वार्षिक प्रतिवेदन
Annual Report 2020

सिंचाई जल प्रबंधन पर अखिल भारतीय समन्वित अनुसंधान परियोजना

All India Coordinated Research Project on Irrigation Water Management

ICAR-IIWM

भाकृअनुप-भारतीय जल प्रबंधन संस्थान
ICAR- Indian Institute of Water Management
Bhubaneswar, Odisha, India

भाकृ अनुप
ICAR

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भाकृअनुप - भारतीय जल प्रबंधन संस्थान
भुवनेश्वर, ओडिशा, भारत

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AICRP-IWM Annual Report 2020

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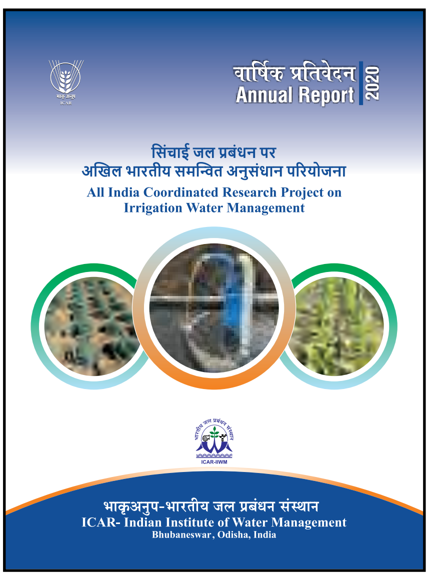

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Preface

The Annual Report of All India Coordinated Project on Irrigation Water Management (AICRP on IWM) contains the research findings of different coordinating centers for the year 2020 along with extension activities, human resource development programme, publications and recommendations of various centers. The consolidated report of the centers is presented under different themes. During the reporting period, the scientists were engaged in carrying out research on improving water use efficiency for different crops and cropping sequences under different sources of irrigation water in various agro climatic conditions of the country. Significant achievements have been made during the reporting year 2020 in spite of Covid-19 Pandemic. On-station and on-farm research endeavors 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 research output not only improved water productivity but also enhanced farmers' income and livelihoods. The AICRP centres also carried out capacity building activities for different stakeholders and implemented tribal sub plan schemes for improving livelihoods of tribal people at different palaces. Some of the pilot interventions contributed in 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. S.K. Chaudhari, Deputy Director General (NRM) and Dr. Adlul Islam, Assistant Director General (S&WM), ICAR for their valuable suggestions and cooperation during the reporting period. I also sincerely thank the scientists of AICRP-IWM schemes working at different centers for their untiring efforts for improving irrigation water management scenario of the country. Their sincere efforts resulted in tangible outputs in irrigation water management which could go a long way in improving farmers' income and water productivity. The team work of Dr. Prabhakar Nanda, Principal Scientist, Dr. S. Mohanty, Principal Scientist, Dr. Dibakar Ghosh, Scientist, Dr. O.P. Verma, Scientist of ICAR-IIWM and Pragna Dasgupta, Research Associate, AICRP-IWM is appreciated for compiling and editing the annual report. I thank Dr. Amod Thakur, Principal Scientist, ICAR-IIWM for giving his valuable inputs and ideas during revision of the annual report and design of the cover page.

Bhubaneswar

(A. Mishra)
Director, ICAR-IIWM

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कार्यकारी सारांश

सिंचाई जल प्रबंधन पर अखिल भारतीय समन्वित अनुसंधान परियोजना की प्रमुख उपलब्धियां

इस परियोजना के अंतर्गत वर्ष 2020 के दौरान कुल 26 केंद्रों ने जल की उपलब्धता के आकलन, भूजल पुन:भरण, क्षेत्रीय स्तर पर भूजल का उपयोग, दबावयुक्त सिंचाई प्रणाली का मूल्यांकन, बागवानी और नकदी फसलों में जल प्रबंधन, मृदा-जल-पौधे संबंध पर बुनियादी अध्ययन, नहरी और भूमिगत खारे पानी का संयोजी उपयोग, जल उत्पादकता बढ़ाने के लिए जल निकासी तथा अधिक वर्षा वाले क्षेत्रों में सिंचाई जल और वर्षा जल प्रबंधन का बहुआयामी उपयोग इत्यादि के क्षेत्र में अनुसंधान और विस्तार कार्य किया। वर्ष 2020 के दौरान प्राप्त की गई मुख्य उपलब्धियां नीचे सूचीबद्ध हैं-

नहरी जल और भूजल की उपलब्धता का आकलन

जूनागढ़ केंद्र द्वारा उबेन नदी बेसिन के भूजल संसाधनों का आकलन भूजल प्रवाह सिमुलेशन मॉडल का उपयोग करके किया गया। इस बेसिन के भू-उपयोग और भू-आवरण मानचित्र से पता चला कि कृषि, वन, बंजर भूमि, निर्मित और जल निकायों के अंतर्गत क्रमशः 78.90, 10.08, 7.68, 2.32 और 1.03% क्षेत्र आता है। उबेन बेसिन में क्रमशः 74.13, 16.86 और 8.98% क्षेत्रों की मृदा का प्रकार महीन, चिकनी और चट्टानी है। विजुअल मॉडफ्लो सॉफ्टवेयर का उपयोग करके भूजल प्रवाह मॉडलिंग की गई। मॉडल का अंशांकन स्थिर स्थिति और क्षणिक स्थिति दोनों के लिए किया गया।

उदयपुर केंद्र द्वारा बनास नदी बेसिन पर अनुसंधान किया गया। इस जिले में ऊपरी बनास नदी बेसिन चंबल नदी बेसिन की मुख्य सहायक नदी है और यह राजस्थान के राजसमंद, उदयपुर चित्तौड़गढ़ और भीलवाड़ा जिलों में स्थित है। इस पूरी बेसिन को कुल 21 उप-नदी बेसिनों में विभाजित किया गया; और भू-आकृति संबंधी विशेषताओं के रैखिक, एरियल और भोगोलिक पहलुओं को निर्धारित किया गया। उप-नदी बेसिनों में मृदा और जल संरक्षण संबंधी कार्यों के लिए प्राथमिकता दी गई। उप-नदी बेसिन नंबर 10 को मृदा और जल संरक्षण उपायों के लिए पहली प्राथमिकता देने के लिए इस बेसिन की पहचान की गई।

कोयंबटूर केंद्र द्वारा लोअर भवानी परियोजना (LBP) बेसिन को कुल 187 माइक्रो वाटरशेड्स में विभाजित किया गया और प्रत्येक माइक्रो वाटरशेड को कुल 4833 हाइड्रोलॉजिकल प्रतिक्रिया इकाइयों में विभाजित किया गया जहाँ, मृदा और भूमि उपयोग समान था। वर्तमान परिदृश्य (2001 से 2020), मध्य शताब्दी (2041-2060) और अंतिम शताब्दी (2071-2090) के लिए स्वाट (SWAT) मॉडल का उपयोग करके इस बेसिन के हाइड्रोलॉजिकल मापदंडों का मापन किया गया। यह अनुमान लगाया गया था कि मध्य शताब्दी के दौरान बेसिन की वार्षिक औसत वर्षा 983.2 मिमी प्राप्त हुई और शताब्दी के अंत तक 766.9 मिमी वर्षा प्राप्त होगी। मध्य और शताब्दी के अंत तक दोनों में वर्षा के अपवाह का अनुमान 30% वर्षा के रूप में लगाया गया। वर्तमान परिदृश्य, मध्य शताब्दी और शताब्दी के अंत लिए वार्षिक जल संतुलन का मापन भी किया गया। मध्य और शताब्दी के अंत में औसत वार्षिक वाष्पीकरण को क्रमशः 866 और 907 मिमी तक अनुमानित किया गया जो भविष्य की जलवायु परिस्थितियों में फसलों की अधिक सिंचाई जल की आवश्यकता को दर्शाता है। कुहलूर जल वितरणिका के लिए फसलों की जल मांग पर अनुसंधान किया गया और यह अनुमान लगाया गया कि इस वितरणिका के लिए जल की आपूर्ति-मांग में 29% का अंतर प्राप्त होता है।

लुधियाना केंद्र पर विजुअल मोडफ्लो सॉफ्टवेयर का उपयोग करते हुए पंजाब राज्य के लिए भूजल प्रवाह सिमुलेशन मॉडल को विकसित किया गया। इस मॉडल का अंशांकन परीक्षण व त्रुटि विधि और स्वचालित अंशांकन के संयोजन द्वारा किया गया। वर्ष 1998-2012 तक की अवधि के भूजल स्तर के आकड़ों का उपयोग करके इस मॉडल का अंशांकन किया गया और वर्ष 2013-2017 तक की अवधि के आकड़ों का उपयोग करके इस मॉडल का सत्यापन किया गया। इस कैलिब्रेटेड मॉडल का उपयोग करते हुए 5, 10, 15 और 20 वर्षों के बाद के छह परिदृश्यों के लिए भूजल स्थिति की भविष्यवाणी की गई। ये छह परिदृश्य इस प्रकार थे (1) भूजल पुन:भरण में 2% की वृद्धि (2) भूजल ड्राफ्ट में 2% की कमी (3) भूजल ड्राफ्ट में 3% की कमी (4) भूजल ड्राफ्ट में 5% की कमी, (5) भूजल पुन:भरण में 2% की वृद्धि और ड्राफ्ट में 3% की कमी और (6) भूजल पुन:भरण में 2% की वृद्धि और ड्राफ्ट में 5% की कमी आदि।

जबलपुर केंद्र द्वारा टोंस नदी बेसिन में संभावित भूजल क्षेत्रीकरण के लिए विश्लेषणात्मक पदानुक्रम प्रक्रिया का उपयोग किया गया। इसमें भूविज्ञान, जल निकासी, जल निकासी घनत्व, भूमि उपयोग, भूमि आवरण, ढ़लान, मृदा की बनावट जैसे विभिन्न विषयगत मानचित्रों का उपयोग किया गया। भूजल संभावित क्षेत्र के निर्माण के लिए आर्कजीआईएस में भारित सूचकांक ओवरले विश्लेषण उपकरण का उपयोग किया गया। इस परिणामी मानचित्रों ने टोंस नदी बेसिन के संभावित भूजल क्षेत्रों को तीन श्रेणियों जैसे कि अच्छा, मध्यम और खराब भूजल क्षमता के तहत प्रदर्शित किया। सतना जिले में भूजल क्षमता

अच्छी पाई गई है जो कि 5562.50 वर्ग किलोमीटर के क्षेत्र के बराबर है, यानि कुल बेसिन का 44.50% क्षेत्र इसके अंतर्गत है। इस अध्ययन से यह निष्कर्ष निकला कि भूजल संभावित क्षेत्रों का चित्रण भूजल संभावित क्षेत्र, भूजल के दोहन व विकास तथा बेहतर योजना तैयार करने और प्रबंधन की जानकारी के लिए बहुत ही सहायक है।

रायपुर केंद्र द्वारा छत्तीसगढ़ राज्य के कोरबा और जांजगीर-चांपा जिलों में भूजल संभावित क्षेत्रों को विभिन्न विषयगत मानचित्रों जैसे जल निकासी घनत्व, ढ़लान, भूविज्ञान, भू-आकृति विज्ञान, मृदा की बनावट, कंटूर रेखा, वर्षा, भूजल स्तर में उतार-चढ़ाव, भूमि उपयोग और भूमि आवरण को एकीकृत करके एमसीडीए दृष्टिकोण का उपयोग करके रिमोट सेंसिंग और जीआईएस तकनीकों की सहायता से तैयार किया गया। यहाँ, भूजल संभावित क्षेत्रों को चार श्रेणियों में वर्गीकृत किया गया, अर्थात् निम्न, निम्न से मध्यम, मध्यम से अधिक और बहुत अधिक इत्यादि। इस क्षेत्र का बड़ा हिस्सा (42.72%) निम्न से मध्यम संभावित क्षेत्र के अंतर्गत आता है; 20.27% क्षेत्र मध्यम से उच्च श्रेणी के अंतर्गत आता है; 19.18% क्षेत्र बहुत अधिक संभावित क्षेत्र के अंतर्गत आता है और केवल 17.81% क्षेत्र ही बहुत कम भूजल संभावित क्षेत्र के अंतर्गत आता है। निम्न और निम्न से मध्यम भूजल संभावित क्षेत्रों में पुन:भरण और भंडारण के लिए बनाई जाने वाली उपयुक्त संरचनाओं जैसे कि रिसाव टैंक, चेक बांध और खेत में तालाब को उपयुक्त माना गया। यहाँ, कुल 36 रिसाव टैंक, 39 चेक बांध और 21 तालाबों के निर्माण के लिए स्थलों की पहचान की गई।

दबावयुक्त सिंचाई प्रणाली

शिलांग केंद्र द्वारा वर्ष 2018-19 के दौरान निम्नलिखित उद्देश्यों को ध्यान में रखते हुए प्रयोग शुरू किया गया (i) पहाड़ी क्षेत्रों में टमाटर की फसल के लिए बांस ड्रिप सिंचाई प्रणाली की डिजाइन तैयार करना (ii) सिंचाई की विभिन्न विधियों एवं इन सीटू नमी संरक्षण तकनीकों के बीच आर्थिक जल उत्पादकता, उपज और आय बढ़ाने की सापेक्ष क्षमता की तुलना करना। इस प्रयोग से पता चला कि पलवार के प्रयोग के साथ बांस की ड्रिप सिंचाई प्रणाली में जल उत्पादकता के साथ-साथ आर्थिक पैदावार बढ़ाने की अच्छी क्षमता है। यह एक पर्यावरण के अनुकूल और आर्थिक प्रणाली है जो बाजार में उपलब्ध आदानों (इनपुट्स) पर निर्भर नहीं रहती है।

कोटा केंद्र द्वारा स्प्रिंकलर के नोजल के आकार और इसके अन्य हाइड्रोलिक मापदंडों के प्रदर्शन का मूल्यांकन धनिया की फसल की उत्पादकता पर किया गया। ऑपरेटिंग दबाव 1.5 किग्रा/वर्ग सेमी की तुलना में 2.5 किग्रा/वर्ग सेमी के ऑपरेटिंग दबाव पर छिड़काव सिंचाई से काफी अधिक बीज उपज (1.18 टन/हे) एवं जल उपयोग दक्षता (7.98 किग्रा / हेक्टर-मिमी) प्राप्त हुई तथा अधिक शुद्ध लाभ (₹40185/हे) और लाभ:लागत अनुपात (1.30) भी प्राप्त हुआ। स्प्रिंकलर सिंचाई में 2.5 किग्रा/वर्ग सेमी का ऑपरेटिंग दबाव 1.5 किग्रा/वर्ग सेमी की तुलना में 10.3% तक धनिया की अधिक उपज देता है। इसी तरह, स्प्रिंकलर के 3.1 × 5.1 मिमी नोजल आकार की तुलना में 2.5 × 3.5 के नोजल के आकार से काफी अधिक बीज उपज (1.18 टन/हे) दर्ज हुई जबकि, नोजल के विभिन्न आकार से शुद्ध लाभ और लाभ: लागत अनुपात पर कोई महत्वपूर्ण प्रभाव नहीं पड़ा लेकिन, 2.5 × 3.5 मिमी नोजल आकार के तहत अधिकतम शुद्ध लाभ (₹39399/हे) और लाभ: लागत अनुपात (1.26) प्राप्त हुआ।

उर्वर सिंचन (फर्टिगेशन)

दापोली केंद्र द्वारा शकरकंद-मक्का के फसल क्रम में उर्वर सिंचन (ड्रिप फर्टिगेशन) पर अनुसंधान किया गया। सतही सिंचाई विधि की तुलना में ड्रिप सिंचाई प्रणाली से सिंचाई के कारण दोनों फसलों में क्रमशः 75 और 37.6% तक जल की बचत प्राप्त की जा सकती है। ड्रिप सिंचाई के स्तर (100% फसल वाष्पोत्सर्जन पर सिंचाई) और जल में घुलनशील उर्वरकों के माध्यम से 100% सुझाई गई उर्वरकों की मात्रा के प्रयोग से दोनों फसलों की उपज और उपज के मापदण्डों में काफी वृद्धि हुई। उर्वर सिंचन के इस संयोजन के कारण शकरकंद की कंद उपज (24.63 टन/हे) और मक्का के भुट्टों की उपज (21.73 टन/हे) अधिकतम प्राप्त हुई। परंतु, जल में घुलनशील उर्वरकों के माध्यम से 100% सुझाई गई उर्वरकों की मात्रा के प्रयोग के साथ 50% फसल वाष्पोत्सर्जन पर सिंचाई से दोनों फसलों में अधिक जल उपयोग दक्षता प्राप्त हुई। ड्रिप सिंचाई के स्तर 100% फसल वाष्पोत्सर्जन पर सिंचाई से अधिकतम फसल पद्धति उपज (58.90 टन/हे) प्राप्त हुई जबकि, जल में घुलनशील उर्वरकों के माध्यम से 100% सुझाई गई उर्वरकों की मात्रा के प्रयोग से 59.86 टन/हे की फसल पद्धति उपज उपज प्राप्त हुई। इसी उर्वर सिंचन के संयोजन से शकरकंद-मक्का के फसल क्रम के तहत 2.17 का लाभ: लागत अनुपात प्राप्त हुआ।

परभणी केंद्र पर अरहर की उपज बढ़ाने के लिए ड्रिप फर्टिगेशन के प्रदर्शन का मूल्यांकन किया गया। अरहर की फसल में 0.8 फसल वाष्पोत्सर्जन पर ड्रिप सिंचाई और जल में घुलनशील उर्वरकों के माध्यम से दस भागों में 20-40-20 किलो/हे नाइट्रोजन, फॉस्फोरस एवं पोटेशियम की सुझाई गई मात्रा के प्रयोग के संयोजन को 20% सिंचाई जल एवं उर्वरकों की बचत के साथ अधिक उत्पादकता एवं आय के लिए उपयुक्त पाया गया। फर्टिगेशन में उर्वरकों के दस विभाजन इस प्रकार निर्धारित किए गए 20% N और 40% P बुवाई के 0-30 दिनों के बाद दो भागों में प्रयोग, 30% N व P और 25% K बुवाई के 31-60 दिनों बाद तीन भागों में प्रयोग, 30% N व P और 40% K बुवाई के 61-90 दिनों के बाद ३ भागों में और 20% N एवं 35 % K बुवाई के 91-120 दिनों के बाद दो भागों में प्रयोग इत्यादि।

परभणी केंद्र पर ड्रिप फर्टिगेशन के लिए प्याज की फसल की प्रतिक्रिया का आकलन किया गया। ग्रीष्म मौसम वाले प्याज पर सिंचाई और फर्टिगेशन के प्रयोग से पता चला कि 0.6 फसल वाष्पोत्सर्जन पर ड्रिप सिंचाई तथा वैकल्पिक दिनों पर जल में घुलनशील उर्वरकों के माध्यम से दस बराबर भागों (बुवाई के 30 दिनों बाद 20% N & 40% P दो भाग में, बुवाई के 31-60 दिनों बाद 30% N, P & 25% K 3 भाग में, बुवाई के 61-90 दिनों बाद, 30% N, P & 40% K 3 भाग में, बुवाई के 91-120 दिनों पर 20% N & 35% K 2 भाग में) में 80-40-40 किलो/हे की दर से नाइट्रोजन, फॉस्फोरस व पोटेशियम के प्रयोग के संयोजन को 20% तक सिंचाई जल एवं उर्वरकों में बचत के साथ अधिक उत्पादकता एवं आय के लिए उपयुक्त पाया गया।

बेलवातागी केंद्र पर ड्रिप सिंचाई प्रणाली के माध्यम से गेहूँ की फसल में नाइट्रोजन उर्वरक के प्रयोग पर अनुसंधान किया गया। सिंचाई के विभिन्न स्तरों में से 80% संचयी पैन वाष्पीकरण (CPE) पर सिंचाई से क्रमशः 3.35 और 5.59 टन/हे की अधिक दाना और पुआल की पैदावार प्राप्त हुई और इसके बाद 60% संचयी पैन वाष्पीकरण पर सिंचाई से क्रमश: 2.98 और 5.23 टन/हे की दाना एवं पुआल की उपज प्राप्त हुई। पोषक तत्वों के स्तरों के बीच बुवाई के समय 20% नाइट्रोजन के 5 बराबर भागों में प्रयोग से क्रमशः 3.80 और 6.07 टन/हे की अधिक दाना और पुआल की पैदावार प्राप्त हुई। बुवाई के समय 20% नाइट्रोजन एवं बुवाई के 85 दिनों तक साप्ताहिक अंतराल पर नाइट्रोजन के प्रयोग से क्रमश: 3.85 एवं 5.82 टन/हे की दाना एवं पुवाल उपज प्राप्त हुई। सिंचाई के 60% संचयी पैन वाष्पीकरण के स्तर पर सिंचाई एवं बुवाई के समय 20% नाइट्रोजन के 5 बराबर भागों में प्रयोग से क्रमश: 11.71 किग्रा/हे –मिमी और 13.78 किग्रा/-मिमी तक जल उपयोग दक्षता में उल्लेखनीय वृद्धि प्राप्त हुई।

कोटा केंद्र पर तीन वर्षों के आंकड़ों से पता चला कि बैंगन की फसल को हर तीसरे दिन पर ड्रिप सिंचाई प्रणाली द्वारा वाष्पित जल के 100% स्तर के साथ सिंचित किया जाता है और उर्वरकों की 100% सुझाई गई मात्रा (80-60-60 किलो/हे नाइट्रोजन, फॉस्फोरस एवं पोटेशियम का 3-9 दिनों के अंतराल पर 19 बराबर भागों में प्रयोग) का प्रयोग किया जाता है। ड्रिप फर्टिगेशन के संयोजन यानि 125% वाष्पित जल के स्तर पर सिंचाई + उर्वरकों की सुझाई गई 100% मात्रा के प्रयोग से अधिक फल उपज (23.6 टन/हे) के साथ-साथ अधिक शुद्ध लाभ (₹155800/हे) और लाभ:लागत अनुपात (1.94) प्राप्त हुआ। इस ड्रिप फर्टिगेशन के स्तर के प्रयोग से फलों की उपज में 35.6% तक की वृद्धि प्राप्त हुई और नियंत्रण उपचार (IW/CPE 0.8 अनुपात पर सतही सिंचाई + मृदा में उर्वरकों का प्रयोग) की तुलना में 7.7% तक सिंचाई जल की बचत प्राप्त हुई।

कोटा केंद्र पर जायद के मौसम में चार वर्षों तक सूक्ष्म छिड़काव सिंचाई प्रणाली के माध्यम से सिंचाई द्वारा मूंगफली की फसल उगाई गई। इस फसल में फर्टिगेशन के माध्यम से वाष्पित जल (PE) के 125% स्तर पर सिंचाई + उर्वरकों की सुझाई गई 100% मात्रा (30-60-40 किग्रा/हे N, P_2O_5 एवं K_2O) के प्रयोग से अधिकतम फली उपज (2.41 टन/हे) प्राप्त हुई। नियंत्रण उपचार (सतही सिंचाई विधि द्वारा 0.8 IW/CPE स्तर पर सिंचाई + संपूर्ण एनपीके उर्वरकों का मृदा में प्रयोग) की तुलना में 125% स्तर पर ड्रिप सिंचाई + उर्वरकों की सुझाई गई 100% मात्रा के प्रयोग के कारण मूंगफली की उपज में 34% तक की वृद्धि हुई। हालांकि, फर्टिगेशन के स्तर 75% PE + उर्वरकों की सुझाई गई 100% मात्रा के प्रयोग से अधिकतम जल उपयोग दक्षता (8.49 किलोग्राम/हे-मिमी) और जल उत्पादकता (0.849 किलोग्राम/घनमीटर) प्राप्त हुई।

राहुरी केंद्र पर गन्ने की फसल में उपसतही ड्रिप फर्टिगेशन पर अनुसंधान किया गया। ड्रिप सिंचाई के स्तर 100% फसल वाष्पोत्सर्जन पर सिंचाई और फर्टिगेशन के माध्यम से उर्वरकों की सुझाई गई 80% मात्रा के प्रयोग से अधिकतम गन्ना उपज (136 टन/हे) प्राप्त हुई। इस उपचार संयोजन से प्राप्त अधिकतम उपज 80% फसल वाष्पोत्सर्जन पर सिंचाई और उर्वरकों की सुझाई गई 80% मात्रा के प्रयोग के साथ फर्टिगेशन से प्राप्त उपज (132 टन/हे) के बराबर प्राप्त हुई और शेष सभी उपचारों से काफी बेहतर प्राप्त हुई। अधिकतम जल उपयोग दक्षता 80% फसल वाष्पोत्सर्जन पर सिंचाई से प्राप्त हुई और इसी सिंचाई स्तर के साथ उर्वरकों की सुझाई गई 80% मात्रा के प्रयोग के तहत अधिकतम शुद्ध लाभ (₹214637/हे) और लाभ: लागत अनुपात (2.18) प्राप्त हुआ।

जूनागढ़ केंद्र पर कपास की फसल की उपज और लाभप्रदता को बढ़ाने के लिए ड्रिप फर्टिगेशन के प्रदर्शन का अध्ययन किया गया। जब उर्वरकों की सुझाई मात्रा का 25% बुवाई के समय और शेष उर्वरकों की मात्रा का फर्टिगेशन के माध्यम से प्रयोग किया गया तो अधिकतम कपास (बीज) की उपज (2681 किलोग्राम/हे) जल उपयोग दक्षता (4.24 किलोग्राम/हे-मिमी) एवं उर्वरक उपयोग दक्षता (6.09 किलोग्राम/हे-किग्रा प्राप्त हुई। इसी फर्टिगेशन के स्तर के प्रयोग से अधिक शुद्ध लाभ (₹77182/हे) और लाभ:लागत अनुपात (1.93) प्राप्त हुआ। इसी उपचार से कपास (बीज) की उपज के लिए 2357 लीटर/किग्रा का न्यूनतम वाटर फुटप्रिंट प्राप्त किया जा सकता है जिसमें कृषि योग्य जल और समुद्री वाटर फुट प्रिंट्स क्रमश: 1074 एवं 1283 लीटर/किग्रा हो सकते हैं।

लुधियाना केंद्र पर स्क्वैश और कपास की फसलों में जल की गुणवत्ता और उर्वरता के विभिन्न स्तरों के साथ प्रयोग किया गया। जल की गुणवत्ता के उपचारों के बीच ग्रीष्मकालीन स्क्वैश की पैदावार काफी भिन्न प्राप्त हुई। औसतन, नहरी जल की सिंचाई के साथ ग्रीष्म स्क्वैश की उपज 6.83 टन/हे तथा नहरी और ट्यूबवेल जल की वैकल्पिक सिंचाई के साथ 4.36 टन/हे प्राप्त हुई। जबकि, खराब गुणवत्ता (RAC= 1.10-

1.36 मिलीईक्विवेलेंट/लीटर, EC=3.8-4.2 डेसी सिमन्स/मीटर) वाले ट्यूबवेल के जल की सिंचाई के साथ 2.33 टन/हे की ही उपज प्राप्त हुई। फर्टिगेशन के विभिन्न स्तरों के बीच स्क्वैश की पैदावार नाइट्रोजन की 80% और 100% सुझाई गई मात्रा के प्रयोग से बराबर प्राप्त हुई लेकिन, नाइट्रोजन की 60% सुझाई गई मात्रा के फर्टिगेशन के स्तर से प्राप्त उपज से काफी अधिक थी। कपास में विभिन्न फर्टिगेशन स्तरों के बीच कपास (बीज) की पैदावार बराबर प्राप्त हुई जब नाइट्रोजन की सुझाई गई मात्रा 80% और 100% का प्रयोग किया गया लेकिन, नाइट्रोजन की 60% सुझाई गई मात्रा के प्रयोग की तुलना में काफी अधिक थी। अकेले खराब गुणवत्ता वाले नलकूप के जल से सिंचाई करने नहरी और ट्यूबवेल जल की वैकल्पिक सिंचाई करने से कपास की पैदावार बराबर प्राप्त हुई।

उदयपुर केंद्र पर भिंडी की फसल में स्वचालित ड्रिप सिंचाई प्रणाली पर अनुसंधान किया गया। स्वचालित और पारंपरिक ड्रिप सिंचाई प्रणाली के तहत पैन वाष्पीकरण और सेंसर आधारित सिंचाई के समय निर्धारण ने पौधों की वृद्धि, फसल की उपज और जल उपयोग दक्षता को महत्वपूर्ण रूप से प्रभावित किया। स्वचालित ड्रिप सिंचाई के तहत मृदा नमी सेंसर के आधार पर 100% क्षेत्र क्षमता पर सिंचाई के साथ पौधों की ऊंचाई, फल का वजन, फल की लंबाई, फसल की उपज और जल उपयोग दक्षता अधिकतम पाई गई, साथ ही इसके तहत समान विभाजन में 4 दिन के अंतराल पर फर्टिगेशन के माध्यम से उर्वरकों की 100% सुझाई गई मात्रा का प्रयोग किया गया। हालांकि, पैन वाष्पीकरण आधारित सिंचाई निर्धारण के मामले में, पारंपरिक ड्रिप के तहत उपचार में अधिकतम उपज (5.9 टन/हे) प्राप्त हुई जो कम सिंचाई के उपचार के साथ प्राप्त उपज (5.6 टन/हे) के बराबर थी।

भूजल प्रबंधन

लुधियाना केंद्र पर अनुसंधान के माध्यम से जल संतुलन घटकों का अनुमान लगाया गया और हाइड्रस-1D मॉडल का उपयोग करके रोपित एवं सीधे बीज बुवाई वाले धान के खेत में संभावित भूजल पुन:भरण का अनुकरण किया गया। रोपित एवं सीधे बीज बुवाई विधि में कुल जल इनपुट क्रमशः 2035.5 और 1935.5 मिमी मापित किया गया। रोपित एवं सीधे बीज बुवाई विधि के तहत संभावित फसल वाष्पीकरण का कुल जल आउटपुट में क्रमशः 26.77 और 27.85% का योगदान प्राप्त हुआ। इन्हीं दोनों बुवाई विधियों के तहत कुल जल आउटपुट का क्रमशः 20.43% और 7.89% वर्षा का अपवाह प्राप्त हुआ जबकि, कुल जल आउटपुट का क्रमशः 55.95 और 67.45% गहरा रिसाव प्राप्त हुआ।

पंतनगर केंद्र द्वारा उत्तराखंड राज्य के पहाड़ी क्षेत्रों में चिन्हित प्राकृतिक झरनों का व्यापक मानचित्रण किया गया। इन झरनों के जीर्णोद्धार और पुन:निर्माण का अध्ययन करने के लिए पिथौरागढ़ जिले का चयन किया गया। पिथौरागढ़ जिले के प्राकृतिक झरनों के क्षेत्र सत्यापन, झरनों के प्राथमिक उपयोग पर आंकड़ों का संग्रह, क्षेत्र में झरनों के प्रकार और जल की गुणवत्ता की वर्तमान स्थिति पर पहुंचने के लिए भूविज्ञान के प्रकार पर ध्यान दिया गया। जल की गुणवत्ता की वर्तमान स्थिति का आकलन करने के लिए भौतिक-रासायनिक गुणों के अध्ययन हेतु कुल 18 झरनों से जल के नमूने एकत्रित किए गए। रासायनिक विशेषताओं ने बताया कि कुछ झरनों के जल में 250 मिलीग्राम/लीटर से भी अधिक कैल्शियम की कठोरता पाई गई है और पीने के प्रयोजन के लिए इसके उपयोग से बचना चाहिए जब तक कि इस कठोरता के लिए कुछ उपचार नहीं किया जाए।

उदयपुर केंद्र पर इस जिले के झाड़ोल ब्लॉक में कठोर चट्टानी क्षेत्रों में कृत्रिम भूजल पुन:भरण संरचनाओं की डिजाइन और इनका मूल्यांकन किया गया। भू-आकृति संबंधी विशेषताओं का निर्धारण किया गया और विभिन्न विषयगत मानचित्र जैसे भू-आकृति विज्ञान, ढ़लान, मृदा, स्थलाकृतिक उन्नयन, मानसून पूर्व और बाद की अवधि में भूजल स्तर तथा संचारण आदि पर तैयार किए गए। उपरोक्त विषयगत मानचित्रों का उपयोग करते हुए इस क्षेत्र में मौजूद नदी बेसिन का भूजल संभावित क्षेत्रीकरण किया गया। 'अच्छी' भूजल क्षमता द्वारा कवर किया गया क्षेत्र 8.78 वर्ग किमी (18.5%) है, 'मध्यम' भूजल क्षमता वाला क्षेत्र 24.52 वर्ग किमी (51.7%) और 'खराब' भूजल क्षमता वाला क्षेत्र 14.14 वर्ग किमी (29.8%) पाया गया। इस क्षेत्र के लिए उपयुक्त भूजल पुन:भरण संरचनाओं जैसे कि रिसाव टैंक और सूखे पत्थर की चिनाई वाले तालाब आदि की डिजाइन तैयार की गई। इन संरचनाओं के लिए लागत अनुपात स्पष्ट रूप से इंगित करता है कि निर्माण और जल भंडारण की लागत के मामले में सूखे पत्थर की चिनाई वाला तालाब रिसाव टैंक की तुलना में अधिक किफायती साबित हो सकता है।

फसलों में सिंचाई के समय का निर्धारण

श्रीगंगानगर केंद्र पर तीन वर्षों के प्रयोग द्वारा कपास के लिए इष्टतम सिंचाई जल उपयोग योजना बनाई गई। अधिकतम कपास (बीज) उपज (2.78 टन/हे) 60 मिमी की गहराई के साथ चार सिंचाइयों के तहत प्राप्त हुई जो कि 60 मिमी गहराई के साथ तीन सिंचाइयों के प्रयोग के बराबर थी। तीन सिंचाइयों के साथ कुल 537.1 मिमी जल उपयोग हुआ, जबकि चार सिंचाइयों में 597.1 मिमी जल उपयोग हुआ। इस प्रकार, उपज में कमी के बिना कपास की फसल में बुवाई के 35 दिनों बाद, स्क्वायर गठन और बॉल विकास अवस्था पर 60 मिमी की गहराई की 2 सिंचाइयों के अलावा बुवाई से पहले एक सिंचाई का सुझाव दिया जाता है या 35 दिनों के बाद, बॉल की शुरुआत और बॉल विकास की अवस्था पर 60 मिमी गहराई की 3 सिंचाईयों के अलावा बुवाई से पहले एक सिंचाई करने का सुझाव दिया जाता है इससे इस फसल में चार सिंचाइयों की तुलना में

10% सिंचाई जल की बचत प्राप्त होती है।

पालमपुर केंद्र पर फूल गोभी में सिंचाई और खरपतवार प्रबंधन पर प्रयोग (2018-19 से 2020-21) किया गया और परिणामों से पता चला कि सिंचाई के 0.9 वाष्पित जल के स्तर पर सिंचाई के प्रयोग के साथ फूलगोभी की फसल की अधिक विपणन योग्य कर्ड उपज और शुद्ध लाभ प्राप्त किया जा सकता है। खरपतवार नियंत्रण के लिए पॉलीथिन पलवार का प्रयोग करें। हालांकि, अधिकतम जल उत्पादकता सिंचाई के 0.7 वाष्पित जल के स्तर पर सिंचाई और काली पॉलिथीन पलवार के संयोजन से प्राप्त हुई।

