Chiplima	35	7	0	42	5	47
8	BSKKV, Dapoli	65	7	0	72	10	82
9	NDUAT, Faizabad	59	6	0	65	0	65
10	BCKVV, Gayeshpur	55	8	0	63	0	63
11	CCSHAU, Hisar	40	5	0	45	0	45
12	SKUAST, Jammu	82	8	0	90	0	90
13	MPUAT, Udaipur	45	5	0	50	0	50
14	AU, Kota	90	7	0	97	0	97
15	JAU, Junagadh	35	4	0	39	0	39
16	RVSKVV, Morena	65	5	0	70	5	75
17	NAU, Navsari	83	8	0	91	0	91
18	CSKHPKVV, Palampur	75	5.75	0	80.75	0	80.75
19	GBPUAT, Pantnagar (WM & GWU)	100	10	0	110	0	110
20	VNMAU, Parbhani	60	7	0	67	0	67
21	JNKVV, Jabalpur (PKH & Jabalpur)	118	8	0	126	0	126
22	SKRAU, Pusa (WM & GWU)	90	9	0	99	0	99
23	MPKV, Rahuri (WM & GWU)	115	10	0	125	5	130
24	SKRAU, Sriganganagar	50	5	0	55	0	55
25	IIWM (PCU)	0	6.25	0	6.25	0	6.25
26	AAU, Jorhat (NEH)	120	5	25	150	0	150
27	ICAR-RCNEH, Shillong (NEH)	0	8	0	8	0	8
	Total	**2002**	**213**	**25**	**2240**	**25**	**2265**

भाकृअनुप - भारतीय जल प्रबंधन संस्थान

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