सिंचाई जल प्रबंधन पर
अखिल भारतीय समन्वित अनुसंधान परियोजना

All India Coordinated Research Project on Irrigation Water Management

वार्षिक प्रतिवेदन
ANNUAL REPORT
2018-19

भाकृअनुप
ICAR

भारतीय जल प्रबंधन संस्थान
ICAR-IIWM

भाकृअनुप-भारतीय जल प्रबंधन संस्थान
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भारतीय कृषि अनुसंधान परिषद
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AICRP-IWM Annual Report 2018-19

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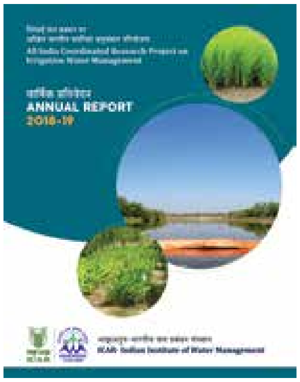

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PREFACE

The Annual Report of All India Coordinated Project on Irrigation Water Management (AICRP on IWM) contains the research findings of different coordinating centres for the year 2018-19, extension of water management technologies, human resource development and publication of outputs of the centres which indicate productivity of the scheme. With the growing demand for water by different sectors, the economic use of water is of paramount importance. I take this opportunity to present the consolidated report of the centres under different themes. The scientists have been engaged in carrying out research on improving water use efficiency in different crops and cropping sequence under different sources of irrigation in different agro climatic conditions of the country. Significant achievements have been made during the reporting year 2018-19. The on-station and on-farm research endeavours of the scientists resulted in replicable water management technologies that helped in improving irrigation application efficiency in canal commands, groundwater recharge, improved water use efficiency and water productivity under pressurized irrigation and saved water and fertilizer inputs. The on station and on farm research output not only improved water productivity but also enhanced farmers' income and livelihoods. The AICRP on IWM centres also carried out capacity building programmes for different stakeholders and implemented tribal sub plan schemes for improving livelihoods of tribal people at different places. Some of the pilot interventions contributed to rainwater harvesting and groundwater recharge in rainfed areas of the country.

I take this opportunity to express my gratitude to Dr. T. Mohapatra, Secretary DARE and Director General ICAR, Govt. of India for his guidance, critical inputs, constant support and encouragement for smooth running of the scheme. I sincerely express the gratitude to Dr. K. Alagusundaram, Deputy Director General (NRM) and Dr. S. K. Chaudhari, Assistant Director General (S&WM), ICAR for their valuable suggestions and timely cooperation during the report period. I thank the research scientists of AICRP on IWM schemes working at different locations for their untiring efforts for improving irrigation water management scenario in the country. Their sincere efforts resulted in tangible outputs in irrigation water management which would go a longway in improving farmer's income and water productivity. I appreciate the team work of Dr. Prabhakar Nanda, Principal Scientist, Dr. S. Mohanty, Principal Scientist, Dr. O.P. Verma, Scientist, ICAR-IIWM and Pragna Dasgupta, Research Associate, AICRP-IWM for compiling the research outcomes of the centres and editing the annual report. I thank Dr. O.P. Verma for Hindi translation of the Executive Summary of the report.

(S. K. Ambast)
Director, ICAR-IIWM

Bhubaneswar

Contents

कार्यकारी सारांश

नहर के जल और भूजल की उपलब्धता का आकलन

पंतनगर केंद्र द्वारा उत्तराखंड एवं उत्तर प्रदेश राज्यों के उधम सिंह नगर और रामपुर जिलों के तराई क्षेत्रों में भूजल संसाधनों का मूल्यांकन किया गया। इक्कीस वर्षों (1994-2014) की अध्ययन अवधि के दौरान नलकूपों की तुलना में पंप सेटों की संख्या में 89.56% तक की वृद्धि हुई। इस अध्ययन क्षेत्र के कुल दस ब्लॉकों में से पांच महत्वपूर्ण ब्लॉक संवेदनशील श्रेणी से अति-शोषित श्रेणी में तब्दील हो गए, जबकि एक ब्लॉक सुरक्षित श्रेणी से अर्ध-संवेदनशील श्रेणी में बदल गया। इन परिवर्तन के कारणों में से फसल के पैटर्न में बदलाव, अधिक जल की मांग वाली फसलों की खेती तथा घरेलू और औद्योगिक उपयोगों के लिए जल की मांग में वृद्धि आदि पाए गए।

उदयपुर केंद्र पर ऊपरी बेराच नदी बेसिन का कुल 1101 वर्ग किमी जलग्रहण क्षेत्र है जिसमें से कृत्रिम भूजल पुन:भरण के लिए 219.2 वर्ग किमी क्षेत्र ही अनुकूल है जो कुल अध्ययन क्षेत्र में केवल 20% का योगदान देता है। इस क्षेत्र में चंदेरसिया, गंडोली, सांगवा, शंभोपुरा, बेरन, नौवा, मावली, अकोडरा, भूतपुरा आदि गाँव शामिल हैं। यहाँ पर भूजल संभावित क्षेत्रों की पहचान की गई और यह पाया गया कि इस बेसिन के क्रमशः 15.99, 37.41, 32.47 और 14.23% क्षेत्र अच्छे, मध्यम, खराब और बहुत खराब श्रेणियों के अंतर्गत पाए गए ।

कोयम्बटूर केंद्र पर लोअर भवानी प्रोजेक्ट (LBP) बेसिन में हाइड्रोलॉजिकल मापदंडों के वर्तमान परिदृश्य (1990-2010) को जानने के लिए SWAT मॉडल का उपयोग किया गया। बेसिन में वार्षिक औसत वर्षा का 896.3 मिमी के रूप में अनुमान लगाया गया। अपवाह का अनुमान 24% वर्षा के रूप में लगाया गया। औसत वार्षिक वाष्पीकरण (ET) औसत वार्षिक का लगभग 41% था। एलबीपी बेसिन की औसत वक्र संख्या 62 थी। वर्तमान परिदृश्य के लिए जल संतुलन की गणना की गई। मई से नवंबर तक वाष्पीकरण की तुलना में वर्षा अधिक थी। इसलिए, बिना किसी जोखिम के दक्षिण-पश्चिम मानसून और उत्तर-पूर्वी मानसून के दौरान फसलों को उगाया जा सकता है।

दबाव सिंचाई प्रणाली

नवसारी केंद्र पर गन्ने की उपज अलग-अलग ड्रिपर डिस्चार्ज के साथ-साथ पौधों की अलग-अलग दूरी के कारण प्रभावित नहीं हुई। गन्ने में सुक्रोज प्रतिशत ने भी उपचारों के बीच महत्वपूर्ण अंतर नहीं दिखाया। 4 लीटर/सेकंड की दर से ड्रिपर डिस्चार्ज के साथ उपसतही इनलाइन लेटरल के तहत एवं 60 सेमी की ड्रिपर की दूरी के साथ ₹ 472452/हेक्टेयर का अधिकतम शुद्ध लाभ प्राप्त हुआ इस उपचार के तहत लेटरल और ड्रिपर क्लॉगिंग की न्यूनतम क्षति को भी देखा गया।

जूनागढ़ केंद्र पर पोरस पाइप प्रणाली के माध्यम से सिंचाई के जल के स्तरों ने बहुत खराब एकरूपता गुणांक दिया (100 सेमी इनपुट 60 मीटर लेटरल लंबाई के मामले में 6.65% से 200 सेमी इनपुट हैड के साथ 30 सेमी लंबाई के मामले में 47%) जो कि 90% से अधिक होना चाहिए था। लेटरल की लंबाई के साथ गीले बल्ब के आकार में एकरूपता भी बहुत भिन्न प्राप्त हुई। इसलिए, वैज्ञानिकों/ नीति निर्माताओं को सिंचाई जल की प्रयोग प्रणाली के रूप में पोरस पाइप प्रणाली को अपनाने की सलाह नहीं दी जाती है।

फर्टिगेशन

चलाकुड़ी केंद्र पर बैंगन की फसल में दो दिनों में एक बार ड्रिप सिंचाई के साथ-साथ बायोचार 2 टन/हे की दर से प्रयोग के कारण उपज में वृद्धि प्राप्त हुई। जल उत्पादकता, पोषक तत्वों की उपयोग दक्षता, शुद्ध लाभ और लाभ : लागत अनुपात भी वृद्धि हुई। प्राप्त परिणामों से बायोचार की वजह से जल धारण क्षमता और पोषक तत्व धारण क्षमता में वृद्धि देखी गई। मृदा के संशोधन के रूप में बायोचार 2 टन/हे के प्रयोग के परिणामस्वरूप बैंगन की पैदावार में 12% की वृद्धि हुई। चूने के प्रयोग की तुलना में बैंगन की फसल की उपज में 25% की वृद्धि हुई। चूने के प्रयोग की तुलना में बायोचार 4 टन/हे के प्रयोग से अगले मौसम की चंवला फसल की उपज में 12% सुधार प्राप्त हुआ। मृदा की अवशिष्ट नमी में उगाई गई बैंगन एवं चंवला की फसलों में पोषक तत्वों के प्रयोग के बिना उपज में वृद्धि प्राप्त हुई जो तत्वों को धारण करने में बायोचार के दीर्घकालिक प्रभाव को दिखाता है।

फैजाबाद केंद्र पर सतही सिंचाई (0.8 IW/CPE पर सिंचाई) और 40% PE पर ड्रिप सिंचाई की तुलना में ड्रिप सिंचाई प्रणाली के तहत नाइट्रोजन की 100% अनुशंसित खुराक के साथ 60% PE के सिंचाई स्तर के प्रयोग से राजमा बीन्स (13.12 टन/हे) की अधिक उपज प्राप्त हुई। लेकिन यह उपज नाइट्रोजन की 75% खुराक के प्रयोग एवं ड्रिप सिंचाई के साथ 80% PE और 60% PE पर एक समान थी। ड्रिप सिंचाई के तहत नाइट्रोजन की खुराक (अनुशंसित खुराक 100 और 75%) के प्रयोग ने सेम की उपज को काफी प्रभावित नहीं किया। सतही और ड्रिप सिंचाई के अन्य उपचारों की तुलना में अनुशंसित नाइट्रोजन की 100% और 75% खुराक के साथ 60% PE पर ड्रिप सिंचाई के तहत क्रमशः 4.30 और 4.19 का अधिक लाभ-लागत अनुपात दर्ज हुआ।

नवसारी केंद्र पर गन्ने की दो मुख्य फसलों और रेटून फसलों की पंक्तियों (60: 120 सेमी) में दो-आंख वाले सेटों के साथ रोपाई की गई और उपसतही ड्रिप लेटरल (7.5 सेमी भू सतह के नीचे) के प्लेसमेंट की मदद से सिंचाई की गई। इस वजह से लगातार और काफी अधिक उपज प्राप्त हुई। अन्य रोपण विधियों (जिसमें अंकुरित कलियां और 21 दिन पुराने पौधे जो पौधे और रेटून फसलों के दौरान सिंगल आई बड्स से तैयार किए गए शामिल थे) कि तुलना में ऊपर बताई गई रोपण विधि से फसल वृद्धि के मापदंडों, उपज की विशेषताओं, गन्ने की पैदावार और शुद्ध लाभ में वृद्धि प्राप्त हुई। उर्वरक की 80% अनुशंसित खुराक (10 से अधिक समान भाग में प्रयोग) के प्रयोगऔर फर्टिगेशन (20 बराबर भाग) के प्रयोग का गन्ने कि उपज पर अधिक प्रभाव नहीं देखा गया।

भूजल प्रबंधन

लुधियाना केंद्र पर निस्पंदन दर और अपवाहित वर्षा जल की गुणवत्ता एवं फिल्टर की गाद हटाने की दक्षता का अध्ययन करने के लिए प्रयोगशाला में समग्र फिल्टर का प्रयोगशाला मॉडल स्थापित किया गया। कृत्रिम रूप से स्पाइकड जल से जल की गुणवत्ता के मापदंडों जैसे गाद हटाना (आरई), ईसी, पीएच, टीडीएस, आरएससी और नाइट्रेट की कमी 15 सेमी मोटाई वाले ईंट के गुच्छे के लिए फिल्टर सामग्री की संख्या से फिल्टर की गाद हटाने की दक्षता 7.71% से बढ़कर बी 30:जी: सीएस: सी संयोजन में 72% तक हो गई। समग्र फिल्टर से गुजरने से पहले और बाद में जल की विद्युत चालकता, पीएच, टीडीएस और आरएससी को प्रयोगशाला में निर्धारित किया गया और परिणामों ने ईसी, पीएच, टीडीएस और आरएससी पर फिल्टर सामग्री का कोई खास प्रभाव नहीं दिखा और और बी 30: जी: सीएस: सी एवं बी 15: जी: सीएस: सी संयोजन से नाइट्रेट हटाने की दक्षता लगभग 24.93% एवं 24.45%: प्राप्त हुई। सबसे अच्छे संयोजन को इसके बाद खेत में स्थापित किया गया और गाद हटाने की दक्षता 74.73% तक प्राप्त हुई, जबकि समग्र फिल्टर से जल पास करने से पहले और बाद में ईसी, पीएच, टीडीएस और आरएससी पर कोई प्रभाव नहीं था। वास्तविक खेत की स्थिति में नाइट्रेट हटाने की क्षमता 20.30% पाई गई।

लुधियाना केंद्र पर पंजाब में उथले और मध्यम ट्यूबवेलों की श्रेणी के तहत बिजली और डीजल टयूबवेल (8 हॉर्सपावर) द्वारा प्रति वर्ष कुल

ऊर्जा की खपत क्रमशः 4183.4 MU और 544.4 MU प्राप्त हुई। इन इलेक्ट्रिक और डीजल ट्यूबवेल्स को बदलने पर 4728 MU (यदि 100% ट्यूबवेल को बदला जाए), 2364 MU (यदि 50% ट्यूबवेल को बदला जाए) और 1182 MU (यदि 25% ट्यूबवेल को बदला जाए) तो ऊर्जा की बचत की जा सकती है। कार्बन उत्सर्जन में 9101x106 किग्रा (यदि 100% ट्यूबवेल की जगह), 4550.5x106 किग्रा (यदि 50% ट्यूबवेल की जगह) और 2275.3x106 किग्रा (यदि 25% ट्यूबवेल की जगह) में कमी होगी। यदि बिजली एवं डीजल ट्यूबवैल्स को बदला जाए तो ₹ 3158 करोड़ की बचत होती है। इसलिए, एसपीवी पंप प्रदाता के आधार पर एसपीवी पंपों की पेबैक अवधि 10 से 15 वर्ष तक होगी। उसके बाद में प्रत्येक वर्ष ₹ 4000 करोड़ से अधिक की बचत होगी।

कोयम्बटूर केंद्र पर इस जिले के थोंडामुथुर ब्लॉक (अधिक शोषित श्रेणी) में विभिन्न कृत्रिम पुन:भरण संरचनाओं के प्रदर्शन का मूल्यांकन किया गया। पुन:भरण संरचनाएं अर्थात, चार चेक डैम, चेक डैम में एक रिचार्ज शाफ्ट और एक पुन:भरण कुंए की पहचान की गई। जल स्तर की जांच के लिए संरचनाओं के पास दस पर्यवेक्षण कुओं की भी पहचान की गई। स्थलाकृतिक सर्वेक्षण किया गया और संरचनाओं के जल संतुलन का अध्ययन करने के लिए चेक बांधों के लिए संरचनाओं के स्टेज-वॉल्यूम संबंध को विकसित किया गया। पर्यवेक्षण कुओं में आवधिक जल स्तर की जांच के बाद मानसून के दौरान सभी पर्यवेक्षण कुओं और पुन:भरण कुंए के जल स्तर में वृद्धि देखी गई। मानसून के तुरंत बाद प्रभाव देखा जाएगा और चेक डैम के लिए आम तौर पर एक महीने की अंतराल अवधि हो सकती है। चेक डैम का प्रभाव क्षेत्र 650 मीटर तक पाया गया।

फसलों में सिंचाई के समय का निर्धारण

जम्मू केंद्र पर बासमती धान के खेत में कल्टीवेटर पडलिंग (किसानों की विधि) एवं पड्लर पडलिंग की तुलना में रोटावेटर पडलिंग विधि को अपनाने से 9.9% अधिक जल की उपयोग दक्षता प्राप्त हुई। रणबीर नहर कमांड क्षेत्र की खेत की रेतीली दोमट मृदा में निरंतर जल भराव की तुलना में जल के सूखने के तीन दिन बाद (3 DADPW) सिंचाई के साथ रोटावेटर पडलिंग के परिणामस्वरूप 30.6% जल की बचत प्राप्त हुई।

मृदा-पौधे-जल-पर्यावरण संबंध पर बुनियादी अध्ययन

फैजाबाद केंद्र पर आलू की फसल में विभिन्न नमी के स्तरों और नाइट्रोजन प्रबंधन के प्रभाव से पता चला कि प्रत्येक कुंड सिंचाई विधि से आलू की अधिक कंद उपज प्राप्त होती है। नमी के स्तर 1.0 IW/CPE से 1.2 IW/CPE के सिंचाई स्तर की तुलना में 145.95 किग्रा/हे-मिमी की जल उपयोग दक्षता के साथ 28.82 टन कंद/हेक्टेयर की अधिकतम आलू की उपज प्राप्त हुई। अन्य नाइट्रोजन प्रबंधन विधियों की तुलना में नाइट्रोजन प्रबंधन उपचार यानी 75% सुझाई गईं नाइट्रोजन की मात्रा+25% नाइट्रोजन को गोबर की खाद के माध्यम से प्रयोग करने पर काफी अधिक आलू की उपज (293.17 क्विंटल/हे) और जल उपयोग दक्षता (148.50 किलोग्राम/हे-मिमी) प्राप्त हुई। प्रत्येक कुंड सिंचाई विधि में 1.0 IW/CPE के सिंचाई स्तर और 75% सुझाई गईं नाइट्रोजन की मात्रा यूरिया के माध्यम से +25% नाइट्रोजन को गोबर की खाद के माध्यम से प्रयोग करने के संयोजन से आलू की अधिकतम पैदावार (315.50 क्विंटल/हे) प्राप्त हुई तथा 4.32 का अधिकतम लाभ लागत अनुपात प्राप्त हुआ।

नवसारी केंद्र पर स्वीट कॉर्न-मूँग फसल अनुक्रम से अधिक उपज और शुद्ध लाभ प्राप्त करने के लिए, मीठे मकई की फसल को 0.8 PEF पर ड्रिप के माध्यम से सिंचित किया जाना चाहिए और साथ ही 120 किलो नाइट्रोजन/हे को फर्टिगेशन के माध्यम से और 30 और 60 दिनों पर केला के रस के 1% छिड़काव को प्रयोग किया जाना चाहिए। अतिरिक्त लाभ प्राप्त करने के लिए स्वीट कॉर्न की फसल के बाद अगले मौसम में मूंग की फसल उगानी चाहिए।

अल्मोड़ा केंद्र पर गेहूँ की फसल के तहत 18 साल के लंबे विश्लेषण से पता चला कि गेहूँ की फसल ने विश्लेषण के शुरुआती वर्षों के दौरान पारंपरिक जुताई के संचालन के साथ अधिक उपज दी। लेकिन आठ साल के बाद पारंपरिक जुताई वाले खेतों की तुलना में शून्य जुताई के साथ गेहूँ की पैदावार अधिक प्राप्त हुई। सिंचाई के स्तरों में वृद्धि से पैदावार में वृद्धि हुई और सभी वर्षों में चार सिंचाईयों के प्रयोग से सबसे अधिक उपज प्राप्त हुई। अठारह वर्षों का औसत 4.12 टन/हे था, जबकि केवल एक सिंचाई के साथ 2.91 टन/हे की उपज प्राप्त हुई। शुरू में धान तुल्य उपज पारंपरिक जुताई वाले खेतों के तहत अधिक थी, लेकिन पांच साल के बाद दो मौसमों में धान की तुल्य उपज पारंपरिक जुताई वाले खेतों की तुलना में शून्य जुताई वाले खेतों में अधिक थी। सिंचाई के स्तरों में वृद्धि से धान की तुल्य उपज में वृद्धि हुई। शून्य जुताई वाले खेतों से प्राप्त शुद्ध लाभ पारंपरिक जुताई वाले खेतों की तुलना में सभी वर्षों में अधिक था।

अल्मोड़ा केंद्र पर गेहूँ और सोयाबीन फसलों में उर्वरकों के प्रत्यक्ष और अवशिष्ट प्रभाव पर 18 साल के लंबे अनुसंधान से पता चला कि गेहूँ में NPK+ गोबर की खाद के प्रयोग ने कई वर्षों तक अधिक उपज (पांच साल का औसत) उत्पादित की (3.9 से 5.59 टन/हे)। इसके के बाद दोनों फसलों में N + FYM, NPK, FYM, और केवल N का प्रयोग करने से प्राप्त हुई, और सबसे कम नियंत्रण उपचार (1.47 से 1.81

टन/हे) में प्राप्त हुई। नियंत्रण उपचार की तुलना में NPK + FYM के प्रयोग से जल उपयोग दक्षता 150 से 300% तक बढ़ गई (3.4 से 4.4 किग्रा/हे-मिमी)। अवशिष्ट उर्वरता के तहत उगाई गई सोयाबीन की फसल से पता चला कि NPK + FYM (गेहूँ में प्रयोग) के प्रयोग के बाद बीते वर्षों में (2.41 से 3.00 टन/हे) अधिक सोयाबीन की उपज प्राप्त हुई। इसके बाद रबी और खरीफ दोनों मौसमों में N + FYM, FYM के प्रयोग और NPK +NPK, NPK नियंत्रण उपचार के प्रत्यक्ष प्रभाव से प्राप्त हुई और सबसे कम उपज (0.19 से 0.09 टन/हे) केवल N उपचार के तहत दर्ज हुई। जल खपत दक्षता और जल उपयोग दक्षता के मामले में भी समान परिणाम प्राप्त हुए। संतुलित उर्वरित खेतों में अवशिष्ट उर्वरता पर उगाई गई सोयाबीन फसल की उपज और इसकी जल खपत दक्षता में बढ़ती प्रवृत्ति प्राप्त हुई जबकि नाइट्रोजन उर्वरित और नियंत्रण खेतों में उपज और जल खपत दक्षता ने घटती प्रवृत्ति को दिखाया।

जोरहाट केंद्र पर रोपित अगेती अहू धान में मृदा की सतह से जल के 15 सेमी घटने पर सिंचाई एवं मृदा की सतह से 5 सेमी और 10 सेमी जल की कमी के बाद सिंचाइयों का प्रभाव लगभग एक समान था और खेत में जल के सूखने के 3 दिनों के बाद सिंचाई करने से अधिकतम दाना उपज प्राप्त हुई।

शिलोंग केंद्र पर धान की फसल (5.93 टन/हे) इसके बाद बॅक गेहूँ (1.68 टन/हे), तोरिया (1.40 टन/हे) और मटर (5.35 टन/हे) में शून्य जुताई के कारण अन्य उपचारों की तुलना से काफी अधिक उपज प्राप्त हुई। वर्ष 2009-2017 के दौरान प्रोडक्सन फंक्सन के प्लॉट के ग्राफ से धान की दाना पैदावार में निरंतर वृद्धि देखी गई और अधिकांश वर्षों में उपज 5.5-7 टन/हे के बीच में थी। शून्य जुताई के परिणाम स्वरूप वर्ष 2009 के आधार पर 1.45% के आधार मूल्य की तुलना में प्रयोग अवधि के अंत में मृदा में कार्बनिक कार्बन (1.62%) का निर्माण हुआ।

शिलोंग केंद्र पर रोपाई वाला धान हमेशा जुताई/अंकुर स्थापना के अन्य तरीकों की तुलना से अधिक उपज देता है। हालांकि, अगर धान में बिना कोई जुताई के बाद रबी में मसूर (पुआल की पलवार) में भी कोई जुताई नहीं की जाए तो पडल्ड रोपित धान की तुलना में 11% अधिक पैदावार और 30% अधिक जल उपयोग दक्षता प्राप्त होती है। दाल के उत्पादन के दृष्टिकोण से बिना कोई जुताई के धान और उसके बाद मसूर को उगाना ही सबसे अच्छा विकल्प है।

शिलोंग केंद्र पर ही तोरिया में जुताई के साथ अवशेष प्रबंधन विधियों के संयोजन का मक्का की फसल पर सफल प्रभाव पड़ा। तोरिया एवं मक्का दोनों ही फसलों के लिए मक्का का डंठल आवरण (MSC) +पोल्ट्री खाद+5 टन/हे की दर से एम्ब्रोसिया (एक खरपतवार) को सबसे अच्छा अवशेष प्रबंधन विकल्प के रूप में पाया गया। इस अवशेष प्रबंधन विकल्प से नियंत्रण उपचार की तुलना में क्रमशः 81% और 34% तक उपज में वृद्धि हुई। जीरो जुताई वाली मक्का की फसल में (मक्का का डंठल आवरण + मुर्गी खाद + 5 टन/हे की दर से एम्ब्रोसिया) अधिकतम 2.62 के रूप में लाभ: लागत अनुपात प्राप्त हुआ।

शिलोंग केंद्र पर ही जुताई और अंत: सस्य/अवशेष प्रबंधन ने खरीफ में मक्का की पैदावार और रबी में तोरिया की उपज को प्रभावित किया। रबी मौसम में अवशेष प्रबंधन के साथ पारंपरिक जुताई (मक्का) के तहत तोरिया की फसल अच्छी हुई। हालांकि, मक्का में शून्य जुताई के साथ मूँगफली की अंत: सस्य फसल को उगाया गया तो अधिकतम लाभ : लागत अनुपात (1.68) प्राप्त हुआ और उपज में 33% की वृद्धि हुई।

शिलोंग केंद्र पर ही गोबर की खाद + 5 टन/हे की दर से पुआल की पलवार के प्रयोग से 177% अधिक राइजोम उपज (10148 किग्रा/हे) और 72% अधिक जल उपयोग दक्षता (10.9 किग्रा/हे-मिमी) प्राप्त हुई। और 1.43 का लाभ : लागत अनुपात प्राप्त हुआ।

जोरहाट केंद्र पर 30 मार्च को मखाना की रोपाई करने से 2.53 टन/हे की अधिक दाना उपज दर्ज हुई। इस समय बुआई करने पर अन्य बुआई की अवधियों की तुलना में 3.05 के लाभ : लागत अनुपात के साथ ₹ 59,535/हे का अधिकतम शुद्ध लाभ प्राप्त हुआ और जल उत्पादकता 0.87 किलोग्राम/घनमीटर प्राप्त हुई।

संयोजी जल उपयोग और जल के बहुआयामी उपयोग

उदयपुर केंद्र पर ऊपरी भेराच नदी बेसिन के दक्षिणी भाग के जीआईएस तकनीक का उपयोग करके भारी धातु मानचित्र तैयार किए गए। भूजल और मृदा में उपस्थित सात भारी धातुओं (Cu, Ni, Zn, Mn, Cd, Fe एवं Pb) के बीच सहसंबंध गुणांक का विश्लेषण किया गया। इस क्षेत्र के भूजल के नमूनों में Ni-Zn, Cd-Pb, Zn-Cd, Zn-Pb और मृदा के नमूनों में Cd-Pb, Zn-Ni और Zn-Pb के बीच एक मजबूत सकारात्मक संबंध प्राप्त हुआ।

ऑपरेशनल रिसर्च प्रोजेक्ट (ORP)

फैजाबाद केंद्र पर गेहूँ की फसल पर अनुसंधान किया गया और 6 वर्षो के परिणामों के आधार पर यह निष्कर्ष निकाला गया कि चांदपुर वितरणिका के ऊपरी, मध्य एवं अंतिम छोर पर बेहतर जल प्रबंधन विधियों (महत्वपूर्ण अवस्थाओं में प्रति सिंचाई 6 सेमी जल, CRI, लेट जोइंटिंग और दूध बनने की अवस्था पर 5 मीटर 10 मीटर की क्यारियों के माध्यम से सिंचाई) से किसानों की विधि की तुलना में 41.82, 40.91 और 39.87 क्विंटल/हे की अधिक उपज प्राप्त हुई, जबकि किसानों की विधि से यह उपज क्रमशः 31.23, 31.15 और 30.19 क्विंटल/हे ही प्राप्त हुई। इस प्रकार, गेहूँ की फसल से लगभग 31-34% अधिक उपज को बेहतर जल प्रबंधन विधियों के तहत प्राप्त किया गया। जल खपत दक्षता (WEE) ऊपरी छोर पर अधिकतम (198.56 किग्रा/हे-सेमी) पाई गई, उसके बाद मध्य और अंतिम छोर यह 194.06 किग्रा/हे-सेमी और 190.64 किग्रा/हे-सेमी पाई गई। किसानों की सिंचाई विधि के मामले में जल खपत दक्षता काफी कम प्राप्त हुई जो वितरणिका के ऊपरी, मध्य और अंतिम छोर पर क्रमशः 97, 96.67 और 95 किलोग्राम/हे-सेमी ही थी। बेहतर जल प्रबंधन विधियों ने किसानों की विधि (1.42-1.51) की तुलना में 2.31-2.45 तक अधिक लाभ : लागत अनुपात प्राप्त हुआ।

फैजाबाद केंद्र पर ही नहर के जल की कम उपलब्धता के तहत फसलों के विविधीकरण पर प्रयोग किया गया और 6 वर्षो के परिणामों के आधार पर यह निष्कर्ष निकाला गया कि चने की फसल के साथ सरसों की अंत:सस्य पद्धति (1: 4) सबसे अच्छी पाई गई। सरसों के साथ गेहूँ की अंत:सस्य पद्धति (1: 9) से गेहूँ की अधिकतम समतुल्य पैदावार 5.24 टन/हे प्राप्त हुई और 3.59 के लाभ : लागत अनुपात के साथ यह फसल पद्धति अधिक लाभदायक पाई गई। जबकि केवल चने की फसल से गेहूँ की तुल्य उपज 5.1 टन/हे और 4.7 टन/हे दर्ज की गई।

फैजाबाद केंद्र पर ही अनुसंधान प्रयोग से निष्कर्ष निकाला गया और यह देखा गया कि नहर और भूजल (2: 1) के संयोजी उपयोग से 6 सेमी जल की बेहतर सिंचाई विधि के माध्यम से महत्वपूर्ण अवस्थाओं में (CRI, लेट जोइंटिंग और दूध बनने की अवस्थाओं पर नहरी जल से दो सिंचाईयां और भूजल से 1 सिंचाई) चैक बेसिन (5 m x 10 m) में किसानों की विधि (3.25 टन/हे) की तुलना में गेहूँ की काफी अधिक दाना उपज (4.34 टन/हे) का उत्पादन हुआ। किसानों की विधि में 10 सेमी गहराई की नहर के जल से दो सिंचाईयां बाढ़ सिंचाई विधि एवं खेत से खेत विधि द्वारा दी गई। किसानों की सिंचाई विधि की तुलना में नहर और भूजल के समुचित उपयोग के माध्यम से सिंचाई में सुधार द्वारा उपज में 33.59% की वृद्धि पाई गई। किसानों की विधि की तुलना में बेहतर सिंचाई प्रबंधन के साथ जल खपत दक्षता (48.43%) भी काफी अधिक प्राप्त हुई। इस प्रकार जल के संयोजी उपयोग द्वारा बेहतर जल प्रबंधन विधियों से 2.31 का अधिक लाभ: लागत अनुपात प्राप्त हुआ।

जम्मू केंद्र पर रणबीर नहरी कमांड के तहत वितरणिका डी -10 और डी -10 ए के लिए मॉडलिंग और अनुकूलन योजना को बनाया गया, जहाँ कुल 13,375 हेक्टेयर क्षेत्र (जिसको जम्मू के बासमती कटोरे के रूप में जाना जाता है) आता है। सिंचाई के जल की आपूर्ति और बासमती धान की जल की मांग के बीच औसत अंतर 37.51% पाया गया। इस अनुकूलन योजना के अनुसार, यदि नहर को भौतिक बाधाओं जैसे प्रत्येक वितरणिका के लिए डिजाइन डिस्चार्ज और संबंधित कमांड क्षेत्रों के कारण केवल 81 से 98 दिनों के लिए संचालित किया जाए तो सिंचाई की आपूर्ति और जल की मांग के बीच अंतर 37.5% से घटकर 20.0% तक हो जाएगा।

जबलपुर केंद्र पर कुल 716.29 हेक्टेयर के कमांड क्षेत्र के साथ खापा लघु सिंचाई परियोजना (दो माइनर: खापा और मगरधा) में तकनीकों को लागू करने से पता चला कि स्प्रिंकलर सिंचाई से बाढ़ सिंचाई की तुलना में 1.46 और 1.49 किलोग्राम/घनमीटर यानि 147% और 140% तक की जल उत्पादकता में वृद्धि हुई। प्रत्येक माइनर के 18 खेतों के अनुसंधान प्रयोगों के तहत गहरी जुताई, पंक्तियों में बुवाई, अधिक उपज वाली किस्मों, स्प्रिंकलर और बॉर्डर स्ट्रिप सिंचाई जैसी बेहतर सिंचाई पद्धतियों और उचित उर्वरकों की मात्रा का उपयोग किया गया जिसके परिणामस्वरूप न केवल जल उत्पादकता में सुधार प्राप्त हुआ बल्कि अधिकतर आदिवासियों किसानों की उन्नति भी हुई।

EXECUTIVE SUMMARY

Assessment of canal water and groundwater availability

At Pantnagar, assessment of groundwater resources was conducted in *Tarai* areas of Udham Singh Nagar district of Uttarakhand and Rampur districts of Uttar Pradesh. During the study period of twenty one years (1994-2014), there was 89.56% increase in the number of pump sets ovcr borewells. Out of ten blocks in the study area, five blocks got transformed from critical to over-exploited category, while one block transformed from safe category to semi-critical category. The reasons of transformation were the change in cropping pattern, cultivation of high water demanding crops and increased demand of water for domestic and industrial uses.

At Udaipur, the upper Berach river basin has 1101 km^2 catchment area, out of which the favourable artificial recharge zone is 219.2 km^2, which contributes only 20% of the total study area. This area comprises of villages including Chandersia, Gandoli, Sangwa, Shambhopura, Beran, Nauwa, Mavli, Akodra, Bhutpura, etc. Groundwater potential zones were identified and it was found that 15.89, 37.41, 32.47 and 14.23% of the basin falls under good, medium, poor and very poor categories, respectively.

At Coimbatore, hydrological parameters of Lower Bhawani Project (LBP) basin were simulated using SWAT model to know the current scenario (1990-2010). Annual average rainfall of the basin was estimated to be 896.3 mm. Runoff was estimated to be 24% of rainfall. Mean annual evapotranspiration (ET) was 41% of mean annual average precipitation. Average curve number of the LBP basin was estimated to be 62. Monthly water balance was simulated for the current scenario. Precipitation was higher than ET from May to November. Hence, crop can be grown during south-west monsoon and north-east monsoon with no risk of crop production.

At Navsari, sugarcane yield was not significantly influenced due to different dripper discharge as well as different spacing. Sucrose percentage in cane did not show significant difference among treatments. Maximum net return of ₹.272452 ha^{-1} was recorded under subsurface inline lateral with dripper discharge of 4 lph and 60 cm dripper spacing. Minimum damage of laterals and dripper clogging were observed under subsurface inline lateral with dripper discharge 4 lph and 60 cm dripper spacing.

At Junagadh, irrigation water applications through porous pipe system gave very poor uniformity coefficient (6.65% in case of 60 m lateral length with 100 cm input head to 47% in case of 30 m lateral length with 200 cm input head) which should be more than 90%. The uniformity in the wetting bulb size along the length of lateral also varies greatly. Therefore, it is recommended to the scientific communities/policy makers that the porous pipe system is not advisable to adopt as irrigation water application system.

Fertigation

At Chalakudy, application of drip irrigation at a frequency of once in two days along with application of biochar @ 2 t ha^{-1} significantly increased yield of brinjal, enhanced water productivity, nutrient use efficiency (NUE), net return and B:C ratio. The results obtained envisaged the water holding capacity and nutrient retention capacity of biochar. Application of biochar @ 2 t ha^{-1} as a soil amendment resulted in increase in brinjal yield by 12%, yield of brinjal ratoon crop by 25% when compared to application of lime. The yield of residual cowpea crop improved by 12% by application of biochar @ 4 t ha^{-1} compared to lime application. Increase in yield of brinjal ratoon crop and cowpea grown in residual moisture obtained without application of nutrients revealed the long term effect of biochar in holding the nutrients.

At Faizabad, drip irrigation at 60% PE with 100% recommended dose of nitrogen (RDN) recorded significantly higher yield of Rajmash beans (13.12 t ha^{-1}) compared to surface irrigation at 0.8 IW/CPE and drip irrigation at 40% PE, but at par with drip irrigation at 80% PE and 60% PE with 75% dose of RDN. Nitrogen doses (100 and 75% RDN) did not affect bean yield significantly under drip irrigation. Drip irrigation at 60% PE with 100% and 75% doses of RDN recorded highest benefit-cost ratio of 4.30 and 4.19, respectively over other surface and drip irrigation treatments.

At Navsari, two plant crops and two ratoon crops of sugarcane planted in paired row (60:120 cm) with two-eye budded sets of cane and irrigated with the help of subsurface placement of drip laterals (7.5 cm bgl) recorded consistent and significantly higher growth parameters, yield attributes, cane yields and net returns than other planting methods which involved sprouted buds and 21 days old plantlets prepared from single eye buds during both plant and ratoons crops. More number of more splits of fertigation (20 equal splits) was not pronounced on cane yield over 10 equal splits fertigation with 80% of recommended dose of fertilizer.

Groundwater management

At Ludhiana, laboratory model of composite filter was installed in field laboratory to study filtration rate and quality of the runoff water and silt removal efficiency of the composite filter. The water quality parameters including silt removal (RE), EC, pH, TDS, RSC and nitrate reduction from artificially spiked water SRE increased with the increasing number of filter materials from 7.71% for brick flakes of 15 cm thickness to 72.7% for B_{30}:G:CS:C combination. The EC, pH, TDS and RSC of water before and after passing through composite filter was determined in the laboratory and the results showed virtually no effect of different filter media on EC, pH, TDS and RSC and nitrate removal efficiency was found to be 24.93 and 24.45% for B_{30}:G:CS:C and B_{15}:G:CS:C combinations, respectively. The best combination then installed in the field and SRE of 74.73% was found whereas there was no effect on EC, pH, TDS and RSC of water before and after passing the composite filter. Nitrate removal efficiency of 20.30% was found in actual field condition.

At Ludhiana, total energy consumption per year by electric and diesel tubewells upto 8 hp under the category of shallow and medium tubewells in Punjab was 4183.4 MU and 544.4 MU, respectively. The amount of energy that can be saved by replacing these electric and diesel tubewells is 4728 MU (if replacing 100% tubewells), 2364 MU (if replacing 50% tubewells) and 1182 MU (if replacing 25% tubewells). There will be reduction in carbon emission by $9101x10^6$ kg (if replacing 100% tubewells), $4550.5x10^6$ kg (if replacing 50% tubewells) and $2275.3x10^6$ kg (if replacing 25% tubewells). The money that will be saved by replacing electric and diesel tubewells will be ₹ 3158 crore. So, payback period of SPV pumps will be 10 to 15 years depending upon the SPV pumps provider. Afterwards, more than ₹ 4000 crore will be saved each year.

At Coimbatore, performance evaluation of various artificial recharge structures was taken up in Thondamuthur block (Over exploited category) of Coimbatore district. Recharge structures, *viz.*, four check dams, one recharge shaft in check dam and one recharge borewell was identified. Ten observation wells near the structures were also identified for monitoring water levels. Topographical survey was carried out and stage-volume relationship of the structures was developed for the check dams in order to study water balance of the structures. Periodical water level monitoring in the observation wells showed a rise in water levels in all the observation wells and recharge borewell during monsoon. Impact will be seen immediately after the monsoons and generally one month lag period for check dam. Zone of influence of the check dam was found to be 650 m.

Irrigation scheduling of crops

At Jammu, adoption of rotavator puddling gave 9.9% higher water use efficiency (WUE) compared to Cultivator puddling

(Farmers' practice) and Puddler puddling in basmati rice field. Rotavator puddling along with irrigation applied three days after disappearance of ponded water (3 DADPW) resulted in 30.6% water saving over continuous ponding in sandy loam soil of Ranbir canal command area.

At Belavatagi, four-year long field experiment revealed that cotton grown with irrigation at 0.8 IW/CPE recorded significantly higher kapas yield (1.90 t ha^{-1}), net return (₹ 55,945 ha^{-1}) and B:C ratio (2.48) compared to farmers' method i.e. irrigation by flood at critical stages (1.62 t ha^{-1}). Among Integrated Nutrient Management (INM) levels, treatment 100% RDF + FYM @ 10 kg ha^{-1} + one row of sunhemp in between two rows of Bt cotton + $ZnSO_4.7H_2O$ @ 25 kg ha^{-1} + $FeSO_4.5H_2O$ @ 25 kg ha^{-1} + Borax @ 5 kg ha^{-1} recorded significantly higher kapas yield of 2.16 t ha^{-1} with water use efficiency of 3.69 kg $hamm^{-1}$, net income of ₹ 66,153 ha^{-1} and B:C ratio of 2.92.

At Gayeshpur, zero-till greengram-jute relay cropping system evaluated for two years under different irrigation regimes and amounts of hydrogel showed strong positive correlation between system equivalent yield and actual evapotranspiration (ET) rate. Thus the gel conditioner (hydrogel) mitigated ET demand of the relay crops for a longer time. Hydrogel @ 2.5 kg ha^{-1} with irrigation at CPE 100 mm increased the system yield (4.50 t ha^{-1}) and water productivity (0.61 kg m^{-3}), being at par with hydrogel @ 5.0 kg ha^{-1} with irrigation at CPE 100 mm (4.87 t ha^{-1} and 0.66 kg m^{-3}, respectively). This approach can help obtain additional pulse yield and saving more irrigation water.

At Kota, application of irrigation schedule IW/CPE 0.8 resulted in significantly higher seed yield of 0.85 t ha^{-1}, net return of ₹ 1,26,530 ha^{-1} and B:C ratio of 4.54 of kalonji (Nigella sativa L.). Application of 100% RDF i.e. 30:60:25 kg NPK ha^{-1} recorded significantly higher seed yield of 0.79 t ha^{-1}, water use efficiency of 3.70 kg ha-mm^{-1}, water productivity (0.37 kg m^{-3}), net return (₹ 1,16,656 ha^{-1}) and B:C ratio (4.30) over 75% RDF but at par with results under 125% RDF.

Basic studies on soil-plant-water-environment relationship

At Faizabad, effect of different moisture regimes and nitrogen management on potato crop showed that every furrow method of irrigation resulted in significantly higher tuber yield of potato. Moisture regimes 1.0 IW/CPE recorded significantly higher potato yield of 28.82 t ha^{-1} with WUE of 145.95 kg ha-mm^{-1} over 1.2 IW/CPE moisture regime being at par with 0.8 IW/CPE moisture regime. Nitrogen management treatment 75% RDN + 25% N through FYM has been found significantly high yielding with potato yield of 29.32 t ha^{-1} and WUE of 148.50 kg ha-mm^{-1} over other nitrogen management practices. Treatment combination every furrow method with 1.0 IW/CPE irrigation schedule and 75% RDN through urea + 25% N through FYM resulted in highest yield of potato 31.55 t ha^{-1} with highest benefit-cost ratio of 4.32.

At Navsari, for achieving higher yield and net profit from sweet corn-greengram sequence, sweet corn crop should be irrigated through drip at 0.8 PEF along with 120 N kg ha^{-1} applied through fertigation and 1% foliar application of banana sap at 30 and 60 DAS. For getting additional benefit, succeeding greengram crop should be taken after harvest of sweet corn.