कोटा केंद्र पर वर्ष 2018 से 2020 तक दक्षिण-पूर्वी राजस्थान के लिए जायद मूंगफली+मक्का अंतरसस्य फसल पद्धति पर सिंचाइयों (IW/CPE 0.8, 1.0, 1.2) और भूमि रूपान्तरण (चौड़ी क्यारी एवं कुंड, समतल भूमि पर बुवाई) के प्रभाव का अध्ययन किया गया। सिंचाई के स्तरों IW/CPE 1.0 और IW/CPE 0.8 की तुलना में सिंचाई के स्तर IW/CPE 1.2 से अधिकतम मूंगफली समतुल्य उपज (3.04 टन/हे) प्राप्त हुई और फसल पद्धति का अधिक शुद्ध लाभ (₹104602/हे) और लाभ-लागत अनुपात (1.76) प्राप्त हुआ। समतल बुवाई की तुलना में चौड़ी क्यारियों में जायद मूंगफली और मक्का की 3:1 के अनुपात में बुवाई करने से अधिकतम मूंगफली समतुल्य उपज (2.82 टन/हे) प्राप्त हुई और फसल पद्धति से अधिक शुद्ध लाभ (₹93542/हे), लाभ:अनुपात (1.59) प्राप्त हुआ। इससे अधिक जल उपयोग दक्षता (3.17 किलो/हे-मिमी) प्राप्त हुई और 10.3% तक सिंचाई जल की बचत भी प्राप्त हुई।

जबलपुर केंद्र पर धान (किस्म-पूसा सुगंधा)-गेहूं (किस्म-JW-1203) फसल प्रणाली के तहत में खरीफ मौसम के दौरान रोपित धान की कटाई से 20 दिन पहले कट ऑफ सिंचाई के बाद रबी में गेहूँ की फसल की बुवाई से पहले सिंचाई करने से 1.11 किग्रा/घनमीटर की अधिकतम जल उपयोग दक्षता प्राप्त हुई। इस उपचार से अधिकतम फसल पद्धति का शुद्ध लाभ ₹112247/हे और लाभ-लागत अनुपात 1.97 प्राप्त हुआ। सीधे बीज बुवाई वाली धान की फसल की कटाई से 10 दिन या 20 दिनों पहले कट ऑफ सिंचाई के बाद रबी के मौसम में शून्य जुताई वाले गेहूँ की फसल में बुवाई के बाद सिंचाई से कम लाभ प्राप्त हुआ।

बठिंडा केंद्र पर ग्रीष्म मौसम के दौरान मूँग की फसल से मृदा में बिना कोई फसल अवशेष की तुलना में मृदा में फसल अवशेष मिलाने और शून्य जुताई के साथ बचे हुए अवशेष मृदा के ऊपर बिछाने से काफी अधिक उपज प्राप्त हुई। गेहूँ की फसल के अवशेष प्रबंधन के ३ स्तरों एवं जुताई की विधियों के तहत 3 (वानस्पतिक वृद्धि, फूल आने और फली भरने की अवस्थाओं पर) और 4 सिंचाइयों (वानस्पतिक वृद्धि, फूल आने, फली बनने और फली भरने की अवस्थाओं पर) के उपयोग से 2 सिंचाइयों (वनस्पति विकास और फूल आने की अवस्थाओं पर) की तुलना में काफी अधिक मूँग की उपज प्राप्त हुई। फसल में 3 सिंचाइयों के प्रयोग से अधिकतम जल उपयोग दक्षता प्राप्त हुई। अवशेष प्रबंधन के तरीकों में अधिक जल उपयोग दक्षता गेहूँ की फसल के अवशेषों को मृदा में मिलाने और बचे हुए अवशेषों को मृदा पर बिछाने के साथ प्राप्त हुई।

मृदा-पौधे-जल-पर्यावरण संबंध पर बुनियादी अध्ययन

चिपलीमा केंद्र पर खरीफ मौसम के दौरान हीराकुंड कमांड क्षेत्र की निचली भूमि में ऊंची और नीची क्यारी विधि पर प्रयोग किया गया और यह देखा गया कि 60 सेमी की ऊंची क्यारियों पर धान-लोबिया फसल पद्धति की बुवाई से अधिक शुद्ध लाभ (₹72,171/हे) और लाभ:लागत अनुपात (2.58) प्राप्त हुआ और साथ ही अधिक धान समतुल्य उपज (7.39 टन/हे) भी प्राप्त हुई।

कोटा केंद्र पर गेहूँ की फसल में बूटिंग और दूध बनने की अवस्थाओं में सिंचाई छोड़ने की तुलना में देर से कल्ले बनने की अवस्था पर एक सिंचाई (60 मिमी) नहीं करने से अधिक दाना उपज (4.24 टन/हे) और जल उपयोग दक्षता (15.14 किग्रा/हे-मिमी) प्राप्त हुई और शुद्ध लाभ (₹59304/हे) तथा लाभ:लागत अनुपात (2.05) भी प्राप्त हुआ। जैव नियंत्रक पुट्रेसिन के 75 PPM की दर से पत्तियों पर छिड़काव से काफी अधिक दाना उपज (4.02 टन/हे) और जल उपयोग दक्षता (14.36 किग्रा/हे-मिमी) प्राप्त हुई, यह पुट्रेसिन की 100 PPM की दर से छिड़काव के बराबर थी। जबकि, 75 PPM पर जैव नियंत्रक पुट्रेसिन के पत्तियों पर छिड़काव से अधिकतम शुद्ध लाभ (₹54177/हे) प्राप्त हुआ।

राहुरी केंद्र पर चारा की मक्के की फसल की संपूर्ण वृद्धि अवधि के दौरान फसल वाष्पीकरण (ETc) और संचयी पैन वाष्पीकरण (CPE) क्रमशः 155.45 और 359.60 मिमी प्राप्त हुआ। टैसलिंग अवस्था में ET/EP अनुपात अधिकतम 0.47 मिमी और सिलकिंग अवस्था में न्यूनतम 0.39 मिमी था। चारा की मक्का की फसल के लिए फसल गुणांक वक्रों को वर्ष 2018-19 के लिए तीसरे क्रम के पोलीनोमीयल फंकसंस द्वारा, वर्ष 2019-2020 के लिए चौथे क्रम और 2020-2021 को बुवाई/रोपण के बाद के दिनों और फसल वृद्धि की कुल अवधि के अनुपात के रूप में दर्शाया गया। चारा की मक्का की फसल के औसत फसल गुणांक मान 0.33 - 1.30 के बीच रहा और औसत गुणांक 0.91 पाया गया।

चलाकुड़ी केंद्र द्वारा दो स्थानों से कपड़े धोने के अपशिष्ट जल के नमूने एकत्रित किए गए और सिंचाई के लिए जल की गुणवत्ता का विश्लेषण किया गया। प्रयोगशाला के विश्लेषण में पाया गया कि यह सभी नमूने सिंचाई के लिए अनुपयुक्त थे। इसलिए, एक मीडिया फिल्टर की डिजाइन तैयार की गई और फिल्टर विकसित किया गया। फिल्टर किए

गए अपशिष्ट जल का फिर से विश्लेषण किया गया और जल को सिंचाई के लिए उपयुक्त पाया गया। सब्जियों को उगाने के लिए फिल्टर किए गए जल के परीक्षण के लिए खेत में अनुसंधान शुरू कर दिया गया है।

बठिंडा केंद्र पर बीटी कपास-गेहूँ फसल पद्धति में खरीफ मौसम के दौरान बीटी कपास पर पलवार और सिंचाई के जल की गुणवत्ता के प्रभाव से पता चला कि धान के पुआल की पलवार और IW/CPE अनुपात 1.0 पर नहरी जल के साथ सिंचाई के परिणामस्वरूप काफी अधिक कपास (बीज) की उपज (3.00 टन/हे) प्राप्त हुई। जबकि, खारा-सोडिक ट्यूबवेल जल से IW/CPE अनुपात 1.0 पर सिंचाई और पुआल की पलवार के उपयोग से केवल 2.17 तन/हे की ही उपज प्राप्त हुई। ट्यूबवेल के जल से सिंचाई (2.53 किग्रा/हे-मिमी) की तुलना में धान के पुआल की पलवार और IW/CPE अनुपात 1.0 पर नहरी जल के साथ सिंचाई से जल उपयोग दक्षता (3.39 किग्रा/हे-मिमी) भी अधिक प्राप्त हुई। इसी प्रकार, रबी के मौसम के दौरान गेहूँ की फसल पर पुआल की पलवार के अवशिष्ट प्रभाव एवं IW/CPE अनुपात 1.0 पर नहरी जल से सिंचाई के कारण अधिक उपज (5.01 टन/हे) प्राप्त हुई जो IW/CPE अनुपात 1.0 पर नलकूप के जल से सिंचाई और पलवार के प्रयोग की तुलना से काफी अधिक उपज (3.43 टन/हे) प्राप्त हुई।

जल का संयोजी उपयोग और बहुआयामी उपयोग

बठिंडा केंद्र पर बरसीम/राईघास-ज्वार फसल पद्धति में केवल नलकूप के जल की सिंचाई की तुलना में जल के संयोजी उपयोग से पता चला कि नहरी जल और नलकूप के खारा सॉडिक जल के साथ वैकल्पिक सिंचाई से बरसीम, राईघास और ज्वार की लगभग 25-30% अधिक हरे चारे की उपज प्राप्त हुई। इस जल के संयोजी उपयोग से यह भी पाया गया कि रबी के मौसम में उगाई गई बरसीम और खरीफ में ज्वार के हरे चारे की उपज में क्रमश: 25.06% और 29.1% की उल्लेखनीय वृद्धि पाई गई।

बेलावतगी केंद्र पर सिंचाई जल के विभिन्न स्रोतों में से नलकूप के जल से सिंचाई से प्राप्त उपज (1.03 टन/हे) की तुलना में तालाब के जल से सिंचाई के कारण काफी अधिक चना की समतुल्य उपज (1.35 टन/हे) प्राप्त हुई लेकिन यह ई-हारमोनाइज्ड जल की सिंचाई से प्राप्त उपज (1.28 टन/हे) के बराबर थी। रबी मौसम की विभिन्न फसलों में से कुसुम से काफी अधिक चना समतुल्य उपज (1.86 टन/हे) प्राप्त हुई और उसके बाद सूरजमुखी (1.36 टन/हे) से प्राप्त हुई। तालाब के जल से सिंचाई के कारण अन्य उपचारों की तुलना में काफी अधिक शुद्ध लाभ (₹37309/हे) और लाभ:लागत अनुपात (2.45) प्राप्त हुआ।

ऑपरेशनल अनुसंधान परियोजना

जम्मू केंद्र पर बागवानी विभाग, केंद्र शासित प्रदेश जम्मू और कश्मीर को जल संग्रहण के लिए सिल्पॉलिन शीट (250 gsm) के साथ पॉलीलाइंड वाटर हार्वेस्टिंग टैंक के निर्माण पर सिफारिशें प्रदान की गई। ये टैंकस सीमेंट रेत ब्लॉक के अनुपात (1: 7: 2) के साथ ढ़के गए। इन जल संग्रहण/ संरक्षण सरचनाओं की लागत ₹1.00-1.25/लीटर के साथ इनकी जल संरक्षण क्षमता 50-250 घनमीटर के बीच थी तथा 50 घनमीटर से कम की भी थी। इसके अलावा, 10 × 10 मीटर, 6 × 6 मीटर और 5 × 5 मीटर की दूरी पर 1.0 हेक्टर और 0.5 हेक्टर के फलों के बाग के लिए ऑनलाइन ड्रिप सिंचाई की लागत फर्टिगेशन उपकरणों के साथ पंप की लागत को छोड़कर ₹55000 - 85000 के बीच थी।

कोटा केंद्र द्वारा चंबल सिंचाई परियोजना के तहत चंबल कमांड क्षेत्र में दाईं मुख्य नहर मानसगांव डिस्ट्रीब्यूटरी और बाईं मुख्य नहर की अंधेड़ डिस्ट्रीब्यूटरी में रबी मौसम के दौरान गेहूं की फसल में बेहतर जल प्रबंधन के साथ कुल 18 प्रदर्शन किए गए। दाईं और बाईं मुख्य नहर दोनों में ऊपरी, मध्य और अंतिम छोर पर तीन-तीन खेतों के साथ नौ किसानों के खेतों का चयन किया गया। किसानों की बाढ़ सिंचाई विधि (नियंत्रण ब्लॉक) की तुलना में बॉर्डर स्ट्रिप सिंचाई विधि द्वारा 80% कम सिंचाई जल (परीक्षण ब्लॉक) के साथ मुख्य जड़ की शुरुआत, देर से कल्ले बनने, फूल आने और दानों में दूध भरने की अवस्थाओं पर चार सिंचाई करने के बेहतर जल प्रबंधन का प्रदर्शन किया गया। दाईं और बाईं मुख्य नहर दोनों में बेहतर सिंचाई जल प्रबंधन से गेहूं की फसल की किस्म राज-4079 ने नियंत्रण ब्लॉकों की तुलना में क्रमशः 10.38 और 9.48% अधिक दाना उपज प्राप्त हुई और परीक्षण ब्लॉकों में 160 मिमी तक सिंचाई जल की बचत प्राप्त हुई। दाईं और बाईं मुख्य नहर दोनों के नियंत्रण ब्लॉकों में क्रमशः 9.82 और 9.70 किग्रा/हे-मिमी की तुलना में परीक्षण ब्लॉकों में जल व्यय दक्षता 15.94 और 15.62 किग्रा/हे-मिमी के रूप में अधिक प्राप्त हुई।

मुरैना केंद्र द्वारा माइनर चंबल नहर के कमांड क्षेत्र के ऊपरी, मध्य और अंतिम छोर के विभिन्न स्थानों पर खरीफ के दौरान धान, बाजरा, मूंग, अरहर, ग्वार एवं तिल और रबी मौसम के दौरान सरसों, गेहूं और चना की फसलों के साथ ऑन-फार्म परीक्षण किए गए। इन परीक्षणों में किसानों की पारंपरिक विधि की तुलना में उन्नत तकनीकों जैसे कि लेजर भूमि समतलन, बुवाई के बेहतर तरीके, नमी संरक्षण और सिंचाई के कुशल तरीकों का परीक्षण किया गया। नहर के ऊपरी छोर पर अरहर-गेहूं के बाद धान-गेहूं की फसल पद्धति लाभकारी पाई गई। नहर के मध्य छोर पर अरहर-गेहूं के बाद ग्वार-गेहूं, जबकि, अंतिम छोर पर बाजरा-सरसों, बाजरा-चना के बाद ज्वार-जौ की फसल पद्धतियों को अधिक उपज, जल उत्पादकता, शुद्ध लाभ, लाभ:लागत अनुपात और सिंचाई जल की बचत के मामले में आशाजनक परिणाम प्राप्त हुए। धान की फसल को छोड़कर सभी फसलों के लिए नहरी कमांड क्षेत्र के ऊपरी, मध्य और अंतिम छोर उपज, आर्थिक लाभ और जल

उत्पादकता के मामले में उन्नत सिंचाई विधियों में से चौड़ी क्यारी और कुंड विधि सबसे अच्छी पाई गई।

जनजातीय उप योजना

राहुरी केंद्र द्वारा महाराष्ट्र राज्य के अहमदनगर जिले की आकोले तहसील के सात आदिवासी गांवों (शेलाड़, वागदारी, धाधमनवान, पैठन, घोटी, पिंपरी और खड़की बीके) के 100 किसानों को 50 ड्रिप और 50 स्प्रिंकलर सिंचाई प्रणाली के सेट वितरित किए गए। इन किसानों ने खरीफ और रबी मौसम के दौरान ड्रिप सिंचाई प्रणाली के साथ आलू, राजमा एवं गेंदा आदि तथा स्प्रिंकलर सिंचाई प्रणाली का उपयोग करके टमाटर, प्याज, गेहूँ, चना, चारा मक्का जैसी फसलें उगाईं। इन 100 किसानों द्वारा ड्रिप और स्प्रिंकलर सिंचाई प्रणाली को अपनाने के प्रभाव विश्लेषण से पता चला कि पारंपरिक सिंचाई पद्धति की तुलना में ड्रिप सिंचाई और स्प्रिंकलर सिंचाई के माध्यम से रबी फसलों की उपज में क्रमशः 23-80% और 18-75% तक की वृद्धि हुई। कुल मिलाकर किसानों की आय में 20-40% तक का सुधार प्राप्त हुआ।

पूसा समस्तीपुर केंद्र द्वारा बिहार राज्य के मधुबनी जिले के पचबनिया गाँव (पोस्ट ऑफिस-तर्डीहा, पोलिस थाना-मधेपुर) में एक सौर वृक्ष आधारित सिंचाई प्रणाली स्थापित की गई। इस पद्धति में 5 किलोवाट क्षमता का सोलर ट्री और 5 हॉर्स पावर के सबमर्सिबल पंप वाला एक ट्यूबवेल शामिल किया गया। यह प्रणाली कुल 18 आदिवासी किसानों को लाभार्थियों के रूप में वर्ष भर मुफ्त सिंचाई सुविधा प्रदान करेगी। फ्लेक्सिबल पाइपों का उपयोग कर लगभग 12 किसानों के दूसरे समूह तक इस सोलर ट्री का लाभ बढ़ाया जा सकता है।

उदयपुर केंद्र पर हल्दी की फसल में ड्रिप सिंचाई प्रणाली के प्रदर्शन ने बताया कि एक किसान के खेत में काली पॉलीथिन की पलवार के साथ 90% के फसल वाष्पोत्सर्जन के स्तर पर सिंचाई करने से 18.20 टन/हे की अधिकतम और उल्लेखनीय रूप से अधिक कंद उपज प्राप्त हुई।

नवसारी केंद्र द्वारा आठ अनुसूचित जाति के किसानों को प्रदर्शन के लिए चुना गया और उनके खेतों में सिंचाई जल पहुंचाने के लिए सिंचाई पाइप प्रदान किए गए। प्रत्येक किसान को 3.0 इंच व्यास और 6.0 मीटर लंबाई के तीन मोड़ वाले 12 सिंचाई पाइप प्रदान किए गए। ये सिंचाई पाइप प्रति किसान 0.75 हेक्टर भूमि को सिंचाई सुविधा प्रदान करने के लिए पर्याप्त हैं, जिससे कुल 6.0 हेक्टर क्षेत्र को पाइपलाइन सिंचाई पद्धति के साथ शामिल किया जा सकता है।

इसी प्रकार, पालमपुर केन्द्र पर पॉलीलाइन वाटर हार्वेस्टिंग टैंक का निर्माण कर ड्रिप सिंचाई प्रणाली की स्थापना की गई। इस टैंक में मानसून के वर्षा जल को संरक्षित किया गया और ड्रिप सिंचाई प्रणाली के माध्यम से विभिन्न फसलों के खेतों में प्रदर्शन के लिए उपयोग किया गया।

परभणी केंद्र द्वारा महाराष्ट्र राज्य के इस जिले की मानवत तहसील के भोसा गाँव के बहुत गरीब अनुसूचित जाति के किसानों की फसल उत्पादकता और स्थायी आजीविका बढ़ाने के लिए हस्तक्षेप किया गया। इस गाँव के अनुसूचित जाति के किसानों को कुल छ: छिड़काव सिंचाई प्रणाली के सेट वितरित किए गए और छिड़काव सिंचाई प्रणाली के संचालन के संबंध में निर्देशित किया गया।

कोटा केंद्र पर रबी मौसम 2019-20 के दौरान गेहूँ की फसल पर कुल 57 प्रदर्शन किए गए जिनमें से 20 प्रदर्शन गरदा कमांड क्षेत्र में गेहूँ में महत्वपूर्ण वृद्धि अवस्थाओं में सिंचाई की विधि पर और गैर कमान क्षेत्र में कुल 23 प्रदर्शन उच्च घनत्व पॉलीथीन (एचडीपीई) पाइपलाइन का उपयोग करके जल वहन और उठाने के द्वारा गेहूं की महत्वपूर्ण वृद्धि अवस्थाओं में सिंचाई करने और 14 प्रदर्शन स्प्रिंकलर सिंचाई के तहत गेहूँ में महत्वपूर्ण वृद्धि अवस्थाओं पर सिंचाई करने पर किया गया।

Executive Summary

Salient Achievements of AICRP on Irrigation Water Management

During the year 2020, 26 centres carried out research and extension work in the field of assessment of water availability, groundwater recharge, groundwater use at regional level, evaluation of pressurized irrigation system, water management in horticultural and high value crops, basic studies on soil-water-plant relationship and their interaction, conjunctive use of surface water and groundwater, drainage for enhancing water productivity, multiple use of water and rainwater management in high rainfall areas, etc. Salient achievements for the year 2020 are enlisted below.

Assessment of canal water and groundwater availability

At Junagadh, assessment of groundwater resources of the Uben basin was done using groundwater flow simulation model. Land use and land cover map revealed that areas under agriculture, forest, wasteland, built up and water body are 78.90, 10.08, 7.68, 2.32 and 1.03% respectively. The Uben basin is having soil types of fine, clayey and rocky in 74.16, 16.86 and 8.98% areas respectively. Groundwater flow modelling was done using Visual MODFLOW software. Calibration of the model was done for both steady state and transient conditions.

At Udaipur, upper Banas river basin is the main tributary of Chambal river basin and it is located in the Rajsamand, Udaipur, Chittorgarh and Bhilwara districts of Rajasthan. The entire basin was divided into 21 sub-basins; and linear, aerial and relief aspects of geomorphologic characteristics were determined. The sub-basins were prioritised for soil and water conservation works. Sub-basin no. 10 was identified as the basin to be given first priority for soil and water conservation measures.

At Coimbatore, Lower Bhavani Project (LBP) basin was divided into 187 micro watersheds and each micro watershed was further subdivided into 4833 hydrological response units having unique soil and land use. Hydrological parameters of LBP basin were simulated using SWAT for current scenario (2001 to 2020), mid century (2041-2060) and end century (2071-2090). It was estimated that, the annual average rainfall of the basin during mid century is 983.2 mm and 766.9 mm for end century. Runoff was estimated as 30% of rainfall in both mid and end century. Annual water balance was simulated for current scenario, mid century and end century. Mean annual evapotranspiration was estimated as 866 and 907 mm in the mid and end century respectively which shows higher crop water requirement in future climatic conditions. Crop water demand for Kuhalur distributary was worked out and it was estimated that there is 29% supply demand gap for the distributary.

At Ludhiana, a groundwater flow simulation model was developed for the state of Punjab using Visual MODFLOW software. Calibration of the model was done by combination of trial and error method and automated calibration. Calibration was done using the observed groundwater level data for the period 1998-2012 and validation was done using the data for the period 2013-2017. Using the calibrated model, groundwater status was predicted for six scenarios after 5, 10, 15 and 20 years. The six scenarios were (1) 2% increase in recharge, (2) 2% decrease in draft, (3) 3% decrease in draft, (4) 5% decrease in draft, (5) 2% increase in recharge and 3% decrease in draft, and (6) 2% increase in recharge and 5 percent decrease in draft.

At Jabalpur, analytical hierarchy process was used for potential groundwater zoning in the Tons river basin. Different thematic maps such as geology, drainage, drainage density, land use land cover, slope, soil texture were used. Weighted index overlay analysis tool in ArcGIS was used for the creation for groundwater potential zone. The resultant map demonstrated possible groundwater potential zone of the Tons basin under three categories such as good, moderate and poor groundwater potential. In Satna district, groundwater potential is good, which accounts for an area of 5562.50 km^2 i.e, 44.50% of total basin area. From the study, it was concluded that delineation of groundwater potential zones is helpful for the information of groundwater prospective zone, extraction and development of groundwater and better planning and management.

At Raipur, the groundwater potential zones in the Kobra and Janjgir-Champa districts of Chhattisgarh were generated using Multi Criteria Decision Analysis (MCDA) approach by integrating various thematic maps viz., drainage density, slope, geology, geomorphology, soil texture, lineament, rainfall, groundwater fluctuation and land use land cover using remote sensing and GIS techniques. The groundwater potential zones were categorized into four categories, namely low, low to medium, medium to high, and very high. Major part of the area (42.72%) fell under the low to medium potential zone, 20.27% area fell under medium to high categories, 19.18% area fell under very high potential zone and only 17.81% area fell in very low groundwater potential zone. The appropriate structures to be constructed for recharging and storage in low and low to medium groundwater potential zones were considered to be percolation tanks, check dams, and farm ponds. Sites were identified for 36 percolation tanks, 39 check dams and 21 farm ponds.

Pressurized irrigation systems

At Shillong, low-cost bamboo drip irrigation technology was developed to enhance yield and economic water productivity for tomato crop in hilly upland condition. Highest tomato yield of 24.86 t ha^{-1} was recorded under bamboo drip and straw mulching, which was statistically similar to yields obtained under conventional drip with straw mulching (22.80 t ha^{-1}) as well as mini-sprinkler irrigation with straw mulching (24.49 t ha^{-1}). Economic water productivity with bamboo drip+mulch, conventional drip+mulch and mini-sprinkler+mulch were Rs. 282, 313 and 248 per cubic metre of water applied. But benefit-cost ratio with bamboo drip+mulch was highest i.e. 2.8 compared to conventional drip (2.0) and mini-sprinkler irrigation (2.5) both with mulching.

At Kota, performance of sprinkler nozzle size and hydraulic parameters on productivity of coriander were assessed. Sprinkler irrigation at operating pressure 2.5 kg cm^{-2} gave significantly higher seed yield (1.18 t ha^{-1}), water use efficiency (7.98 kg ha-mm^{-1}), net return (₹40185 ha^{-1}) and B-C ratio (1.30) as compared to operating pressure 1.5 kg cm^{-2}. Operating pressure at 2.5 kg cm^{-2} gave 10.3% higher yield as compared to 1.5 kg cm^{-2}. Nozzle size 2.5 × 3.5 mm recorded significantly higher seed yield (1.18 t ha^{-1}) as compared to 3.1 × 5.1 mm nozzle size, whereas, different nozzle size couldn't bring the significant variation in net return and B-C ratio but maximum net return (₹39399 ha^{-1}) and B-C ratio (1.26) was fetched under 2.5 × 3.5 mm nozzle size.

At Jammu, sprinkler irrigation in rice-wheat cropping system showed that irrigation in all the physiological stages of wheat (S_3) and irrigation at pre-sowing, CRI stage and late booting stage of wheat (S_2) gave higher grain yields of 3.53 and 3.45 t ha^{-1} among sprinkler irrigation treatments and recommended surface irrigation (control) during *rabi* season. There was 37 to 48% water saving for growing wheat with sprinkler irrigation compared to surface irrigation. Following *kharif* rice crop showed higher grain yields with sprinkler irrigation from panicle initiation to 15 days before harvest (S_3) and sprinkler irrigation after puddling to 15 days before harvest (S_2). But recommended surface irrigation practice (control) resulted in 7.5% higher rice grain yield over the sprinkler irrigation methods; although water use efficiency was 16.22% higher with sprinkler irrigation over recommended surface irrigation.

At Chiplima, optimization of sprinkler irrigation for groundnut crop for Hirakud command area was done. Results show that sprinkler irrigation at 90% CPE led to significantly higher number of pods per plant (13.6), pod weight per plant (28.8 g), pod yield (1.84 t ha^{-1}) and haulm yield (1.09 t ha^{-1}), along with highest net return (₹50193 ha^{-1}) and benefit-cost ratio (2.2) over other sprinkler irrigation schedules and farmers' traditional practice.

Fertigation

At Dapoli, a field experiment on drip fertigation was conducted in sweet potato-sweet corn crop sequence. The water saving of 75.0 and 37.6%, respectively can be achieved in both the crops by drip over surface irrigation method. The treatment I_1 (Irrigation at 100% ET_c) and F_1 (100% RDF through water soluble fertilizer-WSF) significantly enhanced yield and yield attributes of both the crops. Sweet potato tuber yield (24.63 t ha^{-1}) and sweet corn cob yield (21.73 t ha^{-1}) was highest in the treatment combination I_1F_1 i.e. irrigation at 100% ET_c with 100% RDF. The water use efficiency was highest in treatment combination I_3F_1 i.e. (Irrigation at 50% ET_c with 100% RDF through WSF) under both crops. The highest system yield (58.90 t ha^{-1}) was obtained in treatment I_1 i.e. irrigation at 100% ET_c and F_1 i.e. 100% RDF (59.86 t ha^{-1}). Under sweet potato-sweet corn cropping sequence, the B-C ratio of system was highest (2.17) in the treatment combination I_1F_1 followed by I_1F_2 (2.15).

At Parbhani, performance of drip fertigation on enhancing yield of pigeonpea was evaluated. Results of irrigation and fertigation for pigeonpea crop indicated that drip irrigation at 0.8 ET_c scheduled at alternate day along with 20-40-20 N, P_2O_5 , K_2O kg ha^{-1} in ten splits through water soluble fertilizer; out of which 20% N and 40% P in two splits at 0-30 days after sowing (DAS), 30% N, P and 25% K in three splits at 31-60 DAS, 30% N, P and 40% K in 3 splits at 61-90 DAS and 20% N and 35% K in two splits at 91-120 DAS was found promising for realizing higher productivity and profitability of pigeonpea with saving of 20% water and fertilizer.

At Parbhani, response of onion crop to drip fertigation was assessed. Irrigation and fertigation experiment on summer onion revealed that drip irrigation at 0.6 ET_c scheduled at alternate day along with 80-40-40 N, P_2O_5 , K_2O kg ha^{-1} in ten splits through water soluble fertilizers with N and K_2O in 10 equal splits @ 8 kg ha^{-1} and 4 kg ha^{-1} respectively and P_2O_5 in 5 equal splits @ 8 kg ha^{-1} at an interval of 7 days from transplanting to 70 days after transplanting was found optimum for realizing economical yield of onion with saving of 40% water and 20% fertilizers.

At Belavatagi, an experiment on split application of nitrogen in wheat through drip was conducted. Among moisture levels, I_2-80% cumulative pan evaporation (CPE) recorded higher grain and straw yields of 3.35 and 5.59 t ha^{-1}, respectively followed by I_1-60% CPE (grain: 2.98 t ha^{-1} and straw: 5.23 t ha^{-1}). Among the nutrient levels, application of N_5: 20% basal N of N_4 + 5 splits of N recorded significantly higher grain and straw yields of 3.80 and 6.07 t ha^{-1}, respectively followed by N_6: 20% basal N of N_4 + weekly interval of N up to 85 DAS (grain: 3.85 t ha^{-1}, straw: 5.82 t ha^{-1}). Significantly enhanced water use efficiency was noticed with I_1-60% CPE (11. 71 kg ha-mm^{-1}) and N_5 (13.78 kg ha-mm^{-1}) in main and sub-plot treatments, respectively.

At Kota, three years pooled data revealed that brinjal crop irrigated every third day based on 100% of evaporated water by drip irrigation method and applying 100% recommended doses of fertilizers (80-60-60 N, P_2O_5, K_2O kg ha^{-1}) in 19 equal splits gives best result. Application of drip fertigation at 125% potential evapotranspiration (PET) + 100% RDF recorded higher fruit yield (23.6 t ha^{-1}), net return (₹155800 ha^{-1}) and B-C ratio (1.94). Application of drip fertigation at 125% PET + 100% RDF resulted in 35.6% increase in fruit yield and saved 7.7% irrigation water as compared to control (surface irrigation at IW/CPE 0.8 + NPK fertilizer as soil application).

At Kota, groundnut crop was grown during *zaid* season through micro-sprinkler irrigation for four years. Irrigation schedule at 125% potential evapotranspiration (PET) + 100% RDF (30-60-40 N, P_2O_5, K_2O kg ha^{-1}) through fertigation recorded maximum pod yield (2.41 t ha^{-1}) of groundnut. As compared to control (surface irrigation at IW/CPE 0.8 + entire NPK as soil application), irrigation schedule at 125% PET + 100% RDF increased the yield of groundnut by 34%. However, irrigation schedule at 75% PET + 100% RDF through fertigation recorded maximum water use efficiency (8.49 kg ha mm^{-1}) and water productivity (0.849 kg m^{-3}).

At Rahuri, a field experiment was conducted on subsurface drip fertigation in sugarcane crop. The maximum millable cane and yield were observed in irrigation treatment I_4 (100% ET_c) and fertigation treatment F_4. The maximum yield was observed in I_4F_4 treatment combination (136 t ha^{-1}) which was at par with treatment I_3F_4, 80% ET_c and 80% NPK through fertigation (132 t ha^{-1}) and was significantly superior over all remaining treatments. The highest water use efficiency was recorded in I_3 (80% ET_c) and the net monetary return was maximum under I_3F_4 (₹214637 ha^{-1}). The maximum B-C ratio of 2.18 was observed in treatment I_4F_4 followed by I_4F_3 and I_3F_4.

At Junagadh, performance of drip fertigation on enhancing yield and profitability of cotton crop was studied. The highest seed cotton yield of 2.68 t ha^{-1}, water use efficiency of 4.242 kg ha-mm^{-1}, fertilizer use efficiency of 6.09 kg ha-kg^{-1}, net return of ₹77182 ha^{-1} and B-C ratio as 1.93 was obtained when 25% NPK of RDF as basal and remaining NPK through fertigation was applied. The lowest total water foot prints of 2357 L kg^{-1} of seed cotton yield can be achieved when 25% NPK of RDF as basal and remaining NPK through fertigation was applied, among which green and blue water footprint can be 1074 L kg^{-1} and 1283 L kg^{-1}, respectively.

At Bathinda, an experiment was conducted in squash and cotton crops with varied water quality and fertigation levels. The summer squash yield were significantly different among water quality treatments. On an average, the observed summer squash yield was 6.83 t ha^{-1} with canal water followed by 4.36 t ha^{-1} with alternate irrigation of canal and tubewell water and 2.33 t ha^{-1} with poor quality tube well water (RSC=1.10-1.36 meq L^{-1}; EC=3.8-4.2 dS m^{-1}). Among different fertigation schedules, summer squash yields for fertigation level of 80% and 100% recommended dose of nitrogen were at par but significantly higher than fertigation level of 60% recommended dose of nitrogen. In cotton, among different fertigation schedules, the seed cotton yields were at par when 80% and 100% of recommended dose of nitrogen was applied and were significantly higher than application of 60% recommended dose of nitrogen. The seed cotton yield when irrigating with poor quality tubewell water (RSC=1.10-1.36 meq L^{-1}; EC=3.8-4.2 dS m^{-1}) alone was significantly lower than other water quality treatments. However, seed cotton yield was at par with canal water alone and alternate of canal/tubewell water treatments.

At Udaipur, a field experiment was conducted on automated drip irrigation in okra crop. The pan evaporation and sensor based irrigation scheduling under automated and conventional drip irrigation system significantly affected the plant growth, crop yield and water use efficiency of okra crop. The plant height, fruit weight, fruit length, crop yield and water use efficiency were found maximum with irrigation scheduled at 100% field capacity, based on soil moisture sensor under automated drip irrigation along with 100% recommended dose of fertilizer through fertigation in equal splits at 4-day interval. However, in case of pan evaporation based irrigation scheduling, highest yield (5.9 t ha^{-1}) was recorded in treatment T_5 under conventional drip which were at par with treatment T_2 (5.6 t ha-cm^{-1}) with less water applied.

Groundwater and rainwater management

At Ludhiana, water balance components were estimated through field experiment and potential groundwater recharge in transplanted (TPR) and direct seeded rice (DSR) was simulated using HYDRUS-1D model. The total measured water input from TPR and DSR was 2035.5 and 1935.5 mm, respectively. Potential crop evapotranspiration accounted for 26.77 and 27.85% of total water output for TPR and DSR, respectively. Runoff accounted for 20.43 and 7.89% of total water output for TPR and DSR, respectively, whereas the deep percolation accounted for 55.95 and 67.45% of the total water output in TPR and DSR, respectively.

At Pantnagar, comprehensive mapping of natural springs, identified in Uttarakhand hilly region was done. In order to conduct the field studies on the springs for their rejuvenation and restoration, district Pithoragarh was selected. Focus was given to the natural springs of the Pithoragarh district for their field verification, collection of data on the primary use of the spring, type of geology to arrive at the type of springs in the area, and current status of water quality. Water samples were collected from 18 springs for the study of physico-chemical properties to judge the present status of water quality. The chemical characteristics indicated that the spring water from a few springs has calcium hardness beyond 250 mg L^{-1} and its use for drinking purposes should be avoided until some treatment for hardness is done.

At Udaipur, design and evaluation of artificial groundwater recharge structure in hard rock areas was carried out in Jhadol block of Udaipur district. The geomorphological characteristics was determined and various thematic maps like geomorphology, slope, soil, topographic elevation, pre and post monsoon water table, transmissivity etc. were prepared. Using above thematic maps, groundwater potential zoning of the river basin was done. The area covered by 'good' groundwater potential is 8.78 km^2 (18.5% area), 'moderate' groundwater potential is 24.52 km^2 (51.7% area), and 'poor' groundwater potential is 14.14 km^2 (29.8% area). The appropriate recharge structure viz., percolation tank and dry stone masonry pond was also designed for the region. The cost ratios for these structures clearly indicate that the dry stone masonry pond is more economical than percolation tank in terms of cost of construction and water storage.

At Jammu, *in situ* rainwater conservation for hybrid maize crop (var. *Star*-9) was carried out during *kharif* 2020. Tied ridge method along with straw mulch and tied ridge method without mulch resulted in statistically similar maize grain yield of 2.22 and 2.20 t ha^{-1}, respectively. There was about 15% higher yield under tied ridge + mulch compared to traditional ridge-furrow + mulch. Rainwater productivity under tied ridge + mulch was 3.96 kg ha-mm^{-1}, with benefit-cost ratio of 1.45.

Irrigation scheduling of crops

At Sriganganagar, optimal water use plan for cotton was found with three years of experimentation. Maximum seed cotton yield (2.78 t ha^{-1}) was obtained under four irrigations with irrigation depth of 60 mm, which was at par with application of three irrigations with 60 mm depth. Total water applied with three irrigations was 537.10 mm against 597.1 mm with four irrigations, both 60 mm depth. Thus, it was recommended to apply post-sowing irrigations with 60 mm depth to cotton crop at 35 DAS, square formation and boll development stages or at 35 DAS, boll initiation and boll development stages without reduction in yield, and 10% water saving over four irrigations.

At Palampur, an experiment (2018-19 to 2020-21) was conducted on irrigation and weed management in cauliflower and results revealed that significantly higher marketable curd yield and net returns for cauliflower crop can be obtained with application of water at 0.9 PE level and using polythene mulch to control weed. However, the highest water productivity was obtained from irrigation level of 0.7 PE and black polythene mulch.

At Kota, influence of irrigation schedules (IW/CPE 0.8, 1.0, 1.2) and land configurations (broad bed furrow, flat sowing) on *zaid* groundnut + sweet corn intercropping system was studied for south-east Rajasthan from 2018 to 2020. Application of irrigation at IW/CPE 1.2 recorded maximum and significantly higher groundnut equivalent yield (3.04 t ha^{-1}), system net return (₹104602 ha^{-1}) and system benefit-cost ratio (1.76) over IW/CPE 1.0 and IW/CPE 0.8. Sowing of *zaid* groundnut and sweet corn in the ratio of 3:1 in broad bed furrow resulted in maximum and significantly higher groundnut equivalent yield (2.82 t ha^{-1}), system net return (₹93542 ha^{-1}), system B-C ratio (1.59), water use efficiency (3.17 kg ha-mm^{-1}) and 10.3% water saving over flat sowing.

At Jabalpur, in rice (*Pusa Sugandha*) - wheat (JW-1203) cropping system, transplanted rice with cutoff irrigation at 20 days before harvesting during *kharif* followed by irrigation before sowing of wheat in *rabi* gave highest water use efficiency of 1.11 kg m^{-3}, fetched maximum system net return of ₹112247 ha^{-1} and benefit-cost ratio of 1.97 compared to direct seeded rice under cutoff irrigation at 10 days or 20 days before harvest followed by irrigation before sowing or after sowing of zero tillage wheat.

At Bathinda, the grain yield of summer greengram was significantly higher in both residue incorporation and leftover residue zero tillage treatment as compared to no residue addition. Application of 3 (at vegetative, flowering and pod filling stages) and 4 irrigations (at vegetative, flowering, pod filling and pod formation stages) gave significantly higher greengram yield than 2 irrigations (at vegetative growth and flowering stages) under all 3 wheat residue management and tillage practices. Highest water use efficiency was found with application of 3 irrigations. Among residue management practices, higher water use efficiency was obtained with wheat residue incorporated and leftover residue treatment while least in the treatments where no residue was retained in soil.

Basic studies on soil-plant-water-environment relationship

At Chiplima, an experiment was conducted in raised and sunken bed system in low lands of Hirakud command during *kharif* season, and it was observed that the elevation difference of 60 cm with rice-cowpea cropping system gave higher net returns (₹72,171 ha^{-1}), rice equivalent yield (7.39 t ha^{-1}) and B-C ratio (2.58).

At Kota, in wheat, skip one irrigation (60 mm) at late tillering stage recorded significantly higher grain yield (4.24 t ha^{-1}), water use efficiency (15.14 kg ha-mm^{-1}), net return (₹59304 ha^{-1}) and B-C ratio (2.05) as compared to skip irrigation at booting and milking stages. Foliar spray of bioregulator putrescine 75 ppm recorded significantly higher grain yield (4.02 t ha^{-1}) and water use efficiency (14.36 kg ha-mm^{-1}), and remained on par with putrescine 100 ppm. Maximum net return (₹54177 ha^{-1}) was fetched in foliar spray of bioregulator putrescine at 75 ppm.

At Rahuri, crop evapotranspiration (ET_c) and cumulative pan evaporation (CPE) during entire growth period of fodder maize crop was 155.45 and 359.60 mm respectively. The ET/EP ratio was maximum 0.47 at tasseling stage and lowest 0.39 at silking stage. The crop coefficient curves for fodder maize were represented by the polynomial functions of the third order for the year 2018-19, fourth order for the year 2019-2020 and 2020-2021 as the function of the ratio of days since sowing/planting to total crop growth period. The average crop coefficient values of fodder maize were varied from 0.33 - 1.30 with average value of 0.91.

At Chalakudy, laundry wastewater samples from two locations were collected and quality of water for irrigation was analyzed. Laboratory analyses found the samples were unsuitable for irrigation. Hence a media filter was designed and developed. The filtered laundry wastewater was again analyzed and the water was found suitable for irrigation. Field experiment for testing the filtered water for growing vegetables has been started.

At Bathinda, in *Bt* cotton-wheat cropping system, effect of mulching and irrigation water quality on *Bt* cotton during *kharif* season showed that rice straw mulching and irrigation with canal water (CW) at IW/CPE 1.0 resulted in significantly higher seed cotton yield (3.00 t ha^{-1}) compared to yield (2.17 t ha^{-1}) obtained with the use of straw mulch and saline-sodic tubewell water (TW) at IW/CPE 1.0. Water use efficiency was also higher with mulching and CW irrigation (3.39 kg ha-mm^{-1}) over mulching and TW irrigation (2.53 kg ha-mm^{-1}). Residual effect of straw mulch on succeeding wheat crop during *rabi* season showed significantly higher yield (5.01 t ha^{-1}) with TW irrigation at IW/CPE 1.0 compared to yield (3.43 t ha^{-1}) obtained with CW at IW/CPE 1.0 in the mulched plots.

Conjunctive use of water and multiple use of water

At Bathinda, conjunctive use of water on berseem/ryegrass-sorghum cropping system showed that irrigations with alternate canal water and saline sodic tubewell water (CW-TW) showed about 25-30% higher green fodder yield of berseem, ryegrass and sorghum over irrigation with tubewell water alone. It was also found that berseem grown in *rabi* season followed by sorghum in *kharif* showed significant increase in green fodder yield by 25.06% and 29.1%, respectively with alternate use of canal water and tubewell water compared to use of tubewell water alone.

At Belavatagi, among the different sources, irrigation with pond water recorded significantly higher chickpea equivalent yield (1.35 t ha^{-1}) as compared to bore well water (1.03 t ha^{-1}) and it was on par with e-harmonized water (1.28 t ha^{-1}). Among the different *rabi* crops, safflower recorded significantly higher chickpea equivalent yield (1.86 t ha^{-1}) followed by sunflower (1.36 t ha^{-1}). Economic analysis indicated that irrigation from pond water gave significantly higher net return (₹37309 ha^{-1}) and B-C ratio (2.45) as compared to other treatments.

At Ayodhya, conjunctive use of canal water and groundwater was conducted at 10 farmers' fields located at middle and tail ends of Awanpur distributary. Conjunctive use of canal water and groundwater at the ratio of 2:1 with 6 cm irrigation at CRI, late jointing and milking stages of wheat in check basin (5 m×10 m) recorded higher grain yield of 4.15 t ha^{-1}, net return of ₹48868 ha^{-1} and benefit-cost ratio of 2.58 over yield of 3.36 t ha^{-1}, net return of ₹29328 ha^{-1} and B-C ratio of 1.99 under farmers' practice.

Operational Research Project (ORP)

At Jammu, recommendations were provided to Department of Horticulture, union territory of Jammu & Kashmir on construction of polylined water harvesting tanks lined with silpaulin sheets (250 GSM) and covered with cement sand blocks of ratio (1:7:2) as water storage/ harvesting structures at ₹1.00-1.25 L^{-1} of different capacities ranging between 50-250 m^3 and less than 50 m^3. Apart from this, costs for on-line drip irrigation for 1.0 ha and 0.5 ha fruit orchards spaced at 10 m × 10 m, 6 m × 6 m and 5 m × 5 m were provided along with fertigation equipments which ranged between ₹55000-85000 excluding the cost of pump.

At Kota, total 18 demonstrations with improved water management in wheat was done during *rabi* season at different reaches of Manasgaon distributary in right main canal (RMC) and Andhed distributary in left main canal (LMC) of Chambal command under Chambal irrigation project. Nine farmers' fields were selected, with three fields each at head, middle, and tail ends in both RMC and LMC. Improved water management of applying four irrigations at crown root initiation, late tillering, flowering and milking stages of wheat crop by border strip irrigation method with 80% cut-off (test block) was demonstrated against farmers' practice of flood irrigation (control block). Wheat crop var. *Raj*-4079 showed 10.38 and 9.48% higher grain yield, and 160 mm water saving in the test blocks compared to the control blocks in RMC and LMC, respectively. Water expense efficiency was 15.94 and 15.62 kg ha-mm^{-1} in the test blocks compared to 9.82 and 9.70 kg ha-mm^{-1} in the control blocks in RMC and LMC, respectively.

At Morena, on-farm trials were conducted at different locations of head, mid and lower reaches of minor Chambal canal command in rice, pearl millet, greengram, pigeonpea, clusterbean, sesame during *kharif*, and in mustard, wheat and chickpea during *rabi*. The trials were intervened with improved practices such as laser land levelling, improved methods of sowing, moisture conservation and irrigation methods and compared against the respective farmers' conventional practices. At the head reach, cropping systems of pigeonpea–wheat followed by rice–wheat was found beneficial. At the mid reach, pigeonpea–wheat followed by clusterbean–wheat, whereas at tail reach pearlmillet–mustard, pearlmillet–chickpea followed by clusterbean–barley showed promising results in terms of higher yield, water productivity, net return, water saving and benefit-cost ratio. Among the improved irrigation methods, broad bed and furrow was found to be the best in terms of yield, economic benefits and water productivity in head, mid and tail reaches of the canal command area for all crops, except rice.

Tribal Sub Plan (TSP) and Scheduled Caste Sub Plan (SCSP)

At Rahuri, 50 drip and 50 sprinkler irrigation sets were distributed to 100 farmers from seven tribal villages (Shelad, Vagdari, Dhamanvan, Paithan, Ghoti, Pimpri and Khadki bk.) of Akole tahsil of Ahmednagar district of Maharashtra. The farmers grew crops like potato, rajma, marigold with drip system and tomato, onion, wheat, chickpea, fodder maize using sprinkler system during *kharif* and *rabi* seasons. Impact analysis on adoption of drip and sprinkler irrigation systems of 100 farmers showed that there was enhanced yield of *rabi* crops by 23-80% and 18-75% through drip irrigation and sprinkler irrigation, respectively over traditional irrigation practice. Overall farmers' income improved by 20-40%.

At Pusa, a solar tree based irrigation system has been installed in village- Pachbania, District- Madhubani, Bihar. The system consists of a solar tree of capacity 5.0 kW and a tubewell with 5.0 hp submersible pump. The system will provide irrigation to 18 tribal farmer beneficiaries round the year free of cost. The benefit of solar tree can be extended to another group of about 12 farmers using flexible pipes.

At Udaipur, drip irrigation in turmeric crop demonstrated in one farmer's field showed that application of irrigation scheduled at 90% ET_c with black silver mulch gave maximum and significantly higher tuber yield of 18.20 t ha^{-1}.

At Navsari, eight scheduled caste farmers were selected for the demonstration, and irrigation pipes were provided for conveying water to their fields. Every farmer was provided 12 irrigation pipes of 3.0 inches diameter and 6.0 m length and having three bends. These irrigation pipes are adequate to cover 0.75 ha of land per farmer, thereby covering total 6.0 ha with irrigation pipeline. Similarly, at Palampur centre, a polyline water harvesting tank was constructed and drip irrigation system was established. Monsoon rainwater was harvested, and used for field demonstration of various crops through drip.

At Parbhani, intervention was carried out to enhance crop productivity and sustainable livelihood security of very poor scheduled caste (SC) farmers of Bhosa village, Manwat taluka of Parbhani district, Maharashtra. Six sprinkler irrigation sets were distributed to the SC farmers of the village and guided regarding operation of sprinkler irrigation system.

At Kota, during *rabi* 2019-20, total 57 demonstrations on wheat crop were conducted out of which 20 demonstrations were on method of irrigation at critical stages in wheat at Garda command and non command area, 23 demonstrations on wheat on conveyance and lifting of water by using high density polyethylene (HDPE) pipeline for irrigation at critical stages and 14 demonstrations on wheat under sprinkler irrigation at critical stages.

Introduction

All Indian Coordinated Research Project on Water Management (WM) and All India Coordinated Research Project on Groundwater Utilization (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 network centres and their controlling institutions under AICRP on Irrigation Water Management are given in Table I. Geo-referenced map of the network centres and project coordinating unit has been depicted in Figure I.

Table I. AICRP on IWM centres and their controlling universities

Sl. 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	Ayodhya	NDUAT, Ayodhya
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

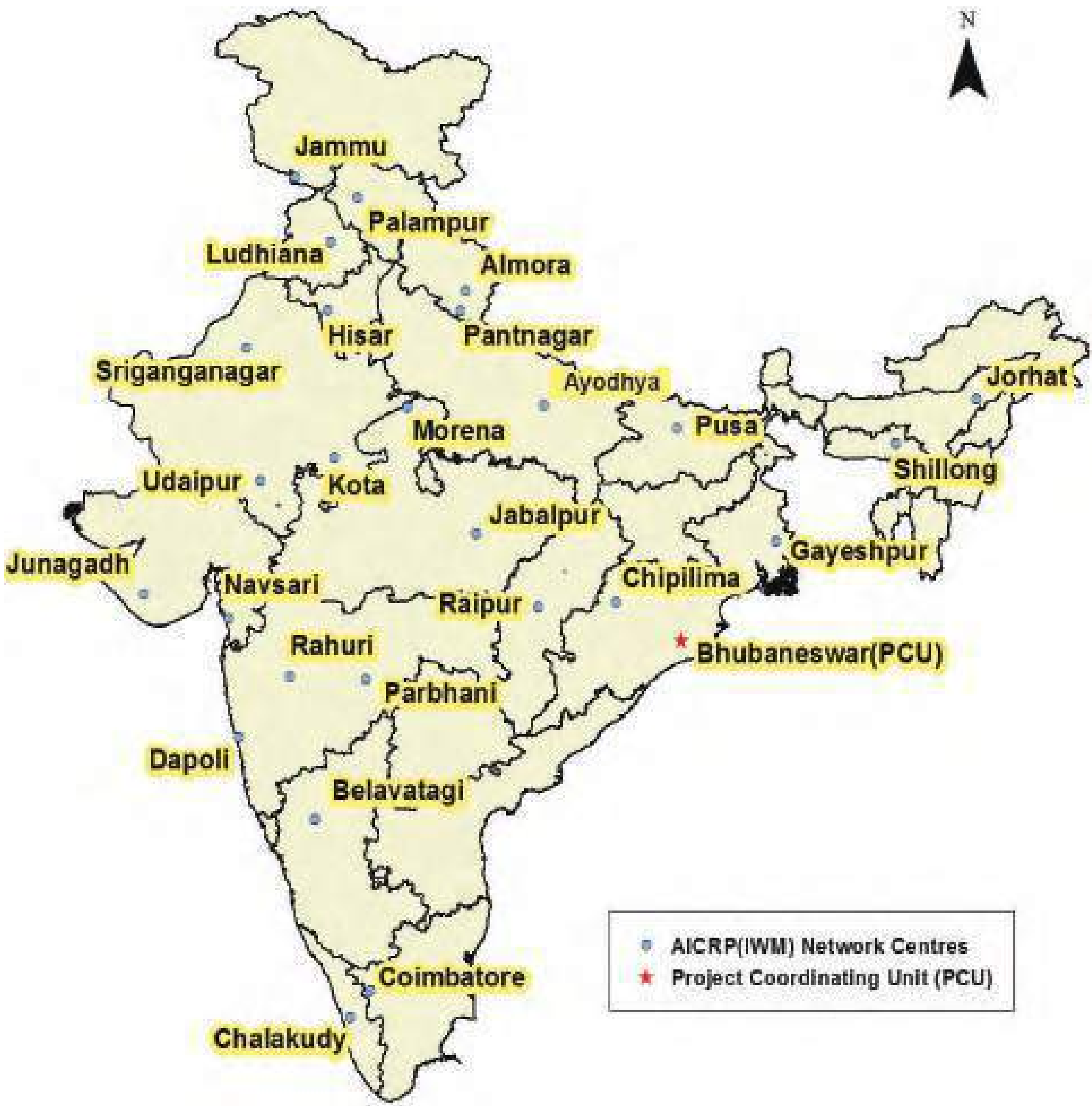


Figure I. Geo-referenced location map of twenty-six network centres and Project Coordinating Unit of AICRP on IWM

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 II.

Table II. 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	-	-	-

ECOSYSTEM	AER Description	AESR	Description of AESR	Irrigation region	Centre	Controlling organization
		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	-	-	-

ECOSYSTEM	AER Description	AESR	Description of AESR	Irrigation region	Centre	Controlling organization
	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	Ayodhya	NDUA&T, Ayodhya
	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	-	-	-

ECOSYSTEM	AER Description	AESR	Description of AESR	Irrigation region	Centre	Controlling organization
	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	-	-	-

ECOSYSTEM	AER Description	AESR	Description of AESR	Irrigation region	Centre	Controlling organization
	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	-	-	-

Note: AER, agro-ecological region; AESR, agro-ecological sub 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 III.

Table III. 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
Ayodhya	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. Junagadh

1.1.1. Assessment and management planning of groundwater resources of Uben river basin

Uben river basin lies on the northern side of Girnar mountain in Junagadh district, Gujarat. Length of Uben river is 68 km and the river basin has a catchment area of 999 km^2. Sentinel-2 satellite imagery (10 m resolution) was used to prepare land use maps and land use classification of the study area was done using supervised classification. Land use and land cover maps revealed that areas under agriculture, forest, wasteland, built up and water body is 78.9, 10.08, 7.68, 2.32 and 1.03% respectively. Figure 1(a) shows the land use map of the study area.

The soil map of the study area was extracted from the map obtained from national Institute of Space Applications and Geoinformatics, Gandhinagar. The Uben river basin is having soil types of fine, clayey and rocky of 74.16, 16.86 and 8.98% area, respectively. It was seen that the fine soil exists in a major part of the basin. Surface runoff was estimated by curve number method. Runoff in three regions of the Uben river basin was found as follows (1) Junagadh, 392.32 mm, (2) Bhesan, 333.05 mm and (3) Vanthali, 460.82 mm. Weighted annual runoff of the Uben river basin was found as 394.83 mm. Groundwater resources estimation was done by water table fluctuation method and it was found as 524.89 MCM. Figure 1(b) shows the soil map of the study area.

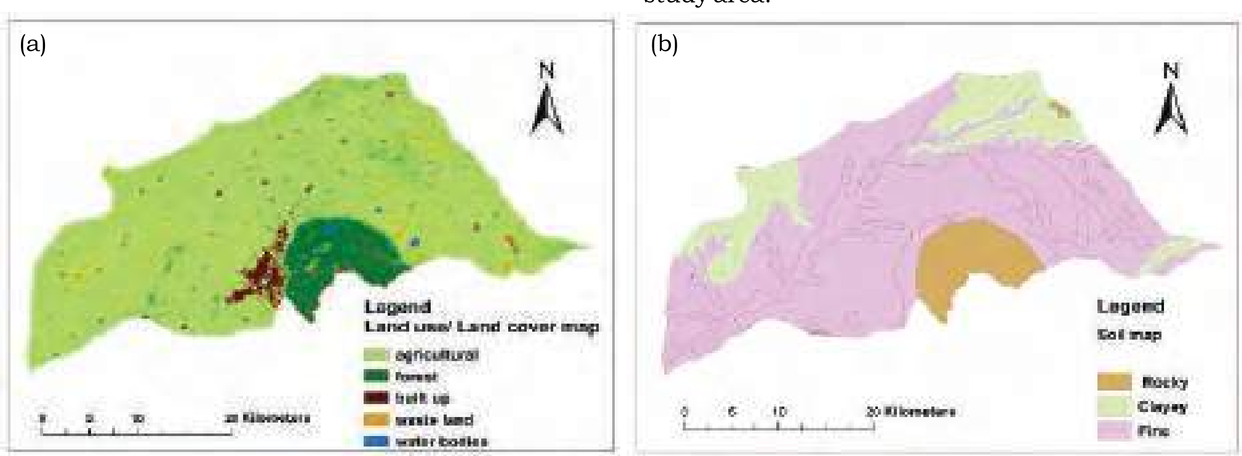


Figure 1. (a) Land use map and (b) soil map of Uben river basin

Groundwater flow modeling for the study area was done using Visual MODFLOW software. The top and bottom elevation of the layers were imported to the model as GIS shape files. The location of pumping wells and observation wells were assigned to the model. The location of well screen and pumping schedules were also assigned to the model. The model was divided into 15 zones and hydraulic conductivity and specific storage values were assigned to each zone. Boundary conditions in the form of river boundary and recharge were assigned to the model. Calibration of the model was done using trial and error method by changing the input parameters so that the observed and simulated groundwater levels match as much as possible.

After calibration of the model, calibrated hydraulic conductivity values of the basin were obtained as 1.00E^{-04} (m s^{-1}) for unconfined aquifer of Evenagar, 1.5E^{-04} (m s^{-1}) and 3.00E^{-04} (m s^{-1}) for unconfined aquifer and confined aquifer of Patala respectively, 1.50E^{-04} (m s^{-1}) for unconfined aquifer of Makhiyala and 2.63E^{-04} (m s^{-1}) for unconfined aquifer of Ravani-Rupavati. The steady-state model resulted in

87.355968 MCM, 262.064435 MCM and 436.778956 MCM groundwater resource of Uben river basin for 10, 30 and 50% rainfall recharge, respectively. The transient state model estimated lower values of groundwater resource as 25.108301 MCM, 75.323914 MCM and 125.541242 MCM for 10, 30 and 50% rainfall recharge.

As per the output of the model, in the map of hydraulic conductivity of confined aquifer, area of higher hydraulic conductivity is 73% area (721.93 km^2) of the basin which may be treated with deep groundwater recharge structures like tubewell and open well recharge techniques. As per the map of hydraulic conductivity of unconfined aquifer, the area of higher hydraulic conductivity is 43% area (427.52 km^2) of the basin where surface recharge structures are suggested to be constructed. The western part of the basin has lower hydraulic conductivity in both aquifers which should be treated with surface water harvesting structure to enhance water resources in the basin. Bhesan region is suitable for low water requiring crops like coriander and cumin. Junagadh and Vanthali regions are suitable for high water requiring crops like wheat, vegetables, garlic, onion and horticultural crops.

1.2. Udaipur

1.2.1. Delineation of groundwater potential zones of Upper Banas river basin

Upper Banas river is the main tributary of Chambal river basin. It is located in the Rajsamand, Udaipur, Chittorgarh and Bhilwara districts which falls in semi-humid region of Rajasthan bounded by 73° 22' 55.6'' to 75° 01' 27.05'' E Longitude and 24° 43' 21.98'' to 25° 24' 22.92'' N Latitude. The 56% area of total basin falls in the Rajsamand and Bhilwara district of Rajasthan. The Upper Banas river basin has been divided into 122 systematic square grids of 7.5 km × 7.5 km size. To represent the whole area at least one well was selected from each grid for collecting water quality sample and water table fluctuation data. The systematic square grids map of Upper Banas river basin is shown in Figure 2.

Geomorphological analysis

For the geomorphological analysis, measurements were made from the digitized drainage pattern and basin boundary. In the present study, the map showing drainage details have been prepared from geometrically rectified toposheets. The drainage pattern of delineated upper Banas river basin was exported to ARC/INFO software for morphometric analysis. The parameters computed include stream order, stream length, stream frequency, bifurcation ratio, drainage density, stream frequency, form factor, circulatory ratio, elongation ratio, relief ratio, ruggedness number and channel slope by standard methods and formulae. The input parameters for the present study such as area, perimeter, elevation, stream length etc. were obtained from digitized coverage of drainage network map in GIS environment. The total drainage area of upper Banas river basin drain is 4940 km^2.

Figure 2. Grid map of upper Banas river basin

Prioritization of sub-basins

The morphometric parameters were compounded and a final rating scale was generated for the study area as shown in Table 1. Sub-basins were prioritized according to these rating. Based on the average value of compound parameters, the sub-basins having the lowest rating value was assigned the highest priority number of 1, next higher value was assigned second priority number of 2 and so on. The sub-basin, which got the highest compound parameters value, was assigned last priority. It was found that the lowest compound parameters value of 7.13 occurred in the sub-basin number 10 that is given highest priority for conservation measures. The next priority is given to sub-basin 3, sub-basin 9, sub-basin 8, sub-basin 17, sub-basin 13, sub-basin 21, sub-basin 5, sub-basin 11, sub-basin 4, sub-basin 1, sub-basin 12, sub-basin 14, sub-basin 15, sub-basin 6, sub-basin 18, sub-basin 20, sub-basin 16, sub-basin 2, sub-basin 19 and sub-basin 7 respectively. Thus, soil and water conservation measures can first be applied to sub-basin number 10 and then to other depending on their priority.

Table 1. Prioritization result of sub-basins based on morphometric analysis

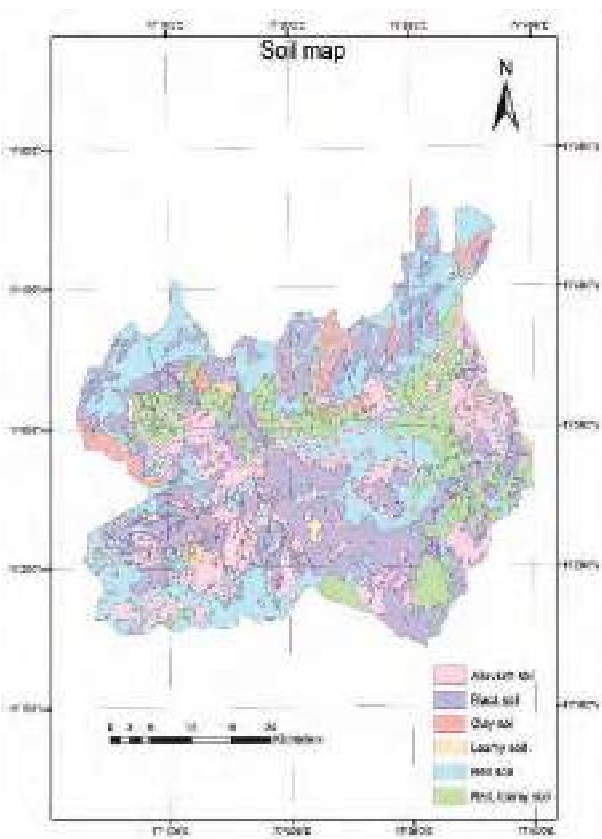
Sub-basin (SB)	Bifur-cation ratio	Drainage density	Stream frequ-ency	Texture ratio	Circul-atory ratio	Form factor	Elong-ation ratio	Compact-ness constant	Compound parameter	Final priority
SB1	11	17	14	3	13	10	10	9	10.88	11
SB2	13	12	12	16	5	18	18	17	13.88	19
SB3	1	18	21	1	11	2	2	11	8.38	2
SB4	12	14	13	2	17	11	11	5	10.63	10
SB5	17	4	17	7	2	6	6	20	9.88	8
SB6	16	8	20	14	8	9	9	14	12.25	15
SB7	15	16	18	8	15	21	21	7	15.13	21
SB8	10	11	19	4	10	3	3	12	9.00	4
SB9	4	9	15	6	4	7	7	18	8.75	3
SB10	9	3	10	11	1	1	1	21	7.13	1
SB11	14	1	11	5	19	15	15	3	10.38	9
SB12	8	10	5	9	6	17	17	16	11.00	12
SB13	5	13	4	13	14	8	8	8	9.13	6
SB14	20	2	6	18	3	13	13	19	11.75	13
SB15	18	7	1	20	9	14	14	13	12.00	14
SB16	21	5	7	15	7	16	16	15	12.75	18
SB17	7	6	8	21	12	4	4	10	9.00	5
SB18	3	15	9	10	18	20	20	4	12.38	16
SB19	19	19	3	17	21	19	19	1	14.75	20
SB20	6	20	16	12	20	12	12	2	12.50	17
SB21	2	21	2	19	16	5	5	6	9.50	7

1.3. Coimbatore

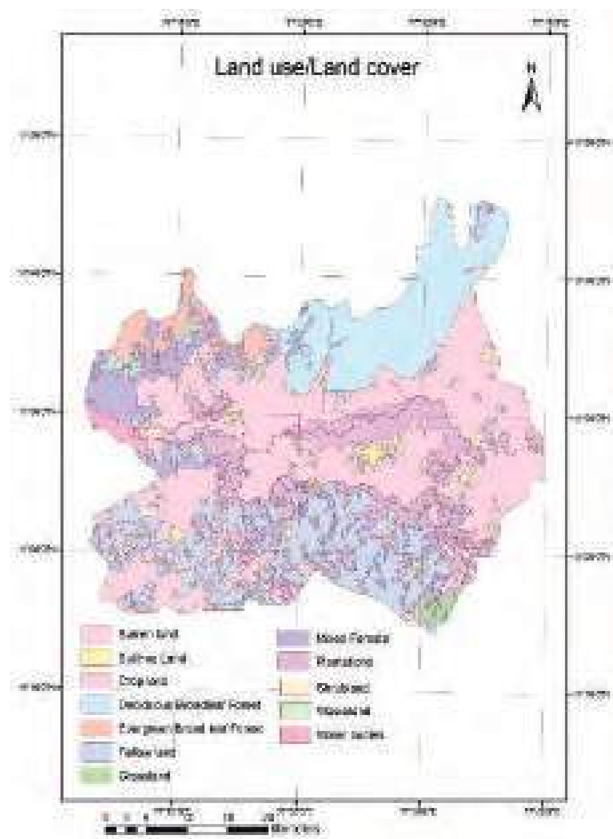
1.3.1. Application of Soil and Water Assessment Tool Model for estimation of surface water resources and temporal water demand for sustainable water management in LBP basin

The study was undertaken using Soil and Water Assessment Tool (SWAT) to simulate the surface and groundwater availability and change on hydrology, focusing on trends of precipitation, evapo-transpiration and water yield in Lower Bhabani Project (LBP) basin. 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 ha of land in Gopichettipalayam, Bhavani, Erode and Dharapuram taluks in Erode district and Karur taluk in Tiruchi district in the state of Tamil Nadu.

The simulation of the water balance of an area by SWAT model requires a large amount of special and time series datasets in order to establish the water balance equation. Slope map was generated from DEM map. The slope in the study area varies from 2 to 42% with majority of the area between 2 to 12%. Forty types of series of soils are available in LBP basin. The Land use / Land cover data was prepared from Land use / Land cover map of National Remote Sensing Centre; 60% of the study area being under agriculture. Figure 3 shows the input maps used in SWAT modelling. Land use classes and soil types were overlaid to define the Hydrologic Response Units (HRUs) for each of the sub watersheds for the SWAT model. Runoff was predicted separately for each HRU and routed to obtain the total runoff for the watershed. Using the SRTM DEM, the stream network of LBP basin was generated and basin was divided into 187 micro watersheds and each micro watershed was further subdivided into 4833 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 LBP basin from the ensemble of 16 Global Climate Models output for A1B scenario and the effect of climate change on the water yield, potential evapotranspiration and soil water was assessed.



Soil Map of LBP basin



Land use map of LBP basin

Figure 3. Input maps for SWAT Modelling

The SWAT model estimated relevant water balance components in addition to the annual and monthly streamflow. The most important elements of water balance of a basin are precipitation, surface runoff, lateral flow, base flow and evapotranspiration. The hydrological parameters were simulated by SWAT for LBP basin for current period (2001 to 2020), mid-century (2041-2060) and end-century (2071-2090). The annual water balance of the basin for the current hydrology, mid-century and end-century was also simulated as shown in Table 2. From these components, actual evapotranspiration contributed a larger amount of water loss from the basin. High evapotranspiration rate predicted could be attributed to the type of vegetation cover and high temperature associated with the area. The values of the average annual evapotranspiration as a relative percentage to average annual rainfall is 33% for the current period, 31% for mid-century and 40% for end-centaury.