At Almora, in 18-year long analysis for wheat crop showed that wheat crop gave higher yield with conventional tillage operation during the initial years of analysis. But after eight years higher wheat yield was recorded under zero tilled plots than conventional plots. Increasing levels of irrigation increased the yield and four irrigations gave highest yield in all the years, with an eighteen years average of 4.12 t ha^{-1} compared to 2.91 t ha^{-1} with only one irrigation. The rice equivalent system yield was initially higher under conventional plots but after five years rice equivalent yield of two seasons was higher in zero tilled plots than conventional tillage plots. The increasing level of irrigation increased the rice equivalent yield. The net returns under zero tilled plots were higher in all the years than conventional plots.

At Almora, an 18-year long study on direct and residual effect of fertilization on wheat and soybean crops showed that application of NPK+FYM in wheat gave higher yield (five years' average) over the years (3.9 to 5.59 t ha^{-1}) followed by N+FYM, NPK, FYM, NPK applied in both crops, N alone and with lowest recorded in control (1.47 to 1.81 t ha^{-1}). Water use efficiency increased by 150 to 300% with application of NPK+FYM compared to the control (3.4 to 4.4 kg ha-mm^{-1}). Soybean grown under residual fertility revealed that higher soybean yield was recorded over the years (2.41 to 3.00 t ha^{-1}) by application of NPK+FYM (applied in wheat) followed by N+FYM, FYM, and direct effect of application of NPK+NPK in both *rabi* and *kharif* seasons, NPK, control and lowest yield (0.19 to 0.09 t ha^{-1}) was recorded under treatment where N alone was applied in wheat. The WEE and WUE followed the same trends. The yield and WEE of soybean grown on residual fertility showed increasing trend in balanced fertilized plots and decreasing trend in nitrogen and control plots.

At Jorhat, in transplanted early *ahu* rice, irrigation at 15 cm depletion of water from soil surface being at par with 5 cm and 10 cm depletion of water from soil surface and irrigation at 3 days after disappearance of ponded water recorded the highest grain yield of rice.

At Shillong, zero tillage in rice (5.93 t ha^{-1}) followed by buckwheat (1.68 t ha^{-1}), toria (1.40 t ha^{-1}) and pea (5.35 t ha^{-1}) resulted in significantly higher grain yield over other treatments. From the plot of production function, continuous increase of grain yield of rice was observed during 2009-2017 and yield was in the range of 5.5-7.0 t ha^{-1} in most of the years. Zero tillage resulted in buildup of soil organic carbon (1.62%) at the end of the experiment period over base value of 1.45% as on 2009.

At Shillong, puddled transplanted rice always produce higher yield over other methods of tillage/seedling establishment methods. However, if no tillage is followed in rice followed by *rabi* lentil (with straw mulch) ensures 11% higher yield and 30% higher WUE over puddled transplanted rice. From pulse production point of view best option is 'No tilled rice followed by lentil (mulched)'.

At Shillong, tillage combined with residue management practices in toria had significant positive effect on succeeding maize. Maize stalk cover (MSC) + Poultry manure + *Ambrosia* (a weed sp.) @ 5 t ha^{-1}, was found as the best residue management option for both toria and maize (81 & 34% yield increase over control, respectively). Zero tilled maize (MSC + Poultry manure + *Ambrosia* @ 5 t ha^{-1} recorded highest B:C ratio of 2.62.

At Shillong, yields of maize and succeeding toria as influenced by tillage and intercropping/residue management. Toria do well under conventional tillage (maize) with residue retention in *rabi* season. However, zero tilled maize intercropped with ground nut paired row recorded highest B:C ratio of 1.68 and yield enhancement by 33%.

At Shillong, FYM + Straw mulch (@ 5 t ha^{-1} each) recorded 177% higher rhizome yield (10148 kg ha^{-1}) and 72% higher WUE (10.9 kg ha-mm^{-1}) with a B:C of 1.43.

At Jorhat, planting of makhana on 30th March recorded significantly higher seed yield of 2.53 t ha^{-1} with highest net return of ₹ 59,535 ha^{-1}, water productivity of 0.87 kg m^{-3} and benefit-cost ratio of 3.05 than that of other planting dates. Also, plant spacing of 125 cm x 120 cm fetched highest seed yield, net return and benefit-cost ratio compared to other plant spacings.

Conjunctive use and multiple use of water

At Udaipur, heavy metal maps of southern part of upper Bearch river basin were prepared under GIS environment using IDW technique. The correlation coefficient analysis was performed among seven heavy metals in groundwater and soil namely, Cu, Ni, Zn, Mn, Cd, Fe and Pb. A strong positive correlation was observed between Ni-Zn, Cd-Pb, Zn-Cd, Zn-Pb in water sample and Cd-Pb, Zn-Ni and Zn-Pb in soil samples of the region.

Operational Research Project (ORP)

At Faizabad, experiment on wheat crop has been concluded and based on six years results, it may be concluded that the improved water management practice (6 cm water per irrigation at critical stages, CRI, late jointing and milking through checks of 5 m x 10 m) gave higher wheat yield of 4.18, 4.09 and 3.99 t ha^{-1} at head, middle and tail end of Chandpur distributory in comparison to farmers practice in which these were 3.12, 3.12 and 3.02 t ha^{-1}, respectively. Thus, about 31.33-33.91% higher wheat yield was obtained under improved water management practice over farmer's practice of wheat crop. The water expense efficiency (WEE) was found to be highest (198.56 kg ha-cm^{-1}) at head followed by middle and tail end at which it was 194.06 kg ha-cm^{-1} and 190.64 kg ha-cm^{-1} under improved irrigation practice, respectively. The water expense efficiency was quite low in case of farmer's practice which was 97.00, 96.67 and 95.00 kg ha-cm^{-1} at head, middle and tail end of the distributory respectively. The improved water management practice obtained the high benefit-cost ratio to the tune of 2.31-2.45 in comparison to farmers practice in which it was 1.42-1.51.

At Faizabad, based on six-year experiment on diversification of crops under poor availability of canal water it was concldued that the intercropping of mustard with gram crop (1:4) was best as it gave the highest equivalent wheat yield of 5.24 t ha^{-1} and was most remunerative with B-C ratio of 3.59 followed by intercropping of mustard with wheat (1:9) and pure stand of gram for which the equivalent wheat yields were as 5.18 and 4.67 t ha^{-1}, respectively.

At Faizabad, experiment has also been concluded and it has been observed that the conjunctive use of canal and ground water (2:1) through improved irrigation practice of 6cm water at critical stages (CRI, late jointing and milking, two irrigation from canal and one from tube-well water) in check basin (5x10 m^2) produced significantly higher grain yield (4.34 t ha^{-1}) of wheat as compared to farmers practice (3.25 t ha^{-1}) in which two irrigations from canal with 10cm of water by flooding, field to field method were given. The increase in yield was found to be 33.59% in case of improved irrigation practice through conjunctive use of canal and ground water over farmers practice. WEE was also found significantly higher (48.43%) with improved irrigation practice in comparison to farmers practice. The improved water management practice of conjunctive use of water recorded the higher benefit-cost ratio of 2.31.

At Jammu, modeling and optimization plan was done for distributaries D-10 and D-10A covering 13,375 ha (known as Basmati bowl of Jammu) under Ranbir canal command. The average gap between irrigation water supply and water demand for basmati rice was 37.51%. As per the optimization plan, if canal is operated for only 81 to 98 days due to physical constraints such as design discharge and corresponding command areas for each distributary, then gap between irrigation supply and water demand will get reduced from 37.5% to 20.0%.

INTRODUCTION

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

Revised mandates of AICRP on Irrigation Water Management after merger of AICRP on WM and AICRP on GWU

1. Assessment of surface water 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 landholders' 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-plant-water-environment relationship under changing scenarios of irrigation water management
5. To evolve management strategies for conjunctive use of surface water and groundwater resources for sustainable crop production

List of existing centres and their controlling institutions under AICRP on Irrigation Water Management (Table 1)

Table 1. Centres and their controlling universities

S.No.	Location of Centre	Controlling University/ICAR Institute
1	Almora	VPKAS, Almora
2	Bathinda, Ludhiana	PAU, Ludhiana
3	Belavatagi	UAS, Dharwad
4	Bhavanisagar, Madurai, Coimbatore	TNAU, Coimbatore
5	Bilaspur, Raipur	IGKVV, Raipur
6	Chalakudy	KAU, Thrissur
7	Chiplima	OUAT, Bhubaneswar
8	Dapoli	DBSKKV, 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	AU, Kota
16	Morena	RVSKVV, Gwalior
17	Navsari	NAU, Navsari
18	Palampur	CSKHPKVV, Palampur
19	Pantnagar	GBPUAT, Pantnagar
20	Parbhani	VNMKV, Parbhani
21	Powarkheda, Jabalpur	JNKVV, Jabalpur
22	Pusa	Dr.RPCAU, 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 of the country are given in Table 2.

Table 2. Distribution of the centres of AICRP on Irrigation Water Management across the Agro-ecological Subregions (AESRs) of India and irrigation commands represented by the centres

ECOSYSTEM	AER Description	AESR	Description of AESR	Irrigation region	Centre	Controlling organization
ARID ECOSYSTEM	1 Western Himalayas, cold arid eco-region	1.1	Eastern aspects of Ladakh Plateau, cold, hyper-arid ecosub-region (ESR) with shallow skeletal soils, very low AWC and LGP < 60 days	-	-	-
		1.2	Western Aspects of Ladakh plateau and North Kashmir Himalayas, cold to cool, typic–arid ESR with shallow, loamy-skeletal soils, low AWC and LGP 60-90 days	-	-	-
	2 Western plain, Kachchh and parts of Kathiawar Peninsula, hot arid eco-region	2.1	Marusthali, hot hyper-arid ESR with shallow and deep sandy desert soils, very low AWC and LGP <60 days	IGNP Bhakra	Sriganganagar Bathinda	SKRAU, Bikaner PAU, Ludhiana
		2.2	Kachchh Peninsula (The Great Rann of Kachchh as inclusion), hot hyper-arid ESR with deep loamy saline and Alkali soils, low AWC and LGP < 60 days	-	-	-
		2.3	Rajasthan Bagar, North Gujarat plain and South-western Punjab plain, hot typic-arid ESR with deep, loamy desert soils (inclusion of saline phase), low AWC and LGP 60-90 days	Bhakra	Hisar	CCSHAU, Hisar
		2.4	South Kachchh and north Kathiawar peninsula, hot arid ESR with deep loamy saline and alkali soils, low AWC and LGP 60-90 days	-	-	-
	3 Karnataka plateau (Rayalseema as inclusion), hot arid ESR with deep loamy and clayey mixed red and black soils, low to medium AWC and LGP 60-90 days	-	-	-	-	-
SEMIARID ECOSYSTEM	4 Northern plain (and Central Highlands including Aravallis, hot semi-arid eco-region	4.1	North Punjab plain, Ganga-Yamuna Doab and Rajasthan upland, hot semi-arid ESR with deep loamy alluvium-derived soils (occasional saline and sodic phases), medium AWC and LGP 90-120 days	-	Ludhiana	PAU, Ludhiana

		4.2	North Gujarat plain (inclusion of Aravalii range and east Rajasthan uplands), hot dry semi-arid ESR with deep loamy grey brown and alluvium derived soils, medium AWC and LGP 90-120 days	-	Udaipur	MPUAT, Udaipur
		4.3	Ganga-Yamuna Doab, Rohilkhand and Avadah plain, hot moist semi-arid ESR with deep, loamy alluvium-derived soils (sodic phase inclusion), medium to high AWC and LGP 120-150 days	-	-	-
		4.4	Madhya Bharat Plateau and Bundelkhand uplands, hot, moist semi-arid ESR with deep loamy and clayey mixed red and black soils, medium to high AWC and LGP 120-150 days	Chambal	Morena	RVSKVV, Gwalior
	5 Central Highlands (Malwa) Gujarat plain and Kathiawar Peninsula, semi-arid eco-region	5.1	Central Kathiawar Peninsula, hot dry Semi-arid ESR with shallow and medium loamy to clayey black soils (deep black soils as inclusion), medium AWC and LGP 90-120 days	-	Junagadh	JAU, Junagadh
		5.2	Madhya Bharat plateau, Western Malwa plateau, eastern Gujarat plain, Vindhyan and Satpura range and Narmada valley hot moist semi-arid ESR with medium and deep, clayey black soils (shallow black soils as inclusions), medium to high AWC and LGP 120-150 days	Chambal	Kota	AU, Kota
		5.3	Coastal Kathiwar Peninsula, hot moist semi-arid ESR with deep loamy coastal alluvium-derived soils (saline phases inclusion), low to medium AWC and LGP 120-150 days	-	-	-
	6 Deccan plateau, hot semi-arid eco-region	6.1	South-western Maharashtra and North Karnataka Plateau, hot dry semi-arid ESR with shallow and medium loamy black soils (deep clayey black soils as inclusion) medium to high AWC and LGP 90-120 days	-	-	-
		6.2	Central and western Maharashtra plateau and north Karnataka plateau and north western Telangana plateau, hot moist semi-arid ESR with shallow and medium loamy to clayey black soils (medium and deep clayey black soils as inclusion) medium to high AWC and LGP 120-150 days	Jayakwadi Mula	Parbhani Rahuri	VNMKV, Parbhani MPKV, Rahuri

		6.3	Eastern Maharashtra plateau, hot moist semi-arid ESR with medium and deep clayey black soils (shallow loamy, to clayey black soils as inclusion), medium to high AWC and LGP 120-150 days	-	-	-
		6.4	Moderately to gently sloping North Sahyadris and western Karnataka plateau, hot dry sub-humid ESR with shallow and medium loamy and clayey black soils (deep clayey black soils as inclusion), medium to high AWC and LGP 150-180 days	Malaprabha	Belavatagi	UAS, Dharwad
	7 Deccan plateau (Telengana) and Eastern Ghats, hot semi-arid eco-region	7.1	South Telengana Plateau (Rayalsema) and Eastern Ghat, hot dry semi-arid ESR with deep loamy to clayey mixed red and black soils, medium AWC and LGP 90-120 days	-	-	-
		7.2	North Telangana plateau, hot moist semi-arid ESR with deep loamy and clayey mixed red and black soils, medium to very high AWC and LGP 120-150 days	-	-	-
		7.3	Eastern ghat (south), hot moist semi-arid/dry subhumid ESR with medium to deep loamy to clayey mixed red and black soils, medium AWC and LGP 150-180 days	-	-	-
	8 Eastern Ghats and Tamil Nadu uplands and Deccan (Karnataka) plateau, hot semi-arid eco-region	8.1	Tamil Nadu uplands and leeward flanks of south Sahyadris, hot dry semi-arid eco-subregion with moderately deep to deep, loamy to clayey, mixed red and black soils medium AWC and LGP 90-120 days	Periyar Vaigai Periyar Vaigai	Coimbatore Madurai	TNAU, Coimbatore TNAU, Coimbatore
		8.2	Central Karnataka Plateau, hot moist semi-arid ESR with medium to deep red loamy soils, low AWC and LGP 120-150 days	-	-	-
		8.3	Tamil Nadu uplands and plains, hot moist and ESR with deep red loamy soils, low AWC and LGP 120-150 days	Lower Bhavani	Bhavanisagar	TNAU, Coimbatore
SUBHUMID ECOSYSTEM	9 Northern plain, hot subhumid (dry) eco-region	9.1	Punjab and Rohilkhand plains, hot dry/moist subhumid transitional ESR with deep, loamy to clayey alluvium-derived (inclusion of saline and sodic phases) soils medium AWC and LGP 120-150 days	-	-	-

		9.2	Rohilkhand, Avadh and south Bihar plains, hot dry subhumid ESR with deep loamy alluvium-derived soils, medium to high AWC and LGP 150-180 days	Sharda Sahayak	Faizabad	NDUA&T, Faizabad
	10 Central Highlands (Malwa and Bundelkhand), hot subhumid (dry) eco-region	10.1	Malwa plateau, Vidnyan scarpland and Narmada valley, hot dry subhumid ESR with medium and deep clayey black soils (shallow loamy black soils as inclusion), high AWC and LGP 150-180 days	- Tawa	Jabalpur Powarkheda	JNKVV, Jabalpur JNKVV, Jabalpur
		10.2	Satpura and Eastern Maharashtra plateau, hot dry subhumid ESR with shallow and medium loamy to clayey black soils (deep clayey black soils as inclusion), medium to high AWC and LGP 150-180 days	-	-	-
		10.3	Vidhyan Scarpland and Baghelkhand plateau, hot dry subhumid ESR with deep loamy to clayey mixed red andblack soils, medium to high AWC and LGP 150-180 days	-	-	-
		10.4	Satpura range and Wainganga valley, hot moist subhumid ESR with shallow to deep loamy to clayey mixed red and black soils, low to medium AWC and LGP 180-210 days	-	-	-
	11 Moderately to gently sloping Chhattisgarh/ Mahanadi basin, hot moist/ dry subhumid transitional ESR with deep loamy to clayey red and yellow soils, medium AWC and LGP 150-180 days	-	-	Hasdeo Bango -	Bilaspur Raipur	IGKVV, Raipur IGKVV, Raipur
	12 Eastern plateau (Chhotanagpur) and Eastern Ghats, hot subhumid eco-region	12.1	Garjat Hills, Dandakaranya and Eastern Ghats, hot moist subhumid ESR with deep loamy red and lateritic soils, low to medium AWC and LGP 180-210 days	Hirakud	Chiplima	OUAT, Bhubaneswar
		12.2	Eastern Ghats, hot moist subhumid ESR with medium to deep loamy red and lateritic soils, medium AWC and LGP 180-210 days	-	-	-

	13 Eastern plain, hot subhumid (moist) eco-region	13.1	North Bihar and Avadh plains, hot dry to moist subhumid ESR with deep, loamy alluvium derived soils, low to medium AWC and LGP 180-210 days	Gandak	Pusa	RAU, Samastipur
		13.2	Foothills of central Himalayas, warm to hot moist subhumid ESR with deep loamy to clayey Tarai soils, high AWC and LGP 180-210 days	-	-	-
	14 Western Himalayas, warm subhumid (to humid with inclusion of perhumid) eco-region	14.1	South Kashmir and Punjab Himalayas, cold and warm dry semi-arid/dry subhumid ESR with shallow to medium deep loamy brown forest and Podzolic soils, low to medium AWC and LGP 90-120 days	-	-	-
		14.2	South Kashmir and Kumaun Himalayas, warm moist to dry subhumid transitional ESR with medium to deep loamy to clayey brown forest and podzolic soils, medium AWC and LGP 150-210 days	Yamuna Ravi and Tawi	Almora Jammu	VPKAS, Almora SKUAST, Jammu
		14.3	Punjab Himalayas warm humid to perhumid transitional ESR with shallow to medium deep loamy brown forest and podzolic soils, low to medium AWC and LGP 270-300 + days	-	Palampur	HPKVV, Palampur
		14.4	Kumaun Himalayas, warm humid to perhumid transitional ESR with shallow to medium deep loamy red and yellow soils, low AWC and LGP 270-300 + days	-	-	-
		14.5	Foothills of Kumaun Himalayas (subdued), warm humid/perhumid ESR with medium to deep, loamy Tarai sols, medium AWC and LGP 270-300 + days	-	Pantnagar	GBPUAT, Pantnagar
HUMID-PERHUMID ECOSYSTEM	15 Assam and Bengal plains, hot subhumid to humid (inclusion of perhumid) eco-region	15.1	Bengal basin and North Bihar plain, hot moist subhumid ESR with deep loamy to clayey alluvium derived soils, medium to high AWC and LGP 210-240 days	Damodar Valley Corporation (DVC)	Gayeshpur	BCKVV, Mohanpur
		15.2	Middle Brahmaputra plain, hot humid ESR with deep, loamy to clayey alluvium derived soils, medium AWC and LGP 240-270 days	-	-	-

		15.3	Teesta, lower Brahmaputra plain and Barak valley, hot moist humid to perhumid ESR with deep, loamy to clayey alluvium-derived soils, medium AWC and LGP 270-300 days	-	-	-
		15.4	Upper Brahmaputra plain, warm to hot perhumid ESR with moderately deep to deep loamy, alluvium derived soils, medium AWC and LGP > 300 days	Jamuna	Jorhat	AAU, Jorhat
	16 Eastern Himalayas, warm perhumid eco-region	16.1	Foot-hills of Eastern Himalayas (Bhutan foot hills) warm to hot perhumid ESR with shallow to medium, loam-skeletal to loamy Tarai soils, low to medium AWC and LGP 270-300 days	-	-	-
		16.2	Darjeeling and Sikkim Himalayas, warm perhumid ESR with shallow to medium deep loamy brown and Red Hill soils, low to medium AWC and LGP > 300 days	-	-	-
		16.3	Arunanchal Pradesh (subdued Eastern Himalayas), warm to hot perhumid ESR with deep, loamy to clayey red loamy soils, low to medium AWC and PGP > 300 days	-	-	-
	17 North-eastern hills (Purvachal), warm perhumid eco-region	17.1	Meghalaya plateau and Nagaland hill, warm to hot moist humid to perhumid ESR with medium to deep loamy to clayey red and lateritic soils, medium AWC and LGP 270-300 + days	Umiam	Shillong	ICAR Complex for NEH Region, Shillong
		17.2	Purvachal (Eastern range), warm to hot perhumid ESR with medium to deep loamy red and yellow soils, low to medium AWC and LGP > 300 days	-	-	-
COASTAL ECOSYSTEM	18 Eastern Coastal plain, hot subhumid to semi-arid eco-region	18.1	South Tamil Nadu plains (Coastal), hot dry semi-arid ESR with deep, loamy to clayey, alkaline coastal and deltaic alluvium-derived soils, medium AWC and LGP 90-120 days	-	-	-
		18.2	North Tamil Nadu Plains (Coastal), hot moist semi-arid ESR with deep, clayey and cracking coastal and deltaic alluvium-derived soils, high AWC and LGP 120-150 days	-	-	-

		18.3	Andhra plain, hot dry subhumid ESR with deep, clayey coastal and deltaic alluvium derived soils, low to medium AWC and LGP 150-180 days	-	-	-
		18.4	Utkal plain and east Godavari delta, hot dry subhumid ESR with deep, loamy to clayey coastal and deltaic alluvium-derived soils, medium AWC and LGP 180-210 days	-	-	-
		18.5	Gangetic delta, hot moist subhumid to humid ESR with deep, loamy to clayey coastal and deltaic alluvium-derived soils, medium AWC and LGP 240-270 days	-	-	-
	19 Western Ghats and coastal plain, hot humid-perhumid eco-region	19.1	North Sahyadris and Konkan coast, hot humid ESR with medium to deep loamy to clayey mixed red and black soils, medium to high AWC and LGP 210-240 days	Ukai-Kakrapar	Navsari	NAU, Navsari
		19.2	Central and south Sahyadris, hot moist subhumid to humid transitional ESR with deep, loamy to clayey red and lateritic soils, low to medium AWC and LGP 210-270 days	Chalakudy -	Chalakudy Dapoli	KAU, Thrissur DBSKKV, Dapoli
		19.3	Konkan, Karnataka and Kerala coastal plain, hot humid to perhumid transitional ESR with deep, clayey to loamy, acidic, coastal alluvium-derived soils, low AWC and LGP 240-270 days	-	-	-
ISLAND ECOSYSTEM	20 Islands of Andaman-Nicobar and Lakshadweep, hot humid to perhumid island eco-region	20.1	Andaman-Nicobar group of islands, hot perhumid ESR with shallow to medium deep, loamy to clayey red and yellow and red loamy soils, low to medium AWC and LGP > 300 days	-	-	-
		20.2	Level Lakshadweep and group of islands hot humid ESR with shallow to medium deep loamy to sandy black, sandy and littoral soils, low to medium AWC and LGP 240-270 days	-	-	-

AER- Agro-ecological region; AWC- Available water content; LGP- Length of growing period

Locality Characteristics of AICRP on Irrigation Water Management Centres

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

Name of centre	Soil texture	Depth of water table (m)	Annual rainfall (mm)	Source of irrigation
Almora	Loamy sand to clay/silty clay loam	No groundwater. Subsurface water concentrated at specific place and come out in surface in the form of water springs	1150 (Almora) 1003 (Hawalbagh)	Lift irrigation Canal
Belavatagi	Sandy loam to clay	Very deep	556	Canal
Bathinda	Loamy sand to sandy loam	1-4 m	400	Canal Tubewell
Bhavanisagar	Red sandy loam to clay loam	3-10 m	702	Canal
Bilaspur	Sandy loam to clay	> 2 m	1249	Canal
Chalakudy	Loamy sand to sandy loam, slightly acidic	> 2 m	3146	Canal
Chiplima	Sandy loam to sandy clay loam	0.2-5 m	1349	Canal
Coimbatore	Red loamy (Black soil)	5-20 m	774	Dug well Tubewell Canal
Dapoli	Sandy loam to sandy clay loam	0.2-5 m	1349	Canal
Faizabad	Silty loam to silty clay loam	4-7.5 m	1022	Canal Tubewell
Gayeshpur	Sandy loam to clay loam	0.2-2 m	1315	Canal Tubewell
Hisar	Loamy sand to sandy loam	0.4-1 m	430	Canal Tubewell
Jabalpur	Clay loam to clay	>3 m	1354	Canal Tubewell
Jammu	Sandy loam to silty loam	>4 m	1175	Canal
Jorhat	Sandy loam to sandy clay loam, slightly to moderately acidic	0.5-4.5 m	2083	Canal Tubewell
Junagadh	Clay loam (medium black)	2-20 m	800	Tubewell Open well
Kota	Clay loam to clay	0.7-2 m	777	Canal
Madurai	Sandy loam to clay loam	0.5-2 m	858	Canal
Ludhiana	Sandy loam to loamy sand	25-30 m	550	Tubewell Canal
Morena	Sandy loam to sandy clay loam	5-15 m	875	Canal Tubewell

Navsari	Clayey	1-5 m	1418	Canal
Palampur	Silty clay loam to clay loam	1.56-15.44 m (Pre-monsoon) 0.48-12.30 m (Post-monsoon)	1751	*Kuhl* (Natural gravity stream)
Pantnagar	Sandy loam to clay loam	0.5-3 m	1370	Canal Tubewell
Parbhani	Medium to deep black clayey	>1- 3 m	861	Canal Well
Powarkheda	Deep black clay	3-6 m	1087	Canal and Tubewell
Pusa	Sandy loam	2-6 m	1200	Canal Tubewell
Rahuri	Deep black clayey	2-5 m	523	Canal
Raipur	Sandy loam to clay loam	>2 m	1154	Canal Tubewell
Shillong	Sandy loam	>2 m	2400	*Jalkund* ponds
Sriganganagar	Loam to silty clay loam	> 10 m	276	Canal Tubewell
Udaipur	Sandy loam	12-18 m	670	Canal Tubewell

Chapter 1

Assessment of Canal Water and Groundwater Availability

1.1. Pantnagar

1.1.1. Assessment of groundwater availability, behavior and recharging area and groundwater management strategy in *Tarai* regions of Udham Singh Nagar and Rampur districts

A study was conducted in *Tarai* areas of Udham Singh Nagar district of Uttarakhand and Rampur districts of Uttar Pradesh for assessment of groundwater resources. Groundwater resources in this area are over-stressed and most of the parts of Rampur come under critical or overexploited region. Thus a need was felt for detailed study to assess groundwater conditions in the study area, and to suggest preventive measures considering various possible causes of depletion of the water table.

The study area covers parts of Udham Singh Nagar district of Uttarakhand and Rampur district of Uttar Pradesh. The study area comprised of total 10 blocks, out of which four blocks of Udham Singh Nagar district and six blocks of Rampur district lying between latitude 28°23'42" N and 29°22'30" N and longitude 78°53'24" E and 79°35'16" E. The study area is about 359307 ha, with 236700 ha in Rampur district and 122607 ha in Udham Singh Nagar district. The climate of the study area is sub-humid and is characterized by a hot and dry summer and winter. The maximum temperature varies from 44 ˚C to 46 ˚C in May and June in Udham Singh Nagar district and 40 ˚C to 46 ˚C in Rampur district, while the minimum temperature sometimes drops below freezing point in Udham Singh Nagar district and ranges between 4 ˚C to 6 ˚C in January in Rampur district. The average annual rainfall of Udham Singh Nagar district and Rampur district is 1322 mm and 967 mm, respectively. Major crops grown in the study area are wheat, paddy, sugarcane and minor crops are jowar, bajra, maize, pulses, oilseeds and vegetable. The results of the groundwater assessment study were as follows:

1. The maximum depth of water table was 13.1 m at Tanda hydrograph station in Shahabad block of district Rampur in 2010 during pre-monsoon period, while the minimum depth to water table was 0.36 m at Jharkhandi hydrograph station of Bazpur block of district Udham Singh Nagar in 2012 during post-monsoon season.

2. In 1994, depression of water table were observed around Badripur and Kanawra hydrograph stations in Bazpur block, near Mullahkhera and Mudiakhurd

hydrograph stations of Bilaspur block and in the area around Simariya, Tiraha, Sihari hydrograph stations of Milak block during both pre-monsoon and post-monsoon periods.

3. During year 2004, the depression was observed in Badripur and Kanawra hydrograph station areas of Bazpur block, around Mudia Khurd and Mullahkhera hydrograph stations of Bilaspur block and near Simariya and Sihari hydrograph stations of Milak block during pre-monsoon season. During post-monsoon season, there was depression around Badripur and Kanawra hydrograph stations of Bazpur block and Mullahkhera hydrograph station of Bilaspur block.

4. In the year 2014, during pre-monsoon period there were water table depressions around Jogipura hydrograph station in Bazpur block, Jhagarpuri hydrograph station in Gadarpur block and around Mudia Khurd and Mullahkhera hydrograph stations in Bilaspur block, whereas depression was observed around Mullahkhera hydrograph station of Bilaspur block during post-monsoon period.

5. The cause of water table depression in the study area might be less recharge with excessive extraction of groundwater while cause of a mound may be the presence of water body near the hydrograph station.

6. There was a significant increase in the number of pumpsets on borewells by 89.56% during the study period, but increase in the number of government tubewells i.e. 13.75% was not significant. The number of *Rahats* and private tubewells were found decreasing during the study period. However, an increasing trend of area irrigated by minor irrigation structures was observed in the study area during study period, which confirmed continuous increase in groundwater exploitation.

7. An increasing trend in area under high water demanding crops like rice and wheat was observed while the area occupied by minor crops except pulses and vegetables was on decreasing trend.

8. During the study period of twenty one years (1994 to 2014), out of ten blocks of the study area five blocks had transformed to over-exploited category from critical category, while one block from safe category had transformed to semi-critical category (Table 1.1.1). The reasons of transformations of blocks of study area from lower to higher category of groundwater utilization development stage were, the change in cropping pattern, cultivation of high water demanding crops, increased demand of water for domestic and industrial uses which resulted in over-exploitation of groundwater.

Table 1.1.1. Transformation of blocks from lower to higher category of groundwater utilization development stage during study period

S.No.	Name of block	Year	
		1994	2014
1	Bilaspur	Safe	Semi-critical
2	Chamraua	Critical	Over-exploited
3	Milak	Critical	Over-exploited
4	Saidnagar	Critical	Over-exploited
5	Shahabad	Critical	Over-exploited
6	Suar	Critical	Over-exploited

1.2. Udaipur

1.2.1. Delineation of groundwater potential zones of upper Berach river basin of Udaipur district

The Upper Berach river basin of Udaipur district falls in semi-arid region of Rajasthan bounded by $73^0$37.95' to $74^0$4.73' E Longitude and $24^0$32.69' to $24^0$56.62' N Latitude. The gross catchment area of the upper Berach river basin is 1101 km^2. The entire catchment area is having undulating topography with rolling uplands and in-filled valleys in which the velocity of runoff is high whenever the rainfall occurs in the monsoon months. The location map of the Upper Berach river basin is shown in Fig. 1.2.1. In this study, an attempt was made delineation of groundwater potential zones and to develop suitable groundwater recharge strategy. Groundwater quality in the study area was also studied.

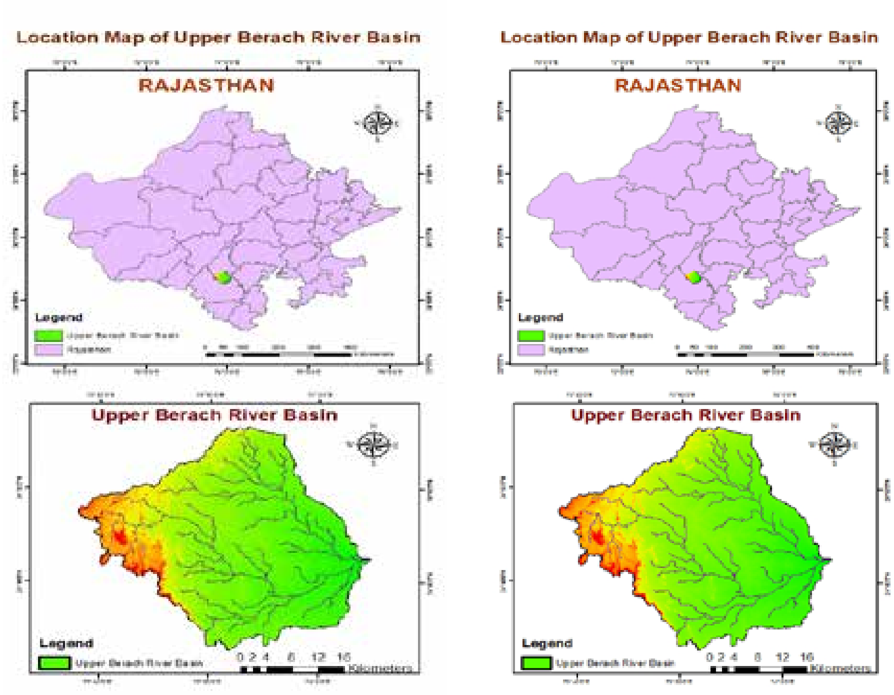

Fig. 1.2.1. Location map of Upper Berach river basin

The different physicochemical parameters such as pH, electrical conductivity (EC), total dissolved solids (TDS), calcium (Ca^{++}), magnesium (Mg^{++}), sodium (Na^{+}), potassium (K^{+}), bicarbonate (HCO_3^{-}), carbonate (CO_3^{--}), chloride (Cl^{-}), and sulphate (SO_4^{--}) present in pre and post monsoon water samples of the study area were determined using standard methods. The maximum and minimum values of these parameters during pre and post monsoon are presented in Table 1.2.1. The variations in individual groundwater quality parameter were observed by preparing water quality maps in GIS environment for pre and post monsoon periods.

Table 1.2.1. Maximum and minimum value of water quality parameters in groundwater samples

Parameter	Pre-monsoon samples (meq L^{-1})			Post-monsoon samples (meq L^{-1})		
	Min.	Max.	Mean	Min.	Max.	Mean
pH	7.1	8.7	7.9	7.1	8.6	8.01
EC	0.38	7.62	2.35	0.28	5.54	1.56
TDS	258	5230	1397.99	172	3120	896.20
Ca	0.80	13.20	3.73	0.50	6.98	2.61
Mg	1.22	30.78	7.62	0.81	19.51	4.89
Na	1.57	57.42	12.63	1.10	38.20	7.93
K	0.03	14.32	0.70	0.03	9.50	0.48
HCO_3	2.00	20.40	6.01	1.08	11.15	4.00
CO_3	0.0	2.0	0.15	0.0	1.80	0.17
Cl	0.67	67.48	14.41	0.60	49.0	9.37
SO_4	0.20	38.40	3.56	0.10	19.8	2.35

meq L^{-1} - milliequivalent per litre

Water quality index maps for pre monsoon and post monsoon periods were prepared by assigning weights to the parameters. Figure 1.2.2 shows that in the pre monsoon period 2.34 km^2 with 0.21 per cent area has excellent water quality in the village of Dholi magri, Khandawali for drinking purpose. The 62.18 km^2 with 5.67 per cent area has good quality in the village of Mandiana dhani, Khemokhera, Varila ka khera, Depar, etc. The 454.90 km^2 with 41.51 per cent area has a poor quality groundwater in the village of Sardarpura, Rampurya, Dingela, Bhansol, etc. The 494.70 km^2 with 45.14% area has a very poor quality groundwater in the village of Kajiyawas, Uthnol, Khera bhansol, Godach, etc. About 81.86 km^2 with 7.47% area groundwater was unsuitable in the village of Larawas, Palana kalan, Prakashpura, Nuroda, Ghasa, Wangrodi, etc. The Fig. 1.2.2 shows that in the post monsoon period 0.57 km^2 with 0.05% has excellent quality water in the village of Dholi magri, Khandawali for drinking purpose. The 47.35 km^2 with 4.32% area has good quality in the village of Baswariya, Majhera Khemokhera, Varila ka khera, Depar, etc. The 557.89 km^2 with 50.90% area has a poor quality groundwater in the village of Dingela, Boyna, Nauwa, Bhatewar, Bhansol, etc. The 467.86 km^2 with 42.69% area has a very poor quality groundwater in the village of Larawas, Dabok, Karanpur, Palana kalan, etc. The 22.32 km^2 with 2.04% groundwater was unsuitable in the village of Nurda, Bikrani, Daroli, Chota gurha etc. The good quality water mainly occurred in the east of the basin area.

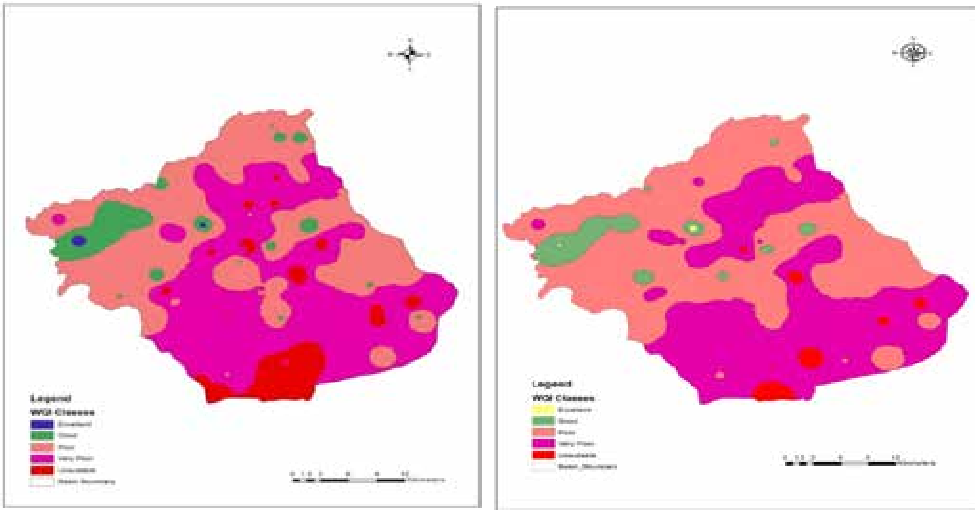

Fig. 1.2.2. Water quality index map for pre and post monsoon period

1.3. Coimbatore

1.3.1. Application of Soil and Water Assessment Tool (SWAT) model for estimation of surface water resources and temporal water demand for sustainable water management in LBP basin

A study was undertaken using Soil and Water Assessment Tool (SWAT) to simulate surface and groundwater availability and change on hydrology, focusing on trends of precipitation, evapotranspiration and water yield in LBP basin. The Lower Bhavani irrigation project is one of the first major irrigation projects completed in Tamil Nadu after independence. The Lower Bhavani dam impounds water in Bhavanisagar near Mettupalayam, in Erode district and though a network of canals provides irrigation for about 83,800 hectare land in Gopichettipalayam, Bhavani, Erode and Dharapuram taluks in Erode district and Karur taluk in Tiruchirapalli district. The area comprised of hilly regions and plain terrain with maximum and minimum altitudes of 1,487 m and 215 m above mean sea level (MSL), respectively. The terrain slopes towards south-east. The study area includes reserve forest, built-up lands, agricultural fields and barren lands. Tanks are mainly rainfed and remain dry throughout the year, except during rainy seasons. The Bhavani river flows from west to east in the study area and confluences with the Cauvery river at Bhavani town. The major crops are paddy, banana, groundnut, turmeric and sugarcane. Bhavani, Gobichettipalyam, Satyamangalam and Andiyur are the major settlements in this region.

The SWAT model requires a variety of detailed information describing the basin *viz.*, information on elevation, slope, soil, land use and climate. The source of the Digital Elevation Model (DEM) used in the study is 90 m resolution Shuttle Radar Topographic Mission (SRTM). The slope map was generated from DEM map; the slope of the majority of the study area is between 2 to 12%. Soil data from the FAO Digital Soil Map of the world was used for defining soils in the LBP basin. The attribute table includes soil texture, depth, drain, nutrient content, AWC (available water capacity) and hydraulic conductivity at different layers. The Land use / Land cover data was prepared from Land use / Land cover map of National Remote Sensing Centre (NRSC) derived from Advanced Wide Field Sensor (AWiFS), 56 m resolution data. Sixty three percent of the study area is under agriculture. Using the SRTM DEM, the GIS interface ArcSWAT 2009 was used to generate stream network. LBP basin was divided into 187 micro watersheds (Fig. 1.3.1) and each micro watershed was further subdivided into 4833 Hydrological Response units (HRUs) having unique soil and land use. SWAT model was executed by keeping all the SWAT input parameters constant except climate variables which were changed according to the period of simulation. The future spatial and temporal rainfall scenarios over the LBP basin from the ensemble of 16 Global Climate Models (GCMs) output for A1B scenario and the effect of climate change on water yield, potential evapotranspiration and soil water was assessed.

The simulated current hydrology of the LBP basin is shown in Fig. 1.3.2. Total rainfall received was 896.3 mm, evaporation was 372.5 mm, surface runoff was 192.89 mm, lateral flow was 37.2 mm, return flow was 262.5 mm and percolation to shallow aquifer was 304.04 mm. Average curve number was 62.87. Mean annual evapotranspiration was 372 mm which was 41% of mean annual average precipitation. The atmospheric moisture demand (PET) of the basin was 1479 mm, indicating the need of water from external / underground sources for successful crop production.

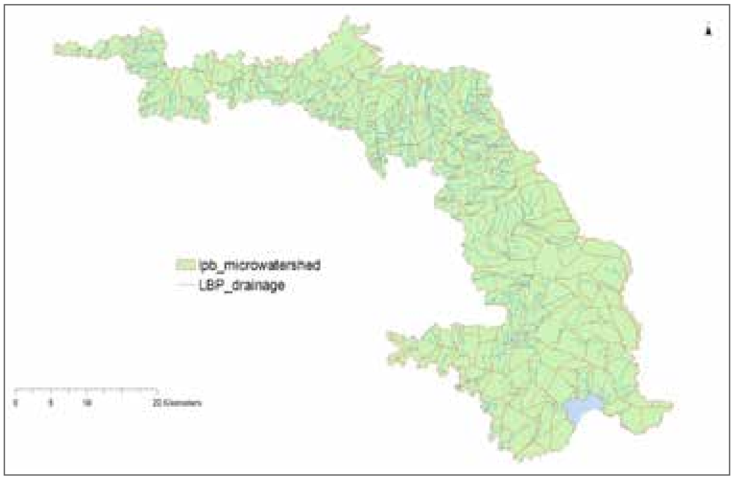

Fig. 1.3.1. Delineation of micro-watersheds in LBP basin using SWAT

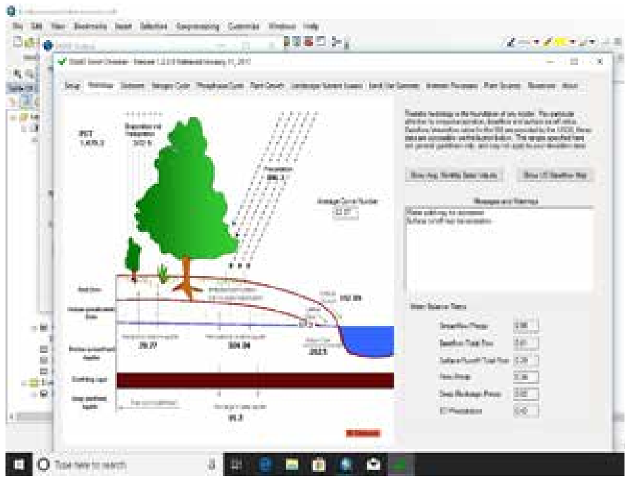

Fig. 1.3.2. Current simulated hydrology of the LBP basin

1.4. Jabalpur

1.4.1. Evaluation of groundwater structures of Bundelkhand

Spatial and temporal changes in ground level were studied in different blocks of Tikamgarh district, Madhya Pradesh, where a number of water conservation structures have been constructed under Bundelkhand special package. Groundwater level in the years 1997-2006 were compared with groundwater levels during 2007-2016. The blockwise conservation structures constructed in Tikamgarh district is given in Table 1.4.1.