Table 2. Average annual simulated water balance of LBP basin

Water balance component	Current period (2001-2020)	Mid-century (2041-2060)	End-century (2071-2090)
Rainfall (mm)	847.62	983.20	766.90
Evapotranspiration (mm)	280.71	306.40	306.80
Surface runoff (mm)	271.24	296.00	232.50
Soil water (mm)	16.95	18.82	14.78
Lateral flow (mm)	159.93	175.20	122.89
Contribution of groundwater to stream flow (mm)	118.79	186.80	89.89

Estimation of crop water demand and irrigation water requirement of Kugulur distributary

The agricultural water demand for Kuhalur distributary located at 33.1.580 miles from the LBP was estimated. The total ayacut area of the selected distributary is 3960.82 ha. The command area is divided into two halves i.e. odd turn and even turns sluice command of equal extent. The ayacut area under odd turn is 2011.55 ha and even turn is 1949.27 ha. Crops grown in this Kugulur distributary are sugarcane, banana, rice, turmeric, tapioca, maize, sorghum, groundnut, gingelly, tobacco, vegetables, coconut, cotton and mulberry. The average crop water demand for existing cropping pattern (2013 to 2020) in the Kugulur distributary of LBP canal command was estimated for turn I and turn II as shown in Table 3 and 4, respectively.

Table 3. Average crop water demand for Turn I

Crop	Area (ha)	Crop water demand (ha-m)
Rice	397.57	516.84
Sugarcane	140.69	256.61
Banana	139.91	372.16
Groundnut	6.47	3.57
Tapioca	22.26	11.13
Turmeric	74.43	122.80
Vegetable cowpea	4.85	2.42
Sorghum	22.67	11.33
Mulberry	6.34	7.60
Yam	4.45	1.33
Coconut	10.71	12.85
Maize	24.69	13.57
Gingelly (Sesame)	2.42	0.8107
Vegetables	19.83	13.881

Table 4. Average crop water demand for Turn II

Crop	Area (ha)	Crop water demand (ha-m)
Sugarcane	109.9	200.40
Banana	100.8	268.13
Rice	64.4	83.72
Tapioca	30.0	15.00
Sorghum	39.6	19.80
Vegetable	18.1	12.69
Groundnut	4.1	2.28
Gingelly (Sesame)	3.2	1.07
Mulberry	16.4	19.68
Cotton	5.3	3.46
Coconut	30.0	36.00
Yam	0.5	0.16
Papaya	0.8	0.40
Turmeric	16.3	26.85
Maize	10.9	6.01
Tobacco	6.0	3.30

1.4. Ludhiana

1.4.1. Simulation of groundwater behaviour for water resources management in Punjab

A single layer model having 33 rows and 30 columns for the Punjab state was developed using MODFLOW software. A constant grid spacing of 10 km × 10 km was used to discretize the area. The boundary of the aquifer was approximated in a linear stepwise fashion. The study area constitutes of 504 cells out of 990 cells, which are included in the simulation process. The bottom elevation of each of the model cell was interpolated from the available lithologs in the study area. A digitized map of the area was imported in MODFLOW to represent the real world location of the study area. Stress periods of 365 days were used to observe the yearly effect of recharge and draft on groundwater system. The input data to the model included spatial parameters like initial hydraulic head, hydraulic conductivity, thickness of layer and specific yield and temporal parameters like recharge and draft. Figure 4 shows the discretised cells for the study area of Punjab.

Model calibration is an iterative process through which model results (e.g., heads) are matched with the observed values by adjusting aquifer parameters within plausible ranges. In the present study, parameter estimation software package and trial and error calibration was used to calibrate the groundwater flow model. Observed hydraulic heads for the period 1998-99 to 2012-13 in the study area were used for calibration purpose. The hydraulic conductivity and specific storage values were adjusted till there is maximum possible matching between observed and simulated values of groundwater level. The calibrated flow model was validated for a fraction of simulation period i.e. from 2013-2017. The calibrated model was used to study the future scenario in six groundwater management strategies, which is outlined in Table 5.

Table 6 shows the area under different groundwater level range and mean groundwater level for different groundwater management strategy (MS) after 5, 10, 15 and 20 years, respectively. After five years, model predicted the increase in mean water table depth (WTD) to 20.48 m from 17.63 m with increase in area under class 5 to 1118 ha, if the current groundwater pumping conditions (as in 2017-18) prevailed. In all the six proposed strategies, there was improvement in mean WTD after 5 years, but the maximum decrease in mean WTD was observed in MS VI i.e. 15.29 m with a difference of 5.19 m as compared to current scenario after 5 years. Also, under MS VI, there was 69% lesser area under class 5 in comparison to the current scenario. All the strategies indicate significant improvement in values of mean WTD.

Table 5. Description of groundwater management strategies (MS)

Strategy	Description
MS I	2% increase in recharge
MS II	2% decrease in draft
MS III	3% decrease in draft
MS IV	5% decrease in draft
MS V	2% increase in recharge and 3% decrease in draft
MS VI	2% increase in recharge and 5% decrease in draft

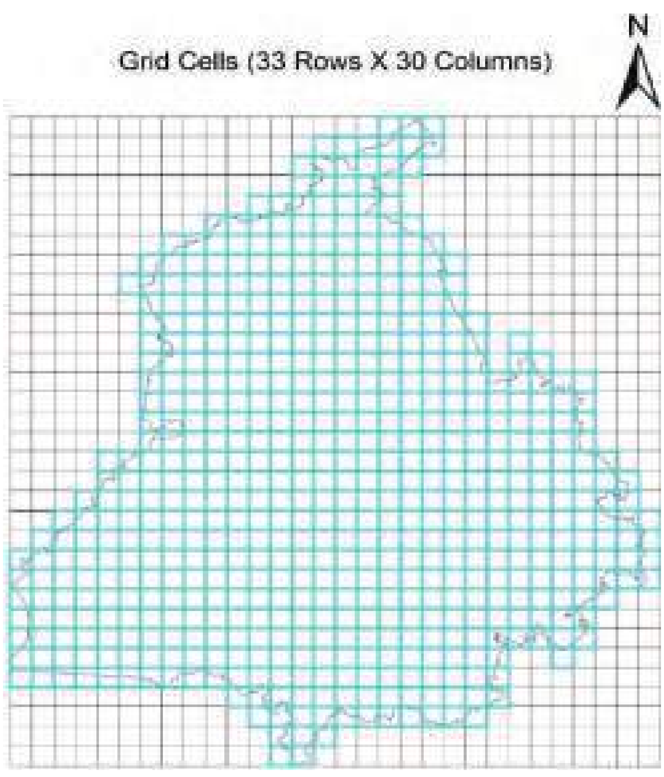


Figure 4. Punjab as discretized cells of study area used for simulation

Table 6. Area (in '000 ha) and mean water table depth (WTD, m) for different strategies for 5, 10, 15 and 20 years

Strategy	Class 1 (0-3 m)	Class 2 (3-10 m)	Class 3 (10-20 m)	Class 4 (20-30 m)	Class 5 (>30 m)	Mean WTD (m)
After 5 years						
Current	287	483	1063	2085	1118	20.48
MS I	312	1093	1969	962	700	15.76
MS II	306	1048	1955	997	730	15.84
MS III	314	1133	1962	947	680	15.70
MS IV	316	1204	2021	932	564	15.55
MS V	319	1345	1993	912	468	15.43
MS VI	320	1375	2112	886	342	15.29
After 10 years						
Current	272	423	967	1692	1682	23.40
MS I	316	1682	2036	942	60	14.12
MS II	308	1652	2019	957	101	14.23
MS III	318	1717	2064	937	0	14.01
MS IV	319	1773	2028	917	0	13.82
MS V	324	1853	1978	881	0	13.69
MS VI	325	1868	1992	851	0	13.51
After 15 years						
Current	262	408	876	1717	1773	26.31
MS I	322	2060	1944	710	0	12.47
MS II	311	2009	1970	745	0	12.61
MS III	326	2090	1915	705	0	12.31
MS IV	322	2125	1894	695	0	12.08
MS V	329	2206	1847	655	0	11.93
MS VI	331	2261	1799	645	0	11.72
After 20 years						
Current	252	398	851	1652	1884	29.41
MS I	325	2513	1750	448	0	10.79
MS II	315	2458	1810	453	0	10.97
MS III	327	2523	1748	438	0	10.58
MS IV	328	2569	1722	418	0	10.32
MS V	333	2664	1656	383	0	10.16
MS VI	334	2720	1635	347	0	9.90

After 10 years, model predicted increase in mean WTD to 23.40 m from 17.63 m with increase in area under class 5 to 1682 ha if the current groundwater pumping conditions (as in 2017-18) prevailed. In all the six proposed strategies, there was improvement in mean WTD after 10 years; but the maximum decrease in mean WTD was observed in MS VI, i.e., 13.51 m with a difference of 9.89 m as compared to current scenario after 10 years. All the strategies indicate significant improvement in values of mean WTD as compared to current scenario. After 15 years, model predicted the increase in mean WTD to 26.31 m from 17.63 m with increase in area under class 5 to 1773 ha if the current groundwater pumping conditions (as in 2017-18) prevailed. In all the six proposed strategies, there was improvement in mean WTD after 15 years; but the maximum decrease in mean WTD was observed in MS VI, i.e., 11.72 m with difference of 14.59 m as compared to current scenario after 15 years. All the strategies indicate significant improvement in values of mean WTD as compared to current scenario. After 20 years, model predicted the increase in mean WTD to 29.41 m from 17.63 m with increase in area under class 5 to 1884 ha if the current groundwater pumping conditions (as in 2017-18) prevailed. In all the six proposed strategies, there was improvement in mean WTD after 20 years; but the maximum decrease in mean WTD was observed in MS VI, i.e., 9.90 m with difference of 19.51 m as compared to current scenario after 20 years. All the strategies indicate significant improvement in values of mean WTD as compared to current scenario. Under different management strategies, area under Class 5 showed the trend of decreasing area in the following order strategy VI <V<IV<III<I<II.

1.5. Jabalpur

1.5.1. Groundwater potential zoning in Tons basin using spatial data

The slope map, drainage density map, land use/land cover map, soil map and geology map of the Tons river basin was prepared. Analytical Hierarchy Process (AHP) was used for potential groundwater zoning in the river basin. For demarcation of groundwater potential zones, weights and scores were decided and assigned for all five thematic maps and their features. Different suitable rank was decided for each given feature on thematic maps. Weight of the different features in thematic map was decided on the basis of their degree of influence to groundwater potential zones. Weight has been given in scale range of 1 to 7. Integration of various thematic maps was performed by overlaying one thematic map over other thematic map in GIS software.

On the basis of weighted overlay, different thematic map such as geology, slope, land use/land cover, soil and drainage density were integrated as per their importance with one another. The groundwater potential zone of the basin was classified into three categories as good groundwater potential, moderate groundwater potential and poor groundwater potential (Figure 5). In Satna district, groundwater potential is good, which accounts for an area of 5562.50 km^2 i.e, 44.50% of total basin area and some of them not showing good groundwater potential. Groundwater potential of Rewa district, is moderate to good, which accounts for an area of 6551.25 km^2 i.e., 50.93% of total basin area. The northern part of Rewa district is showing moderate groundwater potential zone. Groundwater potential of the Sidhi district, accounts for an area of 386.25 km^2 i.e. 3.09% of total basin area. Overall groundwater potential map of the basin shows moderate to good groundwater potential in the Tons basin.

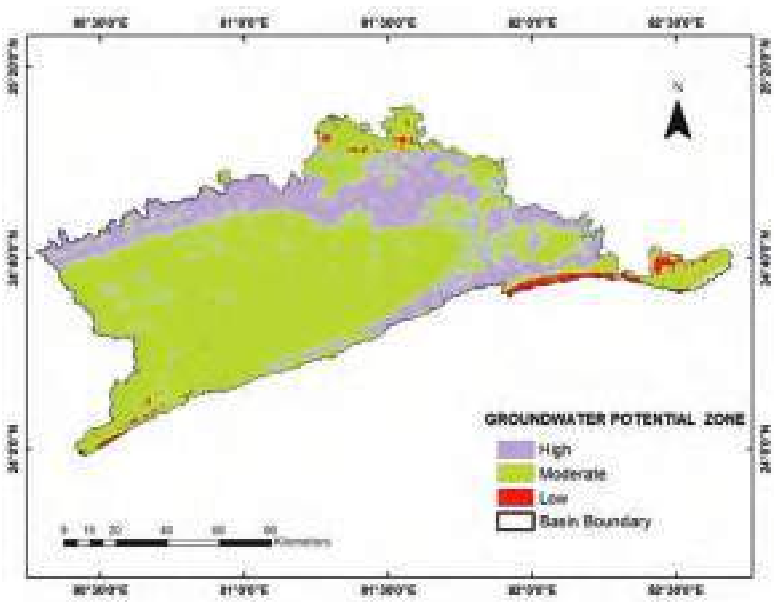


Figure 5. Groundwater potential zone map of Tons river basin

1.6. Raipur

1.6.1. Groundwater recharge planning for Korba and Janjgir-Champa districts in upper Mahanadi Basin using remote sensing and GIS

The study area Mand river basin of upper Mahanadi basin lies between the North altitudes of 21° 42' 15.52" N and 23° 04' 19.75" N and east longitudes of 82° 50' 54.50" E and 83° 36' 01.29" E. The digital elevation model (DEM) of the Mand catchment was generated from Shuttle Radar Topography Mission (SRTM) data. The catchment was divided into thirteen sub-watersheds and morphometric analysis was done for each sub-watershed. The drainage map, land use map, soil map, geology map, geomorphology map etc were prepared using ArcGIS. The land use/land cover map is presented in Table 7. The majority (58.14%) land in the catchment is agricultural land.

The groundwater potential zones were generated using MCDA approach by integrating various thematic maps viz., drainage density, slope, geology, geomorphology, soil texture, lineament, rainfall, groundwater fluctuation and LULC using remote sensing and GIS techniques. The selected nine parameters for groundwater potential were ranked based on the Satty's Analytical Hierarchical Process (AHP).

The groundwater potential zones were categorized into four categories, namely low, low to medium, medium to high, and very high as shown in Figure 6(a). The groundwater potential zone map shows that the major part of the area 42.72% fell under the low to medium potential zone, 20.27% area fell under medium to high categories, 19.18% area fell under the very high potential zone and only 17.81% area fells in very low groundwater potential zone. Suitable groundwater recharge structures i.e. percolation tanks (36 nos.), check dams (39 nos.) and farm ponds (21 nos.) were suggested for construction in the low and low to medium groundwater potential zones as shown in Figure 6(b). These structures will store rainwater as well as help in groundwater recharge.

Table 7. Land use/ cover and area distribution

S.No.	LULC classes	Area (sq.km.)	Area (%)
1.	Agricultural Land	3099.84	58.14
2.	Shallow water body	185.36	3.48
3.	Deep water body	15.73	0.30
4.	Dense forest	329.87	6.19
5.	Open forest	316.77	5.94
6.	Fallow land	540.01	10.13
7.	Barren land	19.97	0.37
8.	Scrubland	718.70	13.48
9.	Settlement	105.82	1.98

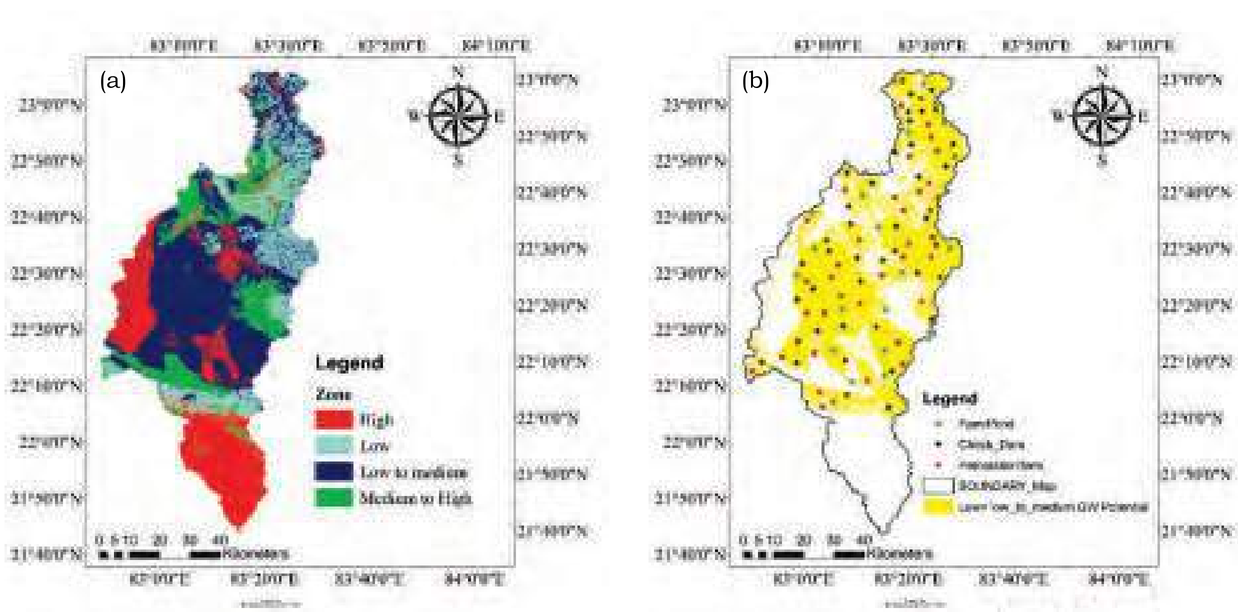


Figure 6. (a) Groundwater potential zone map, (b) Locations identified for groundwater recharge in Mand river basin

Chapter 2

Pressurized Irrigation Systems

2.1. Shillong

2.1.1. Development of low cost bamboo drip irrigation technology for tomato to enhance economic water productivity, yield and income in hilly upland condition

The experiment in tomato crop (cv. Rockey F1 hybrid) was conducted for two consecutive years (2018-19 and 2019-20) in randomized block design having six treatments (Table 8), replicated thrice. The objectives of the experimentation were (i) to design a bamboo drip irrigation system for tomato crop in hilly uplands, and (ii) to compare economic water productivity, yield and relative ability to enhance income among different methods of irrigation and *in situ* moisture conservation techniques. Based on the two years pooled data, it was observed that the performance of various treatments was statistically similar except farmers' practice, and all the treatments performed well over farmers practice in improving fruit yield and water productivity of tomato along with higher economic return (Table 8). The highest fruit yield was recorded by bamboo drip + straw mulch treatment (24.86 t ha^{-1}) and closely followed by drip systems (24.49 t ha^{-1}) and mulch + mini-sprinkler (24.48 t ha^{-1}). Though there is no significant difference in realization of fruit yield, but bamboo drip system may be considered as the best among all as it is eco-friendly, and the materials are easily available locally. There is no need of the farmers to depend on markets to obtain the inputs, other than improved seeds and maintenance cost is also very less. Labours from the home itself can easily construct such type of irrigation systems for their own field according to their requirement. It was also observed that, drip + mulch recorded the highest water productivity and economic water productivity among all the treatments and it was closely followed by bamboo drip and bamboo drip + straw mulch treatments. The farmers practice recorded the lowest values of water productivity and economic water productivity. From economic point of view, bamboo drip recorded highest benefit-cost ratio (3.1) followed by bamboo drip + mulch (2.8), whereas, minimal benefit-cost ratio was recorded with farmers' practice.


Bamboo drip irrigation in tomato

Table 8. Effect of irrigation treatments on tomato yield, water productivity and economics (pooled data)

Treatment	Tomato yield (t ha^{-1})	Water productivity (kg m^{-3})	Economic water productivity (₹ m^{-3})	B-C ratio
Bamboo drip	23.30	9.6	287	3.1
Bamboo drip + straw mulch @ 5 t ha^{-1}	24.86	9.4	282	2.8
Modern drip	24.49	8.3	261	2.4
Modern drip + straw mulch @ 5 t ha^{-1}	22.80	9.8	313	2.0
Straw mulch @ 5 t ha^{-1} + mini-sprinkler	24.48	8.3	248	2.5
Control (mini-sprinkler, life-saving)	12.90	5.5	165	1.2
CD (p=0.05)	2.13	-	-	-

2.2. Kota

2.2.1. Effect of sprinkler nozzle size and hydraulic parameters on productivity of coriander

A field experiment on sprinkler irrigation system was conducted in coriander for last three years (2016-17 to 2019-20) in coriander. The experiment was laid out in split plot design, replicated thrice; varied operating pressure as main-factor and size of the nozzle as sub-factor (Table 9). Pooled data of 3 years revealed that sprinkler irrigation at operating pressure 3.0 kg cm^{-2} gave significantly higher seed yield (1.23 t ha^{-1}), water use efficiency (8.71 kg ha-mm^{-1}), net return (₹43343 ha^{-1}) and benefit-cost ratio (1.41) over lower operating pressure (1.5 kg cm^{-2}) (Table 9). The performance of sprinkler irrigation with operating pressure 2.0 kg cm^{-2} was statistically similar with higher operating pressure (3.0 kg cm^{-2}). On the other hand, as compared to nozzle size 3.1 × 5.1 mm, the application of water with nozzle size 2.5 × 3.5 mm was recorded significantly higher seed yield and it was statistically similar with 2.5 × 2.8 mm. The maximum water use efficiency (7.83 kg ha-mm^{-1}) was recorded with nozzle size 2.5 × 2.8 mm, and it was closely followed by 3.1 × 5.1 mm nozzle size. Though the different nozzle size could not bring the significant variation in net return and benefit-cost ratio, but maximum net return (₹39399 ha^{-1}) and benefit-cost ratio (1.26) was fetched under 2.5 × 3.5 mm nozzle size.

Table 9. Effect of operating pressure and nozzle size through sprinkler irrigation on performance and economics of coriander crop

Treatment	Seed yield (t ha^{-1})					Total water applied (mm ha^{-1})	Water use efficiency (kg ha-mm^{-1})	Mean water productivity (kg m^{-3})	Net return (₹ ha^{-1})	B-C ratio
	2016-17	2017-18	2018-19	2019-20	Pooled					
Operating pressure (kg cm^{-2})										
1.5	1.01	1.24	1.08	0.93	1.07	150	6.86	0.686	31626	0.97
2.0	1.09	1.39	1.09	0.90	1.12	150	7.71	0.771	36235	1.16
2.5	1.16	1.42	1.16	0.96	1.18	150	7.98	0.798	40185	1.30
3.0	1.21	1.60	1.13	0.97	1.23	150	8.71	0.871	43343	1.41
CD (p=0.05)	0.15	0.108	0.06	0.06	0.09	-	-	-	3550	0.13
Nozzle size										
3.1 × 5.1 mm	1.00	1.33	1.09	0.91	1.09	150	7.67	0.767	36692	1.22
2.5 × 2.8 mm	1.17	1.44	1.12	0.94	1.17	150	7.83	0.783	37452	1.16
2.5 × 3.5 mm	1.18	1.46	1.13	0.96	1.18	150	7.95	0.795	39399	1.26
CD (p=0.05)	0.13	0.09	0.05	0.06	0.08	-	-	-	NS	NS
Surface irrigation at IW/CPE 1.0 (60 mm)	1.12	1.23	1.08	0.94	1.09	180	6.05	0.605	33380	1.04

2.3. Jammu

2.3.1. Sprinkler irrigation in basmati rice-wheat sequence under Ranbir canal command

The experiment is being conducted to identify crop growth stages for sprinkler irrigation in wheat and basmati rice which will provide yield advantage and improve water use efficiency (WUE) of wheat-rice cropping sequence in Ranbir canal command. Portable sprinkler set was used with average discharge rate of 4.0 litre per hour and emission uniformity of 88%.

In wheat (HD-2329), three different sprinkler irrigation timings were studied i.e. at pre-sowing and crown root initiation (CRI) stage (S_1), at pre-sowing, CRI stage and late booting stage (S_2) and irrigation in all physiological stages (S_3). Irrigation scheduling treatments were 100% ET_c (I_1), 80% ET_c (I_2) and 60% ET_c (I_3). Sprinkler irrigation was compared with recommended surface irrigation practice where four irrigations were applied each of 60 mm depth. Results showed that S_3 led to significantly higher yield of 3.53 t ha^{-1} over S_1 (2.9 t ha^{-1}), but at par with S_2 (3.45 t ha^{-1}). Irrigation scheduling did not show significant effect on grain yield of wheat, but there was water saving of 37-48% with sprinkler irrigation compared to surface irrigation (Table 10). With sprinkler irrigation methods, WUE was highest with S_2 (9.48 kg ha-mm^{-1}) followed by S_3 (8.29 kg ha-mm^{-1}) and S_1 (7.98 kg ha-mm^{-1}). Water use efficiency with sprinkler irrigation was 16.2% higher than recommended surface irrigation practice.

In rice (Basmati-370), time of sprinkler irrigations were from puddling to 15 days before harvest (S_1), irrigation after puddling to 15 days before harvest (S_2) and irrigation from panicle initiation to 15 days before harvest (S_3). Irrigation scheduling treatments were 100% ET_c (I_1), 150% ET_c (I_2) and 200% ET_c (I_3). Sprinkler irrigation was compared with recommended surface irrigation practice in which puddling was followed by 11 irrigations each of 70 mm depth. Results showed that highest yield (2.59 t ha^{-1}) was obtained under sprinkler irrigation from panicle initiation to 15 days before harvest (S_3) which was at par with yield (2.52 t ha^{-1}) under S_2 i.e. irrigation after puddling to 15 days before harvest (Table 10). But yield under S_3 and S_2 were significantly higher than yield under S_1 (2.23 t ha^{-1}). WUE was highest with S_2 (2.33 kg ha-mm^{-1}). Among the irrigation schedules, 200% ET_c (I_3) recorded highest yield (2.68 t ha^{-1}) which was statistically similar to I_2 (2.58 t ha^{-1}), but significantly higher over I_1 (2.07 t ha^{-1}). Further, it was observed that the recommended irrigation practice recorded higher yield by 7.5% over the sprinkler irrigation methods; although WUE was 16.22% higher with sprinkler irrigation over recommended surface irrigation.

Table 10. Effect of sprinkler irrigation, surface irrigation and irrigation schedules on performance of wheat in *rabi* 2019-20 and rice in *kharif* 2020

Treatment	Wheat (*Rabi* 2019-20)			Rice (*Kharif* 2020)		
	Grain yield (t ha^{-1})	Irrigation (mm)	WUE (kg ha-mm^{-1})	Grain yield (t ha^{-1})	Irrigation (mm)	WUE (kg ha-mm^{-1})
Irrigation method						
S_1	2.90	82.1	7.98	2.23	299.2	2.18
S_2	3.45	82.1	9.48	2.52	364.2	2.33
S_3	3.53	144.2	8.29	2.59	971.0	1.53
CD (p=0.05)	0.33	-	-	0.09	-	-
Irrigation schedule						
I_1	3.37	113.5	8.52	2.07	498.2	1.70
I_2	3.28	102.8	8.55	2.58	544.8	2.04
I_3	3.22	92.1	8.63	2.68	591.4	2.04
CD (p=0.05)	NS	-	-	0.07	-	-
Surface irrigation	3.40	240.0	7.37	2.80	970.0	1.66

Note: Wheat- S_1, irrigation at pre-sowing & crown root initiation (CRI) stage; S_2- irrigation at pre-sowing, CRI stage & late booting stage; S_3, irrigation in all the physiological stages; I_1, 100% ET_c; I_2- 80% ET_c; I_3- 60% ET_c. Rice- S_1, irrigation from puddling to 15 days before harvest; S_2, irrigation after puddling to 15 days before harvest; S_3, irrigation from panicle initiation to 15 days before harvest; I_1, 100% ET_c; I_2, 150% ET_c; I_3, 200% ET_c. Rainfall- 281.2 mm in *Rabi* 2019-20 and 718.0 mm in *Kharif* 2020.

2.4. Chiplima

2.4.1. Assessment of productivity and water use efficiency of groundnut under varied irrigation schedules through sprinkler

The study is being conducted to optimize sprinkler irrigation schedule and improve performance of groundnut crop in Hirakud command area. Total eight treatments on irrigation schedule were studied, out of which seven treatments were sprinkler irrigation at 40, 50, 60, 70, 80, 90, 100% cumulative pan evaporation (CPE) and one treatment on farmers' practice. Results showed that number of pods per plant of 13.6, pod weight per plant of 28.8 g, pod yield of 1.84 t ha^{-1} and haulm yield of 1.09 t ha^{-1} were significantly higher with sprinkler irrigation at 90% CPE (Table 11) compared to other sprinkler irrigation treatments as well as farmers' practice. Lowest pod yield (1.35 t ha^{-1}) and haulm yield (0.93 t ha^{-1}) was observed with farmers' practice. Maximum net return of ₹ 50193 ha^{-1} and benefit-cost ratio of 2.2 was also obtained with sprinkler irrigation at 90% CPE, whereas farmers' practice showed minimum net return (₹ 31,989 ha^{-1}) and benefit-cost ratio (1.5). Water productivity was also lowest (270 kg m^{-3}) with farmers' practice.

Table 11. Performance of groundnut crop under sprinkler irrigation

Irrigation treatment (I)	Pods per plant	Pod weight per plant (g)	Pod yield (t ha^{-1})	Haulm yield (t ha^{-1})	Irrigation applied (mm)	WP (kg m^{-3})	NR (₹ ha^{-1})	B-C ratio
I_1: 40% CPE	10.7	24.2	1.43	0.887	172.8	826	35575	1.7
I_2: 50% CPE	11.1	25.5	1.46	0.979	216.1	675	36015	1.6
I_3: 60% CPE	12.1	26.0	1.51	0.982	259.3	581	37712	1.7
I_4: 70% CPE	12.7	26.9	1.62	0.981	302.5	534	41769	1.8
I_5: 80% CPE	13.2	27.4	1.80	1.062	345.7	521	48985	2.1
I_6: 90% CPE	13.6	28.8	1.84	1.091	388.9	472	50193	2.2
I_7: 100% CPE	12.9	27.9	1.76	1.005	432.1	408	47039	2.0
I_8: Farmers' practice	10.9	24.7	1.35	0.927	500.0	270	31989	1.5
CD (p=0.05)	0.28	0.11	0.01	0.02	-	-	-	-

Note: CPE, cumulative pan evaporation; WP, water productivity; NR, net return; B-C, benefit-cost

Chapter 3

Fertigation

3.1. Dapoli

3.1.1. Impact of irrigation and fertigation levels on growth and yield of sweet potato-sweet corn cropping system

The experiment was initiated during 2016-17 in sweet potato-sweet corn cropping sequence at central experiment station, Wakawali. The experimental design was split-plot with three irrigation levels as main factor and three fertigation levels as sub-factor (Table 12), and the number of replications was three. For comparison, one control treatment was added, where water was applied through furrow irrigation at 60 mm depth after each 5 days and 100% recommended dose of fertilizer was applied through soil application. The results revealed that, water requirement of sweet potato and sweet corn was observed 165 and 312 mm, respectively to achieve higher yield under drip while the amount of water required under surface irrigation to both the crops was 660 and 540 mm, respectively. The water saving of 75.0 and 37.6% can be achieved in sweet potato and sweet corn, respectively by drip over surface irrigation method. The treatment I_1 (irrigation at 100% crop evapotranspiration-ET_c) and F_1 [100% recommended dose of fertilizer (RDF) through water soluble fertilizer-WSF] were found significantly influencing on yield and yield attributes of both the crops (Table 12). Sweet potato tuber yield (24.63 t ha^{-1}) and sweet corn cob yield (21.73 t ha^{-1}) was highest in the treatment combination I_1F_1 i.e. irrigation at 100% ET_c with 100% RDF through WSF followed by I_2F_1 treatment combination. The water use efficiency was highest in treatment combination I_3F_1 (irrigation at 50% ET_c with 100% RDF through WSF) under both crops, whereas, the highest systems yield (62.8 t ha^{-1}) was obtained in the treatment combination I_1F_1 (irrigation at 100% ET_c with 100% RDF through WSF) (Table 13). After harvest of the crops, significantly highest available N, P_2O_5 and K_2O nutrients status was observed in irrigation at 100% ET_c and ferligation at 100% level treatment. Under sweet potato-sweet corn cropping sequence, the net return (₹ 406616 ha^{-1}) and benefit-cost ratio (2.17) of system was highest in the treatment combination I_1F_1 (irrigation at 100% ET_c with 100% RDF through WSF) followed by I_1F_2 treatment combination (net return ₹ 379411 ha^{-1} and benefit-cost ratio 2.15).

Table 12. Effect of irrigation and fertigation levels on yield and yield attributes of crops and available nutrient of post-harvest soil (pooled data)

Treatments	Sweet potato			Sweet corn			Available nutrient (kg ha^{-1})		
	No. of tubers plant^{-1}	Tuber weight (g)	Tuber yield (t ha^{-1})	No. of cobs plant^{-1}	Cob weight (g)	Cob yield (t ha^{-1})	N	P	K
Drip irrigation level (I)									
I_1- 100% ET_c	3.95	67.3	23.0	1.23	386	20.6	187	18.9	424
I_2- 75% ET_c	3.89	63.0	21.7	1.14	373	19.6	180	18.6	375
I_3- 50% ET_c	3.83	61.0	20.2	1.08	357	18.5	169	15.8	318
CD (p=0.05)	0.03	0.5	0.6	0.07	5.0	0.5	1.0	0.3	5.0
Fertigation level (F)									
F_1- 100% RDF	3.98	69.6	23.5	1.20	385	20.7	182	20.0	390
F_2- 75% RDF	3.90	64.7	21.8	1.15	371	19.6	178	17.4	366
F_3- 50% RDF	3.79	57.1	19.5	1.10	360	18.5	175	15.9	360
CD (p=0.05)	0.08	3.4	0.9	0.06	8	0.8	1	0.4	6
Interaction (I × F)									
CD (p=0.05)	0.14	5.9	1.6	0.10	14	1.4	NS	NS	NS
Control (surface irrigation + 100% RDF)	3.86	62.5	21.1	1.15	365	19.2	184	18.4	403

Note: ET_c, crop evapotranspiration; RDF, recommended dose of fertilizer

Table 13. System yield, water use efficiency, economic water productivity and economics of the treatment combinations under sweet potato-sweet corn cropping system (pooled data)

Treatment	System pooled yield (t ha^{-1})	System water applied (m^3)	Water use efficiency (kg m^{-3})		Economic water productivity (₹ m^{-3})	Economics	
			Sweet potato	Sweet corn		Net Income (₹ ha^{-1})	B-C ratio
I_1F_1	62.8	5076	13.4	7.91	148	406616	2.17
I_1F_2	59.2	5076	15.3	7.51	140	379411	2.15
I_1F_3	54.7	5076	11.5	7.09	129	341003	2.08
I_2F_1	60.1	3884	17.1	9.97	186	375891	2.09
I_2F_2	55.6	3884	15.8	9.31	172	337761	2.02
I_2F_3	51.4	3884	14.5	8.79	159	302363	1.96
I_3F_1	56.7	2693	24.2	13.6	253	336451	1.98
I_3F_2	52.6	2693	22.1	12.96	235	304124	1.93
I_3F_3	47.0	2693	19.6	12.27	210	251919	1.81
Control	54.3	11934	3.2	3.69	55	339543	2.09

3.2. Parbhani

3.2.1. Yield enhancement of pigeonpea through drip irrigation and fertigation management

A field experiment was conducted in pigeonpea under split plot design with varying levels of irrigation (main effect) and fertilizer (sub effect) for three years. The objective of the study was to evaluate various effects of irrigation and ferigation levels on yield, water use efficiency and economics of pigeonpea. The irrigation was scheduled at alternate day based on cumulative pan evaporation and water soluble fertilizers were applied as per the treatments through drip irrigation. The data furnished in Table 14 revealed that higher water use efficiency (WUE) was observed in irrigation level 0.8 ET_c while lower WUE was noticed in conventional method during both years of experimentation. Among various fertigation treatments, the maximum WUE was noticed in 100% RDF through drip followed by 80% RDF through drip during 2018-19 and 2019-20. Irrigation applied through drip at 0.8 crop evapotranspiration (ET_c) produced significantly higher seed yield of pigeonpea throughout the experimentation, however it was at par with irrigation level 1.0 ET_c during 2019-20, 2020-21 and pooled mean. On the other hand, 100% RDF through drip produced significantly higher grain yield of pigeonpea, however it was comparable with 80% RDF through drip (F_3) during experimentation and lowest seed yield was recorded in control treatment (no fertilizer). The seed yield of pigeonpea was significantly influenced due to interaction effects of irrigation and fertigation levels. Treatment combination of irrigation at 0.8 ET_c and 100% RDF through drip (I_2F_3) recorded significantly higher pigeonpea yield (2.66 and 2.95 t ha^{-1}), however it was at par with treatment combination of I_2F_2, I_3F_2 and I_3F_3 during all the three years of experimentation and pooled mean. Higher net monetary return was observed with drip irrigation scheduled at 0.8 ET_c (I_2) during 2018-19, 2019-20, 2020-21 and in pooled mean, however it was at par with 1.0 ET_c during second and third year of experimentation. The application of 100% RDF through drip recorded significantly higher net return than rest of the fertigation treatments; however, it was comparable with 80% RDF. Similarly, higher benefit-cost ratio was recorded in irrigation level 0.8 ET_c (I_2) followed by 1.0 ET_c (I_3) and lower in conventional method (I_4) during all the years of experimentation. Among fertigation levels, higher benefit-cost ratio was observed in treatment 80% RDF through drip (F_2) followed by 100% RDF (F_3) and lower in control treatment (F_1).

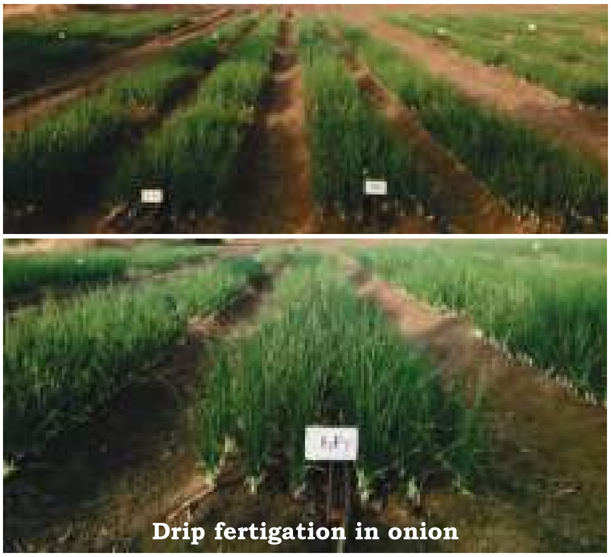
Table 14. Effect of irrigation and fertigation levels on water use efficiency, seed yield and economics of pigeonpea (pooled data)

Treatment	Seed yield (t ha^{-1})				Water use efficiency (kg ha-mm^{-1})	Net return (₹ ha^{-1})	B-C ratio
	2018-19	2019-20	2020-21	Pooled			
Irrigation level (I)							
I_1: Drip at 0.6 ET_c	2.02	2.14	2.05	2.07	2.98	59984	2.01
I_2: Drip at 0.8 ET_c	2.37	2.55	2.45	2.46	3.23	82263	2.39
I_3: Drip at 1.0 ET_c	2.24	2.39	2.30	2.31	2.74	73778	2.25
I_4: Conventional method	1.31	1.60	1.50	1.47	2.27	44251	2.08
CD (p=0.05)	0.11	0.20	0.20	0.15	-	8273	-
Fertigation level (F)							
F_1: Control (No fertilizer)	1.50	1.56	1.51	1.52	2.07	42299	1.94
F_2: 80% RDF	2.16	2.40	2.29	2.28	3.11	75387	2.35
F_3: 100% RDF	2.21	2.43	2.32	2.32	3.17	76044	2.32
F_4: 120% RDF	2.07	2.30	2.19	2.19	2.98	66548	2.12
CD (p=0.05)	0.09	0.13	0.13	0.12	-	6590	-
Interaction (I × F)							
CD (p=0.05)	0.18	0.28	0.28	0.23	-	13182	-

Note: ET_c, crop evapotranspiration; RDF, recommended dose of fertilizer

3.2.2. Response of onion to different irrigation and fertigation levels

In onion crop, a field experiment was conducted in split plot design for three years (2018-19 to 2020-21) with irrigation and fertigation levels as main- and sub-factor, respectively (Table 15). Experimental plots were irrigated on alternate day with drip irrigation as per the treatments based on crop evapotranspiration (ET_c). Water soluble fertilizers were applied as per the treatments through drip irrigation. In addition to this, common micronutrients were also applied to the plots. Different rate of irrigation significantly influenced the bulb yield of onion, and drip irrigation scheduled at 0.80 ET_c (I_3) recorded significantly higher bulb yield, however it was at par with drip irrigation scheduled at 0.6 ET_c (I_2) during all the three years of investigation and in pooled mean (Table 15). Application of 100% RDF through drip (F_3) recorded significantly higher yield of onion bulb however it was at par with 80% RDF through drip (F_2) during all the three years of experimentation and in pooled mean. Treatment combination of drip irrigation at 0.8 ET_c and 100% RDF through drip (I_3F_3) recorded significantly higher yield and it was comparable with treatment combinations of I_2F_3, I_3F_2 and I_2F_2 during all the three years of experimentation and in pooled mean. With increase in irrigation levels the water use efficiency decreased during all the three years of investigation. Drip irrigation scheduled at 0.4 ET_c recorded higher water use efficiency followed by drip irrigation at 0.6 ET_c. In contrast to irrigation levels, the water use efficiency increased with increase in fertigation level up to 100% RDF. Higher water use efficiency was noticed in fertigation treatment 100% RDF through drip followed by 80% RDF through drip during all the three years of experimentation. The maximum net return was calculated with drip irrigation at 0.8 ET_c and 100% RDF through drip (I_3F_3), however it was comparable with treatment combinations of drip irrigation at 0.6 ET_c and 100% RDF (I_2F_3), 0.8 ET_c and 80% RDF (I_3F_2) and 0.6 ET_c and 80% RDF (I_2F_2).



Drip fertigation in onion

Table 15. Effect of irrigation and fertigation levels on bulb yield, water use efficiency and economics of onion (pooled data)

Treatment	Bulb yield (t ha^{-1})				Water use efficiency (kg ha-mm^{-1})	Net return (₹ ha^{-1})	B-C ratio
	2018-19	2019-20	2020-21	Pooled			
Irrigation level (I)							
I_1- Irrigation at 0.4 ETc	55.4	50.1	51.6	52.3	281	100921	2.80
I_2- Irrigation at 0.6 ETc	62.1	56.5	58.7	59.1	218	121175	3.17
I_3- Irrigation at 0.8 ETc	64.4	58.5	61.7	61.5	173	128435	3.30
I_4- Irrigation at 1.0 ETc	59.1	51.5	55.4	55.3	126	109923	2.97
CD (p=0.05)	5.0	5.2	5.1	4.3	-	12826	-
Fertigation level (F)							
F_1- 60% RDF through drip	55.2	49.0	51.7	52.0	192	104940	3.06
F_2- 80% RDF through drip	62.7	56.3	59.2	59.4	220	123782	3.28
F_3- 100% RDF through drip	64.3	58.6	61.3	61.4	227	126334	3.19
F_4- 120% RDF through drip	58.8	52.6	55.3	55.6	205	105399	2.72
CD (p=0.05)	2.8	3.3	2.7	2.9	-	9075	-
Interaction (I×F)							
CD (p=0.05)	6.4	7.2	6.4	5.9	-	17555	-

Note: ET_c, crop evapotranspiration; RDF, recommended dose of fertilizer

3.3. Belavatagi

3.3.1. Nitrogen split application on wheat under different moisture levels through drip in Vertisols

A field experiment on split application of nitrogen in wheat under different moisture levels through drip in vertisols was initiated during 2017-18 and continued up to 2019-20. The pooled data revealed that among moisture levels, I_2-80% cumulative pan evaporation (CPE) recorded higher grain and straw yield of 3.35 and 5.59 t ha^{-1} followed by I_1-60% CPE (2.98 and 5.23 t ha^{-1}) (Table 16). Among the nutrient levels, application of N_5: 20% basal N of N_4 + 5 splits of N recorded significantly higher grain and straw yield of 3.80 and 6.07 t ha^{-1} followed by of N_6: 20% basal N of N_4 + weekly interval of N up to 85 DAS (3.85 and 5.82 t ha^{-1}). Significantly enhanced water use efficiency was noticed in I_1-60% CPE (11.71 kg ha-mm^{-1}) and in treatment N_5 (13.78 kg ha-mm^{-1}), respectively in main and sub treatments. The data also reveals that higher gross and net returns of ₹ 79,199 ha^{-1} and ₹ 53,637 ha^{-1} was recorded in N_5. The benefit-cost ratio was significantly higher in I_2-80% CPE (2.74) among irrigation levels and among the nutrient levels, application of N_5 recorded significantly higher benefit-cost ratio of 3.10. The interaction effect of irrigation levels and nutrient management treatments on different parameters was also varied significantly.

Impact of split application of nitrogen in wheat on chemical properties of post-harvest soil is presented in Table 17. Non-significant differences were observed in pH, EC and soil organic carbon among different treatments. The available N content varied significantly among the irrigation levels and I_1 recorded significantly higher available N content of 221 kg ha^{-1} followed by I_2 (217 kg ha^{-1}) and among the sub treatments, the treatment N_1 recorded significantly higher available N content (230 kg ha^{-1}). The higher amount of available phosphorus and potassium was noticed with 60% CPE (32.3 and 676 kg ha^{-1}), whereas among nutrient management N_3 (34.1 P_2O_5 kg ha^{-1}) and N_1 (719 K_2O kg ha^{-1}) recorded the maximum available phosphorus and potassium, respectively. Among moisture levels, 60% CPE recorded higher amount of zinc, iron, copper and manganese, whereas, N_1 recorded maximum level of micronutrients among various nutrient management practices.

Table 16. Effect of split application of nitrogen on performance of wheat (pooled data)

Treatment	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Water use efficiency (kg ha-mm^{-1})	Net return (₹ ha^{-1})	B-C ratio
Irrigation level (I)					
I_1	2.98	5.23	11.71	36736	2.44
I_2	3.35	5.59	11.32	44417	2.74
CD (p=0.05)	0.88	0.82	0.38	2359	0.09
Fertigation level (F)					
N_1	2.58	4.69	9.40	28386	2.11
N_2	3.22	5.66	11.72	41773	2.63
N_3	2.93	5.28	10.67	35676	2.40
N_4	2.94	4.96	10.69	35787	2.40
N_5	3.80	6.07	13.78	53637	3.10
N_6	3.54	5.82	12.84	48199	2.89
CD (p=0.05)	0.41	1.26	0.24	1462	0.06
Interaction (I×N)					
CD (p=0.05)	0.47	1.45	0.28	1677	0.07

Note: I_1, irrigation at 60% CPE; I_2, irrigation at 80% CPE; N_1, 100% recommended package of practice (RPP) for wheat (100:75:50 N, P_2O_5, K_2O kg ha^{-1} + FYM 7.5 kg ha^{-1}); N_2, 20% basal N of N_1 + 5 splits of N (20% N at 20 DAS + 20% N at 40 DAS + 20% N at 55 DAS + 10% N at 70 DAS + 10% N at 85 DAS); N_3, 20% basal N of N_1 + weekly interval of N upto 85 DAS (9 splits); N_4, 125% RPP for wheat (125:93.75:62.50 N, P_2O_5, K_2O kg ha^{-1} + FYM 7.5 kg ha^{-1}); N_5, 20% basal N of N_4 + 5 splits of N (20% N at 20 DAS + 20% N at 40 DAS + 20% N at 55 DAS + 10% N at 70 DAS + 10% N at 85 DAS); N_6, 20% basal N of N_4 + weekly interval of N upto 85 DAS (9 splits); CPE, cumulative pan evaporation; N, nitrogen, P, phosphorus, K, potassium.

Table 17. Effect of split application of nitrogen on soil nutrient status after harvest of wheat (pooled data)

Treatment	pH	EC (dS m^{-1})	Organic carbon (g kg^{-1})	Available nutrient (kg ha^{-1})			DTPA extractable micronutrients (mg kg^{-1})			
				N	P	K	Zinc	Iron	Copper	Manganese
Irrigation level (I)										
I_1	8.02	0.42	0.78	221	32.3	676	1.32	4.21	1.26	6.77
I_2	8.07	0.43	0.75	217	29.1	650	1.21	3.94	1.18	6.38
CD (p=0.05)	NS	NS	NS	2	0.8	8	0.08	0.10	0.04	0.11
Nutrient management (N)										
N_1	7.92	0.40	0.85	230	32.6	719	1.35	4.25	1.33	6.92
N_2	8.03	0.41	0.74	217	30.5	658	1.25	4.12	1.20	6.58
N_3	8.00	0.40	0.79	229	34.1	691	1.26	4.21	1.29	6.57
N_4	8.10	0.43	0.75	223	30.8	682	1.35	4.10	1.23	6.66
N_5	8.10	0.45	0.76	207	27.1	602	1.14	3.85	1.06	6.29
N_6	8.13	0.45	0.69	209	29.3	626	1.26	3.92	1.20	6.43
CD (p=0.05)	NS	NS	0.15	4	1.6	27	0.06	0.13	0.10	0.20
Interaction (I×N)										
CD (p=0.05)	NS	NS	NS	5	1.9	31	0.07	0.15	NS	0.22

3.4. Kota

3.4.1. Irrigation schedules and fertigation levels in muskmelon–brinjal cropping sequence under drip irrigation

The study was started from summer 2017 with varied levels of drip fertigation in randomized block design replicated thrice. It is evident from pooled data of three years (Table 18) revealed that irrigation schedule at 125% potential evapotranspiration (PET) + 125% RDF (100-75-75 kg N, P_2O_5, K_2O ha^{-1}) through fertigation recorded significantly higher yield (24.4 t ha^{-1}) remained statistically on par with drip fertigation 125% PET + 100% RDF (80:60:60 kg N, P_2O_5, K_2O ha^{-1}) and drip fertigation 100% PET + 125% RDF (100:75:75 kg N, P_2O_5, K_2O ha^{-1}) over rest of the treatments. The yield of brinjal was increased to the tune of 40% over control (surface irrigation at IW/CPE 0.8 + entire NPK as soil application). Drip fertigation at 125% PET saved 40 mm water (7.70%)

as compared to control. On the other hand, drip fertigation at 125% PET + 100% RDF recorded maximum net return (₹155800 ha^{-1}) and benefit-cost ratio (1.94) being statistically on par with drip fertigation at 125% PET + 125% RDF, whereas, maximum benefit-cost ratio was observed under control treatment. The maximum water use efficiency (65.3 kg ha-mm^{-1}) was recorded with drip irrigation at 75% PET + 125% RDF as fertigation and closely followed by drip irrigation at 75% PET + 100% RDF as fertigation (64.2 kg ha-mm^{-1}) and least under control.

Table 18. Effect of irrigation schedule and drip fertigation levels on yield, water use efficiency and economics of brinjal (pooled data)

Treatment	Yield (t ha^{-1})	Water applied (mm)	Water use efficiency (kg ha mm^{-1})	Mean water productivity (kg m^{-3})	Net return (₹ ha^{-1})	B-C ratio
Drip 125% PET+125% RDF as fertigation	24.4	480	50.8	5.08	156662	1.79
Drip 125% PET+100% RDF as fertigation	23.6	480	49.1	4.91	155800	1.94
Drip 125% PET+75% RDF as fertigation	20.9	480	43.5	4.35	135937	1.86
Drip 100% PET+125% RDF as fertigation	22.1	390	56.6	5.66	135562	1.59
Drip 100% PET+100% RDF as fertigation	20.7	390	53.0	5.30	128700	1.64
Drip 100% PET+75% RDF as fertigation	20.1	390	51.6	5.16	129837	1.82
Drip 75% PET+125% RDF as fertigation	19.6	300	65.3	6.53	112462	1.35
Drip 75% PET+100% RDF as fertigation	19.2	300	64.2	6.42	115600	1.51
Drip 75% PET+75% RDF as fertigation	17.7	300	59.1	5.91	107737	1.56
Control (Surface irrigation at IW/CPE 0.8+entire NPK as soil application)	17.4	520	33.4	3.34	117002	2.05
CD (p=0.05)	2.69	-	-	-	9616	0.11

Note: PET, potential evapotranspiration; RDF, recommended dose of fertilizer

3.4.2. Performance evaluation of micro-sprinkler irrigation and fertigation on the productivity of *zaid* groundnut

An experiment was conducted from summer 2017 in randomized block design, replicated thrice, to evaluate the micro-sprinkler irrigation and fertigation on productivity of groundnut. Pooled data of four years (Table 19) revealed that irrigation schedule at 125% potential evapotranspiration (PET) + 100% RDF (30-60-40 kg N, P_2O_5, K_2O ha^{-1}) through fertigation recorded significantly higher pod yield (2.41 t ha^{-1}) and remained statistically on par with irrigation schedule at 125% PET + 50% RDF as soil application + 50% RDF through fertigation (2.30 t ha^{-1}), irrigation schedule at 100% PET + 100% RDF through fertigation (2.10 t ha^{-1}) and irrigation schedule at 100% PET + 50% RDF as soil application + 50% RDF through fertigation (2.07 t ha^{-1}). As compared to control [surface irrigation at IW/CPE 0.8 + entire NPK (30-60-40 kg N, P_2O_5, K_2O ha^{-1}) as soil application], irrigation schedule at 125% PET + 100% RDF increased the yield of groundnut by 34%. However, irrigation schedule at 75% PET + 100% RDF through fertigation recorded maximum water use efficiency (8.49 kg ha mm^{-1}) and water productivity (0.849 kg m^{-3}) and it was closely followed by irrigation schedule at 75% PET + 50% RDF as soil application + 50% RDF through fertigation. In comparison to surface irrigation at IW/CPE 0.8, maximum water saving by 42.5% was recorded under irrigation schedule at 75% PET followed by irrigation schedule at 100% PET (20.0%) and irrigation schedule at 125% PET (2.5%). Irrigation schedule at 125% PET + 50% RDF (15:30:20 kg N,

P_2O_5, K_2O ha^{-1}) as soil application + 50% RDF (15:30:20 kg N, P_2O_5, K_2O ha^{-1}) through fertigation recorded maximum and significantly higher net return (₹68792 ha^{-1}) being at par with irrigation schedule at 125% PET + 100% RDF through fertigation (₹66499 ha^{-1}). Maximum and significantly higher benefit-cost ratio (1.91) was fetched with control treatment and it remained statistically on par with irrigation schedule 75% PET + 100% RDF as soil application and irrigation schedule at 100% PET + 100% RDF as soil application.

Table 19. Effect of irrigation schedule and micro-sprinkler irrigation levels on water use efficiency of *zaid* groundnut (pooled data)

Treatment	Yield (t ha^{-1})	Depth of water applied (mm)	Water use efficiency (kg ha mm^{-1})	Water productivity (kg m^{-3})	Net return (₹ ha^{-1})	B-C ratio
Irrigation at 125% PET+100% RDF as soil application	2.01	390	5.14	0.514	62121	1.58
Irrigation at 125% PET+50% RDF as soil application+50% RDF through fertigation	2.30	390	5.89	0.589	68792	1.46
Irrigation at 125% PET+100% RDF through fertigation	2.41	390	6.19	0.619	66499	1.20
Irrigation at 100% PET+100% RDF as soil application	1.95	320	6.09	0.609	62817	1.76
Irrigation at 100% PET+50% RDF as soil application+50% RDF through fertigation	2.07	320	6.48	0.648	61029	1.40
Irrigation at 100% PET+100% RDF through fertigation	2.10	320	6.57	0.657	54823	1.06
Irrigation at 75% PET+100% RDF as soil application	1.76	230	7.67	0.767	56948	1.78
Irrigation at 75% PET+50% RDF as soil application+50% RDF through fertigation	1.89	230	8.20	0.820	55287	1.38
Irrigation at 75% PET+100% RDF through fertigation	1.95	230	8.49	0.849	50595	1.05
Control (surface irrigation at IW/CPE 0.8+entire NPK (30:60:40) as soil application)	1.80	400	4.50	0.450	59616	1.91
CD (p=0.05)	0.39	-	-	-	3416	0.28

Note: PET, potential evapotranspiration; RDF, recommended dose of fertilizer; NPK, nitrogen phosphorus potassium

3.5. Rahuri

3.5.1. Evaluation of N, P and K fertigation applied alone and in combination for best alternative at varying irrigation levels for suru sugarcane under subsurface drip

A field study was conducted on varied subsurface drip irrigation and fertigation levels in sugarcane crop from 2017. It was observed that, plant height was non-significant due to irrigation levels but was significant due to fertigation levels (Table 20). The maximum plant height was observed in fertigation treatment F_4 which was significantly superior over F_1, F_2 and F_3 treatments, whereas, it was at par with F_5 treatment. The maximum number of internodes was observed in I_4 irrigation treatment (100% crop evapotranspiration-ET_c) and this treatment was significantly superior over all remaining irrigation treatments. The maximum number of internodes was observed in fertigation treatment F_4 and this treatment performed significantly over other treatments. Amongst the irrigation treatments, maximum length of internode was observed in treatment I_1 which was statistically higher over I_3 and was at par with I_2 and I_4. Amongst the fertigation treatments, maximum length of internode was observed in fertigation treatment F_4. Irrigation with 80% ET_c produced maximum intermodal girth of sugarcane, whereas, among fertigation treatments, F_4 performed statistically superior in producing higher girth of internode. The maximum millable cane and yield were observed in irrigation treatment I_4 (100% ET_c) which was significantly superior over all remaining irrigation treatments. Amongst, the fertigation treatments, maximum millable cane and yield were observed in fertigation treatment F_4. The interaction effect of irrigation and fertigation levels on sugarcane yield was significant. The maximum yield was observed in treatment I_4F_4 (136 t ha^{-1}) which was at par with treatment I_3F_4, 80% ET_c and 80% NPK through fertigation (132 t ha^{-1}) and was significantly superior over all remaining treatments. On the other hand, water requirement of sugarcane was noticed highest in 100% ET_c treatment and lowest in 40% ET_c. However, highest water use efficiency was recorded in I_3 (80% ET_c) treatment followed by I_2, I_4 and I_1, whereas, maximum water saving was observed in I_1 (50.18%) followed by I_2 (33.64%) and I_3 (16.80%). From the Table 21, it is clear that different irrigation and fertigation treatment had not any significant impact on properties of post-harvest soil. The gross monetary returns were maximum in treatment I_3F_4 i.e. 80% ET_c and 80% NPK through weekly fertigation followed by treatments I_3F_5 and I_4F_4 (Table 22). The cost of cultivation was highest under treatment I_1F_2 [40% ET_c, N and P through weekly fertigation (30 splits) with K applied as basal] while lowest was observed in control treatments. The net monetary returns were highest under the treatment I_3F_4 (₹ 214637 ha^{-1}) while lowest was under control treatment. The maximum benefit-cost ratio of 2.18 was observed in treatment I_4F_4 followed by treatments I_4F_3 and I_3F_4.

Table 20. Effect of drip irrigation with varied fertigation level on plant growth, yield and water use efficiency of sugarcane (pooled data)

Treatment	Plant height (m)	No. of inter-nodes	Inter-node length (cm)	Girth of inter-nodes (cm)	Millable canes (nos.)	Yield (t ha^{-1})	WUE (kg $ha\text{-}cm^{-1}$)	Water saving over surface irrigation (%)
Drip irrigation schedule								
I_1: 40% ET_c	2.68	22.1	13.7	5.54	6.71	59.6	901	50.2
I_2: 60% ET_c	2.50	23.0	13.4	5.55	6.79	90.1	1023	33.6
I_3: 80% ET_c	2.59	23.6	12.4	5.95	7.35	117.7	1066	16.8
I_4: 100% ET_c	2.44	25.0	13.3	5.73	7.92	130.7	985	-
CD (p=0.05)	NS	1.2	0.7	0.28	0.51	2.4	-	-
Fertigation schedule								
F_1	2.45	22.7	12.6	5.69	6.41	92.6	931	25.2
F_2	2.49	23.6	13.5	5.63	6.48	97.1	977	25.2
F_3	2.45	22.8	13.1	5.49	7.32	98.6	992	25.2
F_4	2.75	24.7	13.9	5.96	7.94	107.9	1086	25.2
F_5	2.64	23.4	12.8	5.70	7.81	101.5	1021	25.2
CD (p=0.05)	0.18	0.8	0.6	0.24	0.56	1.9	526	-
F_6	2.27	22.4	6.9	4.01	5.67	82.2	-	-
F_7	2.22	21.7	6.2	3.85	4.33	69.3	-	-

Note: F_1, 80% N thorough weekly fertigation (30 splits) with P and K applied as basal; F_2, 80% N and P through weekly fertigation (30 splits) with K applied as basal; F_3, 80% N and K through weekly fertigation (30 splits) with P applied as basal; F_4, 80% NPK through weekly fertigation (30 splits) with no basal application; F_5, 80% NPK through fertigation (26 splits) with application of basal dose; F_6, RDF as band placement + surface; F_7, no fertilizer (control); ET_c, crop evapotranspiration; RDF, recommended dose of fertilizer.

Table 21. Effect of drip irrigation with varied fertigation level on chemical properties of post-harvest soil (pooled data)

Treatment	pH	EC (dS m^{-1})	Organic carbon (%)	Available nutrient (kg ha^{-1})		
				Nitrogen	Phosphorus	Potassium
Drip irrigation						
I_1: 40% ET_c	8.39	0.43	0.68	182	18.49	538
I_2: 60% ET_c	8.35	0.44	0.70	179	19.56	533
I_3: 80% ET_c	8.35	0.45	0.69	177	19.69	531
I_4: 100% ET_c	8.31	0.44	0.70	173	20.11	530
CD (p=0.05)	NS	NS	NS	NS	NS	NS
Fertigation						
F_1	8.36	0.44	0.70	177	19.52	535
F_2	8.35	0.43	0.70	177	19.69	534
F_3	8.35	0.43	0.69	176	19.39	531
F_4	8.35	0.44	0.69	178	19.52	532
F_5	8.33	0.45	0.68	181	19.19	533
CD (p=0.05)	NS	NS	NS	NS	NS	NS
F_6	8.39	0.45	0.70	180	18.72	541
F_7	8.31	0.41	0.61	163	16.18	493
Interaction	NS	NS	NS	NS	NS	NS

Note: NS, non-significant

Table 22. Effect of drip irrigation with varied fertigation level on economics of sugarcane (pooled data)

Treatment	Economics (₹ ha^{-1})			
	Cost of cultivation	Gross return	Net return	B-C ratio
I_1F_1	329791	317827	-11964	0.96
I_1F_2	333368	333394	25	0.99
I_1F_3	328061	338389	10329	1.03
I_1F_4	332507	391767	59261	1.17
I_1F_5	332507	348025	15518	1.04
I_2F_1	239114	363270	124157	1.52
I_2F_2	242318	361963	119645	1.49
I_2F_3	238493	350936	112442	1.47
I_2F_4	241697	382722	141025	1.58
I_2F_5	241697	376291	134594	1.56
I_3F_1	188273	324207	135934	1.72
I_3F_2	190775	348607	157832	1.83
I_3F_3	187789	372273	184484	1.98
I_3F_4	190290	404927	214637	2.13
I_3F_5	190290	373154	182864	1.96
I_4F_1	155865	330821	174956	2.12
I_4F_2	157920	335339	177420	2.13
I_4F_3	155467	335597	180130	2.16
I_4F_4	157522	343410	185888	2.18
I_4F_5	157522	312905	155383	1.99
RDF (Band placement+ surface irrigation)	154535	227034	72499	1.47
No fertilizer	138849	166308	27459	1.20

3.6. Junagadh

3.6.1. Cotton crop response to drip fertigation

The experiment was undertaken at JAU farm, Junagadh having calcareous medium black soil falling in textural class of clay on drip fertigation in cotton. The experiment was started during 2018-19 and continued for three years in randomized block design, replicated thrice. The effects of fertigation treatments on numbers of bolls per plant were found significant during both the years (Table 23). However, it was found insignificant in pool analysis. The highest numbers of bolls per plant was found in T_4. Significantly highest seed cotton yield and lint yield were recorded as 2.68 and 1.08 t ha^{-1}, respectively under treatment T_4 having 25% NPK as basal and remaining NPK through fertigation. The effective rainwater, irrigation water and total water were found as 288, 344 and 632 mm, respectively. The lowest water footprint of seed cotton yield was 2357 L kg^{-1}, among which green and blue water footprint were 1074 L kg^{-1} and 1283 L kg^{-1}, respectively under the treatment T_4; while the highest water footprint was found as 3337 L kg^{-1} under control (no fertilizer). The highest water and fertilizer use efficiency of 4.24 kg ha-mm^{-1} and 6.09 kg ha-kg^{-1}, respectively were found in T_4. The highest net return from the cotton cultivation was found as ₹77182 ha^{-1} under treatment T_4 and lowest of ₹ 46809 ha^{-1} under T_{10} having no fertilizer inputs at all. The highest benefit-cost ratio of the cotton cultivation was found as 1.93 under treatment T_4.


View of the field experiment on cotton drip fertigation

Table 23. Effect of fertigation treatment on growth, yield, input use efficiency and economics of cotton (pooled data)

Treatment	No. of bolls plant^{-1}	Seed cotton yield (t ha^{-1})	Lint yield (t ha^{-1})	Total WP (L kg^{-1})	WUE (kg ha-mm^{-1})	FUE (kg ha^{-1} kg^{-1})	NR (₹ ha^{-1})	B-C ratio
T_1: 100% N fertigation, 100% PK basal	35.6	2.33	0.94	2712	3.69	5.30	60969	1.77
T_2: 100% NK fertigation, 100% P basal	36.3	2.40	0.97	2633	3.80	5.46	64361	1.81
T_3: 100% NPK fertigation	43.0	2.18	0.87	2895	3.45	4.96	48006	1.58
T_4: 25% NPK basal, 75% NPK fertigation	46.6	2.68	1.08	2357	4.24	6.09	77162	1.93
T_5: 75% N fertigation, 75% PK basal	33.4	2.21	0.89	2858	3.50	6.70	56718	1.75
T_6: 75% NK fertigation, 75% P basal	39.1	2.20	0.86	2869	3.49	6.68	56268	1.74
T_7: 75% NPK fertigation	35.8	2.14	0.86	2952	3.39	6.49	49473	1.62
T_8: 18.75% NPK basal, 56.25% NPK fertigation	36.7	2.20	0.88	2874	3.48	6.66	53732	1.69
T_9: 100% NPK conventional fertilizers	42.0	2.23	0.89	2829	3.54	5.08	55655	1.71
T_{10}: No fertilizer	33.3	1.89	0.74	3337	3.00	-	46809	1.69
CD (p=0.05)	NS	0.22	0.076	-	-	-	-	-

Note: N, nitrogen; P, phosphorus; K, potassium; WP, water productivity, WUE, water use efficiency, FUE, fertilizer use efficiency; NR, net return; NS, non-significant

3.7. Bathinda (Ludhiana)

3.7.1. Growth and yield response of *Bt* cotton in rotation with summer squash to water quality and fertigation levels under drip system

A field experiment was conducted in split plot design on different fertigation level (main factor) and irrigation water quality (sub factor) in cotton and summer squash crop rotation. The effect of irrigation water quality and fertigation levels on different growth and water use parameters for summer squash is given in Table 24. The data shows that summer squash yields were significantly different among water quality treatments. On an average, the observed summer squash yield was 6.83 t ha^{-1} with canal water followed by 4.36 t ha^{-1} with alternate irrigation of canal and tubewell water and 2.33 t ha^{-1} with poor quality tubewell water alone. Among different fertigation schedules, summer squash yields for fertigation level of 80% and 100% recommended dose of nitrogen were at par but significantly higher than fertigation level of 60% recommended dose of nitrogen.

The effect of irrigation water quality and fertigation levels on different growth parameters of cotton during *kharif* season 2020 are presented in Table 25. Among different fertigation levels, the seed cotton yields were at par when 80 and 100% of recommended dose of nitrogen was applied and were significantly higher than application of 60% recommended dose of nitrogen.

The seed cotton yield when irrigating with tubewell water alone was significantly lower than other water quality treatments. Canal water alone and alternate of canal and tubewell water treatments produced statistically equivalent seed cotton yield. Similar trends were observed in other growth parameters i.e. number of bolls per plant and number of sympods per plant.

Table 24. Irrigation water applied, profile water use, water use, yield and yield attributing parameters of summer squash under different fertigation levels and irrigation water qualities

Treatment	Total water use (cm)	Vine length (cm)	No. of fruits/ plant (no.)	Yield (t ha^{-1})	WUE (kg ha-mm^{-1})
60% recommended dose of nitrogen					
CW	29.30	31.8	6.31	6.10	20.7
CW_g - TW	29.56	16.6	1.85	1.80	6.1
CW/TW	29.30	23.0	3.30	3.60	12.4
Average	29.39	23.8	3.82	3.83	13.1
80% recommended dose of nitrogen					
CW	30.61	35.2	6.91	6.90	22.6
CW_g - TW	29.54	17.5	2.18	2.60	8.8
CW/TW	27.94	24.3	3.99	4.70	16.7
Average	29.36	25.7	4.36	4.73	16.0
100% recommended dose of nitrogen					
CW	28.67	35.9	7.28	7.50	26.0
CW_g - TW	27.82	19.6	2.38	2.50	9.1
CW/TW	27.72	24.8	4.48	4.80	17.2
Average	28.07	26.8	4.71	4.93	17.4
Overall average					
CW	-	34.3	6.84	6.83	-
CW_g - TW	-	17.9	2.14	2.33	-
CW/TW	-	24.0	3.93	4.36	-
CD for fertigation level (p=0.05)	-	NS	0.52	0.62	-
CD for water quality (p=0.05)	-	3.0	0.49	0.45	-
Interaction	-	NS	NS	NS	-

Note: CW, irrigation with canal water; CW_g–TW, irrigation with canal water till germination and subsequent irrigations with poor quality tubewell water; CW/TW, alternate irrigation with canal water and tubewell water; NS, non-significant; WUE, water use efficiency. Irrigation water applied to each treatment = 182 mm.