Table 1.4.1. Block wise no. of conservation structures in Tikamgarh district

Name / No. of structures	Tikamgarh	Baldeogarh	Jatara	Palera	Prithvipur	Niwari
Stop dam	78	137	159	168	46	39
Check dam	11	2	35	15	15	60
Pond	109	85	139	111	112	131
Farm pond	-	-	4	5	-	-
Recharge shaft	10	7	10	10	10	10
Total	208	231	347	309	183	240

The groundwater level data were analyzed to obtain the rate of yearly decline or rise in groundwater levels. The decrease in water level for pre and post-monsoon peroids was observed as 0.102 m per year and 0.308 m per year, respectively in Phase 1 (Fig 1.4.1). Whereas, for Phase 2 there was an increase in water level for pre-monsoon and post-monsoon periods by 0.056 m per year and 0.101 m per year, respectively (Fig 1.4.2). Micro sizing the study to block level registered overall similar trend of arresting the decline in water level and increase in water level rate (Table 1.4.2). The declined rate of 0.308 m per year in Phase 1 was not only arrested but the rise in water level at the rate of 0.101 m per year was observed in Phase 2. Among the blocks, Baldeogarh experienced sharpest decline rate of 0.198 m per year in pre-monsoon and least rate of rise in water level rise i.e. 0.014 m per year. In post-monsoon condition, maximum water level decline of 0.492 m per year was observed in Tikangarh block but it also registered the maximum water level rise of 0.311 m per year. The study demonstrates the utility of conservation structures in arresting the decline of groundwater level and increasing it through groundwater recharge.

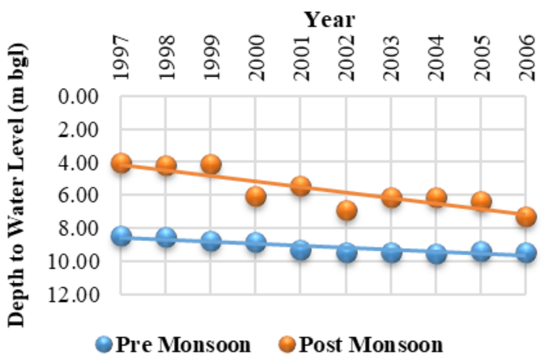

Fig. 1.4.2. Average depth to water Level in Tikamgarh district (2007-2016)

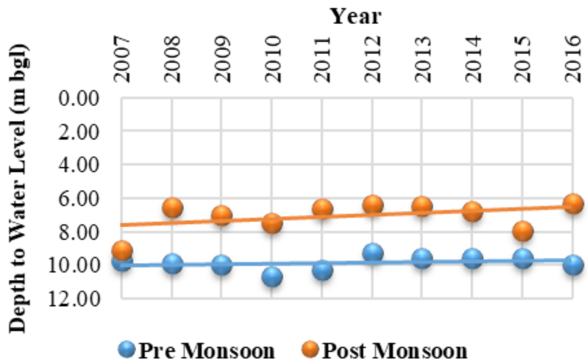

Fig. 1.4.1. Average depth to water level in in Tikamgarh district (1997-2006)

Table 1.4.2. Average rate of depth (m year^{-1}) to water level

Block	Decline (1996-2006)		Rise (2007-2016)	
	Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon
Tikamgarh	0.122	0.492	0.076	0.311
Baldeogarh	0.198	0.389	0.014	0.102
Jatara	0.099	0.212	0.018	0.055
Palera	0.067	0.246	0.025	0.138
Prithvipur	0.064	0.219	0.014	0.104
Niwari	0.104	0.365	0.055	-0.04
Tikamgarh district	0.102	0.308	0.056	0.101

Chapter 2

Pressurized Irrigation System

2.1. Navsari

2.1.1. Study on subsurface lateral having inline dripper of varying discharge rate and spacing in sugarcane

The experiment was conducted to establish subsurface drip as an alternative to surface drip for sugarcane crop (var. CoN 5071). Surface drip was not adopted by farmers due to several constrainsts such as burning of sugarcane trash after harvesting, damage of surface placement system due to *koyata* at the time of harvesting and damage due to mongoose, fox, dogs, etc. during the crop period. Thus performance of subsurface drip having inline drippers with varying discharge rates (D) and dripper spacings (L) was studied from 2014-15 to 2016-17. Depth of lateral placement was 7.5 cm for all the treatments. Control (recommended) comprised of surface lateral with dripper discharge of 4 lph and dripper spacing of 60 cm and irrigation at 0.6 PEF on alternate days. Results showed that highest cane yield of 164, 159, 150 and 158 t ha^{-1} were produced in treatment T_9 i.e. subsurface lateral with D_3 - 4.0 lph and L_3 - 60 cm (Table 2.1.1) during 1st, 2nd, 3rd year of experiment and in the pooled results, respectively. This may happen due to higher discharge, higher water movement suitable for sugarcane growth that ultimately resulted in more yield. Dripper clogging was affected by discharge rates only. Dipper clogging (13.10-13.59%) was high with less dripper discharge rate (1.3 lph) during all the years, whereas it was low (7.16-8.02%) with higher discharge rate (4 lph) after the crop was harvested. Less number of breakages in lateral (1.33 - 3.00/100 m) was observed with subsurface placement of drip lateral (depth 7.5 cm) during all the years, whereas it was more (28/100 m) with surface placement of drip lateral. This was mainly due to harvesting of sugarcane with *koyata*. Maximum net return of ₹ 272452 ha^{-1} was accrued with treatment T_9 (D_3 - 4.0 lph x L_3 - 60 cm, i.e. higher dripper discharge and dripper spacing) than rest of the treatments. Thus the farmers of south Gujarat with heavy rainfall zone cultivating sugarcane in paired row (60:120 cm) under drip irrigation (0.60 PEF) were recommended to adopt subsurface inline lateral (7.5 cm depth) at 1.80 m spacing with 4 lph dripper discharge and dripper spacing at 60 cm to minimize damage and dripper clogging in the laterals and for higher profit.

Table 2.1.1. Performance of sugarcane under subsurface drip irrigation

Treatment	Cane yield (t ha^{-1})				Sucrose (%)	Number of breakages (Damage per 100 m lateral)	Dripper clogging (%)				Drip system cost (₹ ha^{-1})	Net return (₹ ha^{-1})
	2015-16	2016-17	2017-18	Pooled			2015-16	2016-17	2017-18	Pooled		
T_1:D_1-1.3xL_1-40	155	145	135	145	12.2	1.67	15.4	14.3	11.1	13.59	28810	237690
T_2:D_1-1.3xL_2-50	154	149	138	147	12.1	3.00	14.8	12.0	12.5	13.10	27679	243821
T_3:D_1-1.3xL_3-60	157	150	141	149	12.0	2.00	14.8	14.5	10.8	13.36	26548	249952
T_4:D_2-2.0xL_1-40	160	153	139	151	12.5	2.33	9.5	11.6	7.1	9.43	28810	252690
T_5:D_2-2.0xL_2-50	163	154	142	153	12.7	1.33	11.4	12.0	9.1	10.82	27679	258821
T_6:D_2-2.0xL_3-60	164	157	143	154	12.6	3.00	11.9	10.6	8.7	10.41	26548	262452
T_7:D_3-4.0xL_1-40	159	154	145	153	12.2	2.00	8.3	8.9	6.3	7.83	28810	257690
T_8:D_3-4.0xL_2-50	161	157	146	155	12.0	2.67	7.3	9.5	7.2	8.02	27679	263821
T_9:D_3-4.0xL_3-60	164	159	150	158	12.8	2.00	6.1	7.1	8.2	7.16	26548	272452
T_{10}:D-4.0xL-60 (control)	160	150	145	151	12.8	28.00	8.5	8.4	7.2	8.07	23548	257952
SEm ±	6.76	7.77	7.18	4.19	-	-	-	-	-	-	-	-
CD at 5%	NS	NS	NS	NS	-	-	-	-	-	-	-	-
CV %	8.49	10.19	10.10	-	-	-	-	-	-	-	-	-
Interaction effect	**SEm ±**	**CD at 5%**	-	-	-	-	-	-	-	-	-	-
Y	2.29	Sig.	-	-	-	-	-	-	-	-	-	-
Y x T	7.25	NS	-	-	-	-	-	-	-	-	-	-

D: Dripper discharge (lph), L: Dripper spacing (cm), Sig.-Significant, NS-Non-significant, Selling price of cane ₹ 2500 t^{-1}

2.2. Gayeshpur

2.2.1. Response of drip irrigation and mulching on water productivity and yield of strawberry (*Fragaria x ananassa Duch.*)

The experiment was conducted from 2015-16 to 2016-17 to evaluate the efficacies of drip irrigation and conventional surface irrigation (SI) with and without mulch on strawberry crop var. Sweet Charlie (Table 2.2.1). Pooled results of two years showed that maximum yield was 343.44 g per plant with drip at 1.0 ETc (D100) followed by 332.81 g per plant with drip at 0.8 ETc (D80) and lowest under SI (114.95 g). But, water productivity was highest with irrigation regime D80 (13.13 kg m^{-3}) followed by D100 (11.67 kg m^{-3}) and lowest with SI. Among the mulch materials, use of jute geotextyle (BM) resulted in significantly higher berry yield of 357.09 g per plant with lowest yield of 181.09 g per plant under no mulch (NM) condition. Water productivity (WP) was significantly higher with jute geotextile (13.66 kg m^{-3}) among the mulches and lowest (6.68 kg m^{-3}) with no mulch (NM). Thus mulching played significant role in improving water productivity of strawberry crop. Treatment combination i.e. drip irrigation at 0.8 ETc and jute geotextyle mulch (D80 BM) gave significantly higher yield of 549.78 g per plant and WP of 21.85 kg m^{-3}, while lowest berry yield of 95.14 g per plant and WP of 1.94 kg m^{-3} were evaluated under surface irrigation without mulch (SI NM).

Table 2.2.1. Influence of irrigation scheduling and mulching on performance of strawberry

Treatment	Yield (g plant^{-1}) Early (60-80 DAP)	Yield (g plant^{-1}) Mid (81-110 DAP)	Yield (g plant^{-1}) Late (111-140 DAP)	Yield (g plant^{-1}) Total	No. of fruits per plant	Fruit weight (g)	WP (kg m^{-3})
Irrigation schedule							
SI	7.65	66.58	40.75	114.95	15.20	7.07	2.78
D60	27.20	133.90	63.58	224.45	17.30	12.29	10.99
D80	31.96	201.85	98.80	332.81	16.47	18.41	13.13
D100	33.42	189.48	120.68	343.44	18.23	17.43	11.67
CD (0.05)	3.51	14.62	12.22	14.99	1.02	0.83	0.57
Mulching							
PM	23.45	114.10	63.92	201.80	15.37	12.23	7.87
BM	30.63	212.53	113.89	357.09	19.02	17.47	13.66
NM	20.26	105.26	55.37	181.09	14.55	11.46	6.68
SM	25.88	159.93	90.64	276.17	18.25	14.04	10.37
CD (0.05)	2.21	10.67	8.99	12.16	0.64	0.92	0.58
Interaction effect							
SIPM	5.73	60.00	28.68	95.14	13.53	6.63	2.36
SIBM	9.74	85.45	55.35	150.54	19.08	7.39	3.67
SINM	4.79	52.10	25.54	82.28	10.85	7.10	1.94
SISM	10.32	68.77	53.45	131.84	17.33	7.16	3.17
D60PM	26.76	124.47	51.72	202.90	18.96	10.06	10.17
D60BM	29.12	161.31	88.80	279.66	16.36	16.05	13.76
D60NM	25.22	98.45	45.10	168.45	16.91	9.38	7.96
D60SM	27.68	151.38	68.72	247.78	16.97	13.66	12.06
D80PM	25.54	117.81	78.51	221.60	13.00	15.68	8.92
D80BM	41.27	369.26	139.35	549.78	19.27	26.74	21.85
D80NM	25.37	125.71	72.93	224.40	13.78	15.40	8.58
D80SM	35.66	194.62	104.41	334.94	19.81	15.82	13.18
D100PM	35.77	154.11	96.78	287.05	18.03	16.55	10.01
D100BM	42.38	234.09	172.04	447.87	20.54	19.70	15.37
D100NM	25.67	144.79	77.92	248.71	18.34	13.94	8.26
D100SM	29.88	224.95	135.97	390.61	19.35	19.51	13.05
CD1 (0.05)	4.13	19.10	16.81	23.38	11.10	1.84	-
CD2 (0.05)	5.02	22.03	18.96	26.18	11.13	1.79	-

*SI:Surface irrigation at IW/CPE 1.0; D60:Drip at 0.6 ETc; D80:Drip at 0.8 ETc; D100:Drip at 1.0 ETc; PM:Black polythene mulch (30 µm); BM: Jute geotextyle (1000 gsm m^{-2}); NM: No mulch; SM: Paddy straw mulch @ 5 t ha^{-1}

2.3. Parbhani

2.3.1. Response of drip irrigated tomato to different levels of irrigation and mulches

The experiment conducted for two consecutive years (2016 to 2018) with tomato var. NS-629 showed that application of irrigation through drip at 0.80 ETc (I_2) recorded significantly higher fruit yield of tomato (136.74 and 120.31 t ha^{-1}) compared to rest of the irrigation levels during both the years (Table 2.3.1). Significantly higher fruit yield (147.15 and 129.43 t ha^{-1}) and WUE (381.37 and 409.54 kg ha-mm^{-1}) were also observed with silver black polythene mulch followed by black polythene mulch (368.98 and 397.45 kg ha-mm^{-1}), respectively during both the years of experimentation. The yields were at par with black polythene mulch (142.37 and 125.61 t ha^{-1}). Significantly higher net monetary return (NMR) were obtained when irrigation was scheduled at 0.8 ETc and silver black polythene mulch was used; but at par with black polythene mulch during both the years.

Treatment combination of irrigation at 0.8 ETc and silver black polythene mulch (I_2M_2) recorded significantly higher fruit yield (157.36 and 137.94 t ha^{-1}) of tomato, but at par with treatment combinations of irrigation at 0.8 ETc and black polythene mulch i.e. I_2M_1 (155.70 and 133.17 t ha^{-1}) and irrigation at 0.6 ETc and silver black polythene mulch I_1M_2 (154.43 and 129.30 t ha^{-1}) during both the years of experimentation. Treatment combination of I_2M_2 (Irrigation at 0.80 ETc and silver black polythene mulch) recorded significantly higher NMR although it was at par with treatment combination of irrigation at 0.80 ETc and black polythene mulch (I_2M_1) and 0.60 ETc and silver black polythene mulch (I_1M_2).

Table 2.3.1. Performance of drip irrigated tomato to different levels of irrigation and mulching

Treatment	Tomato yield (t ha^{-1})		WUE (kg ha-mm^{-1})		Net return (₹ ha^{-1})		B:C ratio	
	2016-17	2017-18	2016-17	2017-18	2016-17	2017-18	2016-17	2017-18
Irrigation level								
I_1: Drip irrigation at 0.60 ET_c	117.72	106.75	399.28	445.81	298322	248663	2.01	1.86
I_2: Drip irrigation at 0.80 ET_c	136.74	120.31	354.39	380.68	384592	310159	2.27	2.05
I_3: Drip irrigation at 1.0 ET_c	121.74	112.43	255.30	286.36	312843	274386	2.06	1.95
CD at 5%	5.25	3.54	-	-	26419	16095	-	-
Mulch								
M_1: Black PM	142.37	125.61	368.98	397.45	404003	327960	2.31	2.09
M_2: Silver black PM	147.15	129.43	381.37	409.54	423521	343250	2.35	2.13
M_3: Transparent PM	112.10	106.12	316.45	335.78	268787	241635	1.91	1.83
M_4: Control (no mulch)	99.97	91.50	259.09	289.52	231365	198100	1.88	1.76
CD at 5%	7.85	7.28	-	-	33344	32995	-	-
Interaction (I x M)								
CD at 5%	13.59	12.60	-	-	-	-	-	-

2016-17: Total water use for I1, I2 and I3 is 294.8, 385.8 and 476.9 mm, respectively and 385.8 mm for mulching, Rainfall= 21.8 mm; 2017-18 : I_1, I_2 and I_3 are 239.5, 316.0 and 392.6 mm, respectively and 316.0 mm for mulching treatment, Rainfall= 9.7 mm. PM- Polythene mulch

2.4 Belavatagi

2.4.1. Evaluation of irrigation levels to commercial crops under pressurized method (drip) of irrigation in intercropping systems (Chilli, Onion, Garlic, Groundnut, Turmeric and Ginger)

Two years of experiment was conducted to evaluate the feasibility of growing chilli with intercrops like onion, garlic, groundnut, turmeric and ginger under drip system in Malaprabha command area (MCA). Intercropping of Chilli + Onion

/ Groundnut / Garlic / Turmeric on raised bed with paired row (45 – 120 – 45 cm) and drip irrigation at 0.8 ETo resulted in significantly higher chilli equivalent yields of 2.29, 2.10, 1.88, 1.83 t ha^{-1} for the respective intercrops over sole chilli crop yield. Yields of these interctops were at par with yield ontained with irrigation at 1.0 ETo. However, equivalent yield of chilli was significantly higher with Chilli + Groundnut at 0.8 ETo (2.29 t ha^{-1}) with a net return of ₹ 2.73 lakhs and B:C ratio with 30.9% water saving followed by Chilli + Onion, Chilli + Garlic, Chilli + Turmeric with an additional income of ₹ 0.91 lakhs, ₹ 1.18 lakhs and ₹ 0.82 lakhs per hectare, respectively (Table 2.4.1).

Table 2.4.1. Performance of chilli based intercropping system under drip irrigation in Malaprabha command area

Treatment		Chilli equivalent yield (t ha^{-1})	Total water use (mm)	WUE kg ha-mm^{-1}	Water saving (%)	Net returns (₹ lakh ha^{-1})	B:C ratio	Superiority over existing technology / Farmers' practice (%)
Main strip	**Interaction**							
M_1 Irrigation @ ET_o 1.0	Chilli + Groundnut	2.12	805	2.63	18.68	2.48	4.53	₹ 1.30 lakh profit with 18.18% of water saving
	Chilli + Onion	1.78	737	2.32	25.55	1.92	3.56	₹ 1.30 lakh profit with 25.55% of water saving
	Chilli + Garlic	1.96	804	2.44	18.78	2.16	3.77	₹ 0.98 lakh profit with 18.18% of water saving
	Chilli + Turmeric	1.66	1002	1.66	-	1.76	3.40	₹ 0.58 lakh profit
M_2 Irrigation @ ET_o 0.8	Chilli + Groundnut	2.29	684	3.35	30.90	2.73	4.89	₹ 1.55 lakh profit with 30.9% of water saving
	Chilli + Onion	1.88	623	3.01	37.07	2.09	3.87	₹ 0.91 lakh profit with 37.07% of water saving
	Chilli + Garlic	2.10	683	3.07	31.01	2.36	4.03	₹ 1.18 lakh profit with 31.01% of water saving
	Chilli + Turmeric	1.83	843	2.16	-	2.00	3.74	₹ 0.82 lakh profit
Control	Sole Chilli	1.39	990	1.4	-	1.18	2.75	-
-	C.D. (P=0.05)	2.02	-	-	-	0.12	0.44	-

2.4.2. Evaluation of irrigation levels to different pigeonpea based cropping systems under pressurized irrigation (Pigeonpea, Greengram, Blackgram)

Two years of experiment was conducted to evaluate the feasibility of growing pigeonpea with greengram and blackgram as intercrops with drip irrigation in Malaprabha command area. Results indicated that growing Pigeonpea with Greengram / Blackgram at 70% PE resulted in significantly higher pigeonpea equivalent yields of 3.62 (with greengram) and 3.61 t ha^{-1} (with blackgram) compared to sole pigeonpea crop grown in rainfed conditions (1.75 t ha^{-1}). Economics of the system indicated that intercropping of Pigeonpea + Greengram / Blackgram gave net return of ₹ 1.55 to 1.57 lakhs ha^{-1}, which was an additional benefit of ₹ 60,000 over sole pigeonpea crop grown with drip irrigation and additional income of ₹ 90,000 over sole pigeonpea grown under rainfed condition (Table 2.4.2).

Table 2.4.2. Equivalent yield of pigeon pea, water use and economics under drip irrigated pigeonpea based intercropping system in Malaprabha command

Treatment		PEY (t ha^{-1})	Total water use (mm)	WUE kg ha-mm^{-1}	Net return (₹ ha^{-1})	B:C ratio	Superiority over existing technology/ Farmers' practice
Main strip	**Interaction**						
M_1 Irrigation @ 70% PE	Pigeonpea + Greengram	3.63	-	5.21	1.57	4.69	₹ 60,000 profit over only PP with drip and ₹ 90,000 over Rainfed PP
	Pigeonpea + Blackgram	3.61	-	5.15	1.55	4.63	₹.58,000 profit over only PP with drip and ₹ 88,000 over Rainfed PP
	Pigeonpea	2.55	919	2.77	1.06	4.14	₹ 39,000 profit over Rainfed PP
M_2 Irrigation @ 50% PE	Pigeonpea + Greengram	3.42	-	6.94	1.45	4.41	₹ 48,000 profit over only PP with drip and ₹ 78,000 over Rainfed PP
	Pigeonpea + Blackgram	3.53	-	6.92	1.49	4.65	₹ 52,000 profit over only PP with drip and ₹ 82,000 over Rainfed PP
	Pigeonpea	2.38	740	3.21	0.97	3.87	₹ 30,000 profit over Rainfed PP
Control	Rainfed Pigeonpea	1.75	403	4.33	0.67	3.17	-
-	C.D. (P=0.05)	2.10	-	-	0.11	0.37	-

2.5. Junagadh

2.5.1. Evaluation of hydraulic performance of oozing pipe irrigation

The experiment was conducted in JAU Farm, Junagadh with an objective to study the discharge variation and wetting pattern for different lengths of oozing pipe at different operating pressures. Lengths of the pipes were 30 cm, 45 cm and 60 cm with operating pressures of 1 m, 2 m, 4 m and 6 m, respectively. Soil of the research plot was calcareous medium black soil having textural class as clay. Hydraulic head and emitting rate per metre length of oozing pipe were measured using digital manometer and 16 mm watermeter (0.1 Litre LC) fitted at different distances from the inlet with sub-main line at an interval of 5 m. Cross-sections of wetted bulb were measured at initial, middle and end of the oozing pipe length for different treatment combinations. The oozing pipe (22 mm OD, 16 mm ID) when subjected to input pressure heads of 2 m or more, performed poorly in terms of uniformity of emission rate due to wide variation in pressure head along the line source of irrigation. The average deviation from the average emitting rate was calculated by averaging the absolute values of the differences between each of the segments' oozing rates and the average oozing rate. The determined coefficient of variation (CV) and coefficient of uniformity (CU) are presented in Table 2.5.1.

PEY- Pigeonpea equivalent yield

Table 2.5.1. Performance measures of oozing pipe

Lateral length	Hydraulic parameter	Performance parameter	Input pressure head (m)			
			1	2	4	6
30	Pressure head (m)	Mean	31.46	74.29	129.71	163.57
		SD	36.88	51.65	123.03	173.81
		CV	1.17	0.70	0.95	1.06
		Mean deviation	24.69	34.67	75.79	102.04
		CU	-0.26	0.30	0.12	0.07
	Oozing rate (lph m^{-1})	Mean	2.37	3.13	6.53	8.06
		SD	1.86	2.44	6.99	9.69
		CV	0.78	0.78	1.07	1.20
		Mean deviation	1.42	1.83	5.10	6.99
		CU	0.40	0.42	0.22	0.13
45	Pressure head (m)	Mean	25.31	65.67	109.00	127.22
		SD	35.64	52.31	121.81	150.34
		CV	1.41	0.80	1.12	1.18
		Mean deviation	27.57	36.89	89.33	108.52
		CU	-0.09	0.44	0.18	0.15
	Oozing rate (lph m^{-1})	Mean	1.99	2.81	5.67	6.69
		SD	1.93	2.60	6.43	7.98
		CV	0.97	0.92	1.13	1.19
		Mean deviation	1.31	1.81	4.74	5.81
		CU	0.34	0.35	0.16	0.13
60	Pressure head (m)	Mean	19.61	49.33	86.42	109.58
		SD	33.24	50.05	108.47	143.03
		CV	1.69	1.01	1.26	1.31
		Mean deviation	24.69	34.67	75.79	102.04
		CU	-0.26	0.30	0.12	0.07
	Oozing rate (lph m^{-1})	Mean	1.53	2.06	4.10	5.12
		SD	1.84	2.49	5.87	7.35
		CV	1.20	1.21	1.43	1.44
		Mean deviation	1.21	1.70	4.02	5.27
		CU	0.21	0.18	0.02	-0.03

SD-Standard deviation, CV-Coefficient of variation, CU-Coefficient of uniformity

Length of the porous pipe, pressure head inputs and their interaction effects on oozing rate as well as coefficient of uniformity (CU) were found significant. The best combination was the 30 m length and 200 cm pressure head having highest CU of 0.4734 which is at par with CU of 0.4106 in 45 m long pipe with 200 cm pressure head and CU of 0.4603 in 45 m long pipe with 100 cm pressure head. Coefficient of uniformity increased with increase in pressure head up to 200 cm and then decreased with increase in pressure head input from 200 cm to 600 cm. In fact, highest CU of 0.4734 was not an acceptable performance for the irrigation system. Variation in the wetting front increased with increase in head because it directly influenced the oozing rate. In case of input pressure heads of 100 cm and 200 cm, the variation in wetting front is slightly lower. The wetted bulbs were found just similar at the center of the all 3 porous pipes irrespective of pressure head inputs. The variation in wetting front increased with increase in head from 100 cm to 600 cm which may be directly influenced by variation in oozing rate. The variation in wetting front was somewhat lower for 100 cm and 200 cm head, whereas the wetting bulb at the middle end was found more or less similar. The size of the wetted bulb around the oozing pipe during the first hour increased at higher rate compared to that during second and third hours. Size of the wetted bulb was not uniform along the length of the porous pipe because of non-uniform oozing rates.

The porous pipe irrigation is not technically adoptable because it did not conform with the technical criteria of maximum allowable variation in oozing rate/hydraulic head and desirable coefficient of variation. Irrigation water application through porous pipe system gave very poor coefficient of uniformity (6.65% in case of 60 m lateral length with 100 cm input head to 47% in case of 30 m lateral length with 200 cm input head) which should be more than 90%. Uniformity in the wetting bulb size along the length of lateral also varies greatly. Therefore, it was concluded that the porous pipe system is not suitable for adoption as a water application system.

2.6. Raipur

2.6.1. Development and setting up of low cost RF based sensor system for automated drip irrigation system

Modification in the design of the sensor based drip irrigation system was made with compatibility for low cost readily available sensors and provision for display of moisture level through LED display. The low cost sensor based irrigation system was successfully demonstrated with cabbage crop during *rabi* season. The sensor based irrigation controlling system was refined for automated management of irrigation based on available soil moisture content. Fabrication of different parts like processor/controller comprised of programmable logical unit (PLC), internal circuit and wired sensor was completed. The controller works on the principle of close loop control where the sensor which measures soil moisture level and gives output in terms of 4-20 mA signal to input unit of controller, 4 mA signals means substantial moisture and 20 mA signals indicates the deficit moisture level.

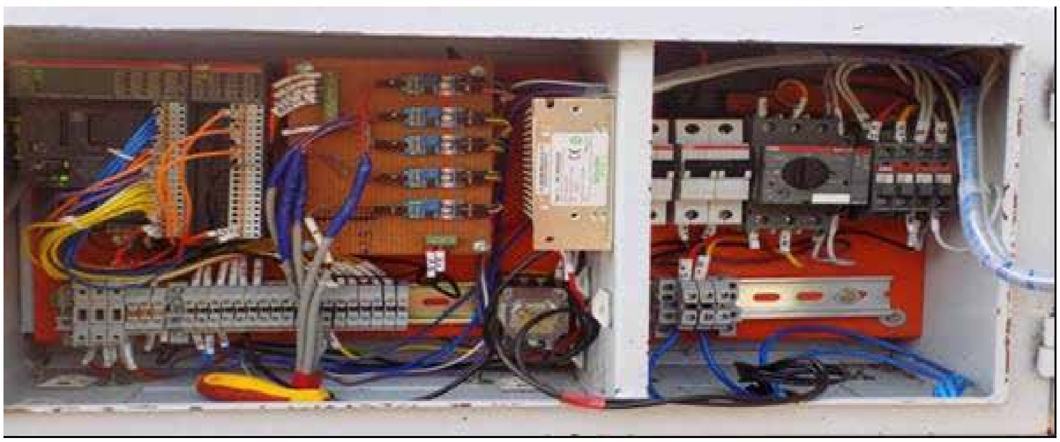

Fig. 2.6.1. Control box with PLC of sensor based irrigation system

The evaluation of the automated sensor based drip irrigation system was done in a cabbage field. A cabbage yield of 27 t ha^{-1} was obtained in sensor based treatment in comparison to 25 t ha^{-1} in the control treatment. Water use efficiency of 73.4 kg ha-mm^{-1} was obtained in sensor based treatment in comparison to 57.13 kg ha-mm^{-1}. There was 15.85% water saving in sensor based irrigation system.

2.7. Kota

2.7.1. Studies on irrigation schedule, land configuration and bioregulator foliar spray on productivity of clusterbean-chickpea cropping sequence

Pooled results of three years (2016-2018) of experiment revealed that application of one irrigation at pod development stage recorded significantly higher clusterbean seed yield (1.57 kg ha^{-1}), water use efficiency (2.53 kg ha-mm^{-1}), water productivity (0.25 kg m^{-3}), net return (₹ 62149 ha^{-1}) and B:C ratio (3.61) compared to rainfed and unirrigated condition at flowering stage (Table 2.7.1). Land configuration with broad bed furrow (3 rows) recorded significantly higher clusterbean seed yield (1.42 kg ha^{-1}), water use efficiency (2.39 kg ha-mm^{-1}), net return (₹ 53166 ha^{-1}) and B:C ratio (3.11) compared to flat bed method. Sowing of three rows of clusterbean on broad bed furrow gave higher water productivity (0.24 kg m^{-3}) over flat bed method. Foliar application of thiosalicylic acid @ 100 ppm resulted in significantly higher clusterbean seed yield (1.42 kg ha^{-1}), water use efficiency (2.43 kg ha-mm^{-1}), water productivity (0.24 kg m^{-3}), net return (₹ 54173 ha^{-1}) and B:C ratio (3.12) over control.

Table 2.7.1. Effect of irrigation scheduling, land configuration and bioregulator spray on performance of clusterbean in clusterbean-chickpea cropping sequence

Treatment	Seed yield (t ha^{-1})	WUE (kg ha-mm^{-1})	WP (kg m^{-3})	Net return (₹ ha^{-1})	B:C ratio
Irrigation schedule					
One irrigation at flowering stage	1.17	2.09	0.210	42416	2.52
Two irrigation at flowering + Pod development stage	1.57	2.53	0.253	62149	3.61
Rainfed	1.17	2.08	0.208	41969	2.49
CD (P=0.05)	0.06	0.10	-	3011	0.18
Land configuration					
Broad Bed Furrow (3 rows)	1.42	2.39	0.239	53166	3.11
Broad Bed Furrow (4 rows)	1.34	2.29	0.230	50453	2.95
Flat bed	1.18	2.03	0.203	42915	2.55
CD (P=0.05)	0.05	0.09	-	2587	0.13
Bioregulator spray					
Thiosalicylic acid (100 ppm)	1.42	2.43	0.243	54173	3.12
Control	1.19	2.04	0.204	43515	2.62
CD (P=0.05)	0.12	0.16	-	5861	0.35

2.7.2. Effect of irrigation schedule and land configuration on the productivity of Colocacia

Two years of experiment revealed that irrigation schedule at IW/CPE 1.0 produced significantly higher tuber yield (19.45 t ha^{-1}), with maximum water use efficiency (20.9 kg ha-mm^{-1}) and water productivity (2.12 kg m^{-3}) over flat bed planting, but at par with IW/CPE 0.8 (Table 2.7.2). Among land configurations, colocacia planting on broad bed furrow method (2 rows) recorded significantly higher tuber yield (18.37 t ha^{-1}) and water use efficiency (19.90 kg ha-mm^{-1}), water productivity (2.04 kg m^{-3}) over flat bed planting, but at par with ridge and furrow method (tuber yield 17.88 t ha^{-1}, water use efficiency 19.40 kg ha-mm^{-1} and water productivity 1.98 kg m^{-3}).

Table 2.7.2. Effect of irrigation scheduling and land configuration on performance of Colocacia crop

Treatment	Tuber yield ($t\ ha^{-1}$)			WUE ($kg\ ha\text{-}mm^{-1}$)			Water productivity ($kg\ m^{-3}$)		
	2017	2018	Pooled	2017	2018	Pooled	2017	2018	Mean
Irrigation schedule									
IW/CPE 0.6	12.38	13.63	13.01	15.9	13.1	14.5	1.589	1.439	1.51
IW/CPE 0.8	17.65	18.38	18.02	21.0	17.5	19.3	2.104	1.825	1.97
IW/CPE 1.0	19.12	19.77	19.45	22.8	19.0	20.9	2.279	1.963	2.12
CD (P=0.05)	1.68	1.36	1.20	2.03	1.68	1.45	-	-	-
Land configuration									
Flat planting	13.86	14.56	14.21	16.8	14.0	15.4	1.682	1.470	1.58
Ridge and furrow	17.43	18.33	17.88	21.2	17.6	19.4	2.117	1.851	1.98
Broad bed furrow (2 rows)	17.87	18.87	18.37	21.7	18.0	19.9	2.172	1.906	2.04
CD (P=0.05)	0.80	0.80	0.66	0.96	0.80	0.77	-	-	-

2.7.3. Performance evaluation of sprinkler irrigation, fertility levels and bio-regulator on the productivity of *zaid* greengram grown after mustard

Three years of experiment with *zaid* greengram showed significantly higher pod yield (0.93 t ha^{-1}), net return (₹ 37409 ha^{-1} and B:C ratio (1.89) with irrigation at IW/CPE 1.2 over other irrigation schedules (Table 2.7.3). While, maximum water use efficiency (2.04 kg ha-mm^{-1}) and water productivity (0.204 kg m^{-3}) were recorded under irrigation at IW/CPE 1.0 compared to IW/CPE 0.8. Significantly higher *zaid* greengram pod yield (0.83 t ha^{-1}), water use efficiency (2.06 kg ha-mm^{-1}), net return (₹ 31272 ha^{-1}) an B:C ratio (1.59) were recorded with the application of 125% RDF + foliar spray of thiosalicylic acid @ 100 ppm while at par with application of 150% RDF + foliar spray of thiosalicylic acid @ 100 ppm over 100% RDF. Whereas, maximum water productivity (0.210 kg m^{-3}) was recorded with application of 150% RDF + foliar spray of thiosalicylic acid 100 ppm closely followed by application of 125% RDF + foliar spray of thiosalicylic acid @ 100 ppm (0.206 kg m^{-3}) as compared to 100% RDF.

Table 2.7.3. Effect of irrigation schedules, fertility levels and bioregulator foliar spray on performance of *zaid* greengram

Treatment	Grain yield ($t\ ha^{-1}$)				WUE ($kg\ ha\text{-}mm^{-1}$)				Net return (₹ ha^{-1})				B:C ratio			
	2016	2017	2018	Pooled	2016	2017	2018	Pooled	2016	2017	2018	Pooled	2016	2017	2018	Pooled
Irrigation schedule																
IW/CPE 0.8	0.61	0.63	0.65	0.63	1.78	1.85	1.92	1.85	18848	20206	21593	20216	1.01	1.08	1.15	1.08
IW/CPE 1.0	0.79	0.82	0.84	0.82	1.98	2.04	2.10	2.04	29497	30967	32347	30937	1.54	1.61	1.68	1.61
IW/CPE 1.2	0.91	0.93	0.96	0.93	1.97	2.03	2.08	2.03	35919	37464	38844	37409	1.82	1.90	1.97	1.89
CD (P=0.05)	0.06	0.06	0.65	0.05	0.13	0.16	0.18	0.11	3574	3443	3960	2764	0.18	0.18	0.21	0.14
Foliar fertilization																
100% RDF	0.70	0.72	0.74	0.72	1.73	1.79	1.85	1.79	24791	26261	27641	26231	1.37	1.45	1.53	1.45
100% RDF + foliar spray of thiosalicylic acid 100 ppm	0.76	0.78	0.80	0.78	1.89	1.95	2.00	1.95	27618	29038	30418	29025	1.45	1.52	1.60	1.52
125% RDF + foliar spray of thiosalicylic acid 100 ppm	0.80	0.83	0.85	0.83	2.00	2.06	2.12	2.06	29832	31302	32682	31272	1.52	1.59	1.66	1.59
150% RDF + foliar spray of thiosalicylic acid 100 ppm	0.82	0.84	0.87	0.84	2.04	2.10	2.16	2.10	30111	31581	32971	31554	1.48	1.56	1.63	1.56
CD (P=0.05)	0.04	0.05	0.05	0.04	0.10	0.13	0.13	0.10	2456	2988	3168	2447	NS	0.16	0.13	0.11

2.7.4. Performance of sprinkler irrigation and moisture stress management practices in wheat grown under zero tillage

Results revealed that sprinkler irrigation in wheat at 0.8 IW/CPE gave significantly higher grain yield (4.58 t ha^{-1}), net return (₹ 61912 ha^{-1}) and B:C ratio (2.76) as compared to IW/CPE 0.4 and 0.6, respectively (Table 2.7.4). While, maximum and significantly higher water use efficiency (28.5 kg ha-mm^{-1}) and water productivity (2.85 kg m^{-3}) was recorded under IW/CPE 0.4 over rest of the irrigation schedules. Seed hardening with $CaCl_2$ (2.0%) and foliar spray of KCl (0.2%) at booting stage recorded maximum and significantly higher grain yield (4.31 t ha^{-1}), water use efficiency (25.2 kg ha-mm^{-1}), net return (₹ 57562 ha^{-1}) and B: C ratio (2.64) as compared to seed hardening with $CaCl_2$ (2.0 %) and its foliar spray (0.1%) at booting stage and KCl (0.2%) foliar spray at booting stage. Similarly, maximum water productivity (2.52 kg m^{-3}) was recorded under seed hardening with $CaCl_2$ (2.0%) and foliar spray of KCl (0.2%) at booting stage followed by seed hardening with $CaCl_2$ (2.0%) and its foliar spray (0.1%) at booting stage (2.30 kg m^{-3}) in comparison to KCl (0.2%) foliar spray at booting stage.

Table 2.7.4. Effect of irrigation schedules and stress management practices on performance of wheat

Treatment	Grain yield (t ha^{-1})			WUE (kg ha-mm^{-1})			Water productivity (kg m^{-3})			Net return (₹ ha^{-1})			B:C ratio
	2016-17	2017-18	Pooled	2016-17	2017-18	Pooled	2016-17	2017-18	Pooled	2016-17	2017-18	Pooled	Pooled
Irrigation schedule													
IW/CPE 0.4	3.34	3.49	3.42	27.8	29.1	28.5	2.78	2.91	2.85	40653	43392	42023	2.02
IW/CPE 0.6	3.82	4.05	3.93	21.2	22.5	21.9	2.12	2.25	2.19	48584	52848	50176	2.34
IW/CPE 0.8	4.42	4.75	4.58	18.4	19.8	19.1	1.84	1.98	1.91	58864	64959	61912	2.76
CD (P=0.05)	0.19	0.22	0.16	1.43	1.68	1.23	-	-	-	3522	4029	2991	0.14
Stress management practice													
Seed hardening with $CaCl_2$ (2.0%) and its foliar spray (0.1%) at booting stage	3.88	4.12	4.00	22.4	23.6	23.0	2.24	2.36	2.30	49617	53944	51781	2.36
Seed hardening with $CaCl_2$ (2.0%) and KCl (0.2%) foliar spray at booting stage	4.16	4.46	4.31	24.4	26.0	25.2	2.44	2.60	2.52	54808	60315	57562	2.64
KCl (0.2%) foliar spray at booting stage	3.53	3.71	3.62	20.7	21.7	21.2	2.07	2.17	2.12	43677	46941	45309	2.13
CD (P=0.05)	0.15	0.18	0.14	1.12	1.32	1.05	-	-	-	2834	3290	2632	0.11

Chapter 3 Fertigation

3.1. Chalakudy

3.1.1. Water conservation and soil amelioration properties of biochar under fertigation

The experiment was conducted for two years (2015-16 to 2017-18) with treatments *viz.*, drip irrigation frequency (daily, once in two day and once in three days) and soil amendments (Biochar @ 2 t ha^{-1}, Biochar @ 4 t ha^{-1} and Lime based on soil test data) to brinjal var. Haritha. Pooled analysis of data showed significantly higher yield (4.04 t ha^{-1}) of brinjal with drip irrigation given daily but it was at par (3.80 t ha^{-1}) with irrigation given once in two days (Table 3.1.1). Application of biochar could significantly improve yield of brinjal and the ratoon crop when compared to application of lime. Residual crop yield of cowpea was significantly higher with the application of biochar @ 4 t ha^{-1}. Interaction effects of irrigation frequency and soil amendment were found non-significant. It was be concluded that application of drip irrigation once in two days along with application of biochar @ 2 t ha^{-1} is the optimum treatment which significantly increased crop yield, enhanced water productivity, nutrient use efficiency (NUE), net return and B:C ratio (Table 3.1.1). The result also obtained envisaged the water holding capacity and nutrient retention capacity of biochar. Application of biochar @ 2 t ha^{-1} as a soil amendment resulted in increase of brinjal yield by 12% and yield of its ratoon crop by 25% when compared to application of lime. Yield of the residual cowpea crop got improved by 12% with application of biochar @ 4 t ha^{-1} against lime application. Increase in yield of the ratoon crop of brinjal and residual crop of cowpea without application of nutrients revealed the long-term effect of biochar in holding nutrients in soil even after harvest of main crop of brinjal.

Table 3.1.1. Effect of irrigation frequency and soil amendments on the plant spread and number of branches of brinjal (pooled analysis)

Treatment	Plant spread			Brinjal yield (t ha^{-1})	Yield of brinjal ratoon crop	Yield of residual cowpea	WP (kg m^{-3})	NUE (unit)	Net return (₹ ha^{-1})	B:C ratio
	Vegetative	Flowering	Fruiting							
Irrigation frequency - 3 numbers										
I_1 : Drip irrigation - Daily	20.70	38.87	59.46	4.04	9.98	1.34	0.76	46.05	74757	2.09
I_2 : Drip irrigation - Once in 2 days	22.42	41.99	55.56	3.80	10.71	1.55	2.15	37.52	48658	1.71
I_3 : Drip irrigation - Once in 3 days	21.43	37.08	61.41	3.21	9.44	1.25	2.19	26.24	18766	1.29
CD (5%)	NS	2.82	NS	0.37	NS	0.11	0.25	4.79	14902	0.22
Soil amendment - 3 numbers										
A_1 : Biochar - 2 t ha^{-1}	21.59	38.83	61.02	3.95	10.80	1.32	1.99	41.88	64073	1.95
A_2 : Biochar - 4 t ha^{-1}	21.98	40.66	59.72	3.63	10.73	1.50	1.49	32.41	32586	1.47
A_3 : Lime-based on soil test	20.98	38.47	55.68	3.50	8.59	1.31	1.61	35.53	45521	1.68
CD (5%)	NS	NS	NS	0.37	1.62	0.11	0.25	4.79	14902	0.22
Interaction effect										
I_1 x A_1	-	-	-	-	-	-	0.80	48.40	82528	2.21
I_1 x A_2	-	-	-	-	-	-	0.71	43.40	64659	1.91
I_1 x A_3	-	-	-	-	-	-	0.76	46.36	77083	2.14
I_2 x A_1	-	-	-	-	-	-	2.77	48.52	83373	2.23
I_2 x A_2	-	-	-	-	-	-	1.61	28.11	17504	1.25
I_2 x A_3	-	-	-	-	-	-	2.06	35.94	45096	1.67
I_3 x A_1	-	-	-	-	-	-	2.39	28.73	26318	1.41
I_3 x A_2	-	-	-	-	-	-	2.14	25.71	15594	1.24
I_3 x A_3	-	-	-	-	-	-	2.02	24.29	14385	1.23
CD (5%)	-	-	-	-	-	-	0.44	8.30	25811	0.38

WP-Water Productivity, NUE-Nitrogen Use Efficiency

Plate 3.1.1. Biochar application in field and Residual cowpea crop

3.2. Parbhani

3.2.1. Precision irrigation and fertigation management in cabbage

The experiment was conducted for two consecutive years (2016 to 2018) with summer okra var. Improved Bahar. Results showed that application of irrigation through drip at 1.0 ETc recorded significantly higher cabbage yield (41.28 t ha^{-1}) over rest of the irrigation treatments, however, it at par with irrigation at 0.8 ETc during both the years of experiment (Table 3.2.1). Application of 125% RDF through drip (F_3) recorded significantly higher yield (36.47 t ha^{-1}) of cabbage, however it was comparable with 100% RDF through drip. Treatment combination of irrigation at 1.0 ETc and 125% RDF (I_4F_3) recorded significantly higher cabbage yield over rest of the irrigation treatments, however it was comparable with treatment combination of irrigation at 1.0 ETc and 100% RDF (I_4F_2) and 0.8 ETc and 100% RDF (I_3F_2) during both the years of experimentation. Significantly higher gross monetary return (GMR) and net monetary return (NMR) values were obtained in irrigation scheduled at 1.0 ETc as compared to rest of the irrigation levels during both the years of study. Significantly higher GMR was recorded in fertigation treatment 125% RDF during both the years of experimentation however it was comparable with 100% RDF during first year of experimentation. Significantly higher NMR was observed in fertigation treatment 100% RDF and was at par with 125% RDF during both the years of experimentation. Treatment combination of irrigation at 1.0 ETc and 125% RDF (I_4F_3) recorded significantly higher GMR value, however it was comparable with treatment combination of irrigation at 1.0 ETc and 100% RDF (I_4F_2) and 0.8 ETc and 100% RDF (I_3F_2). Treatment combination of irrigation at 1.0 ETc and 100% RDF (I_4F_2) recorded higher NMR, however it was at par with irrigation at 1.0 ETc and 125% RDF (I_4F_3) and irrigation at 0.8 ETc and 100% RDF (I_3F_2). The higher B:C ratio was observed in treatment irrigation at 1.0 ETc followed by treatment irrigation at 0.8 ETc. Among fertigation levels higher B:C ratio was recorded in fertigation level of 100% RDF and lower B:C ratio was noticed with 125% RDF. Higher water use efficiency was noticed in drip irrigation at 0.4 ETc followed by 0.6 ETc and 0.8 ETc while in fertigation treatment, higher water use efficiency was observed in 125% RDF followed by 100% RDF during both the years of experimentation.

3.3. Faizabad

3.3.1. Effect of drip irrigation with surface irrigation system on yield of rajmash beans

The experiment was conducted during 2016-2019 to select a suitable moisture and nutrient regime for rajmash crop (var. HUR-137) which gets adversely affected by flood irrigation. Surface irrigation treatments i.e. 5 cm irrigation at 0.8 IW/CPE ratio with 100% N and 75% N were were studied along with drip irrigation treatments at 80%, 60% PE and 40% PE with 100% and 75% N (Table 3.3.1). Results showed that drip irrigation at 60% PE with 100%N (I_5) recorded the significantly higher yield of beans 13.12 t ha^{-1}, maximum benefit of ₹ 212855 ha^{-1} with B-C ratio of 4.30 which were 40.1% and 52.7% higher yield and WUE, respectively compared to surface irrigation (5 cm at 0.8 IW/CPE with 100% N. Drip irrigation at 60% PE with 75%N also showed 62.7% and 47.2% higher yield and WUE, repsectivly compared to surface irrigation (5 cm at 0.8 IW/CPE) with 75% N. Nitrogen doses i.e. 100% recommended dose of nitrogen (RDN) and 75% RDN did not have significant effect on rajmash bean yield under drip irrigation. Thus, it was concluded that 60% with 100% RDN was most remunerative in terms of yield and net return.

Table 3.3.1. Performance of rajmash crop under surface irrigation (5 cm at 0.8 IW/CPE) and drip irrigation

Treatment	Pooled yield (t ha^{-1})	WUE (kg ha-mm^{-1})	Net benefit (₹ ha^{-1})	B:C
I_1- Surface irrigation with 100% N	9.11	21.48	139438	3.27
I_2- Surface irrigation with 75% N	7.81	18.39	114045	2.70
I_3- Drip irrigation @ 80% PE with 100% N	12.59	59.89	202025	4.07
I_4- Drip irrigation @ 80% PE with 75% N	12.01	59.69	192138	3.91
I_5- Drip irrigation @ 60% PE with 100% N	13.12	85.13	212855	4.30
I_6- Drip irrigation @ 60% PE with 75% N	12.71	81.13	205268	4.19

I_7- Drip irrigation @ 40% PE with 100% N	10.09	99.48	151682	3.08
I_8- Drip irrigation @ 40% PE with 75% N	9.53	91.90	141982	2.92
CD at 5%	12.49	-	139438	3.27

Table 3.2.1. Performance of cabbage as influenced by different irrigation and fertigation levels

Treatment	Yield (t ha^{-1})		Water use (mm)		WUE (kg ha-mm^{-1})		NR (₹ ha^{-1})		B:C ratio	
	2016-17	2017-18	2016-17	2017-18	2016-17	2017-18	2016-17	2017-18	2016-17	2017-18
Irrigation level (I)										
I_1 – Irrigation at 0.4 ETc	27.90	23.69	99.34	96.27	280.89	246.03	104080	72272	1.87	1.62
I_2 – Irrigation at 0.6 ETc	34.68	29.62	149.01	144.40	232.74	205.12	155150	117010	2.27	1.98
I_3 – Irrigation at 0.8 ETc	42.64	37.15	198.69	192.54	214.59	192.94	215130	173750	2.71	2.41
I_4 – Irrigation at 1.0 ETc	43.88	38.67	248.36	240.67	176.67	160.66	224500	185200	2.78	2.49
I_5 – Irrigation at 1.2 ETc	38.81	33.38	298.03	288.81	130.24	115.56	186320	145310	2.50	2.20
CD at 5%	1.42	1.86	-	-	-	-	5476	9526	-	-
Fertigation level (F)										
F_1 – 75% RDF through drip	35.11	30.32	198.69	192.54	176.70	157.45	165520	129380	2.43	2.14
F_2 – 100% RDF through drip	38.50	33.19	198.69	192.54	193.78	172.40	184470	144460	2.49	2.18
F_3 – 125% RDF through drip	39.14	33.99	198.69	192.54	196.98	176.51	181120	142300	2.37	2.09
CD at 5%	0.91	1.08	-	-	-	-	4767	5887	-	-
Interaction effect (IxF)										
I_1 x F_1	26.00	21.96	207970	66367	-	-	-	-	-	-
I_1 x F_2	28.34	24.07	226690	75698	-	-	-	-	-	-
I_1 x F_3	29.38	25.03	235040	74752	-	-	-	-	-	-
I_2 x F_1	31.44	28.55	251550	116040	-	-	-	-	-	-
I_2 x F_2	36.29	29.36	290350	115580	-	-	-	-	-	-
I_2 x F_3	36.30	30.95	290430	119400	-	-	-	-	-	-
I_3 x F_1	39.58	33.75	316640	155240	-	-	-	-	-	-
I_3 x F_2	44.51	39.54	356110	192270	-	-	-	-	-	-
I_3 x F_3	43.82	38.16	350530	173750	-	-	-	-	-	-
I_4 x F_1	41.12	35.39	328960	167610	-	-	-	-	-	-
I_4 x F_2	44.86	39.85	358910	194630	-	-	-	-	-	-
I_4 x F_3	45.65	40.76	365230	193380	-	-	-	-	-	-
I_5 x F_1	37.41	31.94	299250	141620	-	-	-	-	-	-
I_5 x F_2	38.50	33.15	308030	144120	-	-	-	-	-	-

I_5 x F_3	40.53	35.03	324270	150190	-	-	-	-	-	-
CD at 5%	1.34	1.53	10658	1316	-	-	-	-	-	-

3.4. Navsari

3.4.1. Effect of precise application of planting material, irrigation and fertilizer through drip on productivity of sugarcane

The experiment was conducted from 2015-16 to 2017-18 in split plot design with drip irrigation and fertigation in the main plot and planting material in the subplot. Control involved recommended practices i.e. 100% RDF + Irrigation at 1.0 IW/CPE, 60 mm depth + 3 eye-budded sets. Paired row planning was done for all treatments. Results showed that sub surface placement of drip laterals was found beneficial in increasing plant height and cane length. Cane yield of plant, ratoon and cycle-1 sugarcane crop was significantly influenced due to individual effect of I and P during both the cycle as well as in pooled analysis. Frequency of fertigation (F) was found non significant on cane yield during both the cases as well as in pooled analysis. Subsurface placement of drip laterals consistently recorded higher cane yield during both crop cycles as well as in pooled results over surface placement in plant crops. In case of planting methods (P), two eye budded set (P_1) planted treatment recorded significantly higher cane yield over remaining planting methods (P_1 and P_3) during both the cycles as well as in pooled basis. Interaction effect of I x P, during both the year of experiment as well as in pooled results turned out to be significant on cane yield, the combination of sub surface placement of drip laterals with two eye budded set planting method (I_2P_1) recorded significantly higher cane yield than remaining combinations of I x P. The cane yield recorded in I_2P_1 treatment combinations were 215, 185 and 176 t ha^{-1} during first cycle, second cycle and in pooled results, respectively. Control v/s rest analysis of the data revealed that surface irrigated control treatment recorded significantly lower cane yield 126, 113 and 118 t ha^{-1} during first cycle, second cycle and in pooled, respectively than drip irrigated treatments mean of plant crop of sugarcane. During both the years of plant and ratoon crops sub surface placement of lateral recorded higher WUE than surface placement of laterals. Similarly, planting material P_1 (Two eye budded sets common practices) and P_3 (21 day old seedlings 45 cm intra row spacing) recorded higher WUE than P_2 (Single sprouted eye bud 45 cm intra row spacing). Among the combinations, I_2P_1 recorded higher values of WUE under plant and ratoon crops than other treatment combinations. Quality parameters of cane *viz.*, brix, sucrose content in juice, purity, C.C.S, fiber and sucrose content in cane of plant as well as ratoon crops were not affected conspicuously due to different treatments. Combination I_2P_1 (Sub surface placement of drip laterals and planting with two eye budded sets, recorded the highest net return of ₹ 601576 ha^{-1} from plant crop and ₹ 508429 ha^{-1} from ratoon crop of sugarcane. The lowest gross and net incomes of ₹ 406000 ha^{-1} and ₹ 355271 ha^{-1} were recorded, respectively from ratoon crop with surface control treatment (Table 3.4.1 & 3.4.2).

Thus sugarcane growing farmers of South Gujarat heavy rainfall zone are recommended to plant two-eye budded sugarcane sets in paired row (60:120 cm). Adopt subsurface inline drip lateral at 7.5 cm below ground level and apply 80% of recommended dose of fertilizer *i.e.* for Plant crop: 200+100+100 N, P_2O_5 and K_2O kg ha^{-1} and for ratoon crop: 240+50+100 N, P_2O_5 and K_2O kg ha^{-1}. The full dose of P_2O_5 and 10% N and K_2O apply as basal, remaining 90% N and K_2O through fertigation in 10 equal splits starting from one month after planting at 15 days interval for getting higher cane yield and net returns along with 20% saving in fertilizer.

Table 3.4.1. Effect of different treatment on cane yield (t ha^{-1})

Treatment[#]	Plant-1	Ratoon-1	Cycle-1	Plant-2	Ratoon-2	Cycle-2	Pooled of two cycles
Irrigation at 0.6 PEF							
I_1	177	131	154	162	116	139	146
I_2	193	149	171	171	147	159	165
CD at 5%	13	5	8	7	13	6	5

Fertigation at 80% RDN							
F_1	185	138	162	165	129	147	153
F_2	185	142	163	168	134	151	157
CD at 5%	NS	5	NS	NS	NS	NS	NS
CV%	10.89	5.25	7.21	6.27	14.75	6.25	6.79
P_1	199	145	172	175	140	158	165
P_2	170	129	150	158	118	138	143
P_3	187	145	166	167	137	152	158
CD at 5%	9	7	5	7	10	6	4
CV%	7.05	6.46	4.63	5.75	10.11	5.81	5.21
I x F							
CD at 5%	NS	NS	NS	NS	NS	NS	NS
F x P							
CD at 5%	NS	NS	NS	NS	NS	NS	NS
I x P							
CD at 5%	13	9	8	10	14	9	6
I x F x P							
CD at 5%	NS	NS	NS	NS	NS	NS	NS
Treatment mean	184	139	162	166	132	149	155
Control (C)	126	124	125	113	109	111	118
C vs. rest							
CD at 5%	16	9	9.15	10	15	9.03	8.76

[#]Irrigation- I_1: Drip irrigation with surface placement of lateral, I_2: Drip irrigation with sub surface placement of lateral (7.5 cm depth); Fertigation- F_1: 10 equal splits at 15 days interval, F_2: 20 equal splits at weekly interval; Planting- P_1: Two eye budded sets (common practices), P_2: Single sprouted eye bud (45 cm intra row spacing), P_3: 21 day old seedlings (45 cm intra row spacing); Control- Recommended practices (100% RDF + Irrigation at 1.0 IW/CPE, 60 mm depth + 3-eye budded sets); RDN-Recommended dose of Nitrogen

Table 3.4.2. Sugarcane crop economics of different treatments (Pooled of two cycles)

Treatment	Cost of cultivation (₹ ha^{-1})		Average cultivation cost of two cycle (₹ ha^{-1})	Average yield of two cycles (t ha^{-1})	Gross Income (₹ ha^{-1})	Net return (₹ ha^{-1})
	Plant	Ratoon				
I_1P_1	96538	63684	80111	148	531320	451209
I_1P_2	94538	63444	78991	139	499010	420019
I_1P_3	120538	66564	93551	150	538500	444949
I_2P_1	98424	65571	81998	182	653380	571383
I_2P_2	96424	65331	80878	147	527730	446853
I_2P_3	122424	68451	95438	166	595940	500503
Control	81749	50729	66239	118	423620	357381

Note:- I_1: Surface placement of drip laterals, I_2: Sub surface placement of drip laterals (7.5 cm bgl)
Sugarcane selling rate: ₹ 3590 t^{-1}, Planting material cost: P_1: Two eye budded sets: ₹ 28000 ha^{-1}, P_2: Sprouted single eye buds ₹ 26000 ha^{-1} (No. 2600), P_3: 21 day old seedlings ₹ 52000 ha^{-1}

3.5. Kota

3.5.1. Drip fertigation studies on water soluble fertilizers for enhancing water productivity and quality of garlic crop in south-eastern Rajasthan

Drip fertigation significantly influenced the yield, water use efficiency and quality of garlic crop in south-eastern Rajasthan (four years pooled data). During *Rabi*, garlic bulb yield obtained under drip method of irrigation was significantly superior as compared to control (surface irrigation). Table 3.5.1 shows significantly higher garlic bulb yield (15.46 t ha^{-1}) obtained with irrigation at 100% PE, that is 10.4% increase in yield over 75% PE (14.00 t ha^{-1}). Similarly, application of 100% recommended dose of fertilizers (120:40:100 kg ha^{-1}) recorded significantly higher bulb yield (15.71 t ha^{-1}) over 50% RDF. Whereas, interaction effect showed that maximum water use efficiency of 27.44 kg ha-mm^{-1} was recorded with irrigation at 75% PE and application of 100% RDF followed by 75% PE with 75% RDF (26.39 kg ha-mm^{-1}) as compared to 100% PE with 50% RDF (17.48 kg ha-mm^{-1}). The RDF (120:40:100 kg ha^{-1} NPK) was applied through water soluble fertilizers (urea, urea phosphate, potassium nitrate, potassium sulphate) through drip irrigation in 11 equal splits (Table 3.5.2). The total quantity of water soluble fertilizers were computed to be 207 kg urea, 70 kg urea phosphate, 20 kg potassium nitrate, 164 kg potassium sulphate and 50 kg NPK. Results also indicated that garlic crop requires higher quantity of fertilizers from planting to vegetative stage (284.5 kg) followed by reproductive to bulb enlargement (191.5 kg) and bulb maturity (35 kg).

Table 3.5.1. Effect of drip fertigation schedules and water soluble fertilizers on bulb yield of garlic crop

Treatment	Garlic bulb yield (t ha^{-1})				
	2015	2016	2017	2018	Pooled
Irrigation schedule					
100% PE	14.49	16.84	16.72	13.81	15.46
75% PE	13.33	15.48	13.70	13.50	14.00
CD (P=0.05)	1.15	1.35	1.75	1.47	1.24
Water soluble fertilizer					
100% RDF	15.06	17.21	16.67	13.89	16.31
75% RDF	14.26	16.78	15.19	13.79	15.41
50% RDF	12.41	14.39	13.77	13.28	13.52
CD (P=0.05)	1.46	2.14	2.14	1.80	1.66
Control					
Surface irrigation at 1.2 IW/CPE ratio + entire NPK (120:40:100) as soil application	12.67	14.50	13.35	11.95	13.12

Table 3.5.2. Effect of irrigation and fertilizer dose on water use efficiency of garlic

Treatment	Mean yield (t ha^{-1})	Depth of Irrigation (mm)	Water use efficiency (kg ha-mm^{-1})			
			100% RDF	75% RDF	50% RDF	Mean
Surface irrigation	13.12	820	-	-	-	16.00
75% PE	14.00	588	27.44	26.39	22.78	25.54
100% PE	15.46	770	20.40	19.49	17.48	19.12
Mean	-	-	23.92	22.94	20.13	-

3.5.2. Intensification of aonla orchard by turmeric production using nitrogen fertigation and different land configuration

Results of two years of experiment with turmeric crop var. Azad in aonla orchard showed that application of irrigation at 80% CPE with 100% nitrogen (N) to turmeric crop resulted in significantly higher tuber yield (18.3 t ha^{-1}), net return (₹ 2,86,345 ha^{-1}) and B:C ratio (3.73) over other treatments (Table 3.5.3). Whereas, maximum water use efficiency (2.27 kg ha-mm^{-1}) and water productivity (0.227 kg m^{-3}) were recorded with irrigation scheduling at 60% CPE and fertilization of 100% nitrogen. Planting of turmeric on broad bed furrow (2 rows) resulted in significantly higher tuber yield (16.9 t ha^{-1}), net return (₹ 2,67,850 ha^{-1}) and B:C ratio (3.86) as compared to ridge planting. Whereas, maximum water use efficiency

(2.25 kg ha-mm^{-1}) and water productivity (0.225 kg m^{-3}) were recorded with 4 rows on broad bed furrow followed by 2 rows (2.18 kg ha-mm^{-1} and 0.218 kg m^{-3}) compared to ridge planting.

Table 3.5.3. Effect of irrigation schedule and land configuration on performance of turmeric crop

Treatment	Turmeric yield (t ha^{-1})			WUE (kg ha-mm^{-1})			Net return (₹ ha^{-1})			B:C ratio		
	2016-17	2017-18	Pooled	2016-17	2017-18	Pooled	2016-17	2017-18	Pooled	2016-17	2017-18	Pooled
Irrigation schedule												
Drip irrigation at 80% CPE with 100% N	17.6	18.9	18.3	2.07	2.16	2.12	272789	299900	286345	3.55	3.90	3.73
Drip irrigation at 80% CPE with 75% N	16.5	17.8	17.2	1.95	2.03	1.98	250744	277633	264189	3.29	3.64	3.47
Drip irrigation at 60% CPE with 100% N	15.0	16.3	15.7	2.21	2.33	2.27	221456	248122	234789	2.87	3.22	3.05
Drip irrigation at 60% CPE with 75% N	14.4	15.7	15.1	2.11	2.25	2.18	209189	235856	222523	2.74	3.09	2.92
CD (P=0.05)	0.73	0.88	0.65	0.11	0.111	0.09	14569	17530	13001	0.18	0.22	0.15
Land configuration												
Broad bed furrow (2 row)	16.1	17.6	16.9	2.12	2.24	2.18	252767	282933	267850	3.64	4.08	3.86
Broad bed furrow (4 row)	16.8	18.0	17.4	2.21	2.30	2.25	238767	263767	251267	2.46	2.72	2.59
Ridge planting (2 row)	14.7	15.9	15.3	1.92	2.03	1.98	224100	249433	236767	3.23	3.59	3.41
CD (P=0.05)	0.99	1.13	0.88	0.13	0.13	0.10	19809	22637	16039	0.24	0.27	0.19

3.6. Palampur

3.6.1. Effect of drip irrigation and fertigation levels on yield and quality of strawberry under protected condition

The experiment was conducted during *Rabi* 2015-16 to 2017-18 for strawberry crop under protected condition. In fertigation treatments, 25% N and K along with 100% P was applied as basal and 75% N and K was applied through fertigation through urea and water soluble fertilizer 0:0:50. Results showed significant increase in marketable yield of strawberry, water use efficiency and B:C ratio with increase from 50%, 75% to 100% NK levels. The conventional fertilizers application methods (control) had significantly higher marketable yields, WUE and B:C ratio compared to drip fertigation (Table 3.6.1). Average results of three years also showed increase in yield with interaction effect of drip irrigation and fertigation levels (Table 3.6.2). However, 0.8 and 1.0 PE and 75% and 100% NK were statistically at par, indicating saving of irrigation water and fertilizer by 20% in general in all study years and mean value also. It was concluded that under protected conditions, drip irrigated strawberry crop should be irrigated with 0.8 PE and fertigated with 75-100% of recommended dose of NK.

Table 3.6.1. Performance of strawberry crop at different drip fertigation levels

Treatment	Marketable yield ($t\ ha^{-1}$)				Water use efficiency ($kg\ ha\text{-}mm^{-1}$)				B:C ratio			
	2015-16	2016-17	2017-18	Mean	2015-16	2016-17	2017-18	Mean	2015-16	2016-17	2017-18	Mean
0.6 PE	3.29	2.75	2.95	3.02	9.20	7.30	8.20	8.20	3.5	3.2	3.2	3.3
0.8 PE	3.21	2.93	3.12	3.09	6.70	6.00	6.50	6.40	3.4	3.1	3.3	3.3
1.0 PE	3.24	3.03	3.20	3.16	5.50	5.10	5.30	5.30	3.4	3.2	3.5	3.4
CD (P=0.5)	NS	0.16	0.13	0.14	0.52	0.50	0.40	0.50	-	-	-	-
50% RDF	2.46	2.28	2.36	2.37	5.40	4.70	4.90	5.00	2.4	2.6	2.6	2.5
75% RDF	3.46	3.16	3.12	3.24	7.70	6.50	6.50	6.90	4.1	3.7	3.6	3.8
100 % RDF	3.82	3.27	3.52	3.54	8.40	6.80	7.40	7.50	4.2	3.6	3.5	3.8
CD (P=0.5)	0.14	0.16	0.13	0.14	0.40	0.50	0.40	0.40	-	-	-	-
Control	3.73	3.55	3.67	3.65	5.80	6.00	5.70	5.80	4.2	4.1	4.0	4.1
Others	3.24	2.90	3.01	3.05	7.10	6.20	6.00	6.40	4.0	4.0	3.9	4.0
CD (P=0.5)	0.21	0.23	0.28	0.24	0.40	0.60	0.40	0.50	-	-	-	-

RDF-Recommended dose of fertilizer

Table 3.6.2. Effect of interaction effect of depth of irrigation and NK fertigation levels on marketable yield ($t\ ha^{-1}$) of strawberry

NK fertigation level	2015-16			2016-17			2017-18			Mean		
	0.6 PE	0.8 PE	1.0 PE	0.6 PE	0.8 PE	1.0 PE	0.6 PE	0.8 PE	1.0 PE	0.6 PE	0.8 PE	1.0 PE
50% RDF	2.39	2.54	2.43	2.12	2.32	2.41	2.18	2.42	2.36	2.45	2.36	2.29
75% RDF	3.71	3.12	3.52	3.02	3.17	3.27	2.86	3.01	3.14	3.45	3.22	3.24
100% RDF	3.75	3.94	3.75	3.10	3.28	3.42	2.96	3.12	3.27	3.82	3.60	3.38
CD (P=0.5)	0.29			0.22			0.25			0.25		

NK- Nitrogen & Potassium; RDF-Recommended dose of fertilizer

Chapter 4

Groundwater Management

4.1. Junagadh

4.1.1. Development of on-line screen-gravel filter for groundwater recharge

Existing design criteria of traditional filter were taken into account to work out specifications of online screen-gravel filter for groundwater recharge. In online screen-gravel filter, base materials were avoided by providing support of metallic screens to the filter layer of fine sand. The filter was tested for three layers of sand i.e. 10 cm, 15 cm and 20 cm. Experiment was made dividing into two parts, (1) testing platform and (2) online system. Masonry testing platform was constructed that included sump tank of dimension 2.5 m × 1 m × 1.25 m, collecting tank-1 of dimension 1.75 m × 1 m × 1.25 m, collecting tank-2 of dimension 0.5 m × 1 m × 1.25 m, screen-gravel filter holding platform of dimension 2.25 m × 2.25 m and filtered water guiding channel of dimension 0.25 m × 0.25 m. The view and construction detail of the screen-gravel filter is shown in Fig. 4.1.1.

The filtration efficiency increased with increase in thichkness of the sand bed. Sand bed of thickness 10 cm, 15 cm and 20 cm gave filtration efficiency of 64%, 86% and 89%, respectively. A relationship was developed between filtration efficiency and sand bed thickness:

$$y = -0.38x^2 + 13.9x - 37$$

where, y = filtration efficiency, x = thickness of sand bed, cm

The recharge flow rate decreased as thickness of sand bed increased. The recharge flow rate for sand bed of thickness 10 cm, 15 cm and 20 cm was 80%, 57% and 45%, respectively. Relationship between flow rate percentage and thickness of sand bed was established as follows:

$$y = 0.0202x^2 - 0.799x + 10.49$$

where, y = recharge flow rate, lps, x = thickness of sand bed, cm

Observations of long duration and varying load tests showed that varying silt load did not affect the filtration efficiency.

Fig. 4.1.1. Bottom, top and side view of construction details of screen gravel filter

4.4. Ludhiana

4.4.1. Evaluation of composite filter for groundwater recharge

The study was done for developing a composite filter for recharge of groundwater from runoff water. Four materials namely, brick flakes, gravel, coarse sand (pea gravel) and granular activated charcoal were used for construction of the filter (Table 4.4.1).

Table 4.4.1. Size of filter media and their hydraulic conductivity

Material	Geometric size (mm)	Thickness (cm)	Hydraulic conductivity (cm s^{-1})
Brick flakes (B)	35-45	15 and 30	-
Gravel (G)	10-15	15	2.50
Coarse sand (Pea gravel) (CS)	2-4	15	1.70
Granular activated charcoal (C)	2-5	15	1.75

Silt removal efficiency (SRE) of 72.7% was highest with material combination of Brick flakes (30 cm): Gravel: Coarse sand: Activated granular charcoal with the maximum filtration rate of 1.5 litres per second. Nitrate removal efficiency was 24.93 and 24.45% with filter combinations B_{30}:G:CS:C and B_{15}:G:CS:C, respectively. The concentration of nitrate after passing through the composite filter was 56.7 and 56.3 ppm, respectively with B_{30}:G:CS:C and B_{15}:G:CS:C combinations. Practical implication of these observations is that in areas where soluble chemicals (e.g. nutrients like nitrate) are critical pollutants, the above filter media combinations are effective only when it contains activated charcoal. If chemical pollution in runoff water is not present, then filter combination of brick flakes, gravel, pea gravel was found good enough for silt removal. Study on the effect of composite filter on reduction of pH revealed that there was no effect on pH before and after the water passed through brick flakes, gravel, coarse sand or combinations of these materials. After studying the above three materials, granular charcoal (activated) was added as the fourth material in the composite filter and its effect on EC, pH, RSC and TDS was analyzed. After analysis it was found that EC, pH, RSC and TDS remained unchanged before and after water passed through the composite filter containing all the four materials in the following combinations i.e. B_{30}:G:CS:C and B_{15}:G:CS:C.

Plate 4.4.1. Testing composte filter in field condition

4.4.2. Impact of replacing conventional pumpsets with solar pumpsets on economics, energy and environment

The cost of electricity is high in Punjab and with subsidy to farmers the major burden is with the state government. Cost of diesel is also very high, for which the farmers don't get subsidy. So, it is very difficult for them to make large profits from their crop as a large share of the profit is being spent on diesel. Electricity in Punjab is mainly being generated by coal in thermal plants. Burning of coal and diesel produces carbon emissions which are harmful for the environment. A big part of carbon emission in Punjab is attributed to the electric and diesel tubewells. Therefore, a study was done to analyze the efficacy of replacing electric and diesel tubewells with that of solar photovoltaic (SPV) pumps. SPV pumps have only one time installation cost and the running cost is almost negligible. These pumps are also environment friendly. Hence, keeping in view the cost and space requirement, a study was conducted to analyze the cost saving and reduction in carbon emission if we replace the electric and diesel tubewells under the shallow and medium tubewells category upto 8 hp with the SPV pumps. The following conclusions are drawn from the study:

- Total energy consumption per year by electric and diesel tubewells upto 8 hp under the category of shallow and medium tubewells in Punjab is 4183.4 MU and 544.4 MU, respectively.
- Cost per year being spent for electric and diesel tubewells upto 8 hp under the category of shallow and medium tubewells in Punjab is approximately ₹ 2117 crore and ₹ 1041 crore, respectively.
- Amount of energy that can be saved by replacing electric and diesel tubewells upto 8 hp under the category of shallow and medium tubewells in Punjab is 4728 MU (if replacing 100% tubewells), 2364 MU (if replacing 50% tubewells) and 1182 MU (if replacing 25% tubewells).
- Money that needs to be invested for installing SPV pumps in place of electric and diesel tubewells upto 8 hp under the category of shallow and medium tubewells in Punjab without any subsidy ranges from ₹ 30,300 crore to ₹ 46,410 crore (without subsidy) and ₹ 7,575 crore to ₹ 23,684 crore (with subsidy).
- Reduction in carbon emission will be 9101×10^{6} kg (if replacing 100% tubewells), 4550.5×10^{6} kg (if replacing 50% tubewells) and 2275.3×10^{6} kg (if replacing 25% tubewells).
- Carbon emission being generated by shallow and medium tubewells upto 8 hp is maximum in Fazilka district (in both electric and diesel tubewells category) while it is minimum in Bathinda (in case of electric tubewells) and Moga (in case of diesel tubewells).
- The money that will be saved by replacing electric and diesel tubewells will be ₹ 3158 crore. So the payback period of SPV pumps will be 10 to 15 years depending upon the SPV pumps provider. Thereafter, more than ₹ 4000 crore can be saved every year.

4.3. Coimbatore

4.3.1. Performance evaluation of artificial recharge structures in over-exploited blocks of Coimbatore district

The study was taken up extensively in Noyyal sub basin of Thondamuthur block which is located in Coimbatore district of Tamil Nadu. Noyyal river is a tributary of Cauvery and it originates from the Velliangiri hills in the western part of

Tamil Nadu. Noyyal river has seven major tributaries, all originating from first or second order streams in the foothills of the Nilgiris. It flows through Coimbatore, Tiruppur, Karur and Erode districts before joining Cauvery river at Kodumudi in Erode district. The study area is bounded by Kerala in the west, Perur block in the east, Madukkarai in the south and Coimbatore (or) P.N. Palayam block in the north. It has a geographical area of 480 km^2.

Six recharge structures namely, four check dams, one recharge shaft in check dam and one recharge borewell were identified in the study area. Ten observation wells near the structures were also identified for monitoring the water levels. Basic particulars of the study area were collected. Location of the recharge structures and observation wells were found by GPS and is shown in Fig. 4.3.1.

Fig. 4.3.1. Location of recharge structures

Table 4.3.1. Specification of the recharge structures

a. Check dam

Structure name	Max storage area (ha)	Max storage depth (m)	Catchment area (km^2)
CD1	0.17	1.3	1.10
CD2	0.20	1.5	1.36
CD3	0.22	1.5	1.40
CD4	0.26	1.5	1.38

b. Recharge shaft

Bore size and depth	6.5” diameter to depth of 100 m
Filtering chamber surround the shaft	Circular pit of 5 m diameter and 4.5 m depth around the shaft filled with filtering media
Slotted PVC casing pipe	Diameter= 6.5”, Length=12 m

c. Recharge borewell

Bore size and depth	6.5” diameter to depth of 100 m
Filtering pit	Square= 3 m x 3 m x 1.5 m filled with filtering media
Slotted PVC casing pipe	Diameter= 6.5”, Length=6 m to 12 m

4.4. Rahuri

4.4.1. Performance evaluation of filter technology for artificial groundwater recharge through borewell on the farms/fields

The recharge filter developed by Rahuri centre was tested at two sites in farmers' fields of Digras village in Ahmednagar district of Maharashtra. The filter unit consisted of a pit of diameter 2 m and depth of 2 m around the casing pipe of borewell. Runoff water from the surrounding field was diverted towards the filter unit, which was then passed through the filter. The casing pipe was at the centre of the pit. Holes of size 4-5 mm were made on the casing pipe with 1-2 cm distance between them. Perforated casing pipe of the borewell was covered with mesh having size of 2 mm to prevent blockage of the casing pipe. Filter materials such as brick flakes, angular gravel, pea gravel and sand were used in the four-layer filter. Brick flakes (BF-I) of size 24-28 mm, Sand (SG-I) of size 0.6-2 mm were used. Two types of gravel i.e. angular gravel (AG-I) of 9.5-15.5 mm and pea gravel (PG-I) of 20-24 mm were used for the study. Thickness of the layer of brick flakes, sand, angular gravel, pea gravel was 25 cm, 50 cm, 50 cm and 50 cm, respectively. Plate 4.4.1 shows the arrangement of different filter materials in the recharge filter. Observations and results obtained in terms of the filtration efficiency and total runoff volume through the filter of borewell is presented in Table 4.4.1 and 4.4.2 at Location-I and Location-II, respectively. From the Table 4.4.1, it was observed that the four-layer filter showed filtration efficiency in the range of 83.4 - 86.1% with an average filtration efficiency of 84.8%. From Table 4.4.2, it was observed that the four-layer filter has given filtration efficiency in the range of 79.2% - 89.1% with an average filtration efficiency of 83.8%. The overall filtration efficiency of the four-layer filter was satisfactory in the farmers' field.

First layer of pea gravels

Second layer of angular gravels

Third layer of fine sand

Fourth layer of brick flakes

Plate 4.4.1. Arrangement of different filter materials in the recharge filter

Table 4.4.1. Filtration efficiency of the four layer filter at Location-I

Sl. No.	Rainfall (mm)	Area (ha)	Total runoff volume (L)	Location-I		
				Inlet NTU	Outlet NTU	FE (%)
1	61.4	0.5	46050	371.7	57.3	84.6
2	26.2	0.5	19650	451.3	74.7	83.4
3	56.2	0.5	42150	403.0	56.0	86.1
4	14.8	0.5	11100	450.3	67.3	85.0
5	9.4	0.5	7050	354.7	53.0	85.0
					Average	**84.8**

Table 4.4.2. Filtration efficiency of the four layer filter at Location-II

Sl. No.	Rainfall (mm)	Area (ha)	Total runoff volume (L)	Location-II		
				Inlet NTU	Outlet NTU	FE (%)
1	61.4	0.75	69075	289	60.3	79.2
2	26.2	0.75	29475	220	39.5	82.0
3	56.2	0.75	63225	294	32.0	89.1
4	14.8	0.75	16650	319	60.1	81.1
5	9.4	0.75	10575	278	35.0	87.4
					Average	**83.8**

4.5. Pusa

4.5.1. Design and evaluation of drainage-cum-recharge well under north Bihar condition

Drainage-cum-recharge structure was designed and evaluated for north Bihar conditions. Recharge filters were constructed using four materials namely, colour gravel, sand, jute, coconut fibre, charcoal, rice husk, saw dust, activated charcoal and white gravel. Performance of the filters was evaluated with twenty-one different filter combinations having different material thickness ranging from 15-45 cm and filter length ranging from 45-135 cm prepared and evaluated in terms of filtration rate and solid removal efficiency. Highest filtration rate was observed with Filter combination-3(a) consisting of colour gravel (15 cm), sand (15 cm) and charcoal (15 cm) having total filter length of 45 cm. When compared with filter length of 135 cm, highest filtration rate was observed with filter combination-3(c) consisting of colour gravel (45 cm) + sand (45 cm) + charcoal (45 cm). The lowest filtration rate was observed for filter combination-5(b) consisting of colour gravel (45 cm) + sand (45 cm) + saw dust (45 cm) for total filter thickness of 135 cm. Solid removal efficiency was highest with filter combination-3(c) having colour gravel (45 cm) + sand (45 cm) + charcoal (45 cm). Higher retention capacity of saw dust, rice husk and activated charcoal led to lower filtration rate. It was also found that the saw dust, rice husk and activated charcoal swelled after coming in contact with water and made more compact medium than charcoal and coconut fiber which led to lower infiltration rate. Filter combination-3(c) consisting of colour gravel (45 cm), sand (45 cm) and charcoal (45 cm) and total filter length of 135 cm was most promising in terms of filtration rate and solid removal efficiency. Filtration rate and solid removal efficiency for 3(c) combination consisting of colour gravel (45 cm), sand (45 cm) and charcoal (45 cm) were 2.25 L s^{-1} and 77.5%, respectively. Filter combination-4 with colour gravel + sand + rice husk and filter combination-5 with colour gravel + sand + saw dust were also promising in terms of solid removal efficiency and lower turbidity level. Groundwater recharge-cum-drainage unit was constructed in the Mela ground for demonstration and further field investigation (Plate 4.5.1).

Groundwater recharge cum drainage unit tested

Plate 4.5.1. Groundwater recharge cum drainage unit installed in Pusa Campus

Groundwater recharge cum drainage unit inaugurated by Hon'ble Vice-Chancellor & Members of Board of Management on 25.01.2019

Chapter 5

Irrigation Scheduling of Crops

5.1. Jammu

5.1.1. Effect of puddling methods and irrigation regimes on water balance in rice

The experiment was conducted from 2015 to 2018 to optimize mechanized mode of puddling and irrigation scheduling to grow rice variety Basmati 370 in light textured soils (sandy loam) of Jammu region. Three years pooled data revealed that grain yield was highest with rotavator puddling (P_2, 2.60 t ha^{-1}) followed by puddler puddling (P_3, 2.43 t ha^{-1}) and cultivator puddling (P_1, 2.35 t ha^{-1}) (Table 5.1.1). Rotavator puddling showed 7.0% and 10.6% yield improvement over puddler and cultivator puddling methods, respectively. Irrigation treatments indicated that alternate wetting and drying (AWD) with three days after disappearance of ponded water (3DADPW) (I_2) yielded 2.44 t ha^{-1} as against 2.60 t ha^{-1} with continuous ponding (I_1), which was statistically non-significant. Irrigation water of 1220 mm was applied under AWD compared to 1593 mm under CF, with water saving of 30.6% over continuous ponding. As per university norms, after completion of on-farm trial (OFT) in collaboration with KVKs for two years, recommendation will be forwarded to the stakeholders/farmers of canal command area through Directorate of Extension for scalability of the technique in 1.0 lakh hectare in Jammu.

Table 5.1.1. Effect of puddling methods and irrigation regimes on rice var. Basmati 370

Treatment	Yield (t ha^{-1})				Total water used (mm)			WEE (kg ha-mm^{-1})				Net return (₹ ha^{-1})	B:C ratio
	2015	2016	2018	Mean	2015	2016	2018	2015	2016	2018	Mean		
P_1	1.95	2.66	2.45	2.35	1822.08	1472.24	1468.36	1.07	1.81	1.67	1.52	47,200	1.26
P_2	2.39	2.80	2.62	2.60	1822.08	1472.24	1468.36	1.31	1.90	1.78	1.66	56,200	1.50
P_3	2.10	2.60	2.58	2.43	1822.08	1472.24	1468.36	1.15	1.77	1.76	1.56	50,080	1.34
$CD_{0.05}$	NS	0.14	NS	-	-	-	-	-	-	-	-	-	-
I_1	2.51	2.71	2.58	2.60	1892.08	1717.24	1713.36	1.33	1.58	1.51	1.47	47,200	1.50
I_2	2.12	2.67	2.52	2.44	1752.08	1227.24	1223.36	1.21	2.18	2.06	1.82	56,200	1.35
$CD_{0.05}$	NS	NS	NS	-	-	-	-	-	-	-	-	-	-

Rainfall=470.8 (2015), 522.4 (2016), 683.6 (2018); Rice sale price=₹.3600 q^{-1}; Cost of cultivation=₹.37,400 ha^{-1}

P_1: Cultivator puddling, P_2: Rotavator puddling, P_3: Puddler puddling; I_1: Continuous submergence I_2: Irrigation at 3 DADPW

5.2. Belavatagi

5.2.1. Effect of irrigation levels and Integrated Nutrient Management (INM) on *Bt* cotton in Vertisols

Field experiment of four years (2014-15 to 2017-18) was conducted to study optimum irrigation and nutrient levels for *Bt* cotton (var. Paras Brahma) production in chickpea-*Bt* cotton cropping system. Results indicated that significantly higher number of bolls per plant was recorded with irrigation level of 0.8 IW/CPE (36.99) and INM level F_3 (41.24). Significantly higher kapas and straw yields of 1.90 and 5.05 t ha^{-1}, respectively were recorded with 0.8 IW/CPE followed by 0.6 IW/CPE (1.76 and 4.86 t ha^{-1}) (Table 5.2.1). Among INM levels, F_3 recorded significantly higher kapas and straw yields of 2.16 and 7.10 t ha^{-1}, respectively followed F_2 (2.02 and 5.21 t ha^{-1}). Among the INM levels, treatment F_3 (100% RDF + FYM @ 10 t ha^{-1} + one row of sunhemp in between two rows of *Bt* cotton + $ZnSO_4$ @ 25 kg ha^{-1} + $FeSO_4$ @ 25 kg ha^{-1} + Borax @ 5 kg ha^{-1}) recorded significantly higher water use efficiency (3.69 kg ha-mm^{-1}) followed by F_2 (3.43 kg ha-mm^{-1}) as compared to F_5 (2.84 kg ha-mm^{-1}). The results showed that irrigation at 0.8 IW/CPE ratio (I_1) recorded maximum net return (₹ 55945 ha^{-1}) and B:C ratio (3.12) followed by I_2 (₹ 49121 ha^{-1} and 2.29). Among the INM levels, higher net return of ₹ 66153 ha^{-1} and B:C ratio of 2.61 were obtained with F_3 followed by F_2 (₹ 60090 ha^{-1} and 2.53).