Table 25. Performance of *Bt* cotton under different fertigation level and irrigation water quality

Treatment	Plant height (cm)	No. of bolls/plant (no.)	No. of sympods/ plant (no.)	Total water use (mm)	Yield (t ha^{-1})	WUE (kg ha-mm^{-1})
60% recommended dose of nitrogen						
CW	173.2	55.9	33.0	676	3.60	5.3
CW_g -TW	170.7	46.3	25.2	661	2.90	4.4
CW/TW	172.3	53.8	30.1	672	3.30	4.9
Mean	172.1	52.0	29.4	670	3.27	4.9
80% recommended dose of nitrogen						
CW	172.9	62.0	37.1	658	3.90	5.9
CW_g - TW	171.5	52.8	30.5	694	3.40	4.9
CW/TW	172.7	60.8	35.6	680	3.90	5.7
Mean	172.4	58.5	34.4	677	3.73	5.5
100% recommended dose of nitrogen						
CW	175.4	67.6	39.4	660	4.20	6.4
CW_g - TW	171.8	58.3	34.0	678	3.70	5.4
CW/TW	173.5	62.6	36.1	675	4.00	5.9
Mean	173.6	62.8	36.5	671	3.97	5.9
Overall average						
CW	173.9	61.8	36.5	-	3.91	-
CW_g - TW	171.4	52.4	29.9	-	3.34	-
CW/TW	172.8	59.1	33.9	-	3.74	-
CD for fertigation level (p=0.05)	NS	5.8	3.4	-	0.41	-
CD for water quality (p=0.05)	NS	4.4	3.1	-	0.29	-
Interaction	NS	NS	NS	-	NS	-

Note: CW, irrigation with canal water; CW_g-TW, irrigation with canal water till germination and subsequent irrigations with poor quality tubewell water; CW/TW, alternate application of canal water and tubewell water; RDN, recommended dose of nitrogen; NS, non-significant; WUE, water use efficiency. Irrigation water applied to each treatment = 282 mm.

Drip fertigation in summer squash

Drip fertigation in *Bt* cotton

3.8. Udaipur

3.8.1. Effective water management under automated drip irrigation for okra

The experiment on automated drip irrigation in okra was conducted at plasticulture farm, CTAE campus, MPUAT Udaipur, the area is characterized by sub humid climate with an average annual rainfall of 637 mm. The experiment was conducted in randomized block design with four replications. The poolled data analysis revealed that the plant height at 90 DAS was recorded maximum in treatment T_3 followed by treatments T_1 and minimum plant height was recorded in treatment T_6, in which fertigation takes place as per farmer practice under flood irrigation (Table 26). The average weight and length of okra fruit were found highest in treatment T_3 (100% FC, based on soil moisture sensor under automated drip irrigation with 100% RDF through fertigation in equal splits at 4-day interval) with values of 12.37 g and 16.2 cm respectively followed by treatment T_1 with values of 10.25 g and 14.1 cm, respectively. While the results obtained from treatment T_4 (in which irrigation scheduling based on 80% of daily pan evaporation data under automated drip irrigation system) on par with result obtained from treatment T_1 which indicate good results for adoption of deficit pan evaporation based irrigation scheduling under drip irrigation. Maximum crop water requirement was recorded under conventional / flood irrigation. The crop yield and water use efficiency were also recorded highest under treatment T_3 with values of 9.8 t ha^{-1} and 0.215 t ha-cm^{-1}, respectively. The maximum net seasonal income, gross seasonal income and benefit-cost ratio was found for treatment T_3 and lowest for treatment T_6.

Table 26. Irrigation water applied, profile water use, water use, yield and yield attributes of summer squash under different fertigation levels and irrigation water qualities

Treatment	Plant height at 90 DAS (cm)	Average weight of fruit (g)	Average length of fruit (cm)	Total irrigation water applied (mm)	Crop water requirement (mm)	Water saving over T_6 (%)	Crop yield (t ha^{-1})	Water use efficiency (t ha-cm^{-1})
T_1	78.3	10.25	14.1	428.5	457.3	54.87	8.05	0.177
T_2	69.97	9.85	13.0	553.0	581.8	42.56	6.35	0.109
T_3	91.57	12.35	16.2	428.5	457.3	54.87	9.8	0.215
T_4	67.92	10	13.5	553.0	581.8	42.56	5.85	0.100
T_5	67.27	9.8	10.8	691.5	720.3	28.89	6.45	0.090
T_6	64.02	9	11.2	983.5	1012.3	-	4.6	0.045
CD (p=0.05)	2.695	1.8	1.7	-	-	-	1.2	-

Note: T_1, 100% field capacity (FC) based on soil moisture sensor under automated drip irrigation (ADI) with 100% recommended dose of fertilizer (RDF) through fertigation in equal splits at 2-day interval; T_2, 80% volume of crop water requirement based on pan evaporation (PE) under ADI with 100% RDF through fertigation in equal splits at 2-day interval; T_3, 100% FC based on soil moisture sensor under ADI with 100% RDF through fertigation in equal splits at 4-day interval; T_4, 80% volume of crop water requirement based on PE under ADI with 100% RDF through fertigation in equal splits at 4-day interval; T_5, 100% FC based on soil moisture sensor under ADI with 100% RDF through farmers' practice; T_6, 100% volume of crop water requirement based on PE under conventional (manual) drip irrigation with 100% RDF through fertigation in equal splits at 6-day interval; DAS, days after sowing; RDF 60-30-30 kg N, P_2O_5, K_2O ha^{-1}.

Automated drip fertigation in okra

Chapter 4

Groundwater and Rainwater Management

4.1. Ludhiana

4.1.1. Simulation of groundwater recharge in rice field

The study was carried out to estimate water balance components through field experiment and to simulate potential groundwater recharge in transplanted and direct seeded rice using HYDRUS-1D model. The various soil water balance components viz., potential crop evapotranspiration, irrigation, rainfall, runoff and soil moisture change were estimated to assess deep percolation component, which represents potential groundwater recharge in water balance equation.

During the experimentation, number of irrigations applied was 24 for transplanted rice (TPR) and 22 for direct seeded rice (DSR) which accumulates to total irrigation water of 1200 and 1100 mm to TPR and DSR, respectively. In case of DSR, irrigation was stopped 30 days prior to harvesting. As a result, cumulative irrigation water applied to DSR was less in comparison to TPR. Surface runoff estimated using curve number method during the entire crop season was 416 and 152.9 mm in TPR and DSR, respectively. Surface runoff in case of TPR was more because of development of hard pan after puddling of the rice field. Potential crop evapotranspiration (PET) estimated using FAO Penman Monteith equation was 545 mm with highest value of 7.76 mm on 45 days after transplanting (DAT) with an average of 4.91 mm per day for crop duration of 111 days in TPR (Figure 7). PET was 539 mm with highest value of 7.28 mm on 67 DAS with an average of 4.14 mm per day for crop duration of 130 days in DSR (Figure 8). Potential soil evaporation (E_p) and potential transpiration (T_p) in TPR was estimated to be 307 and 238 mm, respectively. E_p and T_p in case of DSR was 327 and 211 mm, respectively.

Difference between the initial (transplanting for TPR and sowing for DSR) and final soil moisture content at harvesting was 64.9 and 62 mm for TPR and DSR, respectively. Soil moisture change was more in case of TPR because the initial soil moisture content was at saturation compared to DSR in which the initial soil moisture content was at field capacity. Deep percolation estimated using water balance equation was 1139 and 1305.6 mm in TPR and DSR, respectively (Table 27). There was 14.6% more deep percolation in case of DSR compared to TPR due to higher infiltration rate in non-puddled soil. Total measured water input (including irrigation water applied and rainfall) for TPR and DSR was 2035.5 and 1935.5 mm, respectively. Water output included PET, surface runoff, soil moisture change and deep percolation. PET accounted for 26.77 and 27.85% of the total water output for TPR and DSR, respectively. Surface runoff accounted for 20.43 and 7.89% and deep percolation accounted for 55.95 and 67.45% of the total water output in TPR and DSR, respectively.

Table 27. Water balance components in transplanted and direct seeded rice

Treatment	Water input		Water output			
	Rainfall (mm)	Irrigation (mm)	Potential crop evapotranspiration (mm)	Surface runoff (mm)	Soil moisture change (mm)	Deep percolation (mm)
Transplanted rice (TPR)	835.5	1200	545	416	64.9	1139
Direct seeded rice (DSR)	835.5	1100	539	152.9	62	1305.6

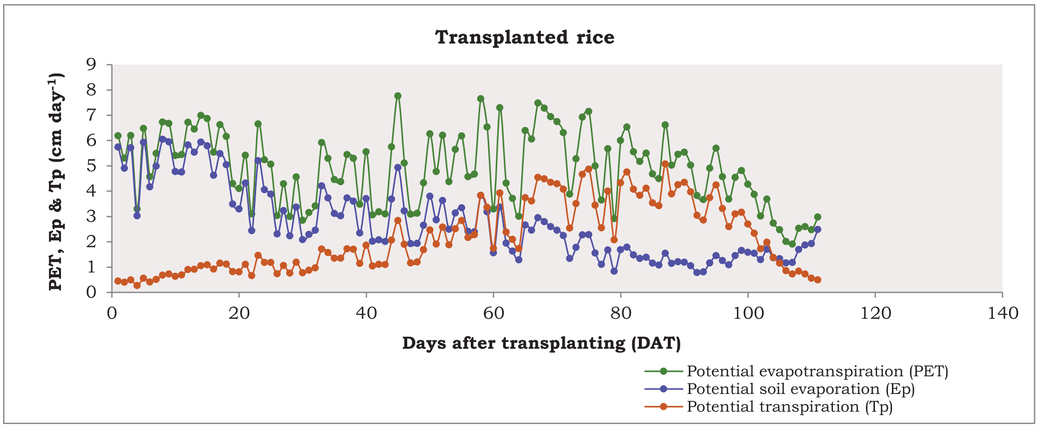


Figure 7. Potential soil evaporation (E_p), potential transpiration (T_p) and potential crop evapotranspiration (PET) in transplanted rice

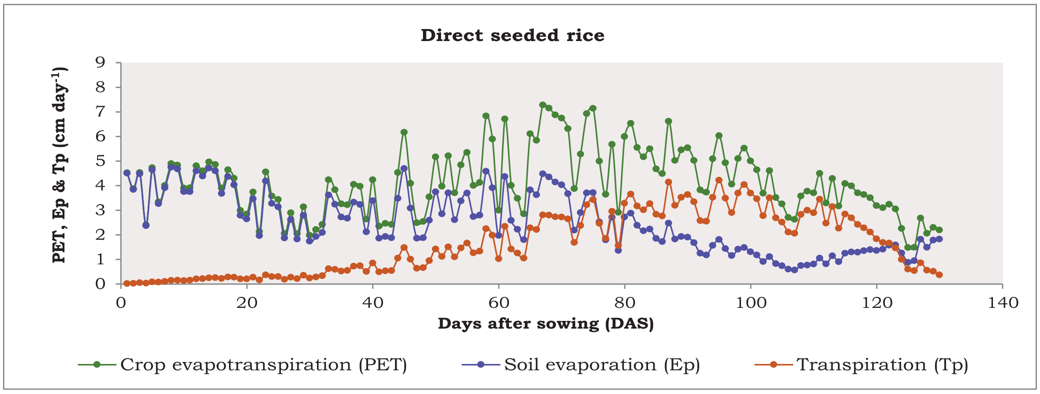


Figure 8. Potential soil evaporation (E_p), potential transpiration (T_p) and potential crop evapotranspiration (PET) in direct seeded rice

4.2. Pantnagar

4.2.1. Rejuvenation and management of natural springs in hilly region of Uttarakhand

Though there are more than 900 springs in the state, most of them have been dried-up because of increase in built-up area, shrinking recharge area and changing rainfall pattern. Though the total rainfall in the state is more or less constant, the intensity has increased and the duration of the event has reduced resulting in surface runoff instead of recharge. The altitude of these springs varied from 222 m to about 2600 m above mean sea level (MSL). The springs have been mapped and shown in Figure 9.

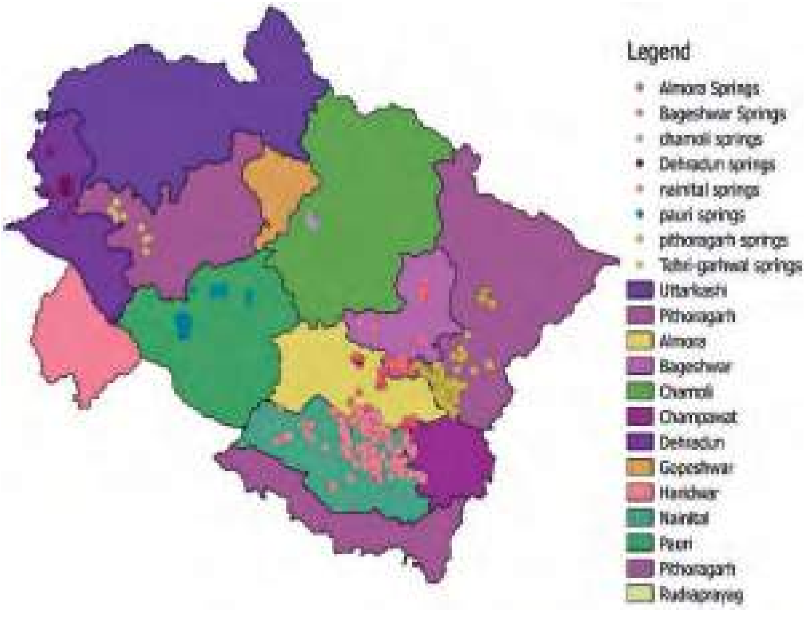


Figure 9. Location of natural springs in Uttarakhand

The study was conducted in the Pithoragarh district of the Uttarakhand state. Pithoragarh is eastern-most district of the state and located in Himalayas. The city of Pithoragarh is located in Saur Valley within the Kumaun division of Uttarakhand at a height of 1645 m above MSL. The district lies between latitude of 29.4°N to 30.3°N and longitude of 80°E to 81°E. The district is surrounded by Almora, Champawat, Bageshwar and Chamoli districts of Uttarakhand and extends over an area of 7217.7 km^2. The geological map of the Uttarakhand was downloaded from Geological Survey of India website as shown in Figure 10. The figure shows that the following three groups of geological formation are present in Pithoragarh.

i) Berinag formation: The Berinag formation constituting the topmost horizon of the inner sedimentary belt has been found surrounding the crystalline masses of the Almora unit. The rock types consist of fine to coarse grained massive quartzite, often sericitic and schistose, with pebble beds, chlorite beds, and interbedded metabasites. Rock formations constituting the inner sedimentary belt have been tightly folded into a few E-W to ESE-WNW trending folds. At places there is strong evidence of thrusting and dislocation by a number of faults.

ii) Pithoragarh formation: The Pithoragarh formation, overlying the Rameshwar formation include stromatolite bearing dolomitic limestone with magnesite, talc, chert, pebble beds with some slate and calcareous slates. Three rock units constitute the Pithoragarh formation namely thalkedar limestone, sor slates and massive Gangolihat dolomites.

iii) Almora crystalline group: The Almora crystalline zone is ENE-WSW trending zone of metamorphic rocks. The southern sedimentary belt which occurs south of the Almora crystalline, is known as the outer sedimentary belt. The northern sedimentary belt occurring north of the Almora crystalline is the inner sedimentary belt, referred to as the Deoban-Tejam zone or the Jaunsar-BerinagNappe.

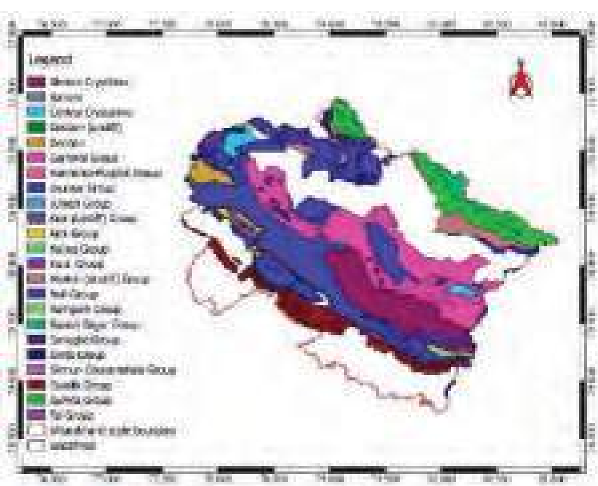


Figure 10. Geological map of Uttarakhand

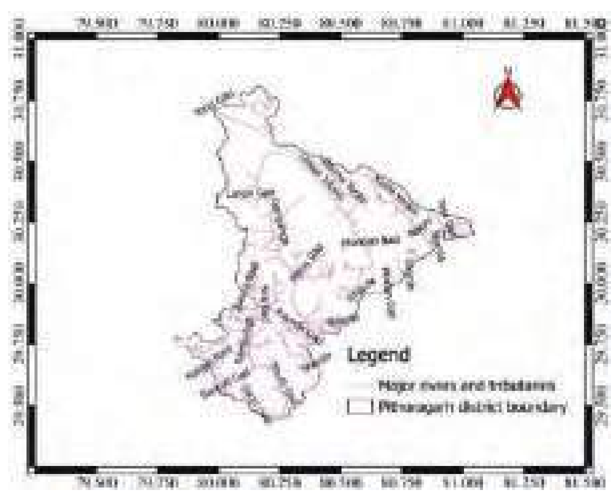


Figure 11. Drainage map of Pithoragarh district

The district is drained by Saryu, Kali Ganga, Ramganga, Gori Ganga, Dhauli Ganga and their tributaries. Prominent tributaries are Mandakini river, Simkhola river, and many *naulas* in uphill direction of rivers. The main drainage patterns are dendritic, sub- dendritic, trellis, sub-rectangular and rectangular. The major rivers i.e. Saryu, Kali Ganga, Ramganga, Gori Ganga, Dhauli Ganga are of antecedent type, whereas the drainage in the structurally disturbed area is of subsequent type. The Pithoragarh district is drained by three major rivers namely the Saryu on the south-western boundary, Gauri Ganga and Ramganga (E) in the middle and Sharda/Kali on the eastern boundary and their tributaries as shown in the Figure 11.

4.3. Udaipur

4.3.1. Design and evaluation of groundwater recharge structure in hard rock areas

Design and evaluation of artificial groundwater recharge structure in hard rock areas of Jhadol block of Udaipur district was carried out. The geomorphological characteristics was determined and various thematic maps like geomorphology, slope, soil, topographic elevation, pre and post monsoon water table, transmissivity etc. were prepared. Further, different thematic maps, pH, electrical conductivity, total dissolved solids maps etc. were also prepared for the Kakan watershed. Groundwater recharge for nineteen sites was estimated by using water table fluctuation method. The minimum computed recharge is 1.148 cm year^{-1} and the maximum value is 12.754 cm year^{-1}. Average value of groundwater recharge for the study area is found to be 6.15 cm year^{-1}. The point estimates of the groundwater recharge were used to prepare a point map of the groundwater recharge for Kakan watershed by using Arc-GIS 10.8 software. Furthermore, this point map was interpolated by using inverse distance weighted technique to generate a raster map of groundwater recharge. This raster map was used as one of the thematic layers for delineating groundwater potential zones and recharge zones for the Kakan watershed as discussed ahead.

Groundwater potential zoning: The eight thematic maps namely hydrogeomorphology, net groundwater recharge, land use/land cover, soil, slope, post-monsoon groundwater depth, transmissivity and topographic elevation were considered for identifying groundwater potential zones in the study area. The groundwater potential map of Kakan watershed as shown in Figure 12 reveals three distinct zones (categories) representing 'good', 'moderate' and 'poor' groundwater potential in the area. The area covered by 'good' groundwater potential zone is about 14.14 km^2 which is 29.8% of total study area. The maximum area has moderate groundwater potential which is about 51.7% (24.52 km^2) of total study area. However, the groundwater potential along east and north-west boundaries of the study area is poor. It covers an area of 8.78 km^2 which is around 18.5% of the total area. This is due to presence of rock outcrops and steep sloping hillocks surrounding the study area. The various classes of groundwater potential zones along with corresponding area are shown in Table 28.

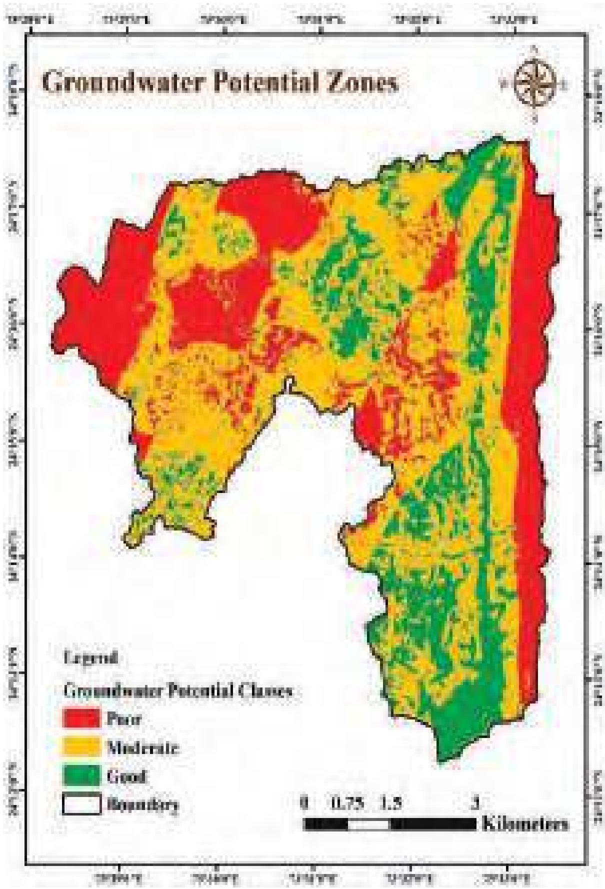


Figure 12. Groundwater potential zones of Kakan watershed

The favourable artificial groundwater recharge zone for the study area was delineated using RS and GIS technique. In this map, light green colour indicates the favourable zone for artificial recharge. For artificial recharge, suitable recharge structures such as percolation tanks, dry stone masonry pond are recommended for construction. The area, which is favorable for artificial recharge is 8.57 km^2, which contributes only 18.06% of the total study area. Map of the suitable zones for artificial recharge of the study area is shown in Figure 13.

Table 28. Groundwater potential zone classes and area under each class

Class	Area (km²)	Area (%)
Poor	14.14	29.8
Moderate	24.52	51.7
Good	8.78	18.5

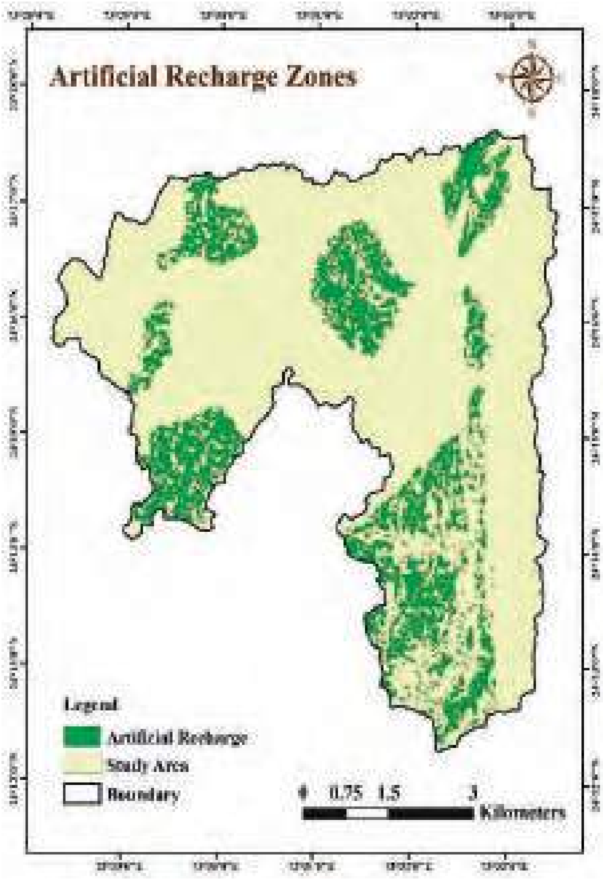


Figure 13. Favorable artificial groundwater recharge zones of Kakan watershed

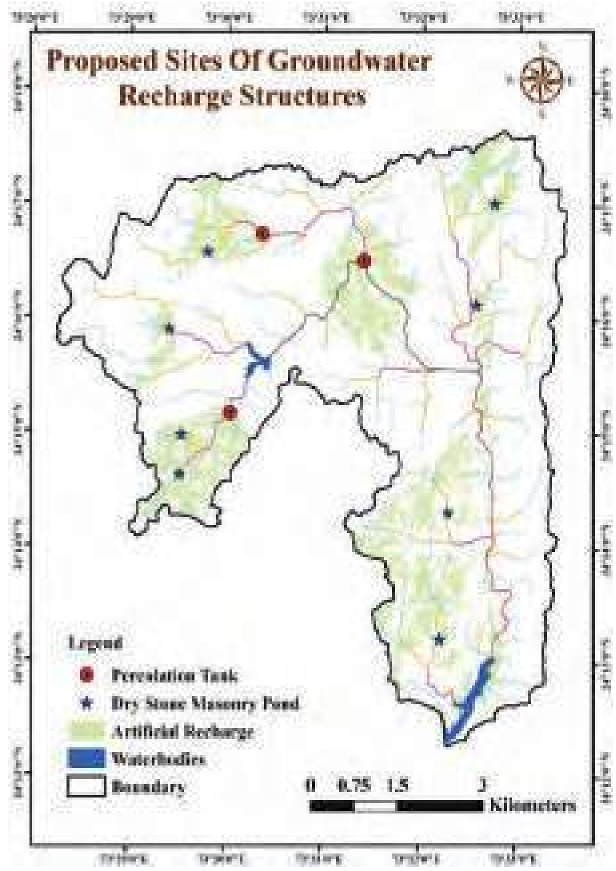


Figure 14. Proposed sites for groundwater recharge structures

Proposed sites for appropriate groundwater recharge structures: Based on the Central Ground Water Board guidelines, the location of suitable sites for groundwater recharge structures were suggested by considering slope, drainage map and artificial recharge zone map of the Kakan watershed. The groundwater recharge structures which are suitable for the study area are embankment type percolation tanks and dry stone masonry pond. Three percolation tanks were found suitable in second and third order stream where the slope ranges between 3 to 5% in coarse loamy and fine loamy type of soil in agricultural land or shrub land where the soil has medium to high infiltration rate. Eight dry stone masonry ponds are proposed in scrubland and agricultural land up to third order stream with a slope range between 5 to 10% in soils with medium infiltration rate. The proposed location of groundwater recharge structures such as dry-stone masonry pond and percolation tanks are shown in Figure 14.

The economic analysis showed that the net profit of three proposed percolation tanks was computed to be about ₹4,85,656, whereas net profit of eight proposed dry-stone masonry ponds was computed to be ₹5,70,372. Benefit-cost ratio of proposed percolation tanks and dry-stone masonry ponds were found to be 1.77 and 2.54, respectively and hence both percolation tanks and dry-stone masonry ponds are economically feasible for the hard rock region of Kakan watershed.

4.4. Jammu

4.4.1. Evaluation of *in-situ* water harvesting methods for improving crop water productivity of maize under sub-tropical area of Jammu

A study is being conducted to enhance water productivity of maize grown in sub-tropical rainfed (*kandi* areas) ecosystem of Jammu province through rainwater conservation. The *kandi* areas of Jammu have undulating topography and low water retentive soils. The *kandi* belt confronts major land and water management problems which trigger low agricultural productivity in general and maize productivity in particular. Due to inadequate and uneven distribution of rainfall during the growth span of maize crop, it is imperative to adopt *in situ* soil moisture conservation measures to mitigate the effects of dry spells in *kharif* sesaon. Also, there is need for safe disposal of excess water caused by heavy storms or incessant rains to protect soil erosion as well as crop.

The experiment was conducted with five water conservation methods viz., flat planting (T_1), ridge and furrow planting (T_2), tied ridge (T_3), T_2 + straw mulch (T_4) and T_3 + straw mulch (T_5), and two nitrogen levels viz., recommended dose of nitrogen (N_1) and 50% of recommended dose of nitrogen (N_2) to grow hybrid maize (var. Star-9) in *kharif* 2020. Rainfall received during the crop growth period was 705 mm, whereas effective rainfall was 560 mm. It may be noted that tied ridging is a potential method for *in situ* water harvesting. Ties are usually 0.50 to 0.65 times the height of the ridges and are constructed across the furrows at intervals of 1.0 to 1.5 m to reduce the possibility of runoff. As a result, water will flow only along the furrow even if the depth of water in the furrow exceeds the height of the ties. In this experiment, tied ridge was laid out at one metre interval. Height of a tied ridge was half of the ridge height.

Experimental results showed that rainfed maize grown under treatment T_5 i.e. tied ridge along with straw mulch had significantly higher yield of 2.22 t ha^{-1} that was at par with yield (2.19 t ha^{-1}) under T_3 i.e. tied ridge (Table 29). There was 15.2% yield improvement with tied ridge + straw mulch (T_5) over ridge and furrow + straw mulch (T_2) treatment. The latter method is being traditionally followed by maize farmers of the region. Rainwater productivity was also highest (3.96 kg ha-mm^{-1}) under T_5. Benefit-cost ratio obtained with tied ridge + straw mulch was 1.45. Effect of nitrogen levels showed that application of recommended dose of nitrogen (N_1) resulted in higher yield (1.97 t ha^{-1}) over the use of 50% of recommended dose of nitrogen (N_2), although there was no significant difference in yields.

Table 29. Performance of maize under water conservation methods and nitrogen levels

Treatment	Maize grain yield (t ha^{-1})	Rainwater productivity (kg ha-mm^{-1})
Water conservation method (T)		
T_1: Flat planting	1.52	2.71
T_2: Ridge and furrow	1.91	3.40
T_3: Tied ridge	2.19	3.92
T_4: T_2 + straw mulch	1.93	3.44
T_5: T_3 + straw mulch	2.22	3.96
CD (p=0.05)	0.04	-
Nitrogen level (N)		
N_1: RDN	1.97	3.50
N_2: 50% of RDN	1.95	3.47
CD (p=0.05)	0.02	-
T × N	NS	-

Note: RDN, recommended dose of nitrogen; NS, non-significant

Chapter 5

Irrigation Scheduling of Crops

5.1. Sriganganagar

5.1.1. Crop yield responses to deficit irrigation in cotton

Cotton crop is grown as a part of summer squash-fallow-cotton cropping sequence in the irrigated areas of North West Plain Zone of Rajasthan. A study was conducted to find an optimal water use plan for cotton that is the main *kharif* crop in the region. Five irrigation scheduling treatments (Table 30) and three treatments on depth of irrigation (50, 60 and 70 mm) were studied for cotton variety RCH-776 BG II. Three years of experimentation (2018 to 2020) showed that maximum seed cotton yield (2.78 t ha^{-1}) was obtained with the application of four irrigations at 35 DAS, square formation, boll initiation and boll development stages which was statistically at par with the application of three irrigations at 35 DAS, square formation and boll development stages (2.76 t ha^{-1}) or at 35 DAS, boll initiation & boll development stages (2.76 t ha^{-1}) and significantly higher over application of two irrigations (2.52 and 2.50 t ha^{-1}). Similarly with increasing depth of irrigation from 50 to 60 mm increased the seed cotton yield significantly, however further increase in depth of irrigation did not affect the production of seed cotton. The interaction effect of irrigation and depth of irrigation was also found significant. Maximum seed cotton yield was recorded when the crop was irrigated four times (I_5) with 60 mm as depth of irrigation, however it was at par with the application of three irrigations (I_3) with 60 cm depth of water. It was recommended to apply three irrigations to cotton crop either at 35 DAS, square formation and boll development stages or at 35 DAS, boll initiation and boll development stages with 60 mm depth of irrigation in order to obtain similar seed cotton yield and 10% irrigation water saving compared to four irrigations.

Table 30. Response of different treatments on seed cotton yield and water use efficiency

Treatment	Cotton yield (t ha^{-1})	Irrigation water applied (mm)	Total water use (mm)	WUE (kg ha-mm^{-1})
Irrigation schedule				
I_1	2.52	203.33	477	5.01
I_2	2.50	203.33	477	5.03
I_3	2.76	263.33	537	4.96
I_4	2.76	263.33	537	4.98
I_5	2.78	323.33	597	4.50
CD at 5%	0.13	-	-	-
Depth of irrigation				
D_1: 50 mm	2.52	223.33	497	4.86
D_2: 60 mm	2.79	251.33	525	5.12
D_3: 70 mm	2.68	279.33	553	4.67
CD at 5%	0.10	-	-	-

Note: I_1, two irrigations at 35 DAS & boll development stages; I_2, two irrigations at 35 DAS & square formation stages; I_3, three irrigations at 35 DAS, square formation & boll development stages; I_4, three irrigations at 35 DAS, boll initiation & boll development stages; I_5, four irrigations at 35 DAS, square formation, boll initiation & boll development stages; DAS, days after sowing; WUE, water use efficiency. Rainfall= 273.77 mm.

Cotton crop under different irrigation schedules

5.2. Palampur

5.2.1. Studies on irrigation and weed management in cauliflower (*Brassica oleracea* var. *botrytis*)

A study was conducted from 2018-19 to 2020-21 to optimize irrigation schedule and weed management in cauliflower crop. Split plot design was adopted where the main plot treatments on irrigation schedule were 0.9, 0.7 and 0.5 pan evaporation (PE). Sub-plot treatments on weed management were black polythene mulching, application of pendimethalin at 1.5 kg ha^{-1} followed by (*fb*) one hand weeding (HW) at 40-45 days after transplanting (DAT), application of pendimethalin at 1.5 kg ha^{-1} *fb* straw mulching, and control treatment (weedy check). Pooled results showed significant interaction effect of irrigation schedule and weed management for curd yield, net return and water productivity of cauliflower crop (Table 31). Increase in irrigation level from 0.5 to 0.9 potential evaporation (PE) resulted in progressive increase in curd yield from 7.08 to 12.80 t ha^{-1} for all the weed management practices. Significantly higher curd yield of 14.46 t ha^{-1} was observed on use of black polythene mulch, irrespective of the irrigation schedule. Yields obtained with weed management of pendimethalin at 1.5 kg ha^{-1} *fb* straw mulching and pendimethalin at 1.5 kg ha^{-1} *fb* 1 HW were at par (11.81 and 11.52 t ha^{-1}) and significantly higher than that of weedy check (5.00 t ha^{-1}). Net return was significantly higher with black polythene mulching and irrigation at 0.9 PE. However, the net returns were at par with the use of pendimethalin at 1.5 kg ha^{-1} *fb* 1 HW and pendimethalin at 1.5 kg ha^{-1} *fb* straw mulching for both 0.7 and 0.9 PE. Significantly higher water productivity of 3.51 kg m^{-3} was obtained with black polythene mulching and irrigation at 0.7 PE. This was followed by black polythene mulching and irrigation at 0.9 PE (3.13 kg m^{-3}). Thus, it was concluded that higher marketable yield of cauliflower and net return can be obtained with application of irrigation at 0.9 PE and use of black polythene mulch. But irrigation schedule of 0.7 PE and black polythene mulching can be adopted under limited water availability.