Table 5.2.1. Effect of irrigation level and INM on performance of *Bt* cotton (pooled over 4 years)

Treatment*	Kapas yield (t ha^{-1})	Straw yield (t ha^{-1})	WUE (kg ha-mm^{-1})	Net return (₹ ha^{-1})	B:C ratio
Irrigation level					
I_1	1.90	5.05	3.24	55945.08	2.48
I_2	1.76	4.86	3.18	49121.60	2.29
I_3	1.62	4.47	3.36	43762.12	2.25
CD (0.05)	0.55	7.45	NS	3146.51	0.10
INM level					
F_1	1.89	4.80	3.22	56198.81	2.55
F_2	2.02	5.21	3.43	60090.92	2.53
F_3	2.17	7.11	3.69	66153.47	2.61
F_4	1.76	3.62	3.00	50004.39	2.34
F_5	1.67	3.20	2.84	47277.83	2.38
CD (0.05)	0.99	7.35	0.24	4139.05	0.12
Interaction effect (Irrigation x INM levels)					
I_1F_1	1.89	4.83	3.22	56198.81	2.55
I_1F_2	2.02	5.65	3.43	60090.92	2.53
I_1F_3	2.17	7.43	3.69	66153.47	2.61
I_1F_4	1.76	3.88	3.00	50004.39	2.34
I_1F_5	1.67	3.42	2.84	47277.83	2.38
I_2F_1	1.81	4.85	3.27	53061.80	2.51
I_2F_2	1.91	5.19	3.45	54828.97	2.39
I_2F_3	2.03	7.20	3.67	60324.38	2.50
I_2F_4	1.59	3.76	2.87	43058.53	2.25

I_2F_5	1.48	3.29	2.67	34334.31	1.80
I_3F_1	1.60	4.72	3.32	44387.95	2.37
I_3F_2	1.71	4.80	3.55	46170.36	2.21
I_3F_3	1.87	6.70	3.89	53236.24	2.34
I_3F_4	1.50	3.22	3.11	39177.56	2.16
I_3F_5	1.41	2.88	2.91	35838.48	2.14
CD (0.05)	NS	NS	NS	NS	0.24

*I_1=0.8 IW/CPE; I_2=0.6 IW/CPE; I_3=Critical stages; F_1 = 100% RDF + FYM @ 10 t ha^{-1}; F_2= 100% RDF + FYM @ 10 t ha^{-1} + one row of sunhemp in between two rows of *Bt* cotton. Sunhemp is grown as green manure crop; F_3 = 100% RDF + FYM @ 10 t ha^{-1} + one row of sunhemp in between two rows of *Bt* cotton + $ZnSO_4$ @ 25 kg ha^{-1} + $FeSO_4$ @ 25 kg ha^{-1} + Borax @ 5 kg ha^{-1}; F_4 = 75% RDF + FYM @ 10 t ha^{-1} + Biofertlizer + one row of sunhemp in between two rows of *Bt* cotton + $ZnSO_4$ @ 25 kg ha^{-1} + $FeSO_4$ @ 25 kg ha^{-1} + Borax @ 5 kg ha^{-1} + maize stalk 10 t ha^{-1}; F_5 = 50% RDF + FYM @ 10 t ha^{-1} + Biofertlizer + one row of sunhemp in between two rows of *Bt* cotton + $ZnSO_4$ @ 25 kg ha^{-1} + $FeSO_4$ @ 25 kg ha^{-1} + Borax @ 5 kg ha^{-1} + maize stalk 10 t ha^{-1}

5.3. Gayeshpur

5.3.1. Enhancing water productivity of zero-till greengram-jute relay system under deficit and adequate irrigation scheduling with hydrogel

Wide variation in yield of zero-till greengram-jute relay system was recorded against nominal change in ET values. However, when ET values were higher (630 mm to 750 mm) a steady increasing trend in system yield was registered with each increment of ET value. From this pattern it can be stated that under relatively dry water regimes, hydrogel played a significant role in enhancing the system yield. In contrast, under relatively wet condition, frequency of irrigation dominated over the hydrogel treatment in yield augmentation. Under dry situation, partitioning of evaporation and transpiration had much variation than the wet situation. So, variation in system yield might be predicted to be 65-75% with ET alone.

Water productivity (WP) is an index to quantify the use efficiency of water resources towards crop production under limited water supply condition. This index plays a crucial role in selecting the appropriate irrigation management. In the present study, WP ranged between 0.43 kg m^{-3} (RF) to 0.49 kg m^{-3} (CPE_{100}) (Table 5.3.1). This indicates the higher requirement of water for relay cropping system. Hydrogel application significantly improved WP from 0.48 to 0.62 kg m^{-3} with Hydrogel @ 5.0 kg ha^{-1}. This indicated the efficiency of gel on sustained supply of water especially during dry spells. Under relatively dry root zone (RF), both evaporation and transpiration remains at suboptimal level resulted in lower ET as well as lower system yield. When the crop was irrigated frequently under CPE_{100}, enough moisture remained in the soil surface as well as in the sub-soil, such environment promoted ET and also system yield (Fig. 5.3.1).

Table 5.3.1. Effect of irrigation regimes and hydrogel doses on evapotranspiration, yield and water productivity of greengram-jute relay system

Treatment	ET (mm)	Yield (t ha^{-1})	Water productivity (kg m^{-3})
RFH_0	506.40	2.13	0.43
$RFH_{2.5}$	516.40	2.40	0.47
RFH_5	529.40	2.75	0.53
$CPE_{250}H_0$	544.40	2.79	0.52
$CPE_{250}H_{2.5}$	553.05	3.24	0.59
$CPE_{250}H_5$	564.35	3.52	0.63
$CPE_{175}H_0$	614.05	2.97	0.49

$CPE_{175}H_{2.5}$	616.20	3.81	0.63
$CPE_{175}H_{5}$	630.80	4.02	0.65
$CPE_{100}H_{0}$	735.90	3.62	0.49
$CPE_{100}H_{2.5}$	739.07	4.50	0.61
$CPE_{100}H_{5}$	746.45	4.87	0.66
CD (0.05)	64.93	0.44	0.06

RF- Rainfed, CPE_{250} - Cumulative pan evaporation 250 mm, CPE_{175} - Cumulative pan evaporation 175 mm, CPE_{100} - Cumulative pan evaporation 100 mm, H_0 - No hydrogel, $H_{2.5}$ - Hydrogel @ 2.5 kg ha^{-1}, H_5 - Hydrogel @ 5.0 kg ha^{-1}

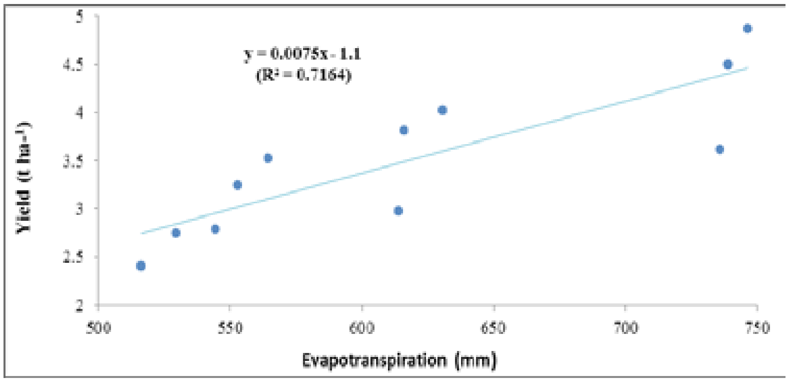

Fig 6.3.1. Relationship between yield and ET under different irrigation regimes and hydrogel doses in greengram-jute relay system

5.4. Kota

5.4.1. Evaluation of irrigation schedules and fertility levels for kalonji (*Nigella sativa* L.) in south-eastern Rajasthan

Two years of experiment revealed that significant difference was observed with application of drip irrigation based on IW/CPE ratio. Significantly higher seed yield (0.85 t ha^{-1}), net return (₹ 1,26,530 ha^{-1}) and B:C ratio (4.54) of kalonji was obtained under irrigation scheduled at IW/CPE 0.8 that remained at par with IW/CPE 0.6 (Table 5.4.1 and 5.4.2). Maximum water productivity of 0.392 kg m^{-3} was recorded under irrigation scheduled at IW/CPE 0.4 compared to irrigation scheduled at IW/CPE 0.8. Among the fertility levels, significantly higher seed yield (0.80 t ha^{-1}), water use efficiency (3.75 kg ha-mm^{-1}), net return (₹ 1,17,755 ha^{-1}) and B:C ratio (4.20) were obtained with application of 125% RDF being at par with 100% RDF. Water productivity (0.375 kg m^{-3}) was highest under application of 125% RDF compared to 75% RDF.

Table 5.4.1. Effect of irrigation scheduling and fertigation on performance of kalonji

Treatment	Seed yield (t ha^{-1})			Water use efficiency (kg ha-mm^{-1})			Water productivity (kg m^{-3})		
	2016-17	2017-18	Pooled	2016-17	2017-18	Pooled	2016-17	2017-18	Mean
Irrigation schedule									
IW/CPE 0.4	0.62	0.63	0.63	3.88	3.96	3.92	0.39	0.40	0.39
IW/CPE 0.6	0.77	0.79	0.78	3.53	3.58	3.56	0.35	0.36	0.36
IW/CPE 0.8	0.84	0.85	0.85	3.01	3.05	3.03	0.30	0.31	0.30
CD (P=0.05)	0.10	0.07	0.07	0.52	0.40	0.36	-	-	-

Fertility level								
75% RDF	0.66	0.67	0.67	3.02	3.08	3.05	0.30	0.31	0.31
100% RDF	0.78	0.79	0.79	3.67	3.73	3.70	0.37	0.37	0.37
125 % RDF	0.79	0.81	0.80	3.73	3.78	3.75	0.37	0.38	0.38
CD (P=0.05)	0.10	0.09	0.08	0.46	0.42	0.37	-	-	-

Table 5.4.2. Effect of irrigation schedules and fertility levels on economics of Kalonji during 2016-17 and 2017-18

Treatment	Net return (₹ ha^{-1})			B:C ratio		
	2016-17	2017-18	Pooled	2016-17	2017-18	Pooled
Irrigation schedule						
IW/CPE 0.4	87706	89017	87924	3.45	3.37	3.33
IW/CPE 0.6	114333	116519	115426	4.22	4.29	4.25
IW/CPE 0.8	124561	127623	126530	4.33	4.57	4.54
CD (P=0.05)	17830	13275	11916	0.68	0.50	0.46
Fertility level						
75% RDF	93501	96563	95470	3.42	3.66	3.62
100% RDF	115563	117749	116656	4.25	4.34	4.30
125% RDF	117536	118848	117755	4.33	4.24	4.20
CD (P=0.05)	17673	16561	14537	0.65	0.61	0.53

RDF-Recommended dose of fertilizers (kg ha^{-1} NPK)

Chapter 6

Basic Studies on Soil-Plant-Water-Environment Relationship

6.1. Faizabad

6.1.1. Effect of different tillage practices and moisture regimes on wheat yield and water use efficiency

The experiment was conducted during 2015-2018 to study effect of different tillage practices and irrigation schedules on wheat crop (var. NDW-1014) in order to select the best treatment combination for wheat crop through better soil environment for favourable plant growth, improved soil micro-fauna and aeration for roots. Interaction effect of conventional tillage with bed planting of wheat (T_3) irrigated at 1.0 IW/CPE (T_2) resulted in significantly higher yield of 4.83 t ha^{-1}, net income of ₹ 55095 ha^{-1} and B:C ratio of 1.87 (Table 6.1.1). Conventional tillage with bed planting led to highest water use efficiency (16.44 kg ha-mm^{-1}) among the tillage practices, whereas WUE was maximum with three irrigations at critical growth stages [I_4: Irrigations at crown root initiation (CRI), late jointing (LT) and milking], followed by I_1 (16.47 kg ha-mm^{-1}) and I_2 (15.14 kg ha-mm^{-1}) with irrigation at 1.0 IW/CPE was 15.14 kg ha-mm^{-1}.

Table 6.1.1. Pooled performace of wheat crop under different moisture regimes and irrigation schedules

Treatment	Grain yield† (t ha^{-1})	Cost of cultivation (₹ ha^{-1})	Gross income (₹ ha^{-1})	Net benefit (₹ ha^{-1})	B:C ratio
T_1I_1	3.33	26200	58275	32075	1.22
T_1I_2	4.40	27200	77070	49870	1.83
T_1I_3	4.30	28200	75192	46992	1.67
T_1I_4	3.34	25200	58392	33192	1.32
T_1I_5	4.32	27200	75658	48458	1.78
T_2I_1	4.03	27400	70583	43183	1.58
T_2I_2	4.64	28400	81258	52858	1.86
T_2I_3	4.60	29400	80500	51100	1.74
T_2I_4	3.73	26400	65217	38817	1.38
T_2I_5	4.52	28400	79042	50642	1.78
T_3I_1	4.45	28500	77817	49317	1.73
T_3I_2	4.83	29500	84595	55095	1.87
T_3I_3	4.72	30500	82658	52158	1.71
T_3I_4	4.29	27500	75133	47633	1.73
T_3I_5	4.67	29500	81725	52225	1.77
T_4I_1	4.21	28300	73617	45317	1.60
T_4I_2	4.60	29300	80558	51258	1.75
T_4I_3	4.52	30300	79042	48742	1.61
T_4I_4	3.99	27300	69833	42583	1.56
T_4I_5	4.47	29300	78167	48867	1.67

†CD at 5% for yield= 0.23

Tillage practices (T): Zero tillage (T_1), Reduced tillage+sowing by seed-cum-ferti drill (T_2), Conventional tillage and sowing on beds (T_3), Conventional tillage + sowing by seed cum ferti drill (T_4). Irrigation schedule (I): 0.8 IW/CPE (I_1), 1.0 IW/CPE (I_2), 1.2 IW/CPE (I_3), Three irrigation at CRI, LT & Milking stage (I_4), 5 irrigation at CRI, Tillering, LT, Flowering & Milking stage (I_5)

6.1.2. Effect of different moisture regimes and nitrogen management in potato crop

The experiment was conducted during *Rabi* 2015-2018 to select irrigation schedule and nitrogen level for optimum yield and economic benefit from potato crop var. Kufri Chandramukhi. It was observd that furrow irrigation method (M_1) resulted in significantly higher yield of 28.93 t ha^{-1} with WUE 146.69 kg ha-mm^{-1} in comparison to alternate furrow irrigation method. Moisture regime 1.0 IW/CPE recorded the significantly higher yield of potato 28.82 t ha^{-1} with WUE of 145.95 kg ha-mm^{-1}. Nitrogen management treatments also have significant effect on potato yield. 75% dose of RDN with 25% N through FYM (N_2) showed high yield of 29.32 t ha^{-1} and WUE of 148.50 kg ha-mm^{-1} among the nitrogen nitrogen management treatments.

Treatment combination of every furrow irrigation (M_1) at 1.0 IW/CPE (I_2) and 75% RDN through urea with 25% N through FYM nitrogen practice (N_2) showed maximum yield of potato 31.55 t ha^{-1} with cost of cultivation of ₹ 47,400 ha^{-1}. Maximum net benefit of ₹ 2,05,000 ha^{-1} and B-C ratio of 4.32 were obtained with the treatment combination (Table 6.1.2). It was followed by furrow irrigation method (M_1) at 0.8 IW/CPE (I_1) and 75% RDN through urea + 25% N through

FYM (N_2), which accrued the second highest net benefit of ₹ 1,99,653 ha^{-1} with B-C ratio of 4.30. Thus it was concluded that every furrow irrigation method resulted in significantly higher potato yield. Moisture regime 1.0 IW/CPE resulted in highest yield being at par with 0.8 IW/CPE. Nitrogen management practice 75% N through urea + 25% N through FYM also led to significantly higher yield over nitrogen management practices in potato cultivation.

Table 6.1.2. Interaction effect of irrigation method, moisture regime and nitrogen management of potato crop

Treatment combination*	Grain yield (t ha^{-1})	Cost of cultivation (₹ ha^{-1})	Net benefit (₹ ha^{-1})	B:C ratio
$M_1I_1N_1$	28.18	45500	179913	3.95
$M_1I_1N_2$	30.76	46400	199653	4.30
$M_1I_1N_3$	27.65	47300	173900	3.68
$M_1I_2N_1$	29.88	46500	192567	4.14
$M_1I_2N_2$	31.55	47400	205000	4.32
$M_1I_2N_3$	29.13	48300	184713	3.82
$M_1I_3N_1$	26.70	47500	166127	3.52
$M_1I_3N_2$	28.04	48400	175893	3.63
$M_1I_3N_3$	26.52	49300	162833	3.30
$M_2I_1N_1$	26.27	44500	165733	3.72
$M_2I_1N_2$	28.35	45400	181427	4.00
$M_2I_1N_3$	26.07	46300	162287	3.51
$M_2I_2N_1$	27.35	45000	173800	3.86
$M_2I_2N_2$	29.98	45900	193940	4.23
$M_2I_2N_3$	26.14	46800	162293	3.47
$M_2I_3N_1$	26.45	45500	166127	3.65
$M_2I_3N_2$	27.71	46400	175307	3.78
$M_2I_3N_3$	25.57	47300	157233	3.32

*M_1- Every furrow irrigation , M_2- Alternate furrow irrigation , I_1- 0.8 IW/CPE, I_2- 1.0 IW/CPE, I_3- 1.2 IW/CPE, N_1- 100% RDN (Recommended dose of Nitrogen) through Urea, N_2- 75% RDN + 25% N through FYM, N_3- 50% RDN + 50% N through FYM (Farm Yard Manure)

6.2. Navsari

6.2.1. Effect of different levels of irrigation, nitrogen and foliar application of banana sap on drip irrigated sweet corn and their residual effect on succeeding summer greengram under South Gujarat conditions

Sweet corn: Interaction effect of various levels of irrigation, nitrogen and BS were not responded significantly during 1st and 2nd years, but during 3rd and in pooled result N x S interaction was found significant. Significantly higher cob yield was registered with treatment combination N_3S_1 (17.1 t ha^{-1}) as compared to rest of the combinations, but it remained at par with treatment combination N_2S_2 (16.4 t ha^{-1}) during 3rd year. Whereas, treatment combination N_2S_2 (16.4 t ha^{-1}) produced significantly superior yield as compared to rest of the combinations in pooled results.

Greengram: Interaction effect of IxN, IxS and NxS were reported significantly during individual years as well as in pooled analysis, except IxS during 2nd year and NxS during 1st year and in pooled analysis. Treatment combination I_3N_3 recorded significantly higher yield as compared to rest of the combinations during 1st year, 3rd year and pooled results, but it was statistically at par with I_1N_2 during 1st year and I_3N_1, I_1N_2 in pooled results. Whereas, treatments combination I_3N_1 found significantly superior as compared to rest of the combination during 2nd year. With respect to I x S, significantly higher grain yield was registered with treatment the combination I_1S_2, I_3S_1 and I_3S_2 during 1st, 3rd year and in pooled results, respectively as compared to rest of the combinations but it was at par with I_3S_1, I_2S_2 during 1st year and I_3S_1, I_1S_2 in pooled analysis. In case of NxS interaction, treatment combination N_1S_2 and N_3S_1 were noted significantly higher grain yield than rest of the combinations during 2nd and 3rd year, respectively but it was at par with N_2S_2 during 3rd year.

Sweet corn equivalent yield (SCEY) and Water use efficiency: Sweet corn equivalent yield computed on the basis of economics revealed that different level of irrigation, nitrogen and BS found significant. Significantly the maximum sweet corn equivalent yield noted with irrigation level I_2 (18.55 t ha^{-1}) as compared to rest of both levels. Similarly, significantly higher equivalent yield was recorded with respect to nitrogen levels treatment N_3 obtained higher SEEY (17.74 t ha^{-1}) as compared to N_1 (15.04 t ha^{-1}), but it was at par with N_2 (17.47 t ha^{-1}). Likewise, foliar application of banana organic sap was reported significantly higher equivalent yield than without spray treatment. Treatment I_2 reported higher WUE of 29.1 kg ha-mm^{-1} along with 10% water saving over I_3 levels.

Economics: Since interaction effect of irrigation, fertigation and foliar spray level on sweet corn equivalent yield was found non significant, therefore economics was calculated on individual effect. Considering sweet corn equivalent yield, the maximum net profit realized under level of irrigation I_2 (₹ 128440 ha^{-1}), nitrogen N_3 (₹ 122898 ha^{-1}) and BS S_2 (₹ 116741 ha^{-1}).

It was concluded that for achieving higher yield and net profit from sweet corn-greengram sequence, sweet corn crop irrigated through drip at 0.8 PEF along with 120 N kg ha^{-1} applied through fertigation and 1% foliar application of banana sap at 30 and 60 DAS. For getting additional benefit, succeeding greengram crop should be taken after harvesting of sweet crop.

Recommendation for the farmers: The farmers of South Gujarat heavy rainfall zone are recommended to adopt drip irrigation (0.8 PEF), fertigation of nitrogen (120 kg ha^{-1}) and 1 % foliar application of banana pseudo stem sap (30 and 60 day after sowing) in sweet corn (*rabi*) and follow greengram (summer) crop sequence for achieving higher net profit and water use efficiency along with 10 % water saving. The full dose of P_2O_5 (60 kg ha^{-1}) and K_2O (40 kg ha^{-1}) as basal in sweet corn, while nitrogen should be applied in form of urea through fertigation in six equal splits at weekly interval starting from 15 day after sowing.

The system details:
Lateral spacing: 1.2 m
Dripper spacing: 0.6 m
Dripper discharge: 4 lph
Operating pressure: 1.2 kg cm^{-2}
Operating frequency: Alternate day
Operating time:
November : 1 hour and 30 minutes to 2 hours and 10 minutes
December : 1 hour and 5 minutes to 1 hour and 30 minutes
January : 54 minutes to 1 hour and 12 minutes
February to March: 1 hour and 10 minutes to 2 hours

6.3. Almora

6.3.1. Effect of tillage and irrigation on rice – wheat cropping system

The experiment was conducted to evaluate irrigation requirement of rice and wheat in relation to tillage operation. Long-term effect of tillage operations on soil properties and yields of rice and wheat were studied from 2001-02 to 2017-18.

Wheat: Five-yearly data analysis for wheat crop revealed that grain yield increased over the years. In the initial years, higher wheat yield was recorded in conventional tillage but after eight years onwards wheat yield was higher with zero tillage compared to conventional tillage. The significantly higher yield, water expense efficiency and water use efficiency were recorded with four irrigations followed by three, two and one pre-sowing irrigation in all the years except 2014-2015. The five yearly yield analyses also revealed that wheat yield increased in zero tilled plots but conventional tillage did not show any such trend; it was static over the years (Fig. 6.3.1).

Rice: Yearly analysis of rice yield revealed that tillage effects were non-significant and in most of the years zero tillage yielded lower yield than conventional except 2006, 2007, 2008, 2010, 2014 and 2017. Rice yield declined over the years. Rice yield was lower in zero tillage due to higher grub and insect pest infestation compared to conventional tillage. Five-yearly analysis of rice yield, WUE and WEE showed similar results (Table 6.3.2). Rice yield increased significantly by increasing level of irrigation highest yield was recorded with four irrigations.

The average wheat yield in initial ten years was higher in conventional tillage than zero tillage but in third five year cycle significantly higher yield was recorded under zero tillage than conventional tillage (Fig. 6.3.3) but rice equivalent yield of the system was higher in the initial five years under conventional tillage but vice versa was true for next two five-year periods (2006-2010 and 2011-2015) (Fig. 6.3.2). Rice equivalent yield also followed similar trend (Fig. 6.3.3). However, net returns (Fig. 6.3.4) were higher under zero tillage than conventional tillage over all the periods. The analyses revealed that physical and chemical properties of soil improved under zero tilled plots due to improvement in organic carbon and reduction in soil loss in comparison to conventional tillage.

Recommendation: Zero tillage is best practice to reduce expenditure cost, energy, and increase returns and improve soil physical properties of rice and wheat crops in the hiily region. In zero-tilled plots, four irrigations applied at pre sowing, tillering/CRI, flowering and grain formation stages of wheat need to be applied for obtaining higher yield but under limited condition three irrigation can be good practice and under very short supply of water two irrigation at pre sowing and tillering / CRI stage can be appropriate practice to irrigate direct seeded rice and wheat crops in hills where water availability is major limiting factor for crop production.

Table 6.3.1. Long-term effect of tillage operations on performance of wheat crop

Tillage	2001-2002 to 2005-2006		2006-2007 to 2010-2011		2011-2012 to 2015-2016		2001-2002 to 2017-2018	
	Yield (t ha^{-1})	WUE (kg ha-mm^{-1})	Yield (t ha^{-1})	WUE (kg ha-mm^{-1})	Yield (t ha^{-1})	WUE (kg ha-mm^{-1})	Yield (t ha^{-1})	WUE (kg ha-mm^{-1})
Zero tillage	3.30	10.4	3.50	11.9	4.20	11.2	3.58	11.0
Conventional	3.67	11.4	3.66	11.7	3.80	9.7	3.57	10.6
CD (P=0.05)	0.22	0.68	0.21	0.76	0.21	0.55	0.10	0.33
Irrigation	Sig	Sig	NS	NS	Sig	Sig	NS	Sig
PRS	2.78	10.8	3.00	12.6	3.42	10.5	2.91	10.8
PRS+CRI	3.37	11.5	3.48	12.4	3.86	10.8	3.48	11.4
PRS+CRI+FL	3.72	10.8	3.78	11.5	4.23	10.4	3.80	10.7
PRS+CRI+FL+GF	4.08	10.4	4.07	10.8	4.50	10.1	4.12	10.3
CD (P=0.05)	0.17	0.53	0.18	0.64	0.17	0.50	0.09	0.30
Remarks	Sig	Sig	Sig	Sig	Sig	NS	Sig	Sig
Annual Mean	3.49	10.9	3.58	11.8	4.00	10.4	3.58	10.8
Year CD (P=0.05)	Sig	1.08	Sig	1.20	Sig	0.87	Sig	0.95
	0.35	Sig	0.33	Sig	0.33	Sig	0.30	Sig

Year x Tillage CD (P=0.05)	Sig	1.52	Sig	1.70	Sig	1.23	Sig	1.35
	0.50	NS	0.47	NS	0.47	NS	0.43	Sig
Year x irrigation CD (P=0.05)	NS	1.18	Sig	1.44	NS	1.11	Sig	1.25
	0.38	Sig	0.40	Sig	0.39	Sig	0.38	Sig
Tillage x Irrigation CD (P=0.05)	Sig	0.75	NS	0.91	Sig	0.70	Sig	0.43
	0.24	NS	0.25	NS	0.25	Sig	0.13	NS
Year x tillage x irrigation CD (P=0.05)	Sig	1.67	NS	2.03	NS	1.57	NS	1.76
	0.53	NS	0.56	NS	0.55	Sig	0.54	Sig

PRS= Presowing irrigation, PRS+CRI/tillering: Presowing + CRI/tillering stage irrigation, PRS+CRI/tillering+Fl: Presowing+ CRI/tillering + flowering stage irrigation, PRS+CRI/tillering+Fl+GF: Presowing+ CRI/tillering + flowering + grain filling stage irrigation; CRI-Crown root initiation; NS- Non-significant, Sig- Significant

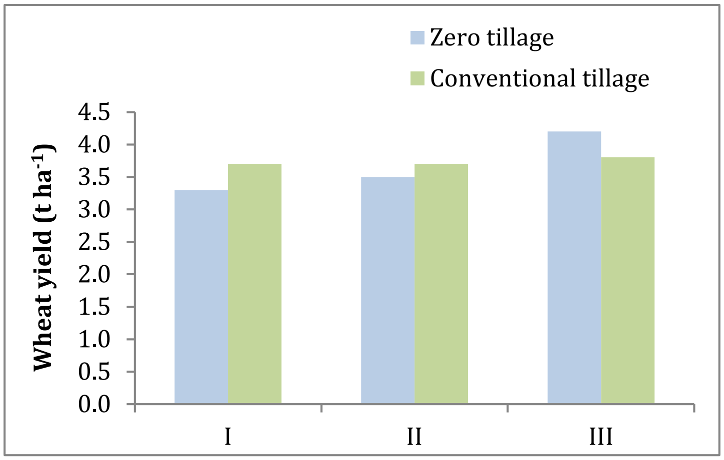

Fig. 6.3.1. Five yearly average of wheat yield under two tillage system

Table 6.3.2. Long-term effect of tillage operations on performance of rice crop

Treatment	Irrigation (mm)	WEE (kg-ha mm^{-1})	WUE (kg-ha mm^{-1})	Net return (000 ₹ ha^{-1})	Net return (per mm applied water in ₹ ha^{-1})
Tillage					
Zero	125.0	2.66	3.28	-18.2	-215.8
Conventional	125.0	3.04	3.74	-21.7	-262.1
CD (P=0.05)	-	0.70	0.86	9.50	104.74
-	-	NS	NS	NS	NS
Irrigation					
Pre	50.0	2.37	3.00	-29.3	-585.9
Pre+tillereing	100.0	3.11	3.85	-17.7	-177.0
Pre+tillering+PI	150.0	2.96	3.60	-17.3	-115.1
Pre+tillering+PI+GF	200.0	2.98	3.57	-15.6	-77.9
CD (P=0.05)	-	0.30	0.38	4.32	51.88
-	-	Sig	Sig	Sig	Sig

PRS= Presowing irrigation, PRS+CRI/tillering: Presowing+CRI/tillering stage irrigation, PRS+CRI/tillering+Flowering: Presowing+CRI/tillering+flowering stage irrigation, PRS+CRI/tillering+Fl+GF: Presowing+CRI/tillering+flowering+grain filling stage irrigation; CRI-Crown root initiation; NS- Non-significant, Sig- Significant

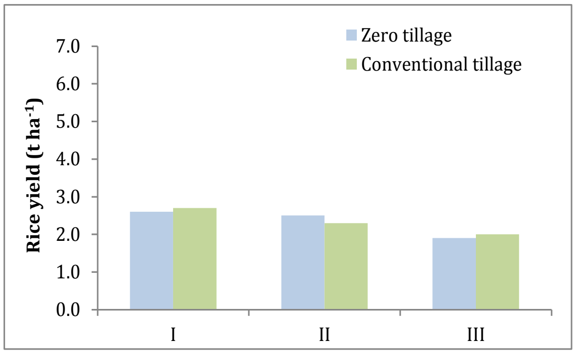

Fig 6.3.2. Five yearly average of rice yield under two tillage system

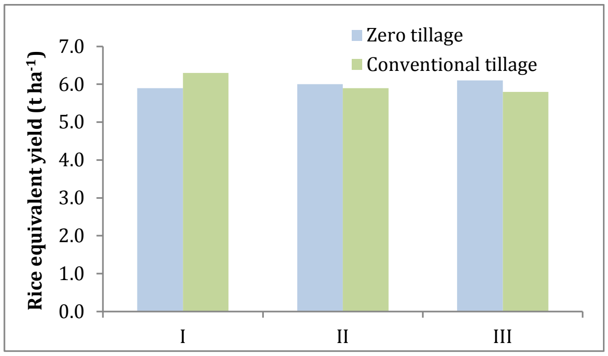

Fig 6.3.3. Five yearly average of rice yield under two tillage system

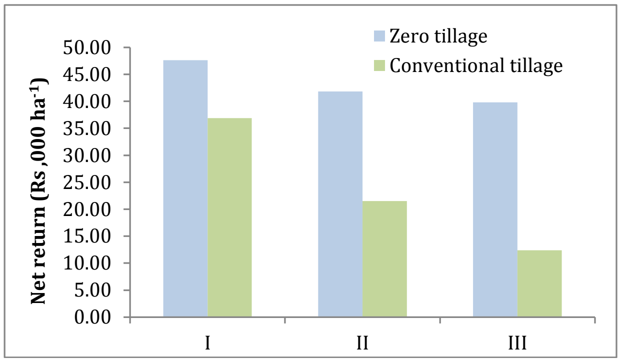

Fig. 6.3.4. Five yearly average of net returns under two tillage systems

6.3.2. Soil moisture and nutrient dynamics in wheat-soybean rotation under irrigated conditions

The experiment was conducted to study direct and residual effects of fertilization on wheat (var. VL 804) and soybean (VLS 2) crops and to monitor changes in nutrients and moisture use pattern in wheat-soybean cropping system.

Wheat: Results showed that grain yield of wheat was significantly affected due to nutrient treatments. Application of recommended NPK+10 FYM t ha^{-1} recorded significantly highest grain yield (5.19 t ha^{-1}) followed by 120 kg N + 10 FYM t ha^{-1} (5.03 t ha^{-1}). The gross returns and gross returns per mm applied water followed the same trend. There was a significant higher net return observed by the application of NPK+FYM, N+FYM, NPK, and NPK in both the season in comparison to application of alone FYM, or alone N and control. The net returns were negative in control, which means that there was loss and the gross returns were lower than the cost of cultivation. Average profile moisture was higher in FYM consisting treatments in comparison to control and alone application of fertilizer except NPK+FYM. The WEE and WUE followed the same trend as of grain yield. The experiment results revealed that the higher water use efficiency and higher returns per mm applied water can be achieved by application of balanced fertilizer. Analysis over the years showed significantly higher yield, WUE and WEE was with application NPK+FYM, followed by N+FYM, NPK +NPK, NPK, FYM and N alone in comparison to control in almost all the years (Table 6.3.3).

Soybean: Seed yield of soybean was affected significantly due to the residual effect of the fertilization. The highest seed yield (3.44 t ha^{-1}) was recorded in NPK+FYM whereas minimum in N applied alone (1.84 t ha^{-1}). Highest residual effect on soybean seed yield was recorded with NPK + FYM. Residual effect was in the order of NPK + FYM (1.06 t ha^{-1}), N+FYM (0.86 t ha^{-1}), FYM (0.74 t ha^{-1}), NPK (0.5 t ha^{-1}) and N effect was negative (-0.54 t ha^{-1}) over the control. The residual effect of NPK +FYM, N+ FYM, FYM was higher than direct effect of NPK+NPK (0.46 t ha^{-1}). The values of water use efficiency ranged from 3.2 (applied N alone during wheat) to 6.0 kg ha-mm^{-1} (NPK + FYM applied in wheat) (Table 6.3.3). The gross, returns and gross returns per mm-applied as well as net returns and net returns per mm applied of water followed the same trend as reported for grain trend.

Analysis over the years showed that soybean yield declined with residual effect of only N applied in wheat and control over the years. Five years average of system (both seasons) showed an increase in wheat equivalent yield over the years with NPK+FYM, N+FYM, FYM, NPK and NPK applied in both seasons. However, system yield declined with application of N alone application and control. The highest gross returns observed by the application of NPK+FYM, followed by N+FYM, NPK+NPK, NPK, FYM control and N alone over the years. The net returns were also higher by the application of NPK+FYM, followed by N+FYM, NPK+NPK, NPK, FYM in over all year except in initial five years (2001-2005) net returns were negative by the application of FYM. The net returns was negative in all the years under control and application of N alone except during 2006-2010 net returns was positive under N alone application plots.

Recommendation: The application of NPK + FYM is recommended in wheat under sufficient supply of nutrients in order to obtain optimum wheat (4.9 to 5.7 t ha^{-1}) production and input use efficiency and soybean can be grown on residual fertility with higher production (2.4 to 3.0 t ha^{-1}). In limited supply N+FYM can be good practice. The alone application of FYM will sustain the production at medium level and can be adopted where fertilizer supply restricted as in case of Uttarkhand hills. The alone application of N, NPK and NPK in both the season should not be adopted as soybean yield did not cross the yield level even by the application of recommended dose of fertilizer in soybean comparison to plots those received FYM during wheat season and soybean was grown on residual fertility without any application of fertilizer and FYM.

Table 6.3.3. Five yearly average of wheat yield and water use efficiency (WUE) under different treatment of fertilizer and manure

Treatment	2001-2005		2006-2010		2010-2015		2014-2018		2001-2018	
	Yield (t ha^{-1})	WUE (kg ha-mm^{-1})	Yield (t ha^{-1})	WUE (kg ha-mm^{-1})	Yield (t ha^{-1})	WUE (kg ha-mm^{-1})	Yield (t ha^{-1})	WUE (kg ha-mm^{-1})	Yield (t ha^{-1})	WUE (kg ha-mm^{-1})
Year	2.92	7.3	3.62	9.0	3.64	8.6	3.54	9.1	3.42	8.4
CD (P=0.05)	0.48	0.85	0.36	0.95	0.52	1.22	0.32	0.86	0.39	0.95
-	Sig	Sig	Sig	Sig	NS	Sig	Sig	Sig	Sig	Sig
Fertilizer/manure										
Control	1.62	4.0	1.81	4.4	1.47	3.4	1.62	4.0	1.66	4.0
FYM	2.28	6.0	2.72	6.9	2.70	6.6	3.02	8.0	2.67	6.8
NPK	3.54	8.7	4.07	9.9	4.11	9.4	3.96	10.0	3.90	9.4
NPK+FYM	3.90	10.0	5.25	13.3	5.59	13.6	5.17	13.6	4.92	12.4
N+FYM	3.47	8.6	4.58	11.3	4.88	11.7	4.57	12.0	4.34	10.7
N alone	2.42	6.1	2.65	6.5	2.33	5.3	2.43	6.1	2.47	6.1
NPK-NPK	3.25	7.7	4.30	10.4	4.38	10.0	4.03	9.8	3.96	9.4
Control	0.27	0.56	0.24	0.62	0.25	0.58	0.21	0.54	0.12	0.30
	Sig	Sig	Sig	Sig	Sig	Sig	Sig	Sig	Sig	Sig
Year x Fertilizer CD (P=0.05)	0.60	1.25	0.53	1.39	0.56	1.30	0.47	1.20	0.50	1.29
	Sig	Sig	NS	Sig	NS	Sig	Sig	Sig	Sig	Sig

NPK-Nitrogen, Phosphorus & Potassium; FYM-Farm Yard Manure; NS- Nonsignificant, Sig-Significant

6.4. Jorhat

6.4.1. Optimum irrigation schedule for growth and yield of early ahu rice

The experiment was conducted with ahu rice var. Dishang with eight irrigation treatments in a rice-rice cropping system from 2016 to 2018. The control included continuous flooding. Irrigation at 15 cm depletion of water from soil surface (T_3) being at par with 5 cm (T_1) and 10 cm (T_2) depletion of water from soil surface, irrigation at 3 days after disappearance of ponded water (T_7) and continuous flooding (T_8) recorded the highest length of panicle, number of grains per panicle and grain and straw yield of rice. In case of effective tillers/hill, continuous flooding recorded the lowest effective tillers/hill. Irrigation at 15 cm depletion of water from soil surface (T_3) being at par with 5 cm (T_1) and 10 cm (T_2) depletion of water from soil surface, irrigation at 3 days after disappearance of ponded water (T_7) recorded the highest effective tillers/hill. Test weight and harvest index were not significantly influenced by different irrigation schedule. Continuous flooding (T_8) recorded the highest irrigation water used (916.5.0 mm). Thus, continuous flooding recorded the lowest irrigation water use efficiency (4.24 kg ha-mm^{1}). The irrigation water use efficiency for treatment T_3 to T_6 were almost same ranging from 8.02 to 8.85 kg mm^{-1}. Economic analysis of irrigation schedules on autumn rice is presented in table 16. From the analysis it has been revealed that irrigation at 15 cm depletion of water from soil surface (T_3) has performed better in terms of net return and benefit cost ratio followed by T_2 (irrigation at 10 cm depletion of water from soil surface) and T_7 (Irrigation at 3 days after disappearance of ponded water) (Table 6.4.1).

Table 6.4.1. Performance of autumn rice under various irrigation schedules

Treatment*	Grain yield (t ha^{-1})			Pooled (t ha^{-1})	Irrigation (mm)	Irrigation WUE (kg ha-mm^{-1})	Net return (₹ ha^{-1})	B:C ratio
	2016	2017	2018					
T_1	3.90	4.24	4.32	4.15	600.0	6.92	27,949	0.81
T_2	4.20	4.42	4.42	4.35	561.5	7.75	31,526	0.93
T_3	4.30	4.52	4.56	4.46	511.5	8.72	33,926	1.03
T_4	3.50	3.89	3.92	3.78	471.5	8.02	24,326	0.75
T_5	3.40	3.85	3.83	3.69	416.5	8.85	23,801	0.75
T_6	3.30	3.52	3.53	3.45	411.67	8.38	20,276	0.74
T_7	4.00	4.26	4.24	4.17	565.0	7.38	28,751	0.86
T_8	3.70	4.01	3.97	3.89	916.5	4.24	19,301	0.33
CD (P = 0.05)	0.5	0.6	0.7	0.6	-	-	-	-

T_1 = Irrigation at 5 cm depletion of water from soil surface; T_2 = Irrigation at 10 cm depletion of water from soil surface; T_3 = Irrigation at 15 cm depletion of water from soil surface; T_4 = Irrigation at 20 cm depletion of water from soil surface; T_5 = Irrigation at 25 cm depletion of water from soil surface; T_6 = Irrigation at 30 cm depletion of water from soil surface; T_7 = Irrigation at 3 days after disappearance of ponded water; T_8 = Continuous flooding

6.5. Chalakudy

6.5.1. Development of cultivation practices for irrigated *Amorphophallus*

Observation on yield of *Amorphophallus* showed that corm weight was greatly influenced by irrigation levels, mulching and spacing. Corm yield was lowest once in 3 days irrigated plot (18.40 t ha^{-1}). Moisture stress has resulted in yield reduction in *Amorphophallus*. Mulching greatly influences yield of *Amorphophallus*, weight of corms in leaf mulched plot was higher than plastic mulched and no mulched plot. Yield in leaf mulched plot was 26.39 t ha^{-1} while in plastic mulched and no mulched plots were 16.94 and 18.40 t ha^{-1}. Yield of the crop was not significantly influenced by spacing. Though not significant, yield was higher in 75 cm x 75 cm spaced plot. Interaction effect of irrigation, mulching and spacing showed that yield was highest in alternate day irrigated plot with 90 cm x 90 cm spacing and leaf mulching.

Effect of treatments on water productivity and B:C ratio showed that leaf mulching of the crop field have significant effect (Table 6.5.1). In leaf mulched plot water productivity in 2016 was 2.03 while it was only 1.85 and 0.89 in 2017 and 2018. Similarly B:C ratio was highest for leaf mulched plot followed by no mulch and plastic mulch plot. Generally yield of the crop was highest in daily irrigated plot, but in 2017 the plots which were irrigated daily were infected by leaf blight disease, so yield reduced.

Pooled data for the three years (Table 6.5.1) showed that mulching had significant effect on the yield and B:C ratio and it was highest with leaf mulched plot in *Amorphophallus*. Plastic mulching had significant effect on weed control but the yield was lower than that of leaf mulched plot. B:C ratio was the lowest in plastic mulched plot due to the high cost of plastic mulch. No significant influence of plant population was observed on crop yield. B:C ratio was significantly higher in the spacing of 90 cm x 90 cm. Experiment showed that irrigation at a frequency of once in three days at a spacing of 90x90 cm along with leaf mulching can increase the yield, water productivity and effectively control weed population.