Table 31. Effect of irrigation level and weed management practices on level on yield, net returns and water productivity of cauliflower

Weed management (*Row*) / Irrigation (*Column*)	0.9 PE	0.7 PE	0.5 PE	Average
	Yield (t ha^{-1})			
Black polythene mulch	17.65	16.72	9.02	14.46
Pendimethalin 1.5 kg ha^{-1} *fb* one HW at 40-45 DAT	13.88	13.26	7.42	11.52
Pendimethalin 1.5 kg ha^{-1} *fb* straw mulch	13.95	13.68	7.79	11.81
Weedy check	5.72	5.11	4.07	5.00
Average	12.80	12.19	7.08	10.69
CD (*p*=0.05)	Irrigation level = 0.44, I×W=0.39 Weed management practice = 0.22, I×W=0.55			
	Net return (₹ ha^{-1})			
Black polythene mulch	123816	109769	-5662	75974
Pendimethalin 1.5 kg ha^{-1} *fb* one HW at 40-45 DAT	115746	106447	18816	80336
Pendimethalin 1.5 kg ha^{-1} *fb* straw mulch	112781	108688	20406	80625
Weedy check	169	-8988	-24533	-11117
Average	88128	78979	2256	56454
CD (*p*=0.05)	Irrigation level= 6599, I×W=5836 Weed management practice = 3369, I×W=8261			
	Water productivity (kg m^{-3})			
Black polythene mulch	3.13	3.51	2.29	2.98
Pendimethalin 1.5 kg ha^{-1} *fb* one HW at 40-45 DAT	2.48	2.80	1.91	2.39
Pendimethalin 1.5 kg ha^{-1} *fb* straw mulch	2.58	2.96	2.01	2.52
Weedy check	1.04	1.10	1.06	1.07
Average	2.31	2.59	1.82	2.24
CD (*p*=0.05)	Irrigation level= 0.07, I×W=0.08 Weed management practice = 0.04, I×W=0.10			

Note: PE, pan evaporation; *fb*, followed by; HW, hand weeding; DAT, days after transplanting


Black polythene mulching in cauliflower

5.3. Chiplima

5.3.1. Assessment of productivity and water use efficiency of different types of maize under varying moisture regimes

Maize is grown as a substitute for rice crop during *rabi* season in the upland conditions of canal irrigated area of West Central Table Land Zone of Odisha, because it generates higher remuneration for farmers. Therefore, an experiment was conducted to improve productivity of maize crop in the area (2.12 t ha^{-1}), which is currently lower than national average (3.93 t ha^{-1}) as well as state average (2.78 t ha^{-1}). The experiment comprised of three surface irrigation schedules of IW/CPE 0.8 (I_1), 0.7 (I_2) and 0.6 (I_3), and three types of maize crop i.e. sweet corn (M_1), baby corn (M_2) and hybrid maize (M_3). Depth of irrigation was 5.0 cm. Pooled resulted of three years (*Rabi* 2017-18, 2018-19 and 2019-20) showed that average green cob yield (8.40 t ha^{-1}), green fodder yield (32.46 t ha^{-1}) was significantly higher when the crops was irrigated with IW/CPE 0.8 followed by IW/CPE 0.7 (Table 32). Sweet corn recorded the highest yields of green cob (8.53 t ha^{-1}) and green fodder (31.10 t ha^{-1}). Baby corn (M_2) recorded the highest number of cobs per plant (2.59). Water use was higher with I_1 (345 mm) followed by I_2 (300 mm) but water productivity was same (0.26 kg m^{-3}) for both the treatments. Net return (₹ 94,063 ha^{-1}) and benefit-cost ratio (3.36) was highest with IW/CPE 0.8. Among the maize types, baby corn was most remunerative with maximum net return of ₹ 104460 ha^{-1} and benefit-cost ratio of 3.63.

Table 32. Pooled effect of irrigation schedules and different maize varieties on yield and economics

Treatment	No. of cobs $plant^{-1}$	Green cob yield (t ha^{-1})	Green fodder yield (t ha^{-1})	Water use (mm)	Water productivity (kg m^{-3})	Net return (₹ ha^{-1})	B-C ratio
Irrigation schedule							
I_1: IW/CPE 0.8	2.36	8.40	32.46	345	0.24	94063	3.36
I_2: IW/CPE 0.7	1.89	7.76	29.59	300	0.26	84579	3.19
I_3: IW/CPE 0.6	1.54	6.19	21.43	240	0.26	60334	2.59
CD (p=0.05)	0.18	0.64	2.68	-	-	-	-
Maize type							
M_1: Sweet corn	1.63	8.53	31.10	300	0.28	70280	2.60
M_2: Baby corn	2.59	7.26	24.28	300	0.24	104460	3.63
M_3: Hybrid maize	1.36	7.42	27.20	300	0.25	28607	1.81
CD (p=0.05)	0.18	0.40	3.81	-	-	-	-


Sweet corn and baby corn grown under varying irrigation schedules

5.4. Kota

5.4.1. Influence of irrigation schedules and land configuration on productivity of groundnut (*zaid*) + sweet corn intercropping system in south-east Rajasthan

An experiment was conducted from 2018 to 2020 to standardize an optimum irrigation schedule and land configuration for increasing water use efficiency of *zaid* groundnut + sweet corn intercropping system in south-east Rajasthan. Irrigation scheduling treatments were IW/CPE 0.8, 1.0 and 1.2, whereas land configuration treatments were flat bed (3:1) and broad bed furrow (3:1). The ratio of 3:1 denotes that one row of sweet corn crop was planted for every three rows of groundnut crop for both the land configurations. Pooled result of three years showed significantly higher pod yield of groundnut (1.85 t ha^{-1}), net return (₹ 70987 ha^{-1}), benefit-cost ratio (2.22), groundnut equivalent yield (3.04 t ha^{-1}), system net return (₹ 130968 ha^{-1}) and system benefit-cost ratio (1.76) obtained under irrigation schedule IW/CPE 1.2 compared to IW/CPE 1.0 and IW/CPE 0.8 during *zaid* season (Table 33). Irrigation at IW/CPE 1.2 recorded 16.35 and 56.27% higher pod yield, 22.95 and 94.07% higher net return, 13.43 and 40.09% groundnut equivalent yield, 21.25 and 73.61% higher system net return over IW/CPE 1.0 and IW/CPE 0.8, respectively. But water use efficiency (2.94 kg ha-mm^{-1}) and water productivity (0.294 kg m^{-3}) were same under IW/CPE 1.0 and IW/CPE 1.2. It was observed that land configurations did not have significant effect on net return, benefit-cost ratio of *zaid* groundnut, as well as on system net return and system benefit-cost ratio. However, pooled data of three years revealed that significantly higher pod yield (1.69 t ha^{-1}) and water use efficiency (3.17 kg ha-mm^{-1}) was recorded under sowing in broad bed furrow compared to that in flat bed. There was 21.58 and 28.34% higher pod yield and water use efficiency for sowing in broad bed furrow, respectively over flat bed sowing.

Table 33. Effect of irrigation schedule and land configuration on performance of groundnut in groundnut + sweet corn intercropping system (Pooled result of three years)

Treatment	Performance of groundnut crop						System performance		
	Pod yield (t ha^{-1})	Total water applied (mm)	WUE (kg ha-mm^{-1})	Net return (₹ ha^{-1})	B-C ratio	Water productivity (kg m^{-3})	Groundnut equivalent yield (t ha^{-1})	System net return (₹ ha^{-1})	System B-C ratio
Irrigation schedule									
IW/CPE 0.8	1.18	478	2.59	36578	1.24	0.259	2.17	79058	1.07
IW/CPE 1.0	1.59	572	2.94	57733	1.88	0.294	2.68	110214	1.49
IW/CPE 1.2	1.85	667	2.94	70987	2.22	0.294	3.04	130968	1.76
CD ($p \leq 0.05$)	0.10	-	NS	5742	0.19	-	0.14	16446	0.13
Land configuration									
Flat bed (3:1)	1.39	600	2.47	47602	1.58	0.247	2.44	95374	1.28
Broad bed furrow (3:1)	1.69	544	3.17	62597	1.98	0.317	2.82	118119	1.59
CD ($p \leq 0.05$)	0.19	-	0.16	NS	NS	-	NS	NS	NS

Note: NS, non-significant

IW/CPE 1.2 + broad bed furrow sowing of groundnut and sweet corn in 3:1

IW/CPE 0.8 + flat sowing of groundnut and sweet corn in 3:1

5.5. Jabalpur

5.5.1. Evaluation of water productivity of rice–wheat cropping system with varying tillage practices

A three-year long experiment (2016-17 to 2018-19) was conducted to determine optimum sowing methods and irrigation management for rice (var. *Pusa Sugandha*) - wheat (var. JW 1203) cropping system. Two sowing methods of rice were implemented i.e direct seeded rice (DSR) and transplanted rice (TPR) during *kharif* season, with two irrigation practices i.e. cut-off irrigation at 20 days before harvest and cut-off irrigation at 10 days before harvest. Therefore, total four treatments were applied to rice crop. After harvest of rice, wheat was sown under zero tillage condition in the same plots during *rabi* season, and two treatments were applied i.e. irrigation before wheat sowing with zero tillage and irrigation after wheat sowing with zero tillage. It is to be noted that the treatments for wheat crop were a superimposition in the plots where DSR and TPR were harvested. Therefore, total four treatments in rice and eight treatments in wheat and rice-wheat system were studied. Results showed that cut-off irrigation at 10 days before harvest of TPR followed by irrigation before wheat sowing gave highest system water productivity of 1.11 kg m^{-3}, net return of ₹112247 ha^{-1} and benefit-cost ratio of 1.97 (Table 34). Minimum net return of ₹ 98735 ha^{-1} and benefit-cost ratio of 1.73 was obtained with cut-off irrigation at 20 days before harvest of TPR followed by irrigation after wheat sowing. Therefore, cut-off irrigation at 10 days before harvesting rice followed by irrigation before sowing wheat under zero tillage condition was recommended to generate maximum income and water productivity from rice-wheat system in Madhya Pradesh.

Table 34. Performance of rice-wheat cropping system under varying sowing methods, irrigation management and zero tillage

Treatment combination	Yield (t ha^{-1})		Net return (₹ ha^{-1})		System performance (Rice-Wheat)		
	Rice	Wheat	Rice	Wheat	Net return (₹ ha^{-1})	B-C ratio	WP (kg m^{-3})
DSR-C20-IBW	4.19	4.72	56904	51066	107971	1.95	1.03
DSR-C20-IAW		4.62		49208	106112	1.92	1.00
DSR-C10-IBW	3.96	4.84	52603	53311	105915	1.92	1.05
DSR-C10-IAW		4.79		52318	104921	1.90	1.04
TPR-C20-IBW	3.85	4.81	47632	52759	100391	1.76	1.05
TPR-C20-IAW		4.72		51103	98735	1.73	1.03
TPR-C10-IBW	4.17	5.12	53765	58482	112247	1.97	1.11
TPR-C10-IAW		4.92		54802	108567	1.90	1.07

Note: DSR, direct seeded rice; TPR, transplanted rice; C20, cut-off irrigation 20 days before harvesting; C10, cut-off irrigation 10 days before harvesting; IBW, irrigation before wheat sowing under zero tillage condition; IAW, irrigation after wheat sowing under zero tillage condition; WP, water productivity; Cost of cultivation: ₹ 21430 (DSR), ₹ 24270 (TPR) and ₹ 35800 (wheat); Sale price: ₹ 18.70 kg^{-1} (rice) and ₹ 18.40 kg^{-1} (wheat).

5.6. Bathinda (Ludhiana)

5.6.1. Enhancing water productivity of summer greengram (*Vigna radiata* L.) with different wheat residue management and irrigation regimes

An experiment was conducted to assess the effect of irrigation regimes and tillage with wheat residue management on summer greengram crop (var. SML 668). Wheat residue management treatments comprised of M_1- Preparatory tillage after removal of wheat residue, M_2- Zero tillage in wheat residue leftover after making wheat straw by straw reaper, and M_3- Incorporation of leftover wheat residue after making wheat straw along with preparatory tillage. Treatments on irrigation level were two irrigations at vegetative and flowering stages (I_1), three irrigations in vegetative, flowering and pod filling stages (I_2), four irrigations in vegetative, flowering, pod filling and pod formation stages (I_3). Amounts of irrigation applied were 15.0, 22.5 and 30.0 cm in I_1, I_2 and I_3 treatments, respectively each of 7.5 cm depth.

Results showed that average grain yields of greengram was significantly higher in both incorporation of residue with tillage (M_3) and zero tillage (M_2) treatments over no residue addition tillage treatment (M_1) (Table 35). Both the residue incorporation and leftover residue zero tillage treatments were statistically at par in terms of yield. Irrigation regimes I_2 and I_3 gave significantly higher greengram yield than I_1 under all the three wheat residue management tillage practices, difference in yield between I_2 and I_3 was statistically non-significant. Among the irrigation regimes, water expense efficiency (WEE) was found to be the highest in I_2. WEE was higher in M_3 and M_2 treatments and least in M_1 where no residue was retained in soil.

Table 35. Performance of summer greengram under varying irrigation and tillage practices

Irrigation regime	Profile water use (cm)	Water used (cm)	Seed yield (t ha^{-1})	WEE (kg ha-mm^{-1})
M_1: Preparatory tillage with no wheat residue				
I_1: Two irrigations	-2.31	22.99	0.408	1.77
I_2: Three irrigations	-2.76	30.04	0.601	2.00
I_3: Four irrigations	-3.36	36.95	0.644	1.74
Average	-2.81	29.99	0.551	1.84
M_2: Leftover wheat residue with zero tillage				
I_1: Two irrigations	-2.92	22.38	0.514	2.29
I_2: Three irrigations	-4.05	28.75	0.710	2.47
I_3: Four irrigations	-4.21	36.10	0.742	2.06
Average	-3.73	29.08	0.655	2.27
M_3: Incorporated wheat residue along with tillage				
I_1: Two irrigations	-2.98	22.33	0.525	2.35
I_2: Three irrigations	-3.92	28.89	0.767	2.65
I_3: Four irrigations	-4.12	36.18	0.791	2.19
Average	-3.67	29.13	0.694	2.40
CD (5%)				
Wheat residue management (A)				0.091
Irrigation regimes (B)				0.066
Interaction (A × B)				NS

Note: I_1, two irrigations at vegetative growth & flowering stages; I_2, three irrigations at vegetative, flowering and pod filling stages; I_3, four irrigations at vegetative, flowering, pod filling & pod formation stages. WEE, water expense efficiency. Rainfall = 10.3 cm.

Chapter 6

Basic Studies on Soil-Plant-Water-Environment Relationship

6.1. Chiplima

6.1.1. Optimization of height of raised beds in raised - sunken bed system in lowlands of Hirakud command area in *kharif* season

An experiment was conducted from *kharif* 2018 to 2020 to enhance water productivity of raised and sunken bed system with optimum elevation difference and crop combination in the lowlands of Hirakud command. Split plot design was adopted where elevation differences of 30 (H_1), 45 (H_2) and 60 (H_2) cm were in the main plot and intercrop combinations of rice+okra (C_1), rice+maize (C_2), rice+tomato (C_3) and rice+cowpea (C_4) in sub-plot. Rice was grown in sunken beds, whereas okra, maize, tomato and cowpea were cultivated on raised beds. It was observed that rice equivalent yield of 7.22 t ha^{-1} was significantly higher under elevation difference of 60 cm between raised and sunken beds compared to 45 cm and 30 cm. Highest system net return of ₹56,605 ha^{-1} and benefit-cost ratio of 2.53 were also obtained with elevation difference of 60 cm (Table 36). Maximum yield of 7.55 t ha^{-1} was obtained with rice+cowpea, but statistically similar to yield of 7.19 t ha^{-1} with rice+okra. Intercrop of rice + cowpea also fetched highest net return (₹87,737 ha^{-1}) and benefit-cost ratio (2.64).

Table 36. Effect of elevation difference and crop combination on crop yield and economics (Pooled average of *kharif* 2018, 2019 and 2020)

Treatment	Rice equivalent yield (t ha^{-1})	Net return (₹ ha^{-1})	B-C ratio
Elevation difference			
H_1 (30 cm)	6.32	46179	2.21
H_2 (45 cm)	6.72	51122	2.35
H_3 (60 cm)	7.22	56605	2.53
CD (p=0.05)	0.36	-	0.12
Crop combination			
C_1 (Rice+Okra)	7.19	81366	2.51
C_2 (Rice+Maize)	6.14	62963	2.15
C_3 (Rice+Tomato)	6.12	62706	2.14
C_4 (Rice+Cowpea)	7.55	87737	2.64
CD (p=0.05)	0.45	-	0.16


Crops grown in raised-sunken bed system in lowlands of Hirakud command

6.2. Kota

6.2.1. Increasing wheat productivity through foliar spray of bioregulator under skip irrigation situation

An experiment was conducted with wheat variety *Raj* 4079 from *rabi* 2017-18 to 2019-20 to improve productivity and economic gain. Split plot design was implemented with three treatments on skip irrigation applied at late tillering stage, booting stage and milking stage in separate plots under main plot. Three treatments on bioregulator foliar spray were also applied with different doses of bioregulator putrescine at 25, 50, 75 and 100 ppm in separate plots under sub-plot. Recommended irrigation for wheat i.e. four irrigations at CRI, late tillering, booting and milking stages was taken as absolute control. Irrigation depth in all the treatments was 60 mm. Pooled results of three years showed that significantly higher grain yield (4.24 t ha^{-1}), water use efficiency (WUE) (15.14 kg ha-mm^{-1}), net return (₹59304 ha^{-1}) and benefit-cost ratio (2.05) was obtained from the treatment where irrigation was skipped at late tillering stage, as compared to skip irrigation at booting and milk stages (Table 37). Skip irrigation at late tillering stage led to increase in grain yield by 11.3 and 16.8% over skip irrigation at booting and milking stages, respectively. Foliar spray of putrescine at 75 ppm recorded significantly higher yield (4.02 t ha^{-1}), with highest net return (₹54177 ha^{-1}), WUE (14.36 kg ha-mm^{-1}) and water productivity (WP) (1.51 kg m^{-3}) among the bioregulator treatments. However, grain yield, WUE and WP obtained with putrescine at 75 and 100 ppm were at par. Thus, an inference was drawn from the study that one irrigation of 60 mm depth can be skipped at late tillering stage to obtain wheat yield similar to that with four irrigations at CRI, late tillering, booting and milk stages.

Table 37. Performance of wheat crop under different irrigation scheduling and foliar spray of bioregulator (Pooled results of three years)

Treatment	Yield (t ha^{-1})	WUE (kg ha-mm^{-1})	Net return (₹ ha^{-1})	B-C ratio	WP (kg m^{-3})
Irrigation at critical growth stage					
Skip irrigation at late tillering stage	4.24	15.14	59304	2.05	1.51
Skip irrigation at booting stage	3.81	13.61	50711	1.75	1.36
Skip irrigation at milking stage	3.63	12.95	47046	1.63	1.29
CD (p=0.05)	0.21	0.73	4272	0.15	0.08
Bioregulator foliar spray					
Foliar spray of putrescine at 25 ppm	3.66	13.07	50012	1.89	1.31
Foliar spray of putrescine at 50 ppm	3.83	13.69	51989	1.85	1.37
Foliar spray of putrescine at 75 ppm	4.02	14.36	54177	1.81	1.44
Foliar spray of putrescine at 100 ppm	4.10	14.48	53237	1.69	1.45
CD (p=0.05)	0.20	0.80	NS	NS	0.07
Absolute control (4 irrigations at CRI, late tillering, booting, milking stages)	4.64	13.75	69938	3.01	1.38

Wheat crop at booting stage

Wheat crop at dough stage

6.3. Rahuri

6.3.1. Estimation of water requirement and development of crop coefficients of fodder maize through lysimetric technique (Collaborative research project: AICRP on IWM and Department of Irrigation and Drainage Engineering)

A study was undertaken to develop the crop coefficient values of fodder maize (var. *African Tall*) for Rahuri region from locally available measurements on crop evapotranspiration (ET_c) from lysimetric experiments and corresponding estimates of reference ET_c; and develop the crop coefficient equations. Weekly fodder maize evapotranspiration data was measured with the lysimeters installed in the experimental farms of the AICRP on Irrigation Water Management, MPKV, Rahuri for three consecutive years (2018 to 2020). Weekly values of crop coefficients were computed for fodder maize as the ratio of weekly ET_c obtained from lysimeter and weekly reference evapotranspiration. As the ET_c values were available for two lysimeters per year, the ET_c values were averaged over both the lysimeters to compute the crop coefficient values.

Crop coefficient (K_c) curves were developed for the reference ET_c estimated by Penman-Monteith. Polynomial equations of different orders with crop coefficient as a function of the ratio of days since sowing/planting to total crop growth period were fitted for the years 2018-19, 2019-20 and 2020-21 in order to estimate crop coefficient of fodder maize. It was found that third and fourth order polynomial equations were suitable for estimation of crop coefficient of fodder maize for 2018-19, 2019-20 and 2020-21. The equations are given below:

Year : 2018 - 19

$$Kc_t = -5.628\left(\frac{t}{T}\right)^3 + 6.669\left(\frac{t}{T}\right)^2 - 0.627\left(\frac{t}{T}\right) + 0.272 \qquad R^2 = 0.803$$

Year : 2019 - 20

$$Kc_t = 13.06\left(\frac{t}{T}\right)^4 - 32.59\left(\frac{t}{T}\right)^3 + 20.84\left(\frac{t}{T}\right)^2 - 1.778\left(\frac{t}{T}\right) + 0.514 \qquad R^2 = 0.814$$

Year : 2020 - 21

$$Kc_t = 13.06\left(\frac{t}{T}\right)^4 - 32.59\left(\frac{t}{T}\right)^3 + 20.84\left(\frac{t}{T}\right)^2 - 1.778\left(\frac{t}{T}\right) + 0.514 \qquad R^2 = 0.856$$

6.4. Chalakudy

6.4.1. Development of a suitable filtering technique for reusing household wastewater for irrigation

A study is being conducted to develop a household wastewater treatment system to make wastewater suitable for irrigation and test the suitability of treated water for irrigating vegetables and growing fish. Reuse of household wastewater is necessary for solving water scarcity problems during summer months in Kerala. Water samples were collected form two locations within 10 km distance from Chalakudy centre. Laundry wastewater was bulked and homogenized and made into one sample. Analyses of physico-chemical parameters of the water samples (Table 38) showed that both the samples were not suitable for irrigation. Then a sand filter system was designed and developed for the treatment of laundry wastewater and tested for suitability for irrigation.

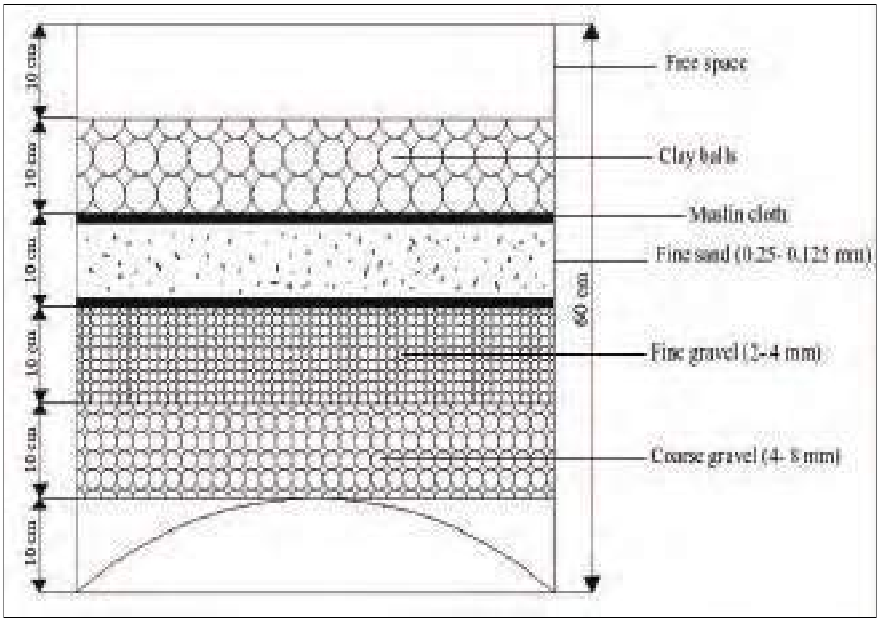
Design, development and testing of filter

The filter was designed and developed for the treatment of laundry wastewater. A fibre tank of capacity 60 litre and dimensions of height 0.6 m and diameter 0.3 m was filled with different materials such as clay balls, fine sand and two layers of gravel. Schematic diagram of the filter is shown in Figure 15(a). The top most portion of filter contains clay balls of 8 to 10 mm size and thickness of 10 cm. A free space of 10 cm is provided at the top layer of the clay balls for ponding wastewater. The next layer of filter media is fine sand of size 0.25 to 0.125 mm and thickness of 15 cm. It is followed by fine gravel layer of size 2 to 4 mm and coarse gravel layer of size 4 to 8 mm. Thickness of both the gravel layers is 10 cm each. A screen mesh is provided at the top and bottom of fine sand layer. At the bottom of the tank an inverted plastic net basket is kept for free flow of water from the upper layers. Also, a tap is provided at the bottom for collecting the filtered water. The developed filter and inside view of the filter are shown in Figure 15(b). Laundry wastewater was collected from the same locations kept in a settling tank of capacity 200 L. From the settling tank, the wastewater was conveyed to the filters kept at right and left sides of the settling tank. After 24 hours of retention time, the filtered water was collected from the filters and analysed. Table 38 shows that that pH, residual sodium carbonate (RSC) and sodium absorption ratio (SAR) are within the permissible limit; hence the filtered water was found suitable for irrigation purpose.

Table 38. Results of laboratory analysis of laundry wastewater before and after filtration

Parameter	Sample I		Sample II		Safe value for irrigation*
	Before	After	Before	After	
pH	8.4	7.8	9.4	6.9	6.5 - 8.5
EC (dS m^{-1})	1.1	0.7	1.4	1.0	1.5
CO_3^{2-} (meq L^{-1})	0.0	0.0	0.0	0.0	-
HCO_3^- (meq L^{-1})	4.8	2.4	3.6	2.4	-
Na^+ (meq L^{-1})	9.3	3.5	13.5	6.5	-
K^+ (mg L^{-1})	7.8	6.1	12	7.4	-
Ca^{2+} (mg L^{-1})	1.6	29.4	8.1	26.5	-
Mg^{2+} (mg L^{-1})	1.4	1.8	1.2	7.4	-
SAR (meq L^{-1})	29.8	3.9	26.9	6.5	10.0
RSC (meq L^{-1})	4.6	0.8	3.1	0.5	1.25
Boron (mg L^{-1})	0.25	0.18	0.30	0.16	<1.0

*Bureau of Indian Standards (1986)



(a)

(b)

Figure 15 (a). Schematic diagram of the cross-sectional view of laundry wastewater filter, (b) Settling tank at the top along with two filters on the ground (*top*) and top view of the filter (*bottom*)

6.5. Bathinda (Ludhiana)

6.5.1. Response of rice straw mulch and irrigation water quality on performance of *Bt* cotton under different levels of irrigation and its residual effect on succeeding wheat crop in *Bt* cotton-wheat cropping system

Field experiment was conducted to study the effect of mulching and irrigation water quality on performance of *Bt* cotton crop (var. RCH 773 BG II), effect of the residual effect of straw mulch on succeeding wheat crop (var. HD 3086), and the effect of mulching and irrigation water quality on soil properties. Water quality treatments comprised of canal water (CW) and tubewell water (TW). TW was saline sodic with RSC, 1.10-1.36 meq L^{-1} and EC, 3.8-4.2 dS m^{-1}. Mulching treatments comprised of straw mulch at 6 t ha^{-1} and no mulch condition. Treatments on irrigation level were I_1: IW/CPE 0.6 (3 nos.), I_2: IW/CPE 0.8 (4 nos.) and I_3: IW/CPE 1.0 (5 nos.).

Bt cotton crop grown during *kharif* season showed that treatment combinations of mulching, irrigation water quality and its application frequency (irrigation level) had significant effect on seed cotton yield (Table 39). Average seed cotton yield was 2.45 t ha^{-1} and 2.28 t ha^{-1} under mulch and no mulch application, respectively. Average seed cotton yield was 2.71 t ha^{-1} under canal water treatment whereas it was 2.02 t ha^{-1} under saline-sodic TW application. Water use efficiency (WUE) was higher under straw mulch compared with no mulch condition. Among irrigation levels, highest WUE was recorded with IW/CPE 0.6 except CW without mulch. Higher WUE was observed with CW in comparison to TW irrespective of mulching treatment.

Wheat crop sown during *rabi* 2019-20 after harvest of cotton, residual effect of straw mulch and water quality had no significant effect on grain yield of wheat (Table 39). However, irrigation level had significant effect on wheat yield and yield attributing parameters. Maximum grain yield of 5.01 t ha^{-1} was observed under irrigation with TW at IW/CPE 1.0 where rice straw mulch was applied. Grain yield (3.43 t ha^{-1}) was minimum with use of CW and IW/CPE 0.6 under no mulch application. WUE was higher under residual mulch conditions and TW irrigation and except for IW/CPE 0.6.

Table 39. Performance of *Bt* cotton followed by wheat crop with residual mulch under different qualities of water and irrigation level

Irrigation level	Crop yield (t ha^{-1})		Irrigation water applied (cm)		Total water applied (cm)		WUE (kg ha-mm^{-1})	
	Wheat	*Bt* cotton	Wheat	*Bt* cotton	Wheat	*Bt* cotton	Wheat	*Bt* cotton
Canal water-without mulch (CW-M$_o$)								
I_1	3.43	2.27	22.5	22.5	38.4	72.0	8.94	3.15
I_2	4.38	2.71	30.0	37.5	46.2	84.7	9.47	3.20
I_3	4.67	2.80	37.5	52.5	50.2	99.3	9.30	2.82
Mean	4.16	2.59	30.0	37.5	44.9	85.3	9.24	3.06
Canal water-with mulch (CW-M$_s$)								
I_1	3.78	2.54	22.5	22.5	38.8	70.4	9.75	3.61
I_2	4.58	2.94	30.0	37.5	46.8	83.8	9.78	3.51
I_3	4.91	3.00	37.5	52.5	49.2	98.4	9.97	3.05
Mean	4.42	2.83	30.0	37.5	44.9	84.2	9.83	3.39
Tubewell water-without mulch (TW-M$_o$)								
I_1	22.5	1.78	22.5	22.5	37.4	68.3	9.82	2.63
I_2	37.5	2.04	30.0	37.5	43.9	83.4	10.21	2.44
I_3	52.5	2.07	37.5	52.5	50.8	95.9	9.45	2.16
Mean	37.5	1.96	30.0	37.5	44.0	82.5	9.83	2.41
Tubewell water-with mulch (TW-M$_s$)								
I_1	3.88	1.92	22.5	22.5	36.9	69.1	10.52	2.78
I_2	4.75	2.14	30.0	37.5	42.2	83.8	11.25	2.56
I_3	5.01	2.17	37.5	52.5	48.7	96.1	10.30	2.25
Mean	4.55	2.08	30.0	37.5	42.6	83.0	10.69	2.53
Overall mean								
CW	4.29	2.71	-	-	-	-	-	-
TW	4.43	2.02	-	-	-	-	-	-
CD (p≤0.05)	NS	0.219	-	-	-	-	-	-
No mulch	4.24	2.28	-	-	-	-	-	-
With mulch	4.48	2.45	-	-	-	-	-	-
CD (p≤0.05)	NS	0.059	-	-	-	-	-	-
I_1	3.69	2.13	-	-	-	-	-	-
I_2	4.55	2.46	-	-	-	-	-	-
I_3	4.85	2.51	-	-	-	-	-	-
CD (p≤0.05)	0.351	0.089	-	-	-	-	-	-
CD (p≤0.05) A×B A×C	- -	0.084 0.126	- -	- -	- -	- -	- -	- -

Rainfall during *rabi* season (for wheat) = 15.1 cm, Rainfall during *kharif* season (for *Bt* cotton) = 44.0 cm;
I_1: IW/CPE 0.6 (3 nos.), I_2: IW/CPE 0.8 (4 nos.) and I_3: IW/CPE 1.0 (5 nos.)

***Bt* cotton crop grown with rice straw mulch in *kharif* season**

Succeeding wheat crop in *rabi* season

Chapter 7

Conjunctive Use and Multiple Use of Water

7.1. Bathinda (Ludhiana)

7.1.1. Evaluation of water productivity of fodder-based cropping sequences for different irrigation water qualities

Field trial was done to study the effect of water quality on fodder yield and water productivity in fodder-fodder crop sequence and to compare the effects of different irrigation water qualities on soil properties. Fodder crops berseem and ryegrass were grown during *rabi* season and sorghum was grown in *kharif* season. Six treatments on quality of water were canal water (CW) alone, saline sodic water (TW) alone, CW-TW (alternately), 1CW-2TW, 2TW-1CW and 1CW-subsequent irrigation with TW. Tubewell water has residual sodium carbonate (RSC) of 1.36 meq L^{-1} and electrical conductivity (EC) of 4200 µmhos cm^{-1}.

Effect of varying qualities of irrigation water on berseem crop (var. BL-10) with respect to green fodder yield (GFY), dry fodder yield (DFY) and water expense efficiency are given in Table 40. GFY was statistically higher with the use of CW, which was at par with CW-TW. The irrigations with alternate CW and TW showed 25.8% higher GFY over irrigation with TW alone. DFY showed same trend as GFY. There was 40.6% reduction in dry fodder yield where all irrigations were given with poor quality water (TW) than CW-TW treatment. In contrary to these the water expense efficiency (WEE) was highest (222.6 kg ha-mm^{-1}) in CW treatment and lowest (169.6 kg ha-mm^{-1}) where all irrigations were given with only tubewell water. Ryegrasss (var. *Punjab Ryegrass* 1) grown with varying qualities of irrigation water showed that GFY was statistically higher in CW, but at par with CW-TW and 1CW-2TW (Table 40). Irrigations with TW alone showed 26.0 and 24.1% reduction in GFY than CW and alternate canal and tubewell water (CW-TW), respectively. DFY showed the same trend as GFY. WEE was highest under CW (232.4 kg ha-mm^{-1}) followed by CW-TW (214.0 kg ha-mm^{-1}) and minimum values (186 kg ha-mm^{-1}) were under TW alone.

Succeeding sorghum crop (var. PSC-4) showed significant increase (25.06% and 29.1%) in GFY with alternate use of water (CW-TW) compared to use of TW alone for sorghum with preceding berseem and ryegrass, respectively. Similar trend was observed for DFY of sorghum. DFY was higher with CW followed by CW-TW and lowest with TW alone. Maximum water expense efficiency (151.5 kg ha-mm^{-1}) was recorded under CW (Table 41). The effect of preceding crop (berseem and ryegrass) and various qualities of water on green fodder yield of sorghum is also given in graphical form in Figure 16.

Table 40. Effect of water quality on berseem and ryegrass during *rabi* season

Treatment	Green fodder yield (t ha^{-1})		Dry fodder yield (t ha^{-1})		Water expense efficiency (kg ha-mm^{-1})	
	Berseem	Ryegrass	Berseem	Ryegrass	Berseem	Ryegrass
CW	118.2	123.5	0.243	0.251	222.6	232.4
TW	84.4	93.0	0.170	0.206	169.6	186.3
CW-TW	113.7	117.2	0.239	0.240	213.3	214.0
1CW-2TW	104.3	115.4	0.203	0.234	202.1	205.3
2TW-1CW	100.3	105.6	0.193	0.209	191.0	187.9
1CW-TW(s)	101.0	106.4	0.193	0.212	184.6	188.7
CD (%)	8.64	6.78	0.019	0.024	-	-

Note: CW, irrigation with canal water; TW, irrigation with tubewell water; 1CW-TW(s), one irrigation with CW and subsequent irrigations with TW. Irrigation water applied to berseem and ryegrass = 36.0 cm. Rainfall = 16.09 cm.