Table 6.5.1. Performance of *Amorphophallus* crop under different irrigation levels, mulching and plant spacing

Treatment	2016			2017			2018			Pooled yield (t ha^{-1})	B:C raio
	Yield (t ha^{-1})	WP (kg m^{-3})	B:C ratio	Yield (t ha^{-1})	WP (kg m^{-3})	B:C ratio	Yield (t ha^{-1})	WP (kg m^{-3})	B:C ratio		
Irrigation levels (I)											
Daily (I_1)	24.28	1.21	0.90	30.41	1.03	1.18	22.70	0.72	0.89	25.80	0.99
Alternate days (I_2)	25.22	1.43	0.96	40.97	1.51	1.57	20.62	0.70	0.79	28.94	1.10
Once in 3 days (I_3)	21.02	1.26	0.79	40.90	1.51	1.48	18.40	0.64	0.72	26.37	0.99
CD (0.05)	10.25	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Mulching (M)											
No Mulch- M_1	14.42	0.80	0.64	26.87	0.93	1.18	18.40	0.61	0.84	19.50	0.88
Plastic Mulch- M_2	19.18	1.06	0.56	34.37	1.26	1.01	16.94	0.57	0.50	23.50	0.69
Leaf Mulch- M_3	36.92	2.03	1.43	51.04	1.85	2.04	26.38	0.89	1.06	38.11	1.50
CD (0.05)	10.70	0.60	0.43	12.70	0.50	0.58	NS	NS	0.45	6.22	0.25
Plant spacing (S)											
S_1- 75 x 75 cm	26.21	1.44	0.92	41.38	1.22	1.14	19.12	0.64	0.66	19.50	0.90
S_2 90 x 90 cm	20.80	1.15	0.84	33.47	1.48	1.68	22.03	0.74	0.94	23.50	1.15
CD (0.05)	8.36	NS	NS	NS	NS	0.47	NS	NS	NS	NS	0.21
Interaction (I x M)											
I_1 x M_1	12.46	0.62	0.53	22.29	0.76	1.02	22.29	0.71	1.02	19.01	0.86
I_1 x M_2	18.21	0.90	0.53	21.66	0.73	0.65	18.75	0.60	0.54	19.54	0.57
I_1 x M_3	42.17	2.09	1.63	47.29	1.60	1.87	27.08	0.86	1.10	38.84	1.53
I_2 x M_1	18.08	1.03	0.81	33.95	1.25	1.56	18.33	0.62	0.83	23.45	1.06
I_2 x M_2	21.17	1.20	0.63	38.54	1.42	1.12	18.54	0.63	0.55	26.08	0.76
I_2 x M_3	36.42	2.07	1.43	50.41	1.86	2.03	25.00	0.85	0.98	37.28	1.48
I_3 x M_1	12.73	0.76	0.60	24.37	0.79	0.96	14.58	0.51	0.67	16.03	0.74

I_3 x M_2	18.16	1.09	0.54	42.91	1.63	1.28	13.54	0.47	0.40	24.87	0.73
I_3 x M_3	32.17	1.93	1.23	55.41	2.10	2.20	27.08	0.95	1.09	38.22	1.51
CD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
I x S											
I_1 x S_1	29.45	1.46	1.03	34.02	0.91	0.94	19.58	0.62	0.67	25.27	0.88
I_1 x S_2	19.11	0.95	0.76	26.80	1.15	1.42	25.83	0.82	1.11	26.32	1.09
I_2 x S_1	25.17	1.43	0.89	44.30	1.39	1.27	21.25	0.72	0.74	28.02	0.97
I_2 x S_2	25.28	1.44	1.02	37.63	1.63	1.88	20.00	0.68	0.83	29.86	1.24
I_3 x S_1	24.02	1.44	0.83	45.83	1.36	1.22	16.52	0.58	0.57	25.50	0.87
I_3 x S_2	18.02	1.08	0.75	35.97	1.65	1.75	20.27	0.71	0.87	27.25	1.12
CD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
M x S											
M_1 x S_1	17.11	0.93	0.70	31.66	0.80	0.90	17.08	0.57	0.70	18.75	0.76
M_1 x S_2	11.74	0.67	0.59	22.08	1.06	1.46	19.72	0.66	0.99	20.24	1.01
M_2 x S_1	18.41	1.02	0.51	34.72	1.25	0.94	18.88	0.63	0.52	23.77	0.65
M_2 x S_2	19.95	1.11	0.63	34.02	1.27	1.09	15.00	0.50	0.47	23.22	0.73
M_3 x S_1	43.11	2.38	1.55	57.78	1.61	1.59	21.38	0.72	0.77	36.27	1.30
M_3 x S_2	30.73	1.68	1.32	44.30	2.10	2.48	31.38	1.05	1.35	39.96	1.71
CD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
I x M x S											
I_1 x M_1 x S_1	20.42	1.01	0.83	25.00	0.66	0.80	19.58	0.62	0.80	19.86	0.81
I_1 x M_1 x S_2	4.50	0.22	0.22	19.58	0.85	1.24	25.00	0.80	1.24	18.16	0.90
I_1 x M_2 x S_1	19.08	0.95	0.52	25.83	0.59	0.48	22.91	0.73	0.63	19.83	0.54
I_1 x M_2 x S_2	17.33	0.86	0.54	17.50	0.88	0.81	14.58	0.46	0.46	19.25	0.60
I_1 x M_3 x S_1	48.84	2.42	1.75	51.25	1.47	1.55	16.25	0.52	0.58	36.14	1.29
I_1 x M_3 x S_2	35.50	1.76	1.52	43.33	1.74	2.19	37.91	1.21	1.61	41.55	1.78
I_2 x M_1 x S_1	21.33	1.21	0.87	38.75	1.07	1.19	18.33	0.62	0.75	22.94	0.93
I_2 x M_1 x S_2	14.83	0.84	0.74	29.16	1.43	1.94	18.33	0.62	0.92	23.97	1.20
I_2 x M_2 x S_1	16.83	0.96	0.46	30.41	1.72	1.28	18.33	0.624	0.50	27.27	0.75
I_2 x M_2 x S_2	25.50	1.45	0.80	46.66	1.12	0.96	18.75	0.64	0.59	24.89	0.78
I_2 x M_3 x S_1	37.34	2.12	1.34	63.75	1.37	1.33	27.08	0.92	0.97	33.83	1.22
I_3 x M_3 x S_2	35.50	2.02	1.52	37.08	2.35	2.74	22.91	0.78	0.98	40.72	1.75
I_3 x M_1 x S_1	8.55	0.57	0.39	31.25	0.66	0.71	13.33	0.46	0.55	13.47	0.55
I_3 x M_1 x S_2	7.08	0.95	0.80	17.50	0.91	1.21	15.83	0.55	0.80	18.60	0.93
I_3 x M_2 x S_1	12.96	1.16	0.53	47.91	1.44	1.05	15.41	0.54	0.43	24.21	0.67

I_3 x M_2 x S_2	8.55	1.02	0.54	37.91	1.82	1.51	11.66	0.41	0.36	25.53	0.81
I_3 x M_3 x S_1	27.83	2.58	1.55	58.33	1.99	1.89	20.83	0.73	0.75	38.83	1.40
I_3 x M_3 x S_2	8.59	1.27	0.91	52.50	2.21	2.51	33.33	1.16	1.44	37.61	1.62
CD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

6.5.2. Soil nutrient dynamics under varying moisture regimes in banana

The experiment was conducted for three years (2016 to 2018) to study the soil moisture status and nutrient uptake pattern of Nendran banana and changes in physical and chemical properties of soil under drip fertigation. Statistical analysis of the pooled data showed that yield of the crop was not significantly affected by dose of fertilizer or mulching of the crop field or source of fertilizer (Table 6.5.2). Fertilizer level could be reduced to 75% by fertigation. Both common fertilizers and water soluble high priced fertilizers performed similar which shows that cheap source of fertilizer like common fertilizers are better. Interaction effect showed that plastic mulching along with 75% RDF gave more yield per plant which was on par with application of 100% RDF without mulch. Similarly mulching along with common fertilizer gave highest yield which was on par with application of liquid fertilizer and without mulching. Interaction effect of three factors showed that yield was highest with plastic mulching of the field with application of common fertilizer at 75% RDF. Studies on economics and B:C ratio (2.40) showed that cultivation of Nendran banana crop is profitable with fertigation using common fertilizer and planting in non-mulched situation.

Study on soil nutrient dynamics under varying moisture regimes in banana under open field precision farming conditions showed that fertilizer level could be reduced to 75% by fertigation. Both common fertilizers and water soluble high priced fertilizers performed similar which shows that cheap source of fertilizer like common fertilizers are better. Yield was significantly higher under non-mulched situation. The effect of mulching though not significant in terms of yield was found effective in terms of weed population. Studies on economics and B:C ratio (2.40) showed that cultivation of Nendran banana crop is profitable with fertigation using common fertilizer and planting in non-mulched situation.

Table 6.5.2. Performance of banana crop and soil nutrient status at different growth stages (Pooled data)

Treatment	Yield (t ha^{-1})	B:C ratio	Nutrient in soil		
			N (kg ha^{-1})	P (kg ha^{-1})	K (kg ha^{-1})
Dose of nutrient					
D_1-125% RDF	20.89	1.52	454.72	294.97	745.71
D_2-100% RDF	20.49	1.56	407.68	418.92	567.65
D_3-75% RDF	21.30	1.76	423.36	430.81	531.53
CD (0.05)	NS	0.11	NS	NS	NS
Mulching					
M_0-No mulch	20.76	1.86	418.13	395.27	554.08
M_1-Plastic mulch	21.03	1.37	439.04	367.86	675.85
CD (0.05)	NS	0.09	NS	NS	NS
Source of fertilizer*					
S_1-Common	20.56	1.90	439.04	409.86	582.38
S_2-Water soluble	21.23	1.33	418.13	353.27	647.55
CD (0.05)	NS	0.09	NS	NS	NS

Interaction effect					
D_1M_0	20.81	1.74	470.40	310.13	649.44
D_1M_1	20.98	1.29	439.04	279.80	841.98
D_2M_0	20.11	1.78	376.32	427.04	537.40
D_2M_1	20.88	1.35	439.04	410.80	597.91
D_3M_0	21.36	2.06	407.68	448.63	475.41
D_3M_1	21.24	1.47	439.04	412.99	587.66
CD(0.05)	7.12	NS	NS	NS	NS
D_1S_1	20.83	1.86	501.76	298.25	874.76
D_1S_2	20.96	1.17	407.68	291.68	616.67
D_2S_1	19.53	1.80	439.04	428.92	465.94
D_2S_2	21.46	1.33	376.32	408.93	669.36
D_3S_1	21.33	2.04	376.32	502.40	406.44
D_3S_2	21.28	1.48	470.40	359.21	656.62
CD (0.05)	NS	NS	NS	NS	NS
M_0S_1	20.49	2.24	439.04	451.64	567.84
M_0S_2	21.02	1.48	397.22	338.89	540.32
M_1S_1	20.63	1.57	439.04	368.07	596.92
M_1S_2	21.44	1.17	439.04	367.65	754.78
CD (0.05)	NS	0.13	NS	NS	NS
Treatment combination					
$D_1M_0S_1$	21.16	2.21	533.12	335.14	850.32
$D_1M_0S_2$	20.46	1.27	407.68	285.12	448.56
$D_1M_1S_1$	20.51	1.51	470.40	261.36	899.19
$D_1M_1S_2$	21.45	1.07	407.68	298.25	784.78
$D_2M_0S_1$	19.35	2.11	407.68	448.91	411.14
$D_2M_0S_2$	20.86	1.45	344.96	405.18	663.65
$D_2M_1S_1$	19.71	1.5	470.40	408.92	520.74
$D_2M_1S_2$	22.05	1.20	407.68	412.68	675.08
$D_3M_0S_1$	20.97	2.39	376.32	570.87	442.06
$D_3M_0S_2$	21.75	1.72	439.04	326.39	508.76
$D_3M_1S_1$	21.68	1.70	376.32	433.94	370.82
$D_3M_1S_2$	20.80	1.25	501.76	392.04	804.49
CD (0.05)	10.06	0.231	NS	NS	NS

* RDF-190-115-300 g NPK per plant

Source of fertilizer: S_1- Urea, Mono Ammonium Phosphate (MAP), Muriate of Potash, S_2- 19:19:19, 12-61-0 (MAP), 13:0:45

6.6. Chiplima

6.6.1. Irrigation and micronutrient interaction study in aerobic rice

Field trial was conducted to study the effect and interaction of micronutrients and irrigation on rice yield and soil health. Different irrigation schedules and fertilizer-micronutrient combinations were applied to aerobic rive variety Pyari (CR Dhan 200). Results showed that irrigation scheduling recorded significantly higher yield attributing characters such as ear bearing tillers per square metre, panicle length and number of filled grains per panicle over all other treatments. Irrigation scheduled after 3 rainless days recorded higher number of ear bearing tillers (277.78), which was at par with Irrigation scheduled after 5 rainless days (280.42). The former treatment also resulted in higher panicle length (24.56 cm), filled grains per panicle (111.68) and test weight (25.26 g) over all other treatments. Among the fertilizer-micronutrient treatments, RDF (80-40-40) + 5 kg Zn ha^{-1} + 0.2% B as foliar spray (2 nos.) recorded significantly higher number of ear bearing tillers (301.04) over other treatments. It also recorded higher panicle length (24.29 cm), number of filled grains per panicle (117.96) and test weight (26.07 g) which were at par with RDF (80-40-40) + 2.5 kg ha^{-1} Zn + 0.2% B as foliar spray (2 nos.) (24.24, 114.70 and 25.90 g).

Table 6.6.1. Effect of irrigation and micronutrient levels on yield and water use efficiency of aerobic rice

Treatment	Grain yield (t ha^{-1})	Water requirement (mm)	Water productivity (kg m^{-3})
Irrigation scheduling			
I_1: Irrigation after 3 rainless days	4.26	869.67	0.49
I_2: Irrigation after 5 rainless days	4.03	642.70	0.63
I_3: Irrigation after 7 rainless days	3.70	592.75	0.62
I_4: Rainfed condition	3.56	542.84	0.65
CD (P = 0.05)	0.19		
Micronutrient level			
N_1: RDF (80-40-40)	3.33	667.70	0.50
N_2: RDF (80-40-40) + 5 kg ha^{-1} Zn + 0.2% B as foliar spray (2 nos.)	4.23	667.70	0.63
N_3: RDF (80-40-40) +5 kg ha^{-1} Zn	3.90	667.70	0.58
N_4: RDF (80-40-40) + 2.5 kg ha^{-1} Zn + 0.2% B as foliar spray (2 nos.)	4.12	667.70	0.62
N_5: RDF (80-40-40) + 2.5 kg Zn ha^{-1}	3.97	667.70	0.59
N_6: RDF (80-40-40) + 0.2% B as foliar spray (2 nos.)	3.76	667.70	0.56
CD (P = 0.05)	0.29		

RDF-Recommended dose of fertilizer

Effect of Micronutrient (Zinc and Boron): Effect of Zinc and Boron on grain yield was studied irrespective of irrigation treatment. Data revealed that the treatment RDF (80-40-40) with 5 kg ha^{-1} Zn + 0.2 % B as foliar spray (2 nos.) obtained highest grain yield of 4.23 t ha^{-1} over all other treatments but it was at par with RDF (80-40-40) with 2.5 kg ha^{-1} Zn + 0.2% B as foliar spray (2 nos.) (4.12 t ha^{-1}).

Water Requirement (WR) and Water Productivity (WP): Water requirement and water use efficiency for different irrigation treatments are presented in the Table 6.6.1. Highest water requirement of 869.67 mm was observed with Irrigation after 3 rainless days, whereas lowest value of 542.8 mm observed in rainfed condition. Water productivity was highest under rainfed condition (0.65 kg m^{-3}), whereas lowest WP with Irrigation after 3 rainless days (0.49 kg m^{-3}).

6.7. Pantnagar

6.7.1. Effect of moisture conservation practices in relation to irrigation on direct seeded rice

The study was conducted from 2016 to 2018 with rice variety Narendra-359. Mean rice grain yield data over three years have been presented in Table 6.7.1. Rice grain yield was not influenced significantly by irrigation levels. All the moisture management practices showed their positive impact on rice grain yield and produced higher rice grain yield than control. Application of vermicompost @ 7.5 t ha^{-1} produced the maximum rice grain yield (5.29 t ha^{-1}). It was comparable with vermicompost @ 5.0 t ha^{-1} and conoweeding treatments. Vermicompost @ 7.5 t ha^{-1} produced 13.2% higher grain yield than control. Crop irrigated at 30 mm CPE level recorded 87.1% higher irrigation WUE than 15 mm CPE level. Among the moisture management practices, vermicompost (VC) application @ 7.5 t ha^{-1} recorded highest irrigation WUE (18.64 kg ha-mm^{-1}) followed by VC mulch 5 t ha^{-1} treatment (18.22 kg ha-mm^{-1}). Net return and B:C was not significantly affected by irrigation levels. Rice irrigated at 15 mm CPE level gave ₹ 659 higher net return than 30 mm CPE level. B:C ratio was higher by 8.3 % with 30 mm CPE level than 15 mm CPE level. Direct seeding of rice at 25 cm row spacing and followed by conoweeding at 30 and 45 DAS gave the maximum net return (₹ 57018 ha^{-1}) and also recorded the maximum B:C ratio (1.46). Vermicompost treatment was not cost effective because of its higher purchasing cost.

Inferences drawn based on the findings are as follows:

- Direct seeding of rice in a sandy loam soil during a season having good rainfall can be irrigated at 30 mm CPE (5-6 days interval).
- Vermicompost @ 5.0 and 7.5 t ha^{-1} were the most productive and irrigation water efficient but not the economically viable because of its higher cost.
- Direct seeding of rice at 25 cm along with twice conoweeding at 30 and 45 DAS was the most profitable option. This can be advocated as it was equally effective with vermi-compost treatment for productivity as well as irrigation water use efficiency.

Table 6.7.1. Performance of direct seeded rice under different irrigation levels and moisture conservation practices

Treatment	Grain yield (t ha^{-1})				Irrigation WUE (kg ha-mm^{-1})				Net return (₹ ha^{-1})	B:C ratio
	2016	2017	2018	Mean	2016	2017	2018	Mean		
Irrigation level										
15 mm CPE	3.59	5.36	6.13	5.03	5.47	26.80	10.22	14.16	47922	1.08
30 mm CPE	4.10	5.11	5.84	5.02	8.97	51.07	19.46	26.50	47263	1.17
CD 5%	0.24	0.16	NS	NS	-	-	-	-	NS	NS
Moisture conservation practice										
Control	3.54	4.81	5.68	4.67	4.56	32.07	12.61	16.43	50758	1.40
APSA -80	4.09	5.14	5.70	4.97	5.28	34.24	12.65	17.39	51903	1.37
Conoweeding	3.66	5.26	6.28	5.06	4.72	35.05	13.96	17.91	57018	1.46
VC mulch 5 t ha^{-1}	3.86	5.46	5.98	5.10	4.97	36.41	13.29	18.22	41389	0.77
VC mulch 7.5 t ha^{-1}	4.09	5.50	6.29	5.29	5.27	36.67	13.98	18.64	36906	0.60
CD 5%	0.26	0.35	0.50	0.19	-	-	-	-	4314	0.11

Irrigation water required for 15 mm CPE during 2016, 2017 & 2018 = 750, 200 & 600 mm; Irrigation water required for 15 mm CPE during 2016, 2017 & 2018 = 400, 100 & 300 mm

6.8. Shillong

6.8.1. Residue management and conservation tillage in rice-based system

The study was conducted for a period of eight years (2009-2017) to evaluate the effect of tillage and residue management in rice based cropping system for increased production and resource conservation with crops rice (cv. Shahsarang 1) during *kharif* season and buckwheat, pea, toria (M-27) during *rabi* season. Tillage treatments included conventional tillage (residue removal), zero tillage for all crops (residue retention), zero tillage for *rabi* crop (residue retention) and reduced tillage (residue incorporation). Results showed that zero tillage in rice followed by buckwheat, toria and pea resulted in significantly higher grain yield as well as WUE in all the crops over other treatments. Plot of production function (Fig. 6.8.1) revealed that there was continuous increase of grain yield of rice during 2009-2017 and yield was in the range of 5.5-7.0 t ha^{-1} in most of the years. Average WUE of pea was highest (76.9 kg mm-ha^{-1}) followed by buckwheat (24.2 kg mm-ha^{-1}) and toria (20.1 kg mm-ha^{-1}) under zero tillage and were significantly higher than the conventionally tilled crops. Zero tillage resulted in build up of soil organic carbon (0-15 cm soil) by 12% (1.62%) at the end of the experiment period over base value of 1.45% as on 2009 (Fig. 6.8.2). At the same time conventionally tilled soils recorded 34% reduction in soil organic carbon over 2009 base value. Under zero tillage, the crops recorded higher B:C ratio and yield enhancement over conventionally tilled crops. Among different crops, pea recorded highest B:C ratio of 1.9 followed by buckwheat (1.43), rice (1.27) and toria (1.19). ZT-Rice followed by pea is the best combination that can be recommended.

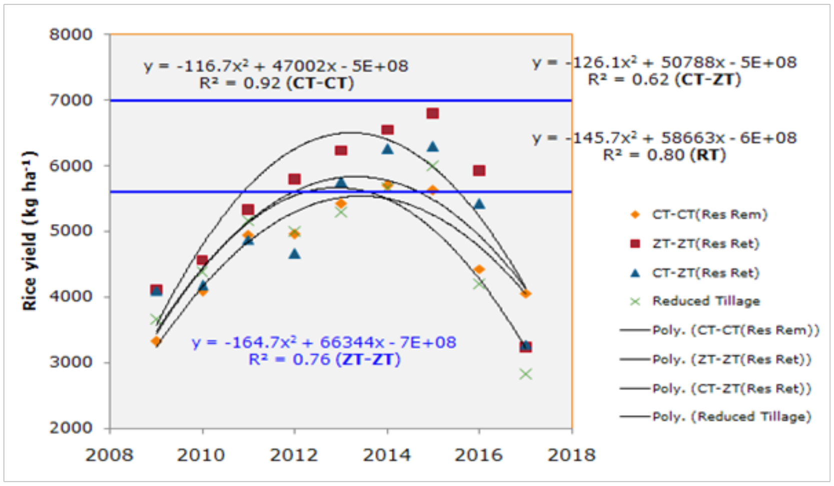

Fig. 6.8.1. Production function of rice under different tillage treatments (2009-17). CT: Conventional tillage, ZT: Zero tillage, Res Rem: Residue removal, Res Ret: Residue retention

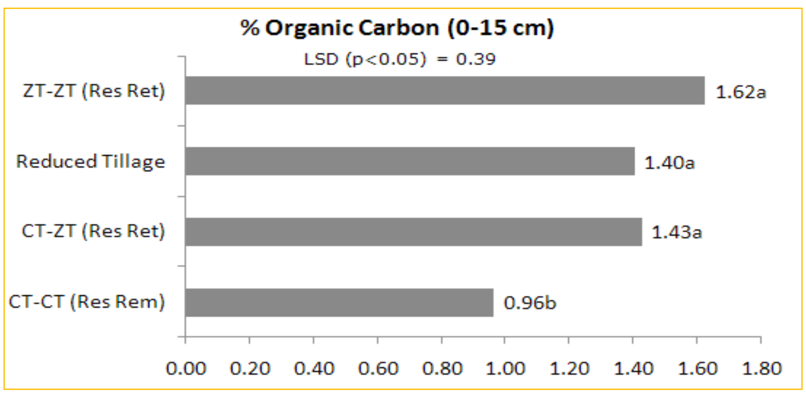

Fig. 6.8.2. Status of soil organic carbon (%) at the end of experiment period (2017) (Base organic carbon value was 1.45% at 2009)

6.8.2. Resource conservation practices in lowland rice cropping system for enhanced productivity and water use efficiency

The study was conducted during 2014-2017 to assess different tillage practices and planting methods under lowland rice cropping system on growth and yield of rice during *kharif* and to study the influence of different tillage practices on the succeeding *rabi* crops. Treatments during kharif season included tillage and planting methods *viz.*, Puddled Transplanted (PT), Unpuddled Transplanted (UPT), Puddled Wet Seeding (PWS), Unpuddled Wet Seeding (UPWS) and No Tillage (NT); while treatments during rabi season included mulch and no mulch. Results showed that puddled transplanted rice produced higher yield over other methods of tillage/seedling establishment methods (Table 6.8.2), which is 45% higher over no tillage. However, if No tillage followed in rice field followed by *rabi* lentil (with straw mulch) ensured 11% higher yield and 30% higher WUE over puddled transplanted rice (Table 6.8.2). Thus, it was concluded that from pulse production point of view best option is 'No tilled rice followed by straw mulched lentil'.

Table 6.8.2. Performance of rice (cv. Shahsarang 1) and lentil crops under resource conservation practices and planting methods

Treatment	Rice		Lentil			
	Grain yield (t ha^{-1})	WUE (kg mm-ha^{-1})	Seed yield (t ha^{-1})		WUE (kg mm-ha^{-1})	
			Mulch	No mulch	Mulch	No mulch
Puddled transplanted	3.83a	6.4a	1.07b	1.18b	15.3b	17.0b
No tillage	2.64b	4.4b	1.38a	0.81h	19.9a	11.6h
CD (0.05)	0.39	0.65	-	-	-	-

6.8.3. Effect of manures and straw mulching on turmeric under terrace condition

The experiment was conducted during 2014-2017 to evaluate the most suitable manure along with straw mulch for higher productivity of turmeric (cv. Lakadong) and better soil moisture conservation under terrace condition. Results showed that FYM + Straw mulch (@ 5 t ha^{-1} each) recorded 177% higher rhizome yield (10.15 t ha^{-1}) and 72% higher WUE (10.9 kg mm-ha^{-1}) (Table 6.8.3) with a B:C ratio of 1.43. It was recommended to grow turmeric with FYM + Straw mulch (@ 5 t ha^{-1} each).

Table 6.8.3. Effect of manures and straw mulch on yield & WUE of turmeric

Treatment	Rhizome yield (t ha^{-1})	WUE (kg mm-ha^{-1})
Control	3.67e	3.9e
Pig manure + Straw mulch (@ 5 t ha^{-1} each)	8.96ab	9.7ab
FYM + Straw mulch (@ 5 t ha^{-1} each)	10.15a	10.9a
CD (0.05)	2.10	2.27

6.8.4. Effect of *in situ* residue management on carry over soil moisture conservation and crop growth under hill agriculture

The experiment was conducted 2006-2017 to develop simple and low cost technique for *in situ* moisture conservation for the second crop during winter season. Treatments included two different tillage practices combined with intercrop/ residue management/manure treatments. Results revealed that tillage combined with residue management practices in toria (cv. M-27) had significant positive effect on succeeding maize (DA 61-A). Maize stalk cover (MSC) + Poultry Manure + *Ambrosia* (an weed sp.) @ 5 t ha^{-1}, was found as the best residue management option for both toria and maize (81 & 34% yield increase over control, respectively) (Table 6.8.4). Zero tilled maize followed by toria (MSC+Poultry manure+*Ambrosia* recorded B:C ratio of 2.62 and 1.18, respectively. Tillage and residue management practices also have influence on soil organic carbon content. Zero tillage combined with maize stalk cover, poultry manure and *Ambrosia* @ 5 t ha^{-1} recorded 36.2% increase in organic carbon content (1.88%) of 0-15 cm soil over 2006 status (1.38%). Whereas, there was 21% reduction in organic carbon content in conventionally tilled soils in 12 years time (Fig. 6.8.4). Thus zero tillage combined with the use of maize stalk cover, poultry manure and *Ambrosia* sp. in maize-toria system was recommended.

Table 6.8.4. Performance of maize and succeeding toria as influenced by tillage and residue management practices

Treatment	Maize	Toria	
	Grain yield (t ha^{-1})	Seed yield (t ha^{-1})	WUE (Toria) (kg mm-ha^{-1})
Tillage			
Zero tillage (ZT)	5.80	0.76	4.1
Conventional tillage (CT)	5.54	0.94	3.3
CD (0.05)	NS	NS	NS
Residue management			
Control	4.88c	0.69b	3.0b
MSC + *Ambrosia* @ 5 t ha^{-1}	5.89ab	0.86b	3.8b
MSC + *Ambrosia* @10 t ha^{-1}	5.64bc	0.80b	3.5b
MSC + Poultry manure + *Ambrosia* @ 5 t ha^{-1}	6.55a (ZT)	1.25a (CT)	5.5a
CD (0.05)	0.49	0.22	0.97

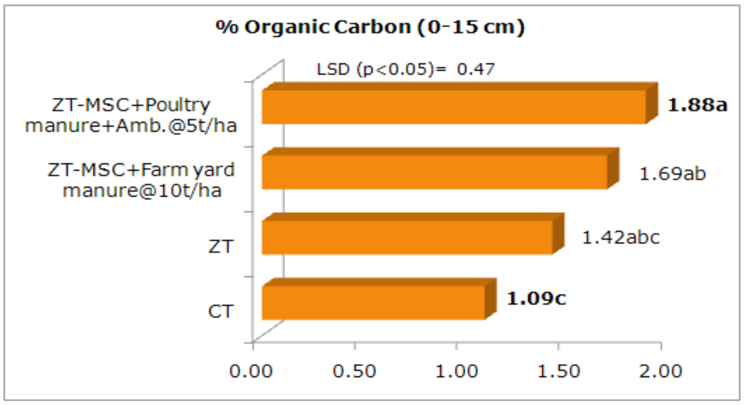

Fig. 6.8.4. Effect of tillage & residue management on soil organic carbon content

6.8.5. Evaluation of resources conserving option on productivity and water use efficiency (WUE) of maize-toria cropping system under terrace condition

The experiment was conducted during 2010-2017 with an objective to find out water efficient maize based cropping system for terrace condition. Results revealed that yields of maize and succeeding toria as influenced by tillage and intercropping/residue management (Table 6.8.5). Toria performed well under conventional tillage (maize) with residue retention in *rabi* season. However, zero tilled maize intercropped with groundnut paired row recorded highest B:C ratio of 1.68 and yield enhancement by 33%. Zero tilled maize intercropped with two rows of groundnut was recommended.

Table 6.8.5. Performance of maize and succeeding toria as influenced by tillage and intercropping/residue management

Treatment	Maize		Toria	
	Grain yield (t ha^{-1})	MEY (t ha^{-1})	Grain yield (t ha^{-1})	WUE (kg mm-ha^{-1})
Tillage				
Zero tillage (ZT)	-	6.10	0.52	3.3
Conventional tillage (CT)	-	5.97	0.74	2.3
CD (0.05)	-	NS	NS	NS
Intercrop/ Residue management				
Maize sole (Res. Rem)	5.41bc (CT)	-	0.64	2.8
Maize sole (Res. Retn)	6.17b (ZT)	-	0.74 (CT)	3.3
Maize + groundnut paired row (Res. Rem)	-	6.27b (ZT)	0.65	2.8
Maize + groundnut paired row (Res. Retn)	-	7.18a (ZT)	0.53	2.3
CD (0.05)	0.75		NS	NS

MEY-Maize equivalent yield

6.9. Jorhat

6.9.1. Effect of crop geometry and dates of planting on growth and yield of makhana (*Euryale ferox* Salisb)

The experiment was conducted to explore possibilities of enhancing wetland productivity through cultivation of makhana. The effect of crop spacing on seed yield of makhana was significant with maximum seed yield of 2.51 t ha^{-1} obtained with spacing of 125 cm x 120 cm. Seed yield of makhana decreased with increase in crop spacing from 125 cm x 120 cm (Table 6.9.1). Dates of planting also had significant effect on seed yield. Planting of makhana on 30th March recorded significantly higher seed yield (2.53 t ha^{-1}) and water productivity (0.87 t ha^{-1}) than that of other planting dates. Net return and B:C ratio of makhana crop were the highest at spacing 125 cm x 120 cm and date of planting March 30.

Table 6.9.1. Performance of makhana crop under different plant spacings and dates of planting

Treatment	Seed yield (t ha^{-1})				Water productivity (kg m^{-3})				Net return (₹ ha^{-1})	B:C ratio
	2016-17	2017-18	2018-19	Pooled	2016-17	2017-18	2018-19	Pooled		
Spacing (cm x cm)										
S_1:120x100	2.23	2.28	2.26	2.26	-	-	-	-	49,550	2.68
S_1:125x120	2.55	2.66	2.32	2.51	-	-	-	-	58,870	3.04
S_1:150x120	2.23	2.09	2.09	2.14	-	-	-	-	46,341	2.63
S_1:175x120	2.21	1.98	1.95	2.05	-	-	-	-	43,805	2.56
CD(P=0.05)	0.94	1.73	0.93	0.49	-	-	-	-	-	-
Date of planting										
D_1:15 Mar	2.29	2.20	2.18	2.22	0.845	0.812	0.754	0.804	48,860	2.69
D_1:30 Mar	2.58	2.51	2.49	2.53	0.892	0.885	0.835	0.870	59,535	3.05
D_1:15 Apr	2.26	2.23	2.22	2.24	0.805	0.840	0.816	0.821	49,315	2.70
D_1:30Apr	2.08	2.05	2.06	2.06	0.703	0.712	0.802	0.739	43,295	2.49
CD(P=0.05)	0.33	0.60	0.32	0.17	-	-	-	-	-	-
	0.94	1.73	0.93	0.49	-	-	-	-	-	-

Chapter 7

Conjunctive Use and Multiple Use of Water

7.1. Pantnagar

7.1.1. Conjunctive use of surface and groundwater in the Tumaria extension main canal command of Udham Singh Nagar district of Uttarakhand

The study of conjunctive use of surface water and groundwater was conducted in the Tumaria extension canal command of Udham Singh Nagar district of Uttarakhand. There are two distributaries and fourteen minors in the command. The length of the main canal, branch canal, and total length of canals of the study area are 10713, 25214 and 35927 m, respectively. The CCA of canal command is 14070 ha. Development and application of linear and non-linear programming (NLP) models was done for the seasonal optimal allocation of resources to maximize the annual return. Total 11 crops were included in the optimization plans. Two proposed plans were (1) Plan 1: the crop-wise proposed area of all crops in the command was less than or equal to existing area of a crop except fodder crops which was equal to existing crop area under that fodder crops in command, and (2) Plan 2: the crop-wise proposed area of major crops in the command was greater than or equal to the area required for the production of food for minimum consumption for population in the command while the crop-wise proposed area of fodder and vegetable crops were equal to existing area of a crop in the command; the crop-wise proposed area of minor crops in this Plan 2 was less than or equal to the area required for the production of food for minimum consumption for population in the command.

On the basis of the study the following results were observed:

A) Status of water resources:

1. The last five years average of net recharge, net discharge and net draft through minor irrigation structures of the command for irrigation were 5018.21 ha-m, 3934.16 ha-m and 3594.24 ha-m respectively. The average groundwater potential of the canal command was 78.38 percent.

2. The total canal water available in a year at field outlet was 1715.59 ha-m. The groundwater draft for irrigation through minor irrigation structures in a year was 3594.24 ha-m. The total annual irrigation water requirement

for exiting cropping pattern was 11237.39 ha-m, and the total groundwater demand was 9533.25 ha-m. The deficit of water for irrigation was estimated to be 5939.01 ha-m in the Tumaria canal command.

3. It was concluded that in the Tumaria canal command sufficient surface and groundwaters were not available as per existing demand for irrigation in the canal command and the additional groundwater or surface water are required to sustain crop production in the canal command. It was also observed that presently the crops in this command are being grown in water stressed condition and thus not giving potential yields.

4. Five year average of additional water available for irrigation up to the critical stage of groundwater utilization was estimated to be 536.96 ha-m. The total allowable groundwater available for irrigation at 0%, 50 % and 100% of this additional water was 3594.24 ha-m, 3862.72 ha-m and 4131.20 ha-m, respectively. These allowable available groundwater values were used in the linear and non linear optimization models for calculating the optimal crop plans.

B) Optimal Crop Plans using Linear /nonlinear Techniques

5. The maximum net return of ₹ 99145 per ha was for sugarcane crop and minimum return of ₹ 9758 per ha was for lentil crop. The total net return, for existing cropping pattern and cropped area, in the command was estimated to be ₹ 914.3 million.

6. In case of optimal crop Plan-1, using linear programming technique (without summer rice) on weekly basis, the allocation of sown area with 100% of additional groundwater was wheat (9926.85 ha), pea (309.16 ha), sugarcane (1243.33 ha), rice (1087.07 ha), maize (1.65 ha) and *urad* (110.37 ha). The net return in this plan was observed as ₹ 547.6 million which was 48.2 million more than the net return from Plan-1 using existing level of water resources.

7. The area allocated under different crops in plan-2 using linear programming technique with 100% use of additional water use corresponding to semi critical stage was wheat (9533.88 ha), lentil (139.2 ha), pea (665.7 ha), mustard (418.46 ha), potato (77.69 ha), rice (3243.32 ha), maize (1.65 ha), *urad* (237.66 ha), soyabean (639.26) and sugarcane (540.39 ha). The optimal crop plan for this case resulted in annual net return of ₹ 526.9 million as compared to ₹ 468.7 million with existing development stage.

8. The best optimal plan was observed as plan-1 using linear programming technique with 100% of addition groundwater and net return was observed as 547.6 million. It was observed that large area of this command is either fallow or rainfed in all seasons due to lack of water resourses. Therefore, change in cropping pattern in the command is required to restore the groundwater potential level.

9. The best plan was observed as Plan-2 using non-linear programming technique (without summer rice) with 100 percent of additional available groundwater. The optimal crop Plan 2 (without summer rice); was wheat, lentil, pea, mustard, sugarcane, potato, *kharif* rice, maize, *urad*, and soybean occupying 12949.90 ha, 87.67 ha, 550.80 ha, 226.63 ha, 182.41 ha, 72.59 ha, 4254.54 ha, 1.35 ha, 269.63 ha, and 635.50 ha, respectively. The net return of this plan was found to be ₹ 708.36 million which was ₹ 208.91 million more than the crop plan-1 (without summer rice) with available groundwater corresponding to existing development stage using linear programming.

7.2. Udaipur

7.2.1. Study on effect of industrial effluent / wastewater on groundwater pollution

Heavy metal contamination due to the industrial effluent in groundwater as well as soil is a major problem in Southern part of Upper Berach river basin. The total 33.26 km^2 area is selected for study on effect of industrial effluent in groundwater. For analyzing the heavy metal in groundwater and soil, groundwater samples and soil samples were collected in sampling bottles and polythene bags respectively by dividing the entire area into 56 systematic grids (1 km x 1 km) as shown in Fig. 7.2.1. The water samples were collected from 38 sites as shown in the figure. The locations of wells were recorded with help of global positioning system (GPS). The samples were analyzed with the help of

Atomic Absorption Spectrophotometer (AAS) to find out the concentrations of different heavy metals such as Iron (Fe), Manganese (Mn), Copper (Cu), Zinc (Zn), Cadmium (Cd), Lead (Pb) and Nickel (Ni). Based on the results of the analysis the different heavy metal map of southern part of Upper Bearch river basin was prepared under GIS environment using IDW technique. Correlation coefficient (r) analysis was performed among seven heavy metals in groundwater and soil namely Cu, Ni, Zn, Mn, Cd, Fe and Pb. The strong positive correlation was found between Ni-Zn, Cd-Pb, Zn-Cd, Zn-Pb in water sample and Cd-Pb, Zn-Ni and Zn-Pb in soil samples.

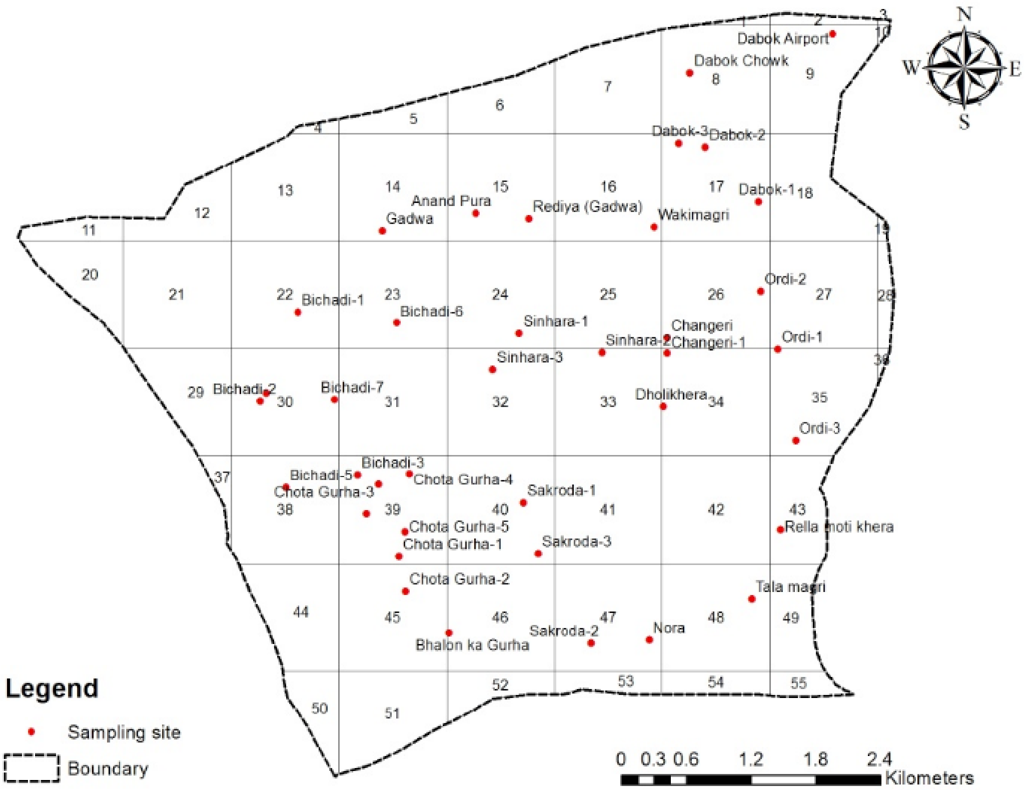

Fig. 7.2.1. Grid map and location map of sample sites

7.3. Rahuri

7.3.1. Conjunctive use planning of surface and groundwater in Musalwadi minor irrigation project under Mula Irrigation Project

The conceptual model for the conjunctive use of surface water and groundwater in a irrigation command area was developed by integrating SWAB-CRYB simulation model and Genetic Algorithm (GA) model considering the uncertainty in the weather parameters. The uncertainty is included in the model by using ISO technique. The Visual Basic Net programming language was used for the development of the model using Visual Studio 2012. The MS Access was used as the data storage tool. The developed conjunctive use model is platform independent and has a simple user interface. The model consists of following modules:

Crop register, Soil register, Weather register, Farm register, Irrigation register for irrigation data input, Canal network register, Aquifer parameter register, Reservoir parameter register, Evaluation mode, Optimization process interface and Result window showing optimized conjunctive use strategy etc.

The developed conjunctive use model was converted into the decision support system for conjunctive use of surface and groundwater (DSS-CUSGW) and applied to the Musalwadi Minor Irrigation Project for testing and validation. The model was applied to the Minor Irrigation Project for *Rabi* (sugarcane, wheat and gram) season for the year 2015-16. The results obtained in respect of optimized conjunctive water use policy, farm wise benefits, crop wise benefits and the net benefits from the command area are presented in Table 7.3.1 and 7.3.2.

Table 7.3.1. Crop wise benefits in minor irrigation project under Mula irrigation project

Crop	Area (ha)	Total water applied (mm)	Surface water (mm)	Groundwater (mm)	Net benefit (₹)
Sugarcane	134.54	190166.83	34773.13	155393.7	10342643.2
Wheat	134.54	44517.91	7250.33	37267.58	5535070.86
Gram	67.26	19819.51	5694.91	14124.6	3911271.84

Table 7.3.2. Command area net benefits of considering penalties with amount required from surface water and groundwater

Strategy ID	Total area (ha)	Total water required (mm)	Surface water required (mm)	Groundwater required (mm)	Total cost (₹)	Total benefit (₹)	Net benefit (₹)	Benefit considering penalty (₹)
8	336.34	254504.3	47718.37	206785.9	38674370	58463356	19788986	19788986

Results indicated that the obtained optimized strategy includes 20 irrigations for simulation period among which 13 irrigations are from surface water and 7 irrigations are from groundwater resulting into ₹ 1,97,88,986 net benefits from 336.34 ha command area. After application of optimum water release policy to irrigated area of 336.34 ha for selected area, total required water was 2,54,504 mm (47,718 mm (19%) surface water and 2,06,786 mm (81%) of groundwater). The crop wise net benefits indicated that the total area under sugarcane was 134.54 ha. The total water applied for sugarcane was 1,90,166 mm (34,773 mm from surface water and 1,55,393 mm from groundwater) from which ₹ 1,03,42,643 net benefits were obtained. For sugarcane crop, total 17 irrigations were applied from which 6 irrigations were from surface water and 11 irrigations from groundwater. The total area under wheat was 134.54 ha. The total water applied for wheat was 44517 mm (7250 mm from surface water and 37267 mm from groundwater) from which ₹ 55,35,070 net benefits were obtained. For wheat crop, total 6 irrigations were applied from which one irrigation was from surface water and 5 irrigations were from groundwater. The total area under gram was 67.26 ha. The total water applied for gram was 19819 mm (5695 mm from surface water and 14124 mm from groundwater) from which ₹ 39,11,271 net benefits were obtained. For gram crop, total 6 irrigations were applied from which 2 irrigations were from surface water and 4 irrigations were from groundwater.

Chapter 8

Operational Research Project (ORP)

Faizabad

1. Improvement of water management practice in wheat at head, middle and tail ends of Chandpur distributory during *rabi* season

Improved water management practice in wheat was tested for six consecutive years (2012-2018) in 1000 m^2 area covering field of fifteen farmers at head (Begumganj minor), middle (Daulatpur minor) and tail ends (Kail minor) of Chandpur distributory. Improved water management practice, i.e. 6 cm water applied at critical stages like CRI, late jointing and milking stages through check basin method (5 m x10 m) gave 31.3-33.9% higher grain yield of rice in comparison to farmers' practice (application of 8-10 cm water by flooding/field to field irrigation). Increase in grain yield under improved practice was more at head and tail sections as compared to middle end of the distributory. From head to tail reaches, improved water management practice recorded higher WEE (198.6 to 194.6 kg ha-cm^{-1}) against the farmer's practice (97.0 to 95.0 kg ha-cm^{-1}). The improved practice saved about 34.59% irrigation comapred to farmers' practice, due to which wheat crop may be grown in additional area of 30-35% with the help of canal irrigation in rice-wheat cropping system (Table F1). A high benefit-cost ratio of 2.31-2.45 was obtained in the reaches compared to 1.42-1.51 under farmers' practice.

Table F1. Performance of rice and wheat crops at head, middle and tail ends of Chandpur distributary (2012 to 2018)

Treatment	Head End				Middle End				Tail End			
	Grain yield (t ha^{-1})	WEE (kg ha-cm^{-1})	Net income (₹ ha^{-1})	B:C ratio	Grain yield (t ha^{-1})	WEE (kg ha-cm^{-1})	Net income (₹ ha^{-1})	B:C ratio	Grain yield (t ha^{-1})	WEE (kg ha-cm^{-1})	Net income (₹ ha^{-1})	B:C ratio
Farmers' practice	3.12	97.00	44653	1.51	3.12	96.67	44153	1.50	3.02	95.00	41833	1.42
Improved practice (IP)	4.18	198.56	70685	1.51	4.09	194.06	68093	2.39	3.99	190.64	65773	2.31
Increase under IP (%)	34.0	104.7	58.3	-	31.1	100.7	54.2	59.3	32.1	100.7	57.2	62.7

2. Crop diversification in ORP under poor availability of canal water during *rabi* season

The study was conducted to diversify cropping system in the tail end of Chandpor distributory, where sole wheat crop got affected due to poor availability of water during *rabi* season. Diversification of crops was conducted at 10 locations on farmers' fields at the tail end of Chandpur distributory in Saraiya village during six consecutive *rabi* seasons (2012-13 to 2017-18) under poor availability of canal water. Results envisaged that the equivalent yield (5.24 t ha^{-1}) and net return (₹ 71,753 ha^{-1}) of wheat was highest case of intercrop of mustard with gram followed by intercrop of mustard with wheat, pure stand of gram and pure stand of wheat (Table F2). Thus intercropping of gram and mustard (4:1) was recommended as a diversified cropping system in place of wheat during *rabi* season under poor availability of water in canal command of Chandpur distributory.

Table F2. Performance of diversified cropping system at tail end of Chandpur distributory during *rabi* 2012-13 to 2017-18

Cropping System	Crop Yield (t ha^{-1})		Wheat equivalent yield (t ha^{-1})		Net return (₹ ha^{-1})	B:C ratio
	Improved practice	Farmers' practice	Improved practice	Farmers' practice		
Pure stand of mustard	1.73	1.30	3.77	2.82	48888	2.87
Pure stand of pea	1.91	1.52	3.50	2.79	43250	2.40
Pure stand of gram	1.99	1.58	4.67	3.70	61708	3.08
Pure stand of wheat	4.61	3.91	4.61	3.91	52088	1.83
Gram + Mustard (4:1)	1.60 + 0.68	1.28 + 0.62	5.24	4.34	71753	3.59
Pea + Mustard (2:2)	1.04 + 0.75	0.91 + 0.64	3.53	3.06	43758	2.43
Wheat + Mustard (9:1)	4.13 + 0.48	2.60 + 0.41	5.18	3.48	62168	2.10

Market value of produce (₹ per quintal): Wheat 1750/-, Gram 4100/-, Pea 3200/-, Mustard 3800/-

3. Conjunctive use of surface water and groundwater at middle of distributory for optimum production

Trial was conducted at village Daulatpur at the middle end of Chandpur distributory during *rabi* 2012-13 to 2017-18 to compare improved and farmers' water management practices in wheat crop. Improved irrigation practice included 6 cm irrigation at critical growth stages (CRI, late jointing and milking stage) in check basin (5x10m^2) with conjunctive use of canal water and groundwater in the ratio 2:1. Results showed higher grain yield of wheat (4.34 t ha^{-1}) compared to farmers' practice (3.25 t ha^{-1}) in which 10 cm canal water was applied twice by flooding with field to field method (Table F3). Improved irrigation practice led to increase in grain yield by 33.6% water expense efficiency (WEE) by 48.4% and net profit by 49.5% compared to farmers' practice.

Table F3. Performance of wheat crop with conjunctive use of canal water and groundwater in the middle end of Chandpur distributory

Treatments	Average wheat yield (t ha^{-1})	Water expense efficiency (kg ha-cm^{-1})	Cost of cultivation (₹ ha^{-1})	Gross income (₹ ha^{-1})	Net income (₹ ha^{-1})	B:C ratio
Improved practice	4.34	240.86	29500	97560	68060	2.31
Farmers' practice	3.25	162.27	28500	73035	43535	1.53

Jammu

Modeling for planning the conjunctive use of water at basin level within the canal commands of Jammu

The study was carried out to quantify demand and supply in distributaries D-10 and D-10A of Ranbir canal water, and find the possibility of meeting deficit irrigation by augmenting groundwater resource in a conjunctive mode. Water demand for Basmati 370 during *Kharif* 2017 was worked out to be 3740 to 318560 ha-cm having relative water supply (RWS) from 0.55 to 0.76 in various majors and minors of the distributaries (Table J1). Prospect of water supply through groundwater in a conjunctive mode was 28-45% to meet up the deficit irrigation under each major and minor for growing Basmati-370 during *kharif* season. But status of groundwater in the region showed that aquifer at shallow depth within different reaches of the canal has fine sand/silt. This results in reduction of discharge within two to three years and clogging of shallow tubewell (*bambi*). Thus farmers were not able to use the groundwater (Table J2).

Table J1. Relative water supply (RWS) during *Kharif* 2017 in distributaries of Ranbir canal command

Distributary	Area (ha)	Canal water diverted (ha-cm)	Water available at field (ha-cm)	Effective rainfall (ha-cm)	Total water supply (ha-cm)	Water demand (ha-cm)	RWS
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Kotlishah Dowla, Tanda Minor	60	2972.7	2080.8	1914	3994.8	6600	0.61
Ratian head to Kapoorpur	3760	172530	120771	119944	240715	4,13,600	0.58
Musachak minor	240	11826	8278.2	7656	15928.2	26,400	0.60
Main Tanda minor	2530.8	187920	131544	80732.5	212276.5	2,78,388	0.76
Chakroi minor	924.8	45603	31922.1	29501.1	61423.2	1,01,728	0.60
Katyal minor	1000	49410	34587	31900	66487	1,10,000	0.60
Badyal-A	40	1620	1134	1276	2410	4,400	0.55
Badyal-B	34	1539	1077.3	1084.6	2161.9	3,740	0.58
Ratian head to Koratana	2896	197640	138348	92382.4	230730.4	3,18,560	0.72
SKUAST Channel	100	4860	3402	3190	6592	11,000	0.60
Khannachak minor	600	29160	20412	19140	39552	66,000	0.60
Samka minor	270	17820	12474	8613	21087	29,700	0.71
Chanduchak minor	920	45360	31752	29348	61100	1,01,200	0.60
Total area	13,375.6	768260.7	5,37,782	4,26,681.6	9,64,458	14,71,316	-

Note: Irrigation supply was provided on alternate week (81 days); Efficiency of the system=70%; Effective rainfall=31.9 cm; Total water requirement=143.5 cm

Table J2. Status of groundwater in distributaries D-10 and D-10A

Name of village	Aquiclude depth (m bgl)	Aquifer depth (m bgl)	Requirement of GW as per RWS	Constraints in using GW use at farmer level
Badyal Brahmna	0-50	25	42-45%	The avg. depth aquiclude ranges from 50 to 100/200 m. Aquifer/perched water table ranges between 20 to 80 m bgl. The aquifer at shallow depth at middle- and tail-end reaches excepting R. S. Pura village has fine sand/silt and gives small discharge and within 2 to 3 years the farmer level tubewell get clogged. Farmers have marginal land holdings.
Badyal-B	0-100	Beyond 50		
Kotli-Shah-Daula	0-50	25	39%	
Korotana-Khurd	0-100	20	28%	
Kapoorpur	0-50	20	42%	
Chakroi	0-100	100	40%	-
Chakroi (Tubewell No. 8)	0-50	50		
Mulachak	0-100	80	40%	
Agrachak	0-200	50-200		
R. S. Pura	0-50	10-20		Farmers have constructed shallow tubewells in R.S. Pura

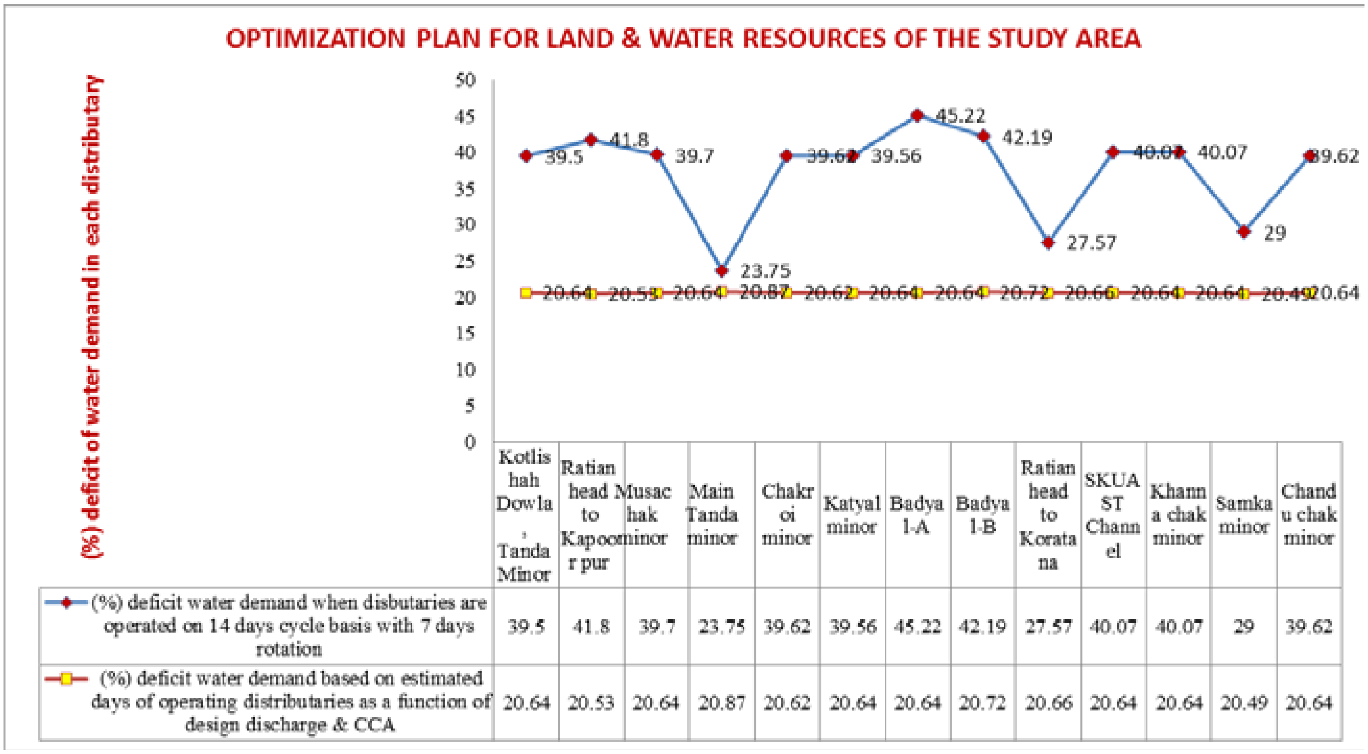

Fig. J1. Optimization cum conjunctive use plan for water resources of the study area

Table J3. Optimization plan for land and water resources of the study area in Ranbir cananl command

S. No.	Name of the distributary	Total water supply during the crop period of 81 days for basmati-370 (ha-cm)	Total water demand during the crop period of basmati-370 (ha-cm)	Designed discharge of each canal within the network ($m^3 s^{-1}$)	Estimated number of days required within canal network to meet up water demand (days)	Deficit water demand (%)*	Estimated total water supply as per actual number of days of operation of each distributary (ha-cm)	Deficit water demand (%)**	Proposed conjunctive use planning of surface water & groundwater (ha-cm)
	1	2	3	4	5 = (3/4)	6	7	8	9
1.	Kotlishah Dowla, Tanda Minor	3994.8	6600	0.04	181	39.50	5237.7	20.64	1. Shallow tubewells (50 Nos) 28224 ha-cm
2.	Ratian head to Kapoorpur	240715	4,136,00	2.46	196	41.80	328699.29	20.53	
3.	Musachak minor	15928.2	26,400	0.17	181	39.70	20951.08	20.64	
4.	Main Tanda minor	212276.5	2,78,388	2.69	120	23.75	220294.42	20.87	
5.	Chakroi minor	61423.2	1,01,728	0.65	182	39.62	80747.20	20.62	
6.	Katyal minor	66487	1,10,000	0.70	181	39.56	87296.23	20.64	
7.	Badyal-A	2410	4,400	0.02	181	45.22	3491.8	20.64	
8.	Badyal-B	2161.9	3,740	0.02	192	42.19	2964.95	20.72	2. Deep tubewells (8 Nos) 13547 ha-cm
9.	Ratian head to Koratana	230730.4	3,18,560	2.83	131	27.57	252756.2	20.66	
10.	SKUAST Channel	6592	11,000	0.07	181	40.07	8729.6	20.64	
11.	Khannachak minor	39552	66,000	0.42	181	40.07	52377.75	20.64	
12.	Samka minor	21087	29,700	0.25	136	29.00	23597.48	20.49	
13.	Chanduchak minor	61100	1,01,200	0.65	181	39.62	80312.53	20.64	-
Total		**964458**	**1370116**	-	-	**37.51**	**1167456**	**20.64**	**(1167456+28224+ 13547)=1209227**

*Crop period = 81 days @ 14 days cycle (7 days rotation) for crop period of 162 days
**Estimated actual number of days for each distributary to operate as a function of design discharge and water demand (%)

- Total culturable command area = 13,375 ha
- Water demand for basmati rice = 1370116 ha-cm
- Water supply on 14 days cyclic basis with 7 days rotation = 964458 ha-cm
- Percentage average deficit water demand = 37.51%
- Water supply as per optimization plan to operate the canal as a function of design discharge and corresponding command area = 11,67,456 ha-cm
- Percentage average deficit water demand = 20.64%
- Water supply as per conjunctive use plan = 1209227 ha-cm

Recommendations:

- Modeling and optimization plan of the study area (13,375 ha of CCA) called the basmati bowl of Jammu. The present gap between irrigation water supply and water demand for basmati rice is on an average 37.51%.
- As per optimization plan, operating the canal for (81 to 98 days) as a result of two physical constraints i.e. design discharge and corresponding command areas for each distributary. The gap between irrigation supply and water demand will get reduced from 37.51% to 20%.
- Adoption of revised operation schedule of the canal by irrigation department, Jammu and proven water saving techniques (like AWD, SRI, Laser leveling etc.) will result in improving average yield of basmati rice from existing 2.5 t ha^{-1} to 3.2 t ha^{-1} in the entire command area. Thus, the net returns of the farmers is expected to improve by ₹ 20,000 per ha.

Parbhani

1. Effect of canal irrigation on water table fluctuation and quality of groundwater in ORP area

Water availability and quality of irrigation water were assessed in Jayakwadi command area. The Operational Research Project (ORP) was undertaken in the vicinity of village Porwad in Parbhani district on an area of 459 ha commanded by minor ML-4 of distributory number B-67 (off take at 182.039 km) through PLBC (Paithan Left Bank Canal). The water users' co-operative society is working well in the ORP area (Plate P1). Conclusions drawn are as below:

- Due to erratic and deficit rainfall and early withdrawal of monsoon, the water table could not recharge markedly both in command and non command areas. However, two canal rotations in October 2018 and January 2019 proved beneficial in recharging wells thus the water table in command area was higher (7.11 m) as compared to non command area (7.51 m) in the month of March 2019.
- Water samples collected from the wells of command and non command were categorized as C_3S_1 type which indicates high saline water which requires sufficient drainage for safer use.
- Cropping intensity in the ORP area was 169% which is 16% less as compared to last year (185%), the probable reason for this may be the erratic and deficit rainfall and paucity of timely availability of canal water.

Depth of water table in command area

Depth of water table in non command area

Plate P1

2. Effect of canal irrigation on water table fluctuation and quality of groundwater in Jayakwadi command area

In order to monitor the water table fluctuations and quality of groundwater, 24 wells from command area of distributaries No. 14 to 21 of left bank canal of Jayakwadi Irrigation Project and 5 wells from adjacent non command area were selected. The study area comes under Ambad Tahsil of Jalna district. The water table depth was measured in selected dug wells in the month of March 2019. Similarly, water samples were collected and analyzed for water quality parameters. Conclusions drawn are as below:

1. In command area, the groundwater level in command area was higher by 6.42 m as compared to non command area in the month of March-2019 due to recharge from canal water.
2. The mean values of pH, CO_3^{--}, HCO_3^-, Cl^-, $Ca^{++} + Mg^{++}$ and Na^+ of groundwater of command area were higher than the non command area.
3. Groundwater from Jayakwadi command and non command area are categorized as C_3S_1 and C_2S_1 as high and medium salinity indicating restrictions on its use.
4. Scheduling of irrigation water through canal irrigation system largely depends on the availability of water storage in the Jayakwadi project.

Chalakudy

On the basis of water quality analysis along the length of Chalakudy River, the main problem in *Elanthikkara* region lying at or below sea level was identified to be sea water intrusion after monsoon making the water highly saline. The lands were left fallow due to unavailability of good quality irrigation water. Hence field demonstrations were done with salt tolerant rice varieties (*Vytilla*) in these salinity prone areas (Plate C1 and C2).

Demonstration trials in paddy fields: Soil and water samples were collected during October 2018 from all the paddy clusters in *Elanthikkara panchayath* to check the suitability for cultivation. This comprised of *Thazhenchira*, *Thazhencirathekku*, *Kuttikkad*, *Keezhupadam*, *Pappanamcode*, *Pandippadam*, *Pathikkerypadam* and *Thathampadam* clusters which extend over a large area of land that are kept fallow as dewatering is impossible during monsoon and are subject to salt water intrusion in the post monsoon period. The analytical results of soil showed all the parameters to be within permissible limits indicating that the soil is suitable for cultivation. In collaboration with *Krishibhavan,* farmer group meetings were convened to identify farmers willing to conduct field demonstrations.

Different varieties of Vytilla *i.e.*, Vytilla 6, 8, 9 and 10 were tried in *Thazhanchira* paddy cluster. Soil and water analyses done during January and February showed salinity up to 2.8 dS m^{-1}. Vytilla 9 recorded yield of 2.5 t ha^{-1}.

Plate C1. Discussion with farmers

Plate C2. Crop ready to harvest

Chapter 9 | Tribal Sub Plan (TSP)

Kota

During 2018-19, sprinkler sets were distributed cooperatively to farmers of tribal village Govardhanpura for improving water use efficiency and crop productivity. Field demonstrations were made on improved water management technologies at Karvari Khurd and Govardhanpura villages of Tehsil-Kishanganj (Baran). Total 55 farmers were given demonstrations, out of which 10 farmers were having large land holding, 20 marginal and 25 small land holdings. Total 4.7 ha was covered under demonstration. Total area benefitted was 15.6 ha.

Interventions used for wheat demonstrations: Package of practices and improved water management practices were demonstrated on high yielding wheat variety Raj 4037. Seed rate was 100 kg ha^{-1}, sowing time was second week of November, fertilizer application was N_{120} P_{60} K_{40} kg ha^{-1}, method of irrigation was border strip method, irrigation given at critical stages, weed control by herbicide application, timing of herbicide application was maintained, judicious use of fertilizers, introduction of sprinkler irrigation system and use of HDPE pipelines for carrying water from local river.

1. Demonstration on package of practices of wheat and improved water management practices in Garda command (method of irrigation and critical stages): Ten demonstrations of wheat were conducted in tribal area under Garda command of Baran district (Plate K1). Table K1 shows that mean grain yield of wheat was 10.07% higher in demonstration block (4.54 t ha^{-1}) than that of farmers' practice (4.12 t ha^{-1}) at tribal belt of Baran district village-Karvari Khurd. Water expense efficiency (16.19 kg ha-mm^{-1}) was also found higher in the test block as compared to the control block (10.30 kg ha-mm^{-1}). In demonstration block, three irrigations were applied at CRI, late tillering and milking stages with the help of border strip method of irrigation (5 m x 40 m) with 6 cm depth using 85% cut-off ratio along with recommended practices of nutrient (N_{120}, P_{60} & K_{40} kg ha^{-1}) and weed management (2,4-D @ 750 g ai ha^{-1}) for wheat. Whereas, in the control block irrigations were applied by flooding method without considering critical growth stages and without following recommended practices of nutrient and weed management.

Table K1. Effect of improved water management practices on grain yield of wheat

Particulars	*Rabi* 2018-19	
	Demonstration block	**Control block**
Irrigation practices	Package of practices and improved water management practices	Farmers' practice
No. of irrigation	3	3
Total water applied (cm)	28	40
Grain yield (t ha^{-1})	4.54*	4.12*
% increase in yield	10.07	-
Water expense efficiency (kg ha-mm^{-1})	16.19	10.30

*Mean value of 10 demonstrations

Plate K1. Border strip method of irrigation in wheat demonstration in Garda command

2. Demonstration on package of practices of wheat and improved water management practices in non command area (irrigation at critical stages): Ten improved water management practices demonstrations on wheat were conducted in non command area of tribal belt (Table K2)

Table K2. Effect of improved water management practices on grain yield of wheat

S. No.	Particulars	*Rabi* 2018-19	
		Demonstration block	**Control block**
1.	Recommended irrigation practices	Recommended package of practices and improved water management practices	Farmers' practice
2.	No. of irrigation	3	3
3.	Total water applied (cm)	28	34
4.	Grain yield (t ha^{-1})	4.39*	3.94*
5.	Increase in yield (%)	11.29	
6.	Water expense efficiency (kg ha-mm^{-1})	15.66	11.59

*Mean value of 10 demonstrations in non command area

3. Demonstrations on wheat for improving water productivity by using HDPE pipeline (Plate K3)

Plate K3. Water carrying through pipe lines from local River for irrigation

Table K3. Effect of improved water management practices on performance of wheat crop in tribal area

S. No.	Particulars	*Rabi* 2018-19	
		Demonstration block	**Control block**
1	Recommended irrigation practices	Water carrying from the local river and irrigation at critical stages	Farmers' practice
2	No. of irrigation	3	3
3	Grain yield (t ha^{-1})	4.47*	4.04*
4	Straw yield (t ha^{-1})	5.41*	4.12*
5	Increase in grain yield (%)	10.64	-
6	Net return (₹ ha^{-1})	70873	49439
7	Net water productivity (₹ m^{-3})	25.31	14.44

*Mean value of 23 demonstrations, Common cost of cultivation= ₹ 16000 ha^{-1}, Sale price of wheat=₹ 18.40 kg^{-1} and straw ₹ 2.5 kg^{-1}, Treatment cost T_1 is ₹ 24900 ha^{-1} @ ₹ 825 ha^{-1} irrigation^{-1} for water lifting and ₹ 650 ha^{-1} irrigation^{-1} for labour and ₹ 3000 as fixed cost, Treatment cost T_2 is ₹ 35200 ha^{-1} @ ₹ 4150 ha^{-1} irrigation^{-1} paid by the farmer and ₹ 650 ha^{-1} irrigation^{-1} for labour

4. Demonstration on wheat under sprinkler irrigation in tribal area

Twelve sprinkler irrigation demonstrations on wheat crop were conducted in tribal village of Karvarikhurd and Gordhanpura of Kishanganj Tehsil, Baran district during *rabi* 2018-19 to evaluate performance of sprinkler irrigation in wheat (Plate K4). One year data (Table D1) revealed that mean grain yield (4.81 t ha^{-1}), net return (₹ 78979 ha^{-1}) and net water productivity (₹ 28.20 m^{-3}) under test block were higher compared to control block. In demonstration block irrigations were applied by sprinkler with recommended package of practices (N_{120},P_{60},K_{40} kg ha^{-1}) whereas in control block irrigations were applied using flooding method taking water from other farmers @ ₹ 4150 ha^{-1} without recommended package of practices.

Plate K4. Sprinkler irrigation demonstration in wheat under tribal area

Dapoli

Construction of Konkan Vijay Bandhara

The three talukas of Palghar district namely Mokhada, Jawhar and Vikramgad were selected for construction of Konkan Vijay bandhara using polyfilm lining for rainwater harvesting on tribal farmers' fields. Total five Konkan Vijay bandhara were constructed in different villages through which 37,488 m^3 rainwater was harvested in the remote and hilly areas of Konkan region of Maharashtra where tribal farmers always face the water scarcity problem. Total 40 tribal farmers and family members were benefitted with this technology and 600 mango grafts and 340 cashew grafts and 1600 jasmine plants were irrigated by the farmers using this technology. The details are given in Table D1. Success rates of mango and cashew grafts were in the range of 72.48 to 88.11% and 88.13 to 91.42%, respectively. Retention period of rainwater storage in Jalkund was 116 to 141 days and it created facility to irrigate crops up to end of April. Land utilization was more than double and water storage capacity utilization ranged from 77.14 to 89.12% due to intervention of Jalkund technology in tribal areas in Konkan region.

Table D1. Konkan Vijay Bandhara at different villages

Number of individuals/colonies/villages benefitted	Physical assets created	Type of assets created
Shri. Baliram Kashinath Vartha + 10 other beneficiary at village Kuload Tal : Mokhada **Dimensions:** 60 x 1.8 x 300 mt. Volume=16,200 m^3	**Konkan Vijay Bandhara-1** Cashew plants: 350 Mango plants: 200 Jasmine: 800 Vegetable: 20 R Area covered 3 ha	Irrigating the mango, cashew plants and cultivation of vegetables and jasmine crop
Shri. Ramdash Khanjode + 20 persons at village Dolhari khurd Dadade Tal: Vikramgad **Dimensions:** 16.80 x 2.00 x 680 mt. Volume=22848 m^3	**Konkan Vijay Bandhara-1** Cashew plants: 200 Mango plants: 100 Jasmine: 400 Custerbean: 3.5 acre Cowpea: 1.5 acre Vegetables: 1 acre	Irrigating the mango, cashew plants and cultivation of vegetables and jasmine crop

Parbhani

Demonstration of different need based agricultural interventions for enhancing the crop productivity on tribal farmers' field

Village- Wai, Taluka- Kalamnuri of Hingoli district and village- Jawarla, Taluka- Kinwat of Nanded district were selected for the demonstrations. The villages have more than 75% tribal population. Wai village comprises of 224 farmers with maximum share of small (124) and medium (100) farmers. The village has population of 1538 with total geographical area of 538 ha, out of which 401 ha is cultivated area. The major water sources in the village are open well and borewells with some area under command of minor dam Devadhari. Surface irrigation is the major irrigation method being used by farmers and productivity of the major crops is low.

1. Demonstration of sprinkler irrigation technology has been done at Wai village. Fifty-three farmers provided with sprinkler irrigation sets. About 30-40% water was saved. Though land and water resources are limited in the village, no case of farmers suicide was reported in last four years due to drought.
2. Demonstration of bullock drawn multipurpose seed cum ferti drill
3. Demonstration of improved varieties of soybean
4. Demonstration of fertilizer and improved variety of wheat
5. Demonstration of portable drip irrigation system for turmeric
6. Demonstration of sprinkler irrigation technology at Village Javarla Dist.Nanded

Chapter 10

Technology Assessed Refined and Transferred

Coimbatore

1. Recharge shaft in percolation pond: Artificial recharge through recharge shaft in percolation pond was taken up by way of allowing the runoff water to pass through silt detention tank, water collection tank-cum-treatment chamber and shaft with filtering chamber. Slotted PVC pipe was erected for easy recharging. This technique is recommended in hard rock area to increase the rate of recharge (23 per cent) and also to reduce the evaporation losses (8%) in percolation pond. Based on the recommendation, AED introduced recharge shaft in percolation pond in 250 blocks (Two numbers in each block) of eighteen districts of Tamil Nadu.

2. Recharge borewell: The recharge borewells directly feed depleted aquifers with fresh water from ground surface. Artificial recharge through recharge borewell was taken up by way of allowing the runoff water to pass through borewell with filtering chamber at places like topographical depressions, abandoned canals and canal escapes where excess surface runoff either accumulates or it is conveyed for disposal. Slotted PVC pipe was erected for easy recharging. The recharge through this technique is fast (17%), negligible evaporation losses and water quality is improvedin nearby observation wells. AED and PWD constructed approximately 2500 recharge shafts in 280 blocks of Tamil Nadu.

3. Abandoned well recharge: To alleviate the problem of groundwater exploitation and to rejuvenate the failed wells, the existing and abandoned dug wells, borewells may be utilized as recharge structure after cleaning and desilting the same. Recharge water should be silt free and for removing the silt contents, the runoff water should pass either through a desilting chamber or filter chamber filled with boulders, gravels, coarse sand and fine sand. The runoff water is guided through open channels and pipes from desilting chamber to the open well or borewell. Due to this technique, there is an increase in well yield by 40%. There are about 1.6 lakh abandoned wells in the state and there is scope to divert the run-off water during heavy rains. AED and NGO implemented this technology in western districts of Tamil Nadu.

4. Single economical drip layout for major annual and commercial crops: Single economical drip irrigation lay out suitable for many annual commercial crops will be of useful to the farmers to go in for any commercial crops without change in the drip layout system. Drip irrigation layout of 1.50 m lateral spacing with 4 lph drippers at 60 cm spacing along the lateral is most suitable for sugarcane, banana, turmeric, tapioca, tomato and other annual crops without altering the layout for several years. Higher water saving from 25 to 40 percent and yield increase from 18 to 30 per cent can be achieved by adopting this technology. This system of layout is adopted in around 20,000 ha in western zone of Tamil Nadu.

5. Drip fertigation in turmeric: Drip irrigation layout of 90 cm lateral spacing with 4 lph drippers at 60 cm apart along the laterals operated for 3 to 4 hours once in 2 days interval. Between two laterals 3 rows of turmeric crop will be accommodated with a row spacing of 30 cm. Within the row the spacing is 10 cm. 36 splits (once in 6 days) of N (150 kg ha^{-1}) and K (108 kg ha^{-1}) through fertigation and P (60 kg ha^{-1}), micro nutrients as soil application. Presently drip fertigation in turmeric is being adopted in 16000 ha in western zone of Tamil Nadu.

6. Drip fertigation in coconut: Drip irrigation spaced 7.5 m between the laterals with ring around the tree with 8 lph drippers 4 numbers operated for 2.5 hours. Twelve splits of N (0.6 kg per tree) and K (2.1 kg per tree) through fertigation. Micronutrients and P (0.32 kg per tree) once in three months applied as soil application. This technology is adopted in nearly one lakh hectare.

7. Drip fertigation in sugarcane under paired row method of planting: Sugarcane planting in the paired row at 75(25x25x25) /120 cm spacing with two budded sets of 8 numbers per running meter is recommended to get higher yield in sugarcane. The drip layout also made at lateral spacing of 195 cm with drippers discharge capacity of 4 lph at 60 cm spacing. The irrigation has to be scheduled once in 3 days with fertigation once in 6 days. Through this technology water saving can be achieved to the tune of 25-40 per cent with yield increase of about 45 per cent. This technology was first transferred to large scale adoption with the help of M/s. Sakthi Sugars in Sivagangai district of Tamil Nadu to an area of 2500 hectares. Subsequently this technology has been given impetus by the Govt. of Tamil Nadu under SUBACS scheme with subsidy component and the same was done by the AICRP – Irrigation Water Management scientists of this centre. Based on the performance of this technology, Govt. of Tamil Nadu sponsored a project for demonstrating this technology under farmers holding under Macro Management Scheme entitled 'Demonstration of paired row and pit method of planting of sugarcane under drip fertigation system (SUBACS)' in twelve districts with a budget of ₹ 140.0 lakh.

8. Sub surface drip fertigation in sugarcane: For mechanized cane cultivation the technology of "Sub surface drip fertigation in sugarcane" is found to be ideal to get higher yield of cane. The sub surface drip fertigation system layout should have lateral spacing of 180 cm and emitter spacing of 60 cm with 4 lph discharge. Drip laterals should be laid at a depth of 25 to 30 cm and the drippers must face upwards. The crop must be irrigated on alternate days for light textured soils and once in three days for heavy textured soils at 100 per cent pan evaporation. Fertigation has to be given once in 7 days with recommended dose of fertilizers (P as basal and N &K through fertigation). About 25-30 per cent water can be saved through this technology with yield enhancement. The technology has been well taken by the sugar industries as well as sugarcane growers in Tamil Nadu with adoption in 12500 ha area.

Belavatagi

- Intercropping of Chilli + Onion with drip (4 L h^{-1} discharge through inner line drippers) should be cultivated give highest yield of onion and maximum chilli pod yield from the cropping system.
- Maize crop can be grown during *kharif* season under drip at 1.0 ET_o recorded significantly higher yield of maize followed by *rabi* crops wheat, Bengal gram and field bean (Avare) under a common drip layout for both the seaons.
- Sunflower crop can be grown during *kharif* season under common drip layout and irrigation at 1.0 ET_o followed by *rabi* crops *viz.*, wheat, Bengal gram and groundnut under drip as compared to farmer's method. Adoption of drip irrigation method for the crops like maize, sunflower, chilli, onion during *kharif* and wheat, chickpea, field bean, groundnut during *rabi* are recommended.
- Irrigating wheat crop at 0.8 IW/CPE ratio with application of RDF + FYM @ 7.5 t ha^{-1} + $ZnSO_4$ @ 20 kg ha^{-1} + $FeSO_4$ 20 kg ha^{-1} recorded significantly higher grain yield, water use efficiency (6.30 kg ha-mm^{-1}) and is recommended.

Farizabad

- Integrated farming system with multiple use of water (such as pisiculture and duckery) was more profitable as compared to the conventional cropping system. Highest benefit-cost ratio of 2.40 was observed in Integrated Farming System as compared to Rice – Wheat + Rai system (B:C 1.60). The farmers of ORP area are very much convinced with this system.

- Pigeonpea grown on raised bed in paired rows at 50 cm spacing and intercropped with 3 rows of urd (100 cm) on raised beds was found to be more productive and remunerative system under poor availability of canal water at tail end of minor of Chandpur distributary in *kharif* season.
- Intercropping of gram + mustard (4:2) was found more economical in *rabi* season under poor availability of canal water.
- Maximum grain yield of wheat was realized when crop was sown with bed planting and fertilized with 125% of recommended dose of N (125 kg ha^{-1}) under the schedule of 4cm irrigation at 1.0 IW/CPE ratio at all the five critical stages. Highest WEE was computed with 4 cm water at 0.8 IW/CPE at CRI, late jointing and milking stages.
- Sowing of green gram on raised beds in paired rows along with furrow irrigation at 1.0 IW/CPE or irrigation at 10 days interval is recommended.
- Conjunctive use of canal and groundwater (2:1) with 6cm irrigation at critical stages (CRI, late jointing and milking stages) in check basin (5x10m^2) in wheat crop has been found high yielding (33.59%) and water efficient (48.43%) and more remunerative with benefit cost ratio of 2.31.
- Drip irrigation @ 60% PE with 75% RDN every 3rd day has been found high yielding and most remunerative irrigation system for Rajmash beans.
- Bed planting of wheat with 1.0 IW/CPE irrigation schedule harvested the significantly higher yield of wheat 4.83 t ha^{-1} with highest benefit cost ratio of 1.87.
- Irrigation schedule 1.0 IW/CPE in every furrow with 75% RDN through urea and 25% N through FYM resulted the significantly higher yield of tuber 31.50 t ha^{-1} with benefit cost ratio of 4.32.

Gayeshpur

Crop	Technology generated	Recommendation
Summer groundnut	Irrigation schedule and sulphur fertilization	Irrigation @ IW/CPE 1.0 coupled with S application @ 10 kg ha^{-1}
Baby corn	Judicious irrigation and spacing	Irrigation @ IW/CPE 1.0 with 45 x 20 cm spacing
Lettuce	Irrigation and nitrogen management	irrigation at IW/CPE 0.8 with 50% N as inorganic +50% N as vermicompost
Rice	Drum-seeded rice in wet season	Traditional transplanting with continuous ponding with 120 kg ha^{-1} N
Turmeric	Irrigation and nutrient schedule	Irrigation schedule at IW/CPE 0.9 with 75% inorganic and 25% organic nutrients
Ginger	Irrigation and nutrient schedule	Irrigation schedule at IW/CPE 0.9 with 75% inorganic and 25% organic nutrients
Lowland summer rice -okra	Raised - sunken bed system of cultivation	CSW at 3:3 Raised-sunken bed configuration
Broccoli-okra-cowpea sequence	Drip-fertigation and mulching	Drip irrigation at 80% ETc with black polythene mulch
Gladiolus	Drip irrigation and integrated nitrogen management	Gravity drip irrigation at 0.8 ETo with conjunctive use of 50% inorganic N plus 50% N through vermicompost
Safflower based intercropping system	Irrigation management	Irrigation schedule at CPE 45 with 4 irrigation (20 cm) in safflower + pea (2:1) cropping with 60-30-30 kg ha^{-1} NPK plus 5 t ha^{-1} of FYM
Summer paddy	Water management interventions on arsenic de-loading in paddy	Deficit irrigation (alternate wetting and drying) scheduling
Broccoli	Arsenic mitigation by conjunctive use of fresh pond water and arsenic contaminated groundwater	Conjunctive use of Arsenic contaminated groundwater and safe surface (pond) water at 1:1 proportion in high As prone groundwater areas.

Jammu

Refinement of technology was done to improve management of irrigation canals of Jammu by stakeholders.

Improving irrigation use efficiency in Jammu region: Policy paper submitted to Govt. of J&K vide letter no.: DR/F-110/5863 dated: 20.11.2018. Which was accepted and acknowledged by the Chairperson Jammu and Kashmir State Water Resource Regulatory Authority, J&K Govt. vide his letter D.O.No. SWRRA/2018/270/3521-22 dated: 26.11.2018

Strengthening of water resources and their effective utilization in rainfed areas both *in situ* and *ex situ* by revival, rejuvenation, rainwater harvesting, pre-emptying droughts and drought management- Jammu (J&K): Policy paper submitted to Govt. of J&K vide letter no.: DR/6099 dated: 03.12.2018.

Junagadh

Rainfall Intensity-Duration-Frequency relationships for designing the water harvesting-cum-groundwater Recharge Structures: The developed Mathematical model and Nomograph for rainfall intensity-duration-frequency relationship is recommended for the design of water harvesting-cum groundwater recharging structures, etc for scientific community/NGOs/Government sectors working on implementations of projects on water harvesting-cum-groundwater recharge.

Rainfall I-D-F and rainfall-runoff relationships for Mahi basin: The runoff coefficient and Mathematical model and Nomograph for rainfall intensity-duration-frequency relationship are recommended for the hydrologic design of flood control as well water conservation structures etc for scientific community/NGOs/Government sectors working on implementations of projects on flood control as well water conservation.

Conjunctive use of surface and groundwater for irrigating wheat crop: Under conjunctive water use planning for wheat crop in Junagadh region, 533.94 cu-m of groundwater draft (7.72%) per hectare can be reduced per irrigation given from check dam. Under conjunctive water use planning for wheat crop, 123.8 kWh power (4.9%) per hectare. can be saved per irrigation given from check dam. It is economical when at least two irrigations are given from surface source. From second irrigation under conjunctive water use planning for wheat crop, the benefit-cost ratio (B:C) rises by 0.038 as compare to without conjunctive water use per irrigation given from check dam. The conjunctive water can reduce up to 101 mm of evaporation loss from surface water sources.

Groundwater potential of the south-west Saurashtra region: The groundwater potential and quality parameters like EC, pH, Na, Ca, Mg, Ca, Mg, CO_3, HCO_3, Cl, Mg/Ca, SAR, RSC, SSP, TSS are proposed. The Groundwater quality classification based on superimposing of three parameters EC, SAR and RSC is proposed. The areas under different classes during pre and post monsoon are proposed. The surface and groundwater potential of the area are proposed as 360 MCM and 4061 MCM. The "Groundwater utilization and Management: policy guidelines for the South West Saurashtra region" is proposed.

Suitability of groundwater quality for drip irrigation: The contour maps of groundwater quality parameter like EC, TDS, pH, Ca, Mg, Na, Fe and Mn and carbonate, bicarbonate, chloride and sulphate, Nitrate-Nitrogen and water hardness based on groundwater sample analysis of 391 wells in 73 talukas of 11 districts of Saurashtra region during rabi season 2012 and 2013 are proposed which can be useful for the farmers for the drip irrigation operation and maintenance. The scientific information along with groundwater quality maps are released for the scientific community.

Groundwater recharge estimation using Remote Sensing and GIS: The Satellite image can be used as decision supports to assess the groundwater recharge through water harvesting structures and crop water requirements using remote sensing and GIS technologies.

Water balance and groundwater recharge assessment in Meghal basin: The total groundwater recharge through rainfall and water harvesting structures in the study area is estimated as 12,592 ha-m. using remote sensing GIS. The two options for the irrigation water management strategies are proposed.

Seawater intrusion impacts on the groundwater quality in South Saurashtra coast: The groundwater quality parameters viz, EC, pH, Ca, Mg, Na, K, CO_3, HCO_3 and Cl, SAR, ESP and RSC and SAR, RSC, RSBC, SSP, TDS, Puri's Salt index, Total Hardness, LSI, Sodium hazard, Potential Salinity, Permeability index, Mg^{++}/Ca^{++}, MAR, Kelli's Ratio, $Ca^{++}/HCO\text{-}_3^-$, Na^+/Cl^-, Mg^{++}/Cl^- and HCO_3^-/Ca^{++} are proposed for the coastal bet area at various distance 5, 10, 15 and 20 km from seacoast during before/after monsoon period. Various criteria are considered in evaluating the quality of irrigation water namely. The mathematical models relating rainfall and groundwater EC are developed for the scientific communities/line departments of state/central governments/NGOs. The information is also useful for the selection of cropping pattern and irrigation water management strategies by the farmers.

Watershed treatment impacts on groundwater quality: The water harvesting measures can be the best option for improving the groundwater quality in coastal belt area. The groundwater quality parameters like viz. total soluble salt content (electrical conductivity, EC), pH, carbonates (CO_3^{--}), bicarbonates (HCO_3^-), chlorides (Cl-), sodium absorption ratio (SAR), residual sodium carbonate (RSC) and soluble sodium percentage (SSP) can be improved by water harvesting measures in watersheds. The groundwater quality has been improved in Treated Area (TA) in compare to non-treated area (NTA).

Groundwater pollution surrounding the dying industrial area of Jetpur town: The quality parameters like pH, Electrical Conductivity (EC), Carbonate (CO_3), Bicarbonate (HCO_3), Chloride (Cl^-), Calcium (Ca), Magnesium (Mg) and Sodium (Na) and micronutrient like Iron (Fe), Manganese (Mn), Zinc (Zn) and Copper (Cu) of river water and groundwater before/after monsoon is proposed in context to agriculture. It is suggested that the effluent from the textile dying industry should be added in river water after proper effluent treatment. This may help in reducing further deterioration of groundwater quality.

Pesticides residues in groundwater of Junagadh region: The parameters like Group of Organic chlorides, Synthetic pyrethroids and herbicides residues in groundwater and groundnut/cotton yield are proposed. The groundwater as well as cotton and groundnut seeds do not contain residues of any group of pesticides and herbicides in Junagadh district of Saurashtra region. The groundwater contained higher nitrate-nitrogen content more than the limit (50 ppm) indicating that the groundwater is harmful to use in drinking purpose for human being. This information can be useful to the policy makes, farmers, Agricultural pesticides manufacturers/importers, Agricultural produce purchasers/exporters, Ago Industries, State government/central governments line departments/NGOs and Academic/research institutes.

Estimation of groundwater recharge in and around Junagadh and Ghed area: The empirical approaches predicted that the amount of recharge on an average was varying between 15 to 18 percent of the annual rainfall for Junagadh and Ghed regions. The figures were well matched with the recommendations given by Central Ground Water Board based on the litho-logical profile information. The architecture of the neural networks was varying when the rainfall and difference of pre and post reading were taken into account. It was interesting to note that a single architecture forecasted the post water level when rainfall and pre water level reading were given as inputs.

Skimming technology and pumping schedule in coastal area of south Saurashtra: The mean of EC of pumped water was found as 8.8 and 12.6 dS m^{-1} respectively at Mangrol well 1 and Well 2 respectively, while it was 3.19 and 2.87 dS m^{-1} at Porbandar Well 3 and Well 4. These all values were found in high to very high category class C_4 and $C_{5.}$ No significant variation were found among the quality parameters like EC, pH, SAR and RSC of samples taken at different pumping time for all of the 4 sites. The farmers are getting limited 8 hours electric supply daily and the observation revealed that the eight hours pumping of open well has no significant effect on quantity of discharge water.

Aquifer mapping of Uben river basin by vertical electrical sounding resistivity technique: 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. Hydrogeological Maps and hydrogeology of Uben basin were prepared using remote sensing and GIS tools. Based on the farmers, NGOs and line department people are advised to construct groundwater recharge structures and shaft recharging technique for augmenting groundwater resources around the area starting from Sakkarbaugh, Vadal, Choki, Makhiyala up to Fareni. Keeping and view the higher horizontal, vertical hydraulic conductivity and transmissibility of unconfined/confined aquifer. The surface water harvesting structures should be encouraged for augmenting the surface water resources in rest parts of the Uben basin.

Coriander crop response to deficit soil moisture in various growth stages under drip irrigation system: The highest yield attributing parameters and grain yield of 1721 kg ha^{-1} and water use efficiency (WUE) of 4.18 kg $ha\text{-}mm^{-1}$ for coriander crop were when no stress condition was maintained in development and flowering stage and irrigated at 0.6 PEF ratio during grain setting stage by drip system. The flowering stage is the most sensitive to irrigation followed by vegetative and grain setting stage.

Evaluation of groundwater recharge techniques for Junagadh region: Total five groundwater-recharging techniques namely on stream check dam, recharge basin, roof water harvesting, open well and connector well recharging techniques were evaluated for Junagadh region. Recommendation were made for farmers, Govt. departments and NGOs that the,

- The on-stream check dam groundwater recharge technique is a cost effective groundwater recharge technique. It results 0.15 cu-m groundwater recharge per square meter of catchment area at the cost of ₹ 1.02 $cu\text{-}m^{-1}$ as per prevailing cost.
- The recharge basin is a cost effective recharge technique.In Junagadh region, itresults in recharge about 0.13 cu-m. groundwater per square meter of catchment area at the cost of ₹ 0.27 $cu\text{-}m^{-1}$.
- The roof water harvesting is an effective groundwater recharge technique. In Junagadh region, it results in groundwater recharge of 0.22 cu-m out of potential runoff of 0.73 cu-m per sq. m of roof area, which may be done through tubewell recharge and remaining 0.51 cu-m may be stored in a sump with a cost of ₹ 34.00 $cu\text{-}m^{-1}$ at prevailing cost. The annual runoff coefficient of 0.71 for roof top is recommended for designing the roof water harvesting system.
- The open well technique is effective for recharging shallow aquifer in Junagadh region which may recharge 0.12 cu-m groundwater per sq.m of bottom area of open well with recharge cost of ₹ 1.94 $cu\text{-}m^{-1}$. The tubewell is effective for deep aquifer recharge, which may recharge 44473 cu-m groundwater per year with recharge cost of ₹ 0.45 and 0.28 $cu\text{-}m^{-1}$ with including and excluding tubewell cos t, respectively.
- Steady state recharge model for Junagadh is recommended to the scientific community for recharging connector well as,

$$Q_{ca} = C \times \Delta h$$

where, Q_{ca} = Recharge rate to confined aquifer in $m^3\ day^{-1}$, Δh = Recharge head in recharge well in metre, C = 0.006 for Junagadh

Kota

Impact assessment study of ORP area: The impact assessment study on *rabi* and *kharif* crops under ORP at both LMC and RMC site of chambal command area was done by surveyed of 100 farmers' during the year 2018 and is summarized in Table K1. In *rabi* the major crops were wheat and mustard while soybean and paddy were in the *kharif*. It was noticed that most of the farmers are adopting the recommended package of practices of the crops, but in some cases, they are using the cultural practices and use of inputs in excess as per the recommendation. The per cent adoption of recommended package of practices especially with respect to cultural practices i.e. proper planting geometry and seed rate are not use by the farmers' whereas, depth of irrigation water applied method of irrigation, application of zinc & potash and chemical weed control in wheat and paddy and while sulphur application in mustard is also less. However, farmers are using seeds of improved variety and adoption scale varied from 48.2 to 83.0%. Similarly, in case of nitrogen fertilizer application, more than 63.1% farmers adopted recommendations in all the crops except soybean crop where the adoption is only 11.3-12.1%. In wheat, mustard and paddy 41.8 to 76.3% farmers are using recommended no. of irrigations but in soybean only about 13.1-14.4% farmers are using no. of irrigations. Due to availability of canal water only 18.4-30.4% of farmers are following the recommendation of depth and method of irrigation (29.9-34.4%). Now a day, farmers have started using border strip method of irrigation due to worthy results of improved water management technology.

Table K1. Adoption rate of the package of different crops in the ORP area (RMC & LMC) during the year 2018

Package	Adoption (%)							
	Wheat		Mustard		Soybean		Paddy	
	RMC	LMC	RMC	LMC	RMC	LMC	RMC	LMC
Improved seed & geometry								
Variety	68.5	67.3	83.0	81.5	48.2	50.1	73.5	72.2
Seed rate	33.1	34.4	39.6	38.2	42.1	43.4	58.6	60.2
Planting geometry	58.4	57.2	35.1	36.4	32.1	33.5	46.7	45.8
Organic manure & fertilizers								
Organic manure	9.2	8.8	-	-	-	-	8.2	8.1
Nitrogen	65.5	66.1	63.1	64.5	11.3	12.1	66.3	67.2
Phosphorus	56.3	59.8	55.7	56.2	26.4	27.1	60.1	66.2
Potash	7.3	7.1	-	-	-	-	11.2	12.4
Sulphur	2.1	2.9	33.4	35.1	-	-	-	-
Zinc	6.1	7.8	-	-	-	-	16.2	17.4
Irrigation								
No. of irrigation	62.4	63.2	41.8	42.2	13.1	14.4	75.4	76.3
Depth of irrigation	23.8	25.6	29.2	24.7	18.4	18.8	29.4	30.7
Method of irrigation	33.4	35.2	32.1	34.4	29.9	30.2	33.2	34.4
Weed management								
Chemical weed control	27.8	29.6	-	-	55.6	59.4	36.3	37.8

Extension activities and transfer of technologies undertaken: AICRP on irrigation water management, Kota centre is actively engaged for the dissemination of improved water management technologies through extensional activities like demonstrations and skill upgradation by field trainings. Under the ORP 54 field demonstrations were conducted out of which 18 at head, 18 at middle and at 12 at tail reaches of the selected distributaries. Besides these, 3 each at RMC and LMC of SRI demonstrations were carried out at farmers' field. The project scientists regularly give advice to the Govt. officers for improved and innovative water management technologies. In addition to this, delivered lectures on soil, water and new irrigation methods to line department field staff. The project scientists also participated in the agriculture technology fairs and disseminate improved water management technologies through All India Radio School. The technologies undertaken are given in the table below:

Crop	Technologies undertaken
Wheat & Soybean	Border strip method of irrigation (5 m x 50 m) with 80 % cut off ratio
Wheat & Soybean	Irrigation at critical stages- **Wheat:** CRI, late tillering, flowering & milking **Soybean:** flowering & pod development

Paddy	Irrigation of 5-7 cm depth of irrigation at 1-3 days after disappearance of ponding water
Paddy	System of Rice Intensification (SRI)
Wheat, Mungbean, Fieldpea, Coriander, Garlic, Onion	Sprinkler and mini sprinkler irrigation

Ludhiana

The scientists working in the scheme has published nine research papers in referred journal, four abstract, one oral presentation and seven extension articles. Organised two workshops for World Bank, The Energy Research Institute and farmers. Scientists remain Invited Speaker two workshops. Various training programmes for the farmers were organized. They also participated in 15 seminars, conferences, symposia, workshops, etc. Fourteen lectures were delivered to the other departments and three field demonstrations in various farmers training programmes. The scientists were involved in installation of demonstrations of groundwater recharge in university and outside university. In addition, all scientists attended six Kisan melas.

Pantnagar

Out station studies includes conjunctive use planning for surface water and groundwater in Tumaria extension canal command, land and water resource management in Gagas river valley and assessment, recharge planning & management strategy for groundwater in the *Tarai* areas. Study on conjunctive use of surface water and groundwater was conducted in the Tumaria extension canal command of Udham Singh Nagar district of Uttarakhand. Two (one Linear and one Non-linear Programming) models / plans were developed for the seasonal optimal allocation of land and water resources to maximize the annual return. Total 11 crops were included in the optimization plans. Total annual canal water availability at field outlet was 1715.55 ha-m and the groundwater draft for irrigation through minor irrigation structures was 3594.24 ha-m. Total annual irrigation water requirement for exiting cropping pattern was 11237.39 ha-m and the total groundwater demand was 9533.25 ha-m. Deficit of water for irrigation was 5939.01 ha-m.

- Best plan using linear programming technique was observed as optimal crop Plan-1 (without summer rice) on weekly basis: Allocation of sown area for this plan with 100% of additional groundwater for wheat (9926.85 ha), pea (309.16 ha), sugarcane (1243.33 ha), rice (1087.07 ha), maize (1.65 ha) and *urad* (110.37 ha). Net return in this plan was ₹ 547.60 million which was ₹ 48.20 million more than the return from using existing water resources.
- Overall best plan was Plan 2 using non-linear programming technique (without summer rice) for wheat (12949.90 ha), lentil (87.67 ha), pea (550.80 ha), mustard (226.63ha), sugarcane (182.41 ha), potato (72.59 ha), *kharif* rice (4254.54 ha), maize (1.35 ha), *urad* (269.63 ha) and soybean (635.50 ha). Net return of this plan was ₹ 708.36 million which was ₹ 208.91 million more than the crop Plan 1 using linear programming.

Udaipur


Technology Fair at CTAE, Udaipur

One week training on Natural Resource Management at CTAE, Udaipur

Farmers training organized by AICRP on IWM team at Dedkiya village

Almora

Demonstration of MIS and modified MIS system at farmers' field: The MIS system has been installed at farmers' field around 5756.0 m^2 total area covered (2012-2018). This year drip system was installed on 125 m^2 area in one farmer field. The practical know how knowledge was given to farmers and also how to maintain drip system. The drip system was modified as per farmers suggestions and it is working very well.

Demonstration of LDPE film lined tank at farmers' field: The micro-water recourses developed under AICRP on water management project. The total water capacity 4009.9 m^3 which in including this 80 m^3 developed this year and it was developed in a farmer's field in one village of Almora district by harvesting water of small stream. The drip system installed around 120 m^2 area in 2017-2018 on selected farmers (Hawalbagh block village Challar Mussauli) field to enhance water productivity.

Chalakudy

Study on soil nutrient dynamics under varying moisture regimes in banana has shown that P at 75% and K at 125% of recommended dose of fertilizer (RDF) can increase yield to an extent of 15.2% 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. Reducing the level of P below 75% reduced the yield considerably.

Field trial at Koratty (Thrissur district)

Field at Thuravoor (Ernakulam district)

Jorhat

Activities taken for transfer of technology: Scientists of the project had to involve with different advisory activities to popularize the improved water management technologies generated by the centre on different aspects like irrigation scheduling, irrigation water quality maintenance, microirrigation and with concepts more crop per drop of water.

Technologies assessed by Jorhat centre

- Effect of recommended water management practices on autumn (*ahu*) rice in farmers' fields in STW commands
- Effect of recommended water management practices on summer (*boro*) rice in farmers' fields in STW commands
- Demonstration on irrigation management in brinjal in STW irrigation
- Irrigation management in yellow sarson after winter rice
- Irrigation management in yellow sarson after winter rice
- Optimizing dyke height for rainwater conservation in rice field and its effect on performance of relay crops in medium land situation

Parbhani

- Inline drip irrigation system at alternate day with 1.0 ETc depth of irrigation may be practiced by the farmer for better and quality yields of ***rabi* onion** and application of 75 kg ha^{-1} nitrogen through water soluble fertilizers in drip system with five equal splits at 15,30,45,60 and 75 days after planting should be adopted.
- For better and quality produce of ***rabi* brinjal,** inline drip irrigation system with one lateral for paired row (0.6 x0.6 m) is recommended to operate at alternate day with 60% of pan evaporation depth.
- For highest yield and economic benefits, **wheat** crop be irrigated by sprinkler method with 5 cm depth at five critical growth stages (CRI, tillering, late jointing/booting, flowering and milk stage).
- For higher yields, gross monetary returns, net monetary returns and B:C ratio of ***rabi* sorghum**, inline drip irrigation system scheduled at 1.0 ETc is recommended for paired row planting of 45x15-75 cm. The recommended fertilizer dose 80:40:40 kg ha^{-1} NPK in 3,2 and 3 splits, respectively till 60 days after sowing is recommended.
- For higher yields, gross and net monetary returns, and B:C ratio of ***rabi* okra** inline drip irrigation system laid at alternate row and scheduled at alternate day with depth of water equal to 40% pan evaporation along with 75% recommended dose of water soluble fertilizers at 75,37.5 and 37.5 kg ha^{-1} NPK, respectively in 5,3 and 5 splits from 0 to 75 days after sowing is recommended.
- For higher yields, gross monetary returns, net monetary returns and B:C ratio of **sweet orange,** inline drip system forming a loop around the tree canopy is recommended along with application of 75% recommended dose of fertilizers (600:300:300 g plant^{-1} NPK) in 12 splits till 240 days after stress withdrawal of *Mrug bahar*.
- For higher fresh rhizome yield, net monetary returns and B:C ratio of **turmeric** planted on 1.5 m wide raised bed with paired row planting (45 x 15 cm), it is recommended to schedule alternate day inline drip irrigation with 80% of cumulative pan evaporation. Similarly drip fertigation with 160:80:80 N, P_2O_5, K_2O kg ha^{-1} to turmeric with N in 5 equal splits @17.5% at an interval of 30 days from 30 DAP to 150 DAP while sixth dose of N @12.5 % at 180 DAP and P_2O_5 and K_2O in three splits of 50%, 25% and 25%, respectively at planting, 60 DAP and 120 DAP is recommended.
- For higher fruit yield and net monetary returns of ***rabi* brinjal,** it is recommended to schedule inline drip irrigation at 80% of pan evaporation daily with fertigation of 80:40:40 kg ha^{-1} of N: P: K; N in 5 equal splits at an interval of 30 days from transplanting to 120 DAP and P and K in three splits of 20, 10 and 10 kg ha^{-1}, respectively at planting, 30 DAP and 60 DAP.

- For higher yields and net monetary returns of **summer groundnut**, it is recommended to adopt inline drip lateral laid at the centre of broad bed furrow (BBF) having top width of 90 cm and three rows of groundnut planted at 30 cm covered by transparent or black polythene mulch and daily irrigation scheduled at 100% of pan evaporation on medium deep soils of Marathwada region.
- For higher yields and net monetary returns of **watermelon**, inline drip irrigation scheduled at 80% of pan evaporation daily with lateral laid at the centre of broad bed furrow of 90 cm top and crop is sown at 50 cm plant to plant spacing on the bed covered with black polythene mulch of 30 micron is recommended.
- In **soybean-chickpea** cropping system for higher yield and economic returns from chickpea it is recommended to apply two irrigations of 60 mm depth first at flowering and second at pod formation stage through sprinkler irrigation.
- For higher grain yield and net monetary returns of post ***kharif*** **maize** it is recommended to schedule alternate day drip irrigation at 80 % cumulative pan evaporation through inline lateral laid at 120 cm apart for paired rows (45x30-75 cm) and drip fertigation of 113:57:57 NPK kg ha^{-1}; N in 8 equal splits @12.5% at an interval of 10 days from 10 to 80 days after sowing while P and K in 2 equal splits at sowing and 30 days after sowing.

Chapter 11

Recommendations

Recommendations for the year 2018-19 by the centres of AICRP on Irrigation Water Management located in the eastern, western, northern and southern parts of India are given with their corresponding agro-ecological subregions (AESRs) and a short description of each AESR.

EAST

Jorhat (AESR 15.4: Warm to hot perhumid ESR with moderately deep to deep loamy, alluvium derived soils): Transplanting makhana crop (Gorgon nut; *nikori*) with spacing of 125 cm x 120 cm between 15 March to 15 April has been recommended for the state of Assam for best for seed yield, economic return and water productivity.

Jorhat (AESR 15.4: Warm to hot perhumid ESR with moderately deep to deep loamy, alluvium derived soils): Irrigation at 15 cm depletion of water from soil surface was recommended for irrigation scheduling of early *ahu* rice. For measurement of irrigation depth equally perforated open plastic pipe as described under new IRRI technique of alternate wetting and drying may be installed in crop field.

Pusa (AESR 13.1: Hot dry to moist subhumid ESR with deep, loamy alluvium derived soils): In case of water scarcity and higher cost of irrigation water, Partial Root Drying method of irrigation to *rabi* Maize crop was recommended to the farmers of north Bihar condition instead of applying conventional irrigation method with less water.

Gayeshpur (AESR 15.1: Hot moist subhumid ESR with deep loamy to clayey alluvium derived soils): It was recommended to apply arsenic contaminated shallow tubewell water and safe pond water in the ratio 1:1 for irrigation to broccoli crop for arsenic mitigation without compromising yield and water productivity.

WEST

Navsari (AESR 19.1: Hot humid ESR with medium to deep loamy to clayey mixed red and black soils): The farmers cultivating sugarcane in paired row (60:120 cm) under drip irrigation (0.60 PEF) in heavy rainfall zone of south Gujarat have been recommended to adopt subsurface inline lateral (7.5 cm depth) at 1.80 m spacing with 4 lph dripper discharge and dripper spacing at 60 cm to minimize damage to dripper and dripper clogging in the lateral and getting higher economic return.

Junagadh (AESR 5.1: Hot dry semi-arid ESR, shallow and medium loamy to clayey black soils)

General recommendation: It is recommended to the farmers, Govt. departments and NGOs that open well technique is effective for recharging shallow aquifer in Junagadh region which may recharge 0.12 cu-m of groundwater per square metre of bottom area of open well with recharge cost of Rs.1.94 m^{-3}.

Scientific recommendation: Under connector well recharge technique, steady state recharge model for Junagadh region was recommended for the scientific community for recharging connector well as,

$Q_{ca} = C \times \Delta h$

where, Q_{ca} = recharge rate to confined aquifer, $m^3\,day^{-1}$, Δh = recharge head in recharge well, m, C = 0.006 for Junagadh

Udaipur (AESR 4.2: Hot dry semi-arid ESR with deep loamy grey brown and alluvium derived soils): According to salinity classification of groundwater farmers of Rawatbhata block (Chittorgarh district), having undulating topography with yellowish brown and hilly soils, having C_2 class of groundwater salinity have been recommended to grow all crops except some sensitive crops (like Lemon, Orange, Chickpea, Greengram, Blackgram, Onion, Tomato). Farmers in areas like Bari Sadri, Begun, Bhadesar, Chittorgarh and Nimahera having groundwater of C_3 class have been recommended to grow Maize, Cowpea, Sugarcane, Wheat, Soybean, Grain sorghum, Brinjal and Lucerne. In Kapasan, Dungla, Gangrar and Rashmi blocks, where very large areas are under high to very high salinity class of groundwater, only salt tolerant crops like Guava, Date palm, Spinach, Sesbania, Cotton, Sunflower, Safflower, Millet, Wheat, Sugar beet, Mustard, Taramira, Berseem and Barley were recommended for cultivation with intensive salinity management practices.

Rahuri (AESR 6.2: Hot moist semi-arid ESR with shallow and medium loamy to clayey black soils (medium and deep clayey black soils as inclusion)): Planting papaya cv. Taiwan 786 at a distance of 1.8 m x 1.8 m under drip irrigation scheduled at 120% ETc every alternate day and fertigation with 75% RDF through water soluble fertilizers (188:188:375 N,P_2O_5 and K_2O g plant^{-1}) along with 10 kg FYM per plant has been recommended in medium deep soils of western Maharashtra for obtaining higher monetary returns and resource use efficiency.

Rahuri (AESR 6.2: Hot moist semi-arid ESR with shallow and medium loamy to clayey black soils (medium and deep clayey black soils as inclusion)): It is recommended to follow normal sowing of wheat variety Samadhan i.e. between 1-15 November in medium black soils of Maharashtra with deficit irrigation strategy i.e. if only one irrigation is available it should be given at 41st days after sowing (DAS) and if two irrigations are available it should be given at 41st and 62nd DAS to obtain more yield and profit.

Rahuri (AESR 6.2: Hot moist semi-arid ESR with shallow and medium loamy to clayey black soils (medium and deep clayey black soils as inclusion)): Crop coefficients developed using lysimeter data have been recommended for the estimation of water requirement of *Suru* sugarcane.

Rahuri (AESR 6.2: Hot moist semi-arid ESR with shallow and medium loamy to clayey black soils (medium and deep clayey black soils as inclusion)): The following equation has been recommended for estimation of daily values of crop coefficient during the crop growth period of *Suru* Sugarcane (Ratoon)

$$Kc_t = 23.38\left(\frac{t}{T}\right)^5 -59.18\left(\frac{t}{T}\right)^4 +52.65\left(\frac{t}{T}\right)^3 -21.23\left(\frac{t}{T}\right)^2 + 4.784\left(\frac{t}{T}\right) + 0.426$$

Where, Kc_t is the crop coefficient of Suru Sugarcane (Ratoon) on tth day; t is day and T is total crop growth period in day.

Rahuri (AESR 6.2: Hot moist semi-arid ESR with shallow and medium loamy to clayey black soils (medium and deep clayey black soils as inclusion)): According to soil and water sampling with GPS and GIS mapping, soil and well water quality in minor no. 3 of Mula Left Bank Canal in Rahuri tahsil of Ahmednagar district is getting saline in nature and well water quality is in the range of moderate to unsuitable for irrigation. Under this condition, it has been recommended to adopt the following cropping pattern in order to overcome degradation of soil and water quality and prevent decrease in yields of different crops. Cropping pattern and land management practices recommended for the canal command is as follows:

- Crop rotation with inclusion of leguminous crops and avoid continuously taking sugarcane after sugarcane
- Inclusion of salt tolerant crops like sugarcane, sugarbeet, cotton, berseem, wheat, jowar/sorghum, maize, sunflower, spinach, cabbage
- Green manuring crops like sunhemp, dhaincha and glyricidia
- Take crops requiring less water
- Irrigated lands should not be kept fallow
- Adoption of drip irrigation systems for all types of cropping patterns
- Application of fertilizers as per soil test

Parbhani (AESR 6.2: Hot moist semi-arid ESR with shallow and medium loamy to clayey black soils): For increased yield, quality produce and economic return from turmeric it has been recommended to apply 60 mm irrigation when cumulative pan evaporation reaches 75 mm at 0.8 IW/CPE and apply 150:50:50 kg ha^{-1} N, P_2O_5 and K_2O compared to other fertilizer combinations.

Parbhani (AESR 6.2: Hot moist semi-arid ESR with shallow and medium loamy to clayey black soils): For higher yield, gross monetary return, net monetary return and B:C ratio from *Bt* cotton crop, it has been recommended to irrigate the crop after every two days with 0.5 CPE depth using in-line drip irrigation system for paired planting at 60 x 60-120 cm as sole crop or 180 x 30 cm with greengram as intercrop along with 75:37.5:37.5 kg ha^{-1} NPK through water soluble fertilizers in 7, 3 and 4 splits, respectively during 7 to 115 days after sowing.

NORTH

Faizabad (AESR 9.2: Hot dry subhumid ESR, deep loamy alluvium-derived soils): Application of 6 cm irrigation in check basin of 5x10 m^2 in wheat crop at critical stages (CRI, late jointing and milking stages) under canal command has been recommended for high yield, B-C ratio and water saving over farmers' practice.

Faizabad (AESR 9.2: Hot dry subhumid ESR, deep loamy alluvium-derived soils): Intercropping of gram with mustard (4:1) has been recommended as diversified cropping system in place of moncrop of wheat during *rabi* season under poor availability of canal water in the command area of Chandpur distributory.

Faizabad (AESR 9.2: Hot dry subhumid ESR, deep loamy alluvium-derived soils): Conjunctive use of canal water and groundwater in the ratio 2:1 with 6 cm irrigation at CRI, late jointing and milking stage of wheat in check basin (5x10 m^2) at middle end of Chandpur distributary has been recommended for higher production of wheat with maximum benefit-cost ratio.

Faizabad (AESR 9.2: Hot dry subhumid ESR, deep loamy alluvium-derived soils): Fertigation at 60% PE with 75% recommended dose of nitrogen (RDN) has been recommended as an efficient and economically viable irrigation system for high yield, net return, water saving and fertilizer saving against conventional irrigation practice.

Faizabad (AESR 9.2: Hot dry subhumid ESR, deep loamy alluvium-derived soils): Bed planting of wheat after conventional tillage with 1.0 IW/CPE irrigation schedule has been recommended for higher production and productivity of wheat crop to obtain higher yield of wheat with higher net return and highest benefit-cost ratio.

Faizabad (AESR 9.2: Hot dry subhumid ESR, deep loamy alluvium-derived soils): Irrigation schedule 1.0 IW/CPE with every furrow irrigation method and nitrogen management practice with application of 75% RDN through urea with 25% N through FYM has been recommended to obtain higher potato, net benefit and B-C ratio.

Jammu (AESR 14.2: Warm moist to dry subhumid transitional ESR with medium to deep loamy to clayey brown forest and podzolic soil): It was recommended for the farmers of Ranbir canal command area of Jammu having light textured soils to follow rotavator puddling to get highest yield and WUE of basmati rice.

Jammu (AESR 14.2: Warm moist to dry subhumid transitional ESR with medium to deep loamy to clayey brown forest and podzolic soil): The middle and tail reach farmers of canal command were recommended to adopt rotavator puddling with alternate wetting and drying practice at three days after disappearance of ponded water (3 DADPW) for getting assured yield and WUE of basmati rice.

Ludhiana (AESR 4.1: Hot semi-arid ESR with deep loamy alluvium-derived soils (occasional saline and sodic phases)): *Eucalyptus* can be successfully grown with saline sodic water, popular with alternate irrigation of canal water and saline sodic water whereas, Dek can be cultivated in rotation of two irrigations with canal water followed by one irrigation with saline sodic water under calcareous loamy sand soil .

Palampur (AESR 14.3: Warm humid to perhumid transitional ESR with shallow to medium deep loamy brown forest and podzolic soils): It has been recommended that under protected conditions drip irrigated strawberry crop should be irrigated with 0.8 PE and fertigated with 75-100% of recommended NK.

SOUTH

Coimbatore (AESR 8.1: Hot dry semi-arid ESR with moderately deep to deep, loamy to clayey, mixed red and black soils): Application of RDF (150:50:50 kg NPK ha^{-1}) along with vermicompost @ 5 t ha^{-1} and Gypsum has been recommended for rice in alkaline water irrigated areas of Tamil Nadu. Microirrigation (drip and sprinkler) can be given after the analysis of irrigation water in the region.

Coimbatore (AESR 8.1: Hot dry semi-arid ESR with moderately deep to deep, loamy to clayey, mixed red and black soils): Ridges and furrow land configuration with micro sprinkler irrigation regime 90% PE has been recommended to obtain higher yield and income from big onion crop compared to check basin method of irrigation in broad bed furrows.

Coimbatore (AESR 8.1: Hot dry semi-arid ESR with moderately deep to deep, loamy to clayey, mixed red and black soils): Artificial recharge through recharge shaft in percolation pond was taken up by way of allowing the runoff water to pass through silt detention tank, water collection tank-cum-treatment chamber and shaft with filtering chamber. Slotted PVC pipe was erected for easy recharging. This technique has been recommended for hard rock areas to increase the rate of recharge by about 23% and also reduce evaporation losses by 8% in percolation ponds. Based on the recommendation, AED has introduced recharge shaft in percolation pond in 250 blocks (Two numbers in each block) of eighteen districts of Tamil Nadu.

Belavatagi (AESR 6.4: Hot dry sub-humid ESR with shallow and medium loamy and clayey black soils (deep clayey black soils as inclusion)): It has been recommended to schedule fertigation at 0.6 IW/CPE (4-5 irrigations) and 125% RDF (150:75:75 N:P_2O_5:K_2O kg ha^{-1}) to *Bt* cotton to save water and fertilizer and obtain higher economic yield in *Vertisols* of Malaprabha command area.

Belavatagi (AESR 6.4: Hot dry sub-humid ESR with shallow and medium loamy and clayey black soils (deep clayey black soils as inclusion)): It has been recommended to grow sunflower during *kharif* season with irrigation at 1.0 ET_o followed by *rabi* crops *viz.*, wheat, Bengal gram and groundnut under common drip layout for both *kharif* and *rabi* crops compared to farmers' method of cultivation. Adoption of drip irrigation method for the crops like maize, sunflower, chilli, onion during *kharif* and wheat, chickpea, field bean, groundnut during *rabi* has been recommended.

Belavatagi (AESR 6.4: Hot dry sub-humid ESR with shallow and medium loamy and clayey black soils (deep clayey black soils as inclusion)): It has been recommended to irrigating wheat crop at 0.8 IW/CPE with application of RDF + FYM @ 7.5 t ha^{-1} + $ZnSO_4$ @ 20 kg ha^{-1} + $FeSO_4$ @ 20 kg ha^{-1} for higher grain yield and water use efficiency.

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BUDGET ALLOCATION 2018-19

Name of Center (University/ Centre/ Institute)	Salary	General		Total General	Capital		Total Capital	SCSP		Total SCSP	TSP	Grand Total
		Res. & Oper.	TA		Equipment	IT		General	Capital			
PAU, Ludhiana	150.00	2.30	0.50	2.80	0.00	0.00	0	0	0	0	0.00	152.80
UAS, Dharward	75.00	1.75	0.40	2.15	0.00	0.00	0	0	0		0.00	77.15
TNAU, Coimbatore	170.00	2.55	0.50	3.05	0.00	0.00	0	0	0		0.00	173.05
IGKV, Raipur	85.00	2.30	0.40	2.70	0.00	0.00	0	1.00	0	1.00	0.00	88.70
KAU, Thrissur	100.00	1.75	0.40	2.15	0.00	0.00	0	0	0	0	0.00	102.15
OUAT, Bhubaneswar	35.25	1.75	0.40	2.15	0.00	0.00	0	1.00	0	1.00	0.00	38.40
BSKKV, Dapoli	125.00	2.10	0.40	2.50	0.00	0.00	0	0	0	0	0.00	127.50
NDUAT, Faizabad	55.00	1.75	0.40	2.15	0.00	0.00	0	0	0	0	0.00	57.15
BCKV, Kalyani Nadia	58.00	1.75	0.40	2.15	0.00	0.00	0	0	0	0	0.00	60.15
CCSHAU, Hisar	50.00	1.25	0.50	1.75	0.00	0.00	0	0	0	0	0.00	51.75
SKUAST, Jammu	95.00	1.75	0.40	2.15	0.00	0.00	0	0	0	0	0.00	97.15
MPUAT, Udaipur	55.00	1.70	0.40	2.10	0.00	0.00	0	0	0	0	0.00	57.10
AU, Kota(Raj.)	70.00	1.70	0.40	2.10	0.00	0.00	0	0	0	0	0.00	72.10
JAU, Junagadh	54.00	1.70	0.40	2.10	0.00	0.00	0	0	0	0	0.00	56.10
RVSKVV, Morena	95.75	1.70	0.40	2.10	0.00	0.00	0	0	0		4.00	101.85
NAU, Navsari	60.00	1.70	0.40	2.10	0.00	0.00	0	0.70	0	0.70	0.00	62.80
CSKHPKV, Palampur	128.00	1.70	0.40	2.10	0.00	0.00	0	0.75	0	0.75	0.00	130.85
GBPUAT, Pantnagar	130.00	2.25	0.50	2.75	0.00	0.00	0	0	0	0	0.00	132.75
VNMKV, Parbhani	60.00	1.70	0.40	2.10	0.00	0.00	0	0	0	0	4.00	66.10
JNKVV, Jabalpur	64.00	2.25	0.40	2.75	0.00	0.00	0	0.70	0	0.70	0.00	67.45
MPAU, Rahuri	150.00	2.25	0.50	2.75	0.00	0.00	0	0.75	0	0.75	0.00	153.50
SKRAU, Bikaner	70.00	1.70	0.40	2.10	0.00	0.00	0	0.70	0	0.70	0.00	72.80
AAU, Jorhat	105.00	1.70	0.40	2.10	1.83	0.00	1.83	0	0.67	0.67	0.00	109.60
Dr.RPCAU, Pusa	60.00	2.10	0.40	2.50	0.00	0.00	0	0.75	0	0.75	0.00	63.25
ICAR-RC-NEH, Umiam	0.00	1.70	0.40	2.10	0.00	0.00	0	0	0	0	0.00	2.10
VPKAS, Almora	0.00	2.00	0.10	2.10	0.00	0.00	0	0	0	0	0.00	2.10
IIWM (PCU)	0.00	11.45	0.00	11.45	0.00	0.17	0.17	0	0	0	0.00	11.62
Sub Total	2100.00	60.30	10.70	71.00	1.83	0.17	2.00	6.35	0.67	7.02	8.00	2188.02

STAFF POSITION 2018-19

Almora	
Chief Scientist	Dr. S.C. Panday
Agronomist	Vacant
Soil Physicist	Dr. S.C. Panday
Agril Engineer	Vacant
Jr. Agronomist	Vacant
Jr. Soil Physicist	Dr. Manoj Parihar
Jr. Agric. Engg.	Er. Sayamnath
Agril. Chemistry	Dr.M.Chaudhari (On study leave)
Belavatagi	
Chief Scientist	Dr. Kumar D. Lamani
Agronomist	Vacant
Soil Physicist	Dr. Punitha B.C.
Agril. Engineer	Dr. P.S.Kanannavar
Jr. Agronomist	Vacant
Coimbatore + Madurai + Bhavanisagar	
Chief Scientist	Dr. A.Raviraj
Agronomist	Vacant
Soil Physicist	Vacant
Asst. Prof. (SWC)	Dr. A. Valliammai
Assistant Professor	Dr.G. Thiyagarajan
Agril. Engineer	Vacant
Asst. Prof. Soil Physicist	Dr. J. Prabhaharan
Jr. Agronomist	Vacant
Chalakudy	
Chief Scientist	Dr. E.K. Kurien
Agronomist	Dr. Mini Abraham
Soil Physicist	Smt. Bhindhu P.S.
Agril. Engineer	Vacant
Chiplima	
Chief Scientist	Dr. A.K. Mohanty
Agronomist	Vacant
Soil Physicist	Vacant
Agril. Engineer	Dr. S.N.Bansude
Jr. Agronomist	Vacant
Dapoli	
Chief Scientist	Dr. R.T. Thokal
Horticulturist	Vacant
Soil Physicist	Vacant
Agril. Engineer	Dr. B.L. Ayare
Jr. Agronomist	Dr. T.N. Thorat
Faizabad	
Chief Scientist	Vacant
Agronomist	Vacant
Soil Physicist	Vacant
Agril. Engineer	Er. R.C. Tiwari
Jr. Agronomist	Dr. B.N. Singh

Gayeshpur	
Chief Scientist	Dr. S.K. Patra
Agronomist	Vacant
Soil Physicist	Vacant
Agril. Engineer	Er. S. Saha
Jr. Agronomist	Mr. R. Poddar
Hisar	
Chief Scientist	Dr. Manoj K. Sharma
Agronomist	Vacant
Soil Physicist	Vacant
Agril. Engineer	Vacant
Jr. Agronomist	Dr. Muli Devi Parihar
Jammu	
Chief Scientist	Dr. A.K. Raina
Agronomist	Vacant
Soil Physicist	Dr. Abhijit Samanta
Agril. Engineer	Vacant
Jr. Agronomist	Dr. Vijay Bharti
Powarkheda + Jabalpur	
Chief Scientist	Dr. M.K.Awasthi
Scientist (SWE)	Dr. Y. K. Tiwari
Agronomist	Vacant
Soil Physicist	Vacant
Agril. Engineer	Vacant
Jr. Agronomist	Vacant
Jorhat	
Chief Scientist	Dr. R.K. Thakuria
Agronomist	Vacant
Soil Physicist	Dr. B.K. Medhi
Agril. Engineer	Vacant
Junagadh	
Chief Scientist	Dr. H.D. Rank
Agronomist	Vacant
Agril. Engineer	Prof. P.B. Vekariya
Soil Physicist	Dr. M.S. Dulawat
Kota	
Chief Scientist	Vacant
Soil Physicist	Dr. R. K.Yadav,Chief Scientist (Acting)
Agronomist	Dr. Baldev Ram
Agril. Engineer	Er. I.N. Mathur
Jr. Agronomist	Vacant
Ludhiana + Bathinda	
Chief Scientist	Dr. Rajan Aggarwal
Asst. Res. Engineer	Dr. Sanjay Satpute
Sr. Scientist (Irrigation)	Vacant
Sr. Soil Physicist	Dr. K.S. Sekhon
Asst. Agronomist	Dr. Anureet Kaur

Asst. Agril. Engineer	Vacant
Morena	
Chief Scientist	Dr. Y.P. Singh
Soil Physicist	Vacant
Agril. Engineer	Er. S.K. Tiwari
Agronomist	Dr. S. S. Tomar
Jr. Agronomist	Vacant
Navsari	
Chief Scientist	Vacant
Associate Prof.	Dr. V.P. Usadadiya (C.S. Incharge)
Soil Physicist	Vacant
Agril. Engineer	Vacant
Jr. Agronomist	Vacant
Palampur	
Chief Scientist	Dr A. K. Goel
Agril. Engineer	Vacant
Agronomist	Dr. Anil Kumar
Soil Physicist	Dr. S.K. Sandal
Jr. Agronomist	Vacant
Pantnagar	
Chief Scientist	Dr. H.C. Sharma
Soil Physicist	Vacant
Sr. Agril Engineer	Dr. Yogendra Kumar
Agronomist	Vacant
Agril. Engineer	Dr. Vinod Kumar
	Dr. U.C. Lohni
Jr. Agronomist	Dr. Gurvinder Singh
Parbhani	
Chief Scientist	Dr.A.S.Kadale (Additional Charge)
Agril. Engineer	Dr. A.S.Kadale
Agronomist	Prof. G.D. Gadade
Soil Physicist	Vacant
Jr. Agronomist	Vacant
Pusa (WM + GWU)	
Chief Scientist	Dr. S.K. Jain
Agronomist	Vacant
Soil Physicist	Vacant

Agril. Engineer	Dr. S.P. Gupta
Sr. Soil Physicist	Dr. A.K. Singh
Jr. Agril. Engineer	Dr. Ravish Chandra
Jr. Agronomist.	Dr. Rajan Kumar
Rahuri (WM + GWU)	
Chief Scientist	Dr. P. S. Bodake
Agronomist	Vacant
Agril. Engineer	Vacant
Research Engineer	Dr. S.D. Dahiwalkar
Soil Physicist	Dr. B.D. Bhakare
Jr. Agronomist	Prof. S.S. Tuwar
Jr. Res. Engineer	Er. S.A. Kadam
Raipur + Bilaspur	
Chief Scientist	Dr. M. P. Tripathi
Agronomist	Vacant
Agricultural Engineer	Dr. Dhiraj Khalkho
Sr. Soil Physicist	Sh. P.K. Keshry
Sr. Agril. Engineer	Dr. Devesh Pandey
Jr. Agronomist	Dr. Geet Sharma
Shillong	
Chief Scientist	Dr. U.S. Saikia
Agronomist	Vacant
Agril. Engineer	Vacant
Soil Physics	Vacant
Jr. Agronomist	Vacant
Jr. Soil Physicist	Vacant
Sriganganagar	
Chief Scientist	Vacant
Soil physicist	Dr. B.S.Yadav
Agronomist	Dr. R.P.S. Chauhan
Agril. Engineer	Vacant
Jr. Agronomist	Vacant
Udaipur	
Chief Scientist	Dr. P.K. Singh
Soil Physicist	Dr. K.K. Yadav
Agril. Engineer	Er. Manjeet Singh
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