Table 41. Effect of water quality on sorghum succeeding berseem and ryegrass in *kharif* season

Treatment	Green fodder yield (t ha-1)	Dry fodder yield (t ha-1)	Water expense efficiency (kg ha-mm-1)
Berseem–Sorghum			
CW	122.1	0.343	151.5
TW	88.5	0.186	119.3
CW-TW	118.1	0.335	147.1
1CW- 2TW	117.3	0.318	143.2
2TW- 1CW	95.1	0.218	117.8
1CW- TW(s)	94.5	0.218	117.2
Ryegrass–Sorghum			
CW	121.4	0.338	152.1
TW	83.5	0.177	113.5
CW-TW	117.8	0.332	148.5
1CW- 2TW	116.9	0.315	144.9
2TW- 1CW	93.3	0.211	114.4
1CW-TW(s)	92.5	0.207	114.4
CD (%)	6.53	0.038	-

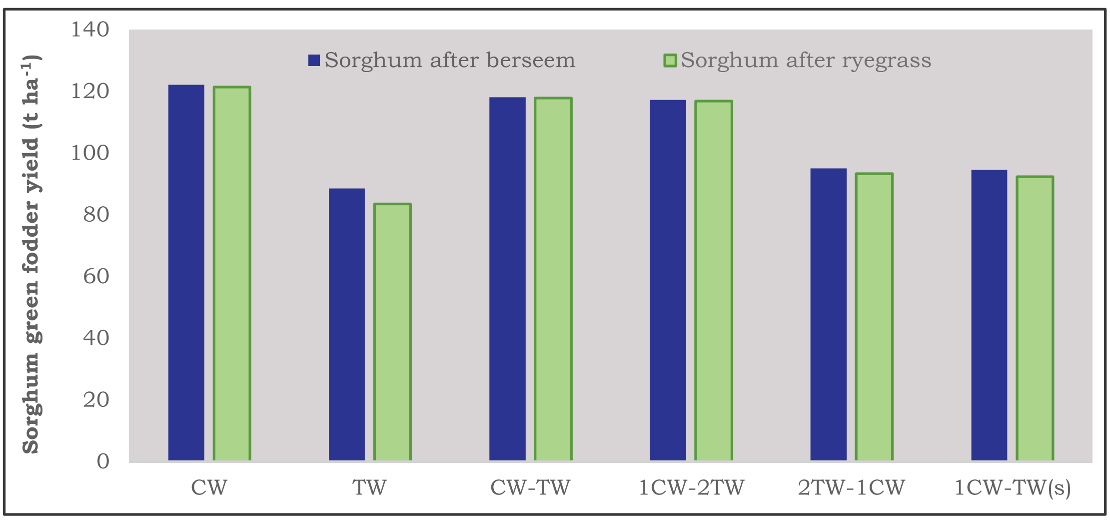


Figure 16. Green fodder yield of sorghum crop with preceding berseem and ryegrass crops under conjunctive use of water

Sorghum crop during *kharif* followed by *rabi* crops of ryegrass and berseem under fodder-fodder cropping sequence

7.2. Ayodhya

7.2.1. Conjunctive use of surface water and groundwater at middle and tail ends of Awanpur distributory to enhance the wheat yield

This experiment was conducted as part of Operational Research Project (ORP) at Panapur minor of Awanpur distributory command area. Wheat crop was grown with conjunctive use of water at 10 farmers' fields in the middle and tail end of the distributary during *rabi* season 2019-20. Improved water management practice (T_1) i.e. 6 cm water by check basin method with canal water and groundwater in the ratio of 2:1 was provided at critical growth stages of wheat (CRI, late jointing and milking stage) and compared with farmers' practice (T_2) i.e. 10-12 cm water by flooding/field to field irrigation as per availability of canal water (~2 irrigations). It was observed that improved water management practice produced significantly higher wheat grain yield of 4.15 t ha^{-1}, water expense efficiency (WEE) of 127.70 kg ha-cm^{-1}, net return of ₹48868 ha^{-1} and benefit-cost ratio of 2.58 (Table 42) compared to farmers' practice (3.36 t ha^{-1}, 88.60 kg ha-cm^{-1}, ₹29328 ha^{-1} and 2.58, respectively). In farmers' practice 20 cm canal water was applied though flooding/ field to field irrigation. Yield obtained with improved irrigation practice was 23.63% higher than the farmers' practice.

Table 42. Performance of wheat with improved water management and farmers' practice

Irrigation system	Average grain yield (t ha^{-1})	Water expense efficiency (kg ha-cm^{-1})	Cost of cultivation (₹ ha^{-1})	Net return (₹ ha^{-1})	B-C ratio
T_1: Conjunctive use of canal water and groundwater (2:1) at critical growth stages	4.15	127.70	31000	48868	2.58
T_2: Canal irrigation with farmers' practice	3.36	88.60	29500	29328	1.99

Note: Unit price of wheat was ₹ 1925 per quintal

Wheat grown under conjunctive use of water in Awanpur distributory command

7.3. Almora

7.3.1. Development of micro-water resource at farmer's field and multiple use of water

Uttarakhand receives large amount of rainfall (670-2800 mm) and has several perennial rivers. Despite this, the hill region faces shortage of water supply for agriculture and other uses. Micro water resources development plan was initiated at farmers' field to meet irrigation and other multiple uses which can provide livelihood security of farmers in hills. The study area is 35 km away from Almora at an elevation of 1800-2250 m from mean sea level. Some farmers were also selected in Hawalbagh block, village Challar Mussoli, Kasoon and Jur kafoon around 0 to 20 km range from Hawalbagh block.

Micro-water resource development

A tank with capacity of 20-198 m^3 was constructed at farmers' field to irrigate vegetable crops and combat intermittent dry spells during *kharif* and provide supplementary irrigation to *rabi* crops. The harvested water from these tanks was delivered with gravity-fed drip or sprinkler irrigation system to high value crops. The drip system was modified as per the suitability of farmer's site and condition. Three types of storage structures i.e. polyfilm, polycement tank as well as poly tank available in the market were installed at farmer's field and joined with drip irrigation system for small terraces to utilize water efficiently. The farmers were advised to schedule irrigation based on water requirement of vegetable crops and rest available surplus water can be diverted towards irrigating *rabi* crops. The farmers were also advised to prioritize crops as per their economic importance and availability of water in the tank.

Multiple water utilization experiment has been established at 15 farmers' fields. Components of the multiple water use system were; water harvesting pond, fish farming, vermicomposting, temperate fruit plantation (kiwi fruit), vegetable cultivation, animal rearing, duckery/poultry, azolla cultivation, small moving polyhouse for vegetable production. The tank has been constructed for storing rainfall, runoff or spring water. Vermicompost units have been developed with total capacity of 119.18 m^3 upto year 2019-20. It was estimated that vermicompost can yield around 1.86 lakh kg in two cycles. Mostly vermicompost was utilized by the farmers on their own field. If vermicompost is sold @ Rs.3 kg^{-1}, a total amount of ₹5.56 lakh can be earned by farmers from two cycles. From cattle component, average milk yield was from 3.0 to 9.0 kg as reported by farmers. The estimated income from six cows is about ₹3.76 lakh, if milk and cow dung is sold by farmers. The land used can be changed with cultivation of vegetable instead of cereals in terraces irrigated with harvested water in tanks. Poultry/duckery component earned ₹15000 to 24500 by selling birds. Gross income of farmers from this component was about ₹12000 in one year. *Azolla* cultivation was carried out by five farmers with 50 m^2 per farmer. Around 1600 kg green azolla was produced in one year.

7.4. Belavatagi

7.4.1. Evaluation of different sources of irrigation water to *rabi* crops in Malaprabha command area

A field experiment was conducted from 2017 to 2019 on different sources of water i.e. pond water, borewell water and e-harmonised borewell water on *rabi* crops like chickpea (var. JG-11), wheat (var. UAS-334), sunflower (var. *Dhara*) and safflower (var. A-1); and its impact on economics and soil physical and chemical properties after harvest. Among the different sources of water, pond water recorded significantly higher chickpea equivalent yield during all three years and in pooled results (1.52, 1.37, 1.16 and 1.35 t ha^{-1}, in 2017, 2018, 2019 and pooled, respectively) compared to borewell water (1.21, 1.01, 0.88 and 1.03 t ha^{-1}, respectively), and it was at par with e-harmonized water (1.39, 1.09, 1.37 and 1.28 t ha^{-1}, respectively) as shown in Table 43. Among the *rabi* crops, safflower recorded significantly higher chickpea equivalent yield in all three years as well as in pooled (2.38, 2.04, 1.16 and 1.86 t ha^{-1}, respectively) followed by sunflower (1.49, 1.32, 1.28 and 1.36 t ha^{-1}, respectively). The results indicated that performances of safflower and sunflower were least affected crops by source of water, whereas chickpea and wheat were much affected by the source of irrigation water. Economics indicates that irrigation with pond water resulted in significantly higher net returns (₹37309 ha^{-1}) and benefit-cost ratio (2.45) from all the *rabi* crops compared to other water sources. Also, there was significant reduction in soil pH after harvest of the *rabi* crops on the use of pond water.

Trial of *rabi* crops under different irrigation sources

Table 43. Effect of irrigation water from different sources on performance of *rabi* crops and on soil properties

Treatment	Chickpea equivalent yield (t ha^{-1})				Net return (₹ ha^{-1})				B-C ratio				pH			
	2017-18	2018-19	2019-20	Pooled	2017-18	2018-19	2019-20	Pooled	2017-18	2018-19	2019-20	Pooled	2017-18	2018-19	2019-20	Pooled
Borewell water (S_1)	1208	1011	883	1034	27282	19411	28599	25097	2.4	2.01	1.46	1.96	8.25	8.43	8.67	8.45
e-harmonized water (S_2)	1392	1088	1373	1284	34659	22478	32763	29967	2.76	2.17	1.93	2.29	8.25	8.34	8.42	8.34
Pond/canal water (S_3)	1520	1365	1158	1348	39781	33548	38598	37309	2.98	2.68	1.69	2.45	7.88	8.05	8.07	8.00
CD ($p\leq0.05$)	100.6	199.9	72.9	124.5	4024.4	7994.6	2645.0	4888.0	0.20	0.39	0.10	0.23	0.08	0.10	0.12	0.10
Chickpea (C_1)	1003	743	1091	946	16399	5966	14419	12261	1.69	1.25	1.55	1.50	8.18	8.35	8.15	8.23
Safflower (C_2)	2383	2042	1156	1860	76957	63329	21516	53934	5.19	4.45	1.84	3.83	8.12	8.15	8.43	8.23
Wheat (C_3)	618	519	1022	720	4229	249	14545	6341	1.21	1.01	1.60	1.27	8.15	8.30	8.26	8.24
Sunflower (C_4)	1490	1315	1282	1362	38043	31038	20864	29982	2.76	2.44	1.78	2.33	8.13	8.28	8.31	8.24
CD ($p\leq0.05$)	121.1	114.5	132.7	122.8	4842.2	4580.8	5142.2	4855.0	0.24	0.22	0.20	0.22	NS	NS	0.15	NS
S_1C_1	715	566	641	641	4873	-1096	11747	5175	1.21	0.95	0.81	0.99	8.25	8.56	8.31	8.37
S_1C_2	2190	1884	2037	2037	69273	57026	54785	60361	4.78	4.11	1.02	3.30	8.29	8.09	8.12	8.17
S_1C_3	510	392	451	451	-111	-4840	7123	724	0.99	0.76	1.57	1.11	8.28	8.43	8.40	8.37
S_1C_4	1416	1203	1310	1310	35091	26554	32117	31254	2.63	2.23	2.43	2.43	8.25	8.61	8.22	8.36
S_2C_1	945	573	759	759	14083	-829	17269	10174	1.59	0.97	2.50	1.69	8.21	8.19	8.34	8.25
S_2C_2	2477	2038	2258	2258	80729	63158	62321	68736	5.4	4.44	2.73	4.19	8.28	8.24	8.13	8.22
S_2C_3	645	418	532	532	5313	-3767	10480	4009	1.26	0.82	1.30	1.13	8.25	8.17	8.20	8.21
S_2C_4	1502	1323	1413	1413	38511	31348	34707	34855	2.79	2.45	1.18	2.14	8.15	8.24	8.11	8.17
S_3C_1	1349	1089	1219	1219	30240	19824	29275	26446	2.27	1.84	1.35	1.82	7.94	8.09	8.04	8.02
S_3C_2	2480	2204	2342	2342	80870	69802	63167	71280	5.41	4.8	1.77	3.99	7.98	8.12	7.11	7.74
S_3C_3	700	746	723	723	7486	9353	13282	10040	1.37	1.46	1.93	1.59	7.91	7.99	8.06	7.99
S_3C_4	1552	1419	1486	1486	40525	35213	36351	37363	2.88	2.63	1.71	2.41	7.80	7.98	7.17	7.65
CD ($p\leq0.05$)	211.7	200.3	206.5	206.2	8468.0	8010.8	7968.7	8149.2	0.41	0.38	0.31	0.37	0.42	0.36	0.52	0.41

Note: NS, non-significant

Chapter 8

Operational Research Project (ORP)

AICRP on Irrigation Water Management (IWM) carries out Operational Research Projects (ORPs) at farmers' fields to demonstrate technologies developed by the centres to the farmers and also to test the feasibility of technologies in field conditions. Some of the OPRs carried out by several centres during 2020 are presented below.

8.1. Gayeshpur

8.1.1. Assessment of microirrigation and farmer's traditional water management practices on different vegetable crops in arsenic contaminated areas of Nadia district in West Bengal

On-farm water management studies were carried out to study arsenic (As) mitigation in vegetable crops through microirrigation systems of drip and sprinkler vis-a-vis farmer's traditional water management practice. Village Ghetugachi of Nadia district was selected because here the groundwater is contaminated with As in varying magnitudes. The village comes under the contaminated region of Nadia district in West Bengal, which is declared as the vegetable export processing zone and export norms strongly adheres to contamination free production. During *rabi* season, major source of irrigation is groundwater through shallow tubewell that showed As concentration of 0.197±0.048 ppm.

Two popular vegetable crops namely, cauliflower and broccoli were grown with traditional surface irrigation management along with drip and sprinkler practices. The analysis of data showed that there was higher As accumulation in the edible parts of both the vegetables under surface irrigation practices. Application of either drip or sprinkler irrigation system reduced As accumulation from 7.91 to 19.27% and 7.28 to 16.5% in edible parts of cauliflower and broccoli, respectively over surface irrigation practices (Figure 17). Water productivity was higher when both the crops were grown with drip or sprinkler system at 0.7 crop evapotranspiration (ET_c), although higher yield was recorded with irrigation at 1.0 ET_c (Table 44 and 45). Drip and sprinkler systems also resulted in low As accumulation in soil. Thus, it was concluded that mitigation of As toxicity in soil and plant system is largely possible through imposition of drip or sprinkler system.

This can be recommended to the farmers for higher crop and water productivity that will assure human health and environmental safety.

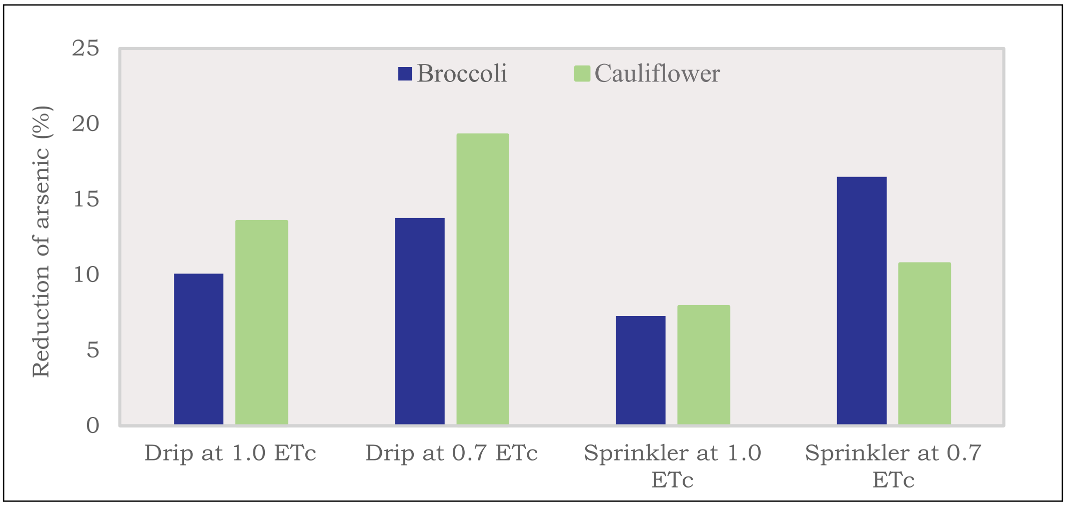


Figure 17. Reduction of arsenic accumulation in cauliflower and broccoli heads with microirrigation over surface irrigation

Table 44. Effect of drip and surface irrigation management on growth, yield and water productivity, arsenic content in soil at harvest and edible parts of broccoli and cauliflower

Treatment	Head diameter (cm)		Head yield (t ha^{-1})		Total water used (mm)		Water productivity (kg m^{-3})		Water saving (%)		Soil As (mg kg^{-1})		Head As (mg kg^{-1})	
	Broccoli	Cauliflower	Broccoli	Cauliflower	Broccoli	Cauliflower	Broccoli	Cauliflower	Broccoli	Cauliflower	Broccoli	Cauliflower	Broccoli	Cauliflower
Surface irrigation	15.17	13.08	16.27	20.54	420.5	410.46	3.87	5.01	-	-	8.22	7.84	0.44	0.38
Drip at 1.0 ET_c	15.34	12.72	17.11	22.56	315.5	352.34	5.42	6.40	24.9	14.16	7.25	6.68	0.39	0.33
Drip at 0.7 ET_c	14.53	11.78	14.91	19.38	256.8	290.52	5.81	6.67	38.9	29.22	6.84	6.48	0.38	0.31
LSD ($p \leq 0.05$)	0.72	0.56	1.51	1.59	-	-	-	-	-	-	0.84	0.42	0.09	0.07

Table 45. Effect of sprinkler and surface irrigation management on growth, yield and water productivity, arsenic content in soil at harvest and edible parts of broccoli and cauliflower

Treatment	Head diameter (cm)		Head yield (t ha^{-1})		Total water used (mm)		Water productivity (kg m^{-3})		Water saving (%)		Soil As (mg kg^{-1})		Head As (mg kg^{-1})	
	Broccoli	Cauliflower	Broccoli	Cauliflower	Broccoli	Cauliflower	Broccoli	Cauliflower	Broccoli	Cauliflower	Broccoli	Cauliflower	Broccoli	Cauliflower
Surface irrigation	14.64	12.16	15.53	19.85	410.48	420.82	3.78	4.72	-	-	6.84	8.14	0.41	0.35
Sprinkler at 1.0 ET_c	14.97	12.22	15.93	21.28	364.84	380.58	4.37	5.59	11.12	9.56	5.86	7.08	0.38	0.33
Sprinkler at 0.7 ET_c	13.62	11.24	14.63	18.12	284.62	254.12	5.14	7.13	30.66	39.61	5.74	6.68	0.34	0.32
LSD ($p \leq 0.05$)	0.66	0.55	1.05	1.46	-	-	-	-	-	-	0.57	0.54	0.03	0.02

8.2. Ayodhya

8.2.1. Improved water management practices in rice and wheat at head, middle and tail ends of Awanpur distributory

During 2019-20, on-farm research was carried out with objective of assessing improved and farmers' water management practices for rice varieties BPT-5204 and *Sarjoo*-52 during *kharif* season and wheat variety PBW-154 during *rabi* season. Fifteen farmers' fields were chosen at head (village Madhupur), middle (villages Panapur and Narayanpur) and tail (village Alwalpur) end of Awanpur distributory. Plot size of 1000 m^2 was taken for the experiment in every farmer's field.

Rice: Improved water management practice (T_1) i.e. application of 7 cm water at 1-4 days after disappearance of ponded water through check basin (10 m×10 m) was tested against farmers' practice (T_2) of applying 10-12 cm water by flooding/field to field irrigation. BPT-5204 and *Sarjoo*-52 being alike varieties with similar performance, average data of the two varieties has been reported. It was observed that improved water management practice resulted in higher average grain yield i.e. 5.11, 4.87 and 4.78 t ha^{-1} at head, middle and tail ends, respectively of Awanpur distributory compared to 4.10, 3.96 and 3.87 t ha^{-1}, respectively with farmers' practice (Table 46). Thus, yield increased in the range of 23.1-24.6% with improved practice. Increase in yield and water expense efficiency (74.17 kg ha-cm^{-1}) was highest at the head end, followed by middle and tail ends.

Wheat: Improved water management practice (T_1) i.e. application of 6 cm irrigation at critical stages (CRI, late jointing, milking stage) through check basin (5×10 m^2) method was tested against farmers' practice (T_2) of applying 8-10 cm irrigation through flooding/field to field irrigation. It was observed that improved water management practice resulted in higher average grain yield of wheat i.e. 4.24, 4.11 and 4.04 t ha^{-1} at head, middle and tail ends, respectively of Awanpur distributary compared to 3.39, 3.30 and 3.30 t ha^{-1}, respectively with farmers' practice (Table 47). Thus, yield increased in the range of 22.7 to 25.0% with improved water management practice. Increase in yield was higher at the head end compared to middle and tail ends of the distributary. Water expense efficiency (WEE) with improved water management was higher by 67.9-71.1% compared to farmers' practice.

Table 46. Performance of rice crop with improved water management at 15 farmers' fields at Awanpur distributary during *kharif* 2020

Treatment	Head end		Middle end		Tail end	
	Yield (t ha^{-1})	WEE (kg ha-cm^{-1})	Yield (t ha^{-1})	WEE (kg ha-cm^{-1})	Yield (t ha^{-1})	WEE (kg ha-cm^{-1})
T_1	5.11	74.17	4.87	70.70	4.78	69.37
T_2	4.10	39.46	3.96	38.08	3.87	37.24
Increase in T_1 w.r.t. T_2 (%)	24.64	87.96	23.10	85.66	23.52	86.27

Table 47. Performance of wheat crop with improved water management at 15 farmers' fields at Awanpur distributory during *rabi* 2019-20

Treatment	Head end		Middle end		Tail end	
	Yield (t ha^{-1})	WEE (kg ha-cm^{-1})	Yield (t ha^{-1})	WEE (kg ha-cm^{-1})	Yield (t ha^{-1})	WEE (kg ha-cm^{-1})
T_1	4.24	130.50	4.11	126.55	4.04	124.43
T_2	3.39	76.27	3.30	74.22	3.30	74.09
Increase in T_1 w.r.t. T_2 (%)	24.99	71.10	24.50	70.51	22.67	67.94

Rice and wheat crop is farmers' field of Awanpur distributory

8.2.2. Diversification of crops during *rabi* season under poor availability of canal water

During *rabi* 2019-20, on-farm research on diversified cropping system was carried out with the objective of assessing improved and farmers' water management practices for *rabi* crops viz., pea (*Rachna*), mustard (*Narendra Rai*-8501), chickpea (*Pusa*-362), wheat (PBW-154) and lentil (IPL-316). Ten farmers' fields were chosen at middle and tail ends of Awanpur distributory. Plot size of 1000 m^2 was taken for the experiment in every farmer's field.

Results envisaged that equivalent wheat yield (4.96 t ha^{-1}) under intercropping of mustard with chickpea was highest followed by pure stand of chickpea (4.45 t ha^{-1}) and intercrop of mustard with lentil (4.24 t ha^{-1}). The economics of different cropping systems (Table 48) clearly indicated that intercrop of mustard and chickpea accrued maximum net return of ₹73511 ha^{-1} and highest benefit-cost ratio of 4.34 followed by sole chickpea crop and intercrop of mustard and lentil which accrued net benefits of ₹63668 and 59598 ha^{-1} with benefit-cost ratios of 3.89 and 3.71, respectively.

Table 48. Performance of diversified cropping system at tail end of Awanpur distributory during *rabi* 2019-20

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		
Mustard	1.73	1.43	3.76	3.11	51390	3.45
Chickpea	1.91	1.52	4.45	3.54	63668	3.89
Lentil	1.89	1.51	3.93	3.14	53676	3.44
Pea	1.81	1.42	3.29	2.58	41238	2.87
Wheat	4.01	3.24	4.01	3.24	44693	2.38
Chickpea+Mustard	1.54+0.63	1.10+0.50	4.96	3.66	73511	4.34
Lentil+Mustard	1.50+0.52	1.19+0.48	4.24	3.51	59598	3.71
Pea+Mustard	1.11+0.72	0.97+0.68	3.58	3.24	46894	3.13
Wheat+Mustard	3.55+0.27	2.95+0.25	4.14	3.48	47168	2.45

Note: Unit price of wheat, mustard, chickpea, lentil and pea was ₹ 1925, 4200, 4500, 4000 and 3200, respectively

8.2.3. Multiple use of water through rice based integrated farming system including pisiculture and duckery at head and middle ends of Awanpur distributory

An intervention was done to develop existing village ponds for water harvesting, efficient use of harvested water for pisciculture and duckery and efficient use of harvested, canal and tubewell water for different cropping systems. Ponds owned by Sri Jai Ram Gaur of Bankegaon village at head end and Sri D.P. Singh of Pali Rosali village at middle end of Awanpur distributary were selected. These two ponds were renovated under MGNREGA and strengthened to store rainwater. Experiments during *rabi* 2019-20 were conducted using only harvested rainwater from the ponds. Crops were sown over an area of 0.80-0.85 hectare. Fish fingerlings were dropped by the farmers in August 2019. *Kharif* and *rabi* crops were grown in all the fields during 2019-20. Table 49 shows that integrated farming system with pisciculture was most productive and remunerative with total net return of ₹161985 ha^{-1} per year (65.20% higher return) and benefit-cost ratio of 3.63 compared to conventional farming system (net return ₹98052 ha^{-1}, benefit-cost ratio 2.51).

Table 49. Performance of integrated farming system and conventional system of cultivation with multiple use of harvested rainwater

Cropping system	Plot area (ha)	Crop yield (t ha^{-1})			Cost of cultivation (₹ ha^{-1})	Gross return (₹ ha^{-1})	Net return (₹ ha^{-1} $year^{-1}$)	B-C ratio
		***Kharif* 2020-21**	***Rabi* 2019-20**					
			Main	**Intercrop**				
1. Conventional system								
i) Rice-wheat+rai	1.0	4.48	3.38	0.36	65000	163052	98052	2.51
2. Integrated farming system (IFS)								
i) Rice-wheat+mustard	0.2	0.91	1.07	0.11	14200	42186	27986	-
ii) Rice-chickpea + mustard	0.2	1.10	0.39	0.20	11700	46400	34700	-
iii) Rice-lentil+ mustard	0.2	1.05	0.37	0.19	11700	42371	30671	-
iv) Rice-pea+ mustard	0.2	1.02	0.29	0.26	11550	40178	28628	-
v) Pisciculture	0.2	Fish	525 kg	-	12500	52500	40000	-
vi) Duckery	-	-	-	-	-	-	-	-
Total (IFS)	1.0	-	-	-	61650	223635	161985	3.63

Note: Unit price (₹ q^{-1}) of rice, wheat, chickpea, mustard, lentil, pea and fish was 1865, 1925, 4500, 4200, 4000, 3200; Unit price of fish was ₹ 100 kg^{-1}.

8.3. Jammu

8.3.1. Scaling up water productivity through modern irrigation technologies under PMKSY

The study was taken up with a goal of improving water use efficiency of fruit crops in canal command areas of Jammu under PMKSY project entitled "More crop per drop of water". The objectives of the study were to i) design low-cost water harvesting poly tanks for orchards in Jammu region, ii) design drip irrigation and fertigation layouts for fruit crops with different spacings, and iii) facilitate promotion of micro-irrigation by Directorate of Horticulture, Jammu among the orchard growers of Jammu region under PMKSY. Collaborative study between AICRP on IWM and Directorate of Horticulture, Jammu was done. Based on the study, it was suggested that the findings can be adopted for scaling up water productivity of fruit crops under PMKSY. The findings were further presented as recommendations to the Directorate of Horticulture, Jammu as listed below:

- Construction of polylined water harvesting tanks as water storage/ harvesting structures lined with silpaulin sheets of 250 gsm and covered with cement, sand and stone blocks in the ratio 1:7:2 at ₹1.0-1.25 L^{-1} of different capacities ranging from 50 to 250 m^3 or less than 50 m^3.
- Poly water harvesting tanks with trapezoidal shape of capacity less than 50 m^3, lined with 250 gsm silpaulin sheet covered with cement, sand and stone block in the ratio of 1:7:2 can be constructed at a cost of ₹1250 m^{-3} or ₹1.25 L^{-1} of water storage.
- On-line drip irrigation system for fruit crops with assured irrigation source for 1.0 ha at the cost (excluding 2 hp pump) ranges between ₹55000 to

60000 for 10 m × 10 m spacing, ₹75000 to 80000 for 6 m × 6 m spacing and ₹80000 to 85000 for 5 m × 5 m spacing including fertigation equipment (Table 50).

- On-line drip irrigation system for fruit crops with assured irrigation source for 0.5 ha at the cost excluding 2 hp pump ranges between ₹35000 to 40000 for 10 m × 10 m spacing, ₹50000 to 55000 for 6 m × 6 m and 5 m × 5 m including fertigation equipment (Table 50).

Promotion of on-line drip irrigation among the stakeholders of Jammu mainly fruit growers will improve productivity and give boost to their income. Moreover, water use efficiency will increase with more crop per drop under PMKSY.

Table 50. Proposed design specifications of drip irrigation system under different spacings and area coverage for fruit crops

S. N.	Area (ha)	Spacing (m)	No. of plants	Water requirement/ plant/ day with 10 mm evaporation (L day^{-1})	Water requirement (L ha^{-1} day^{-1})	Total no. of drippers required per ha (8 lph)	Lateral length (LDPE)- (16 mm) (m)	Lateral length (LDPE)- (12 mm) (m)	Sub-main length (PVC)- (m)	Main line (PVC) - (75 mm) (m)
1.	1.0	10 × 10	100	122	12200	400	1000	300	168	50
2.	0.5	10 × 10	50	122	6100	1200	500	150	84	30
3.	1.0	6 × 6	277	44.1	12250	1200	1800	900	168	50
4.	0.5	6 × 6	138	44.1	6125	600	900	450	84	30
5.	1.0	5 × 5	400	43	17200	1600	2600	1200	168	50
6.	0.5	5 × 5	200	43	8600	800	1000	600	84	30

Note: Some other specifications of drip irrigation system under different spacings and area coverage for fruit crops are as follows:- Number of drippers per fruit plant or tree in light textured soil will be 4 drippers of discharge rate 8 lph, size of pump 2.0 hp, screen filter (1 no.), throttle valve (1 no.), ARV (1 no.), hydro-cyclone filter (1 no.)

8.4. Belavatagi

8.4.1. Propagation of microirrigation to farmers in Malaprabha command

The technologies developed at IWMRC, Belvatagi, Navalgund have shown that field crops like maize, sunflower, chickpea, wheat, cotton, chilli, onion, safflower, etc. can be grown successfully through drip irrigation, while enhancing the water use efficiency. Further, this would result in 25-28% increase in yield besides saving the irrigation water to an extent of 30-40%. With this background the demonstration and propagation of microirrigation in the farmers' fields with farm ponds was taken up with the following objectives:

1. To overcome the acute shortage of irrigation water for cultivation of crops in the command area through adoption of micro irrigation technique.
2. To create awareness among the farmer community and line department personals about the efficient use of water by organizing on-farm and off-farm training activities.
3. To re-orient irrigation water management through participatory research cum demonstration suitable to Malaprabha command area.

Farm pond was constructed in fields under the project "Enhancing water use efficiency using micro irrigation systems in major crops in Malaprabha left bank canal command areas of northern Karnataka". During 2020-21, drip irrigation system was installed in 15 farmers' fields having good source of water with farm ponds. Effectiveness of drip irrigation will be evaluated in terms of increasing crop yield, water saving and water productivity and its economic feasibility in row crops by comparing with conventional method in the farmers' fields.

8.4.2. Assessment of sensor based drip irrigation system at Belavatagi centre

Sensor based automated drip irrigation system was installed in Irrigation Water Management Research Centre, Belavatagi. The system was installed as a refinement for normal drip irrigation system. The unit will operate and has a potential to supply irrigation to 24 acres of land. Studies on the effect of drip automation system for row crops in the region will be initiated, assessed and transferred in future.

Installation of drip automation unit

8.4.3. Assessment of groundwater recharge unit To address the issue of declining groundwater table in Belavatagi region, a groundwater recharge unit was installed in the research station. The objective was to assess the influence of groundwater recharge by double ring technique on the amount of recharge, groundwater quality and fluctuation. The cost of installing the recharge unit was ~ ₹25000. It was observed that the existing tubewell has been recharged with 3.35 lakhs litre of water through rainwater up to year 2020. After point recharge through seven recharge events, a considerable rise in the water table was observed from more than 100 feet below ground level to around 22 feet below ground level. Water quality assessment showed drastic reduction in electrical conductivity of groundwater from more than 10 dS m^{-1} to an average of 1.6 dS m^{-1}. Tubewell yield increased from 0.4 lps to around 2.4 lps.

Installation of groundwater recharge unit

8.5. Kota

8.5.1. Transfer of newly generated water management practices for wheat at farmers' field

During *rabi* 2019-20, field demonstration was carried out at nine locations of Manasgaon distributary of right main canal (RMC) and Andhed distributary in left main canal (LMC) to popularize newly generated water management technology for judicious use of water as per crop requirement, enhancing crop production at farmers' fields and maintaining soil health for sustainable productivity. Nine farmers' fields were selected, with three fields each at head, middle and tail ends of Manasgaon distributary of RMC. Another set of nine farmers' fields were selected, with three fields each at head, middle and tail ends of Andhed distributary of LMC. Therefore, total number of demonstrations was 18. Area under each demonstration at head, middle and tail ends of RMC and LMC was 0.1 ha. In the test blocks, four irrigations were applied at CRI, late tillering, flowering and milk stages of wheat crop. Irrigation depth was 6 cm and border strip method of irrigation with 80% cut-off ratio was followed. In the control block, wild flood irrigation system was followed by farmers. Farmers applied irrigation without consideration of physiological stages. Wheat crop var. *Raj*-4079 grown with improved water management showed 9.48 and 10.38% higher grain yield in test blocks (LMC and RMC, respectively) compared to the control blocks where farmers' practice of flood irrigation was followed (Table 51). In the demonstrations, water saving of 16 cm was obtained with improved water management practice over farmers' practice. Water expense efficiency in test block at both RMC and LMC were also higher, it was 15.94 and 15.62 kg ha-mm^{-1} as compared to control block of 9.82 and 9.70 kg ha-mm^{-1}, respectively (Table 52).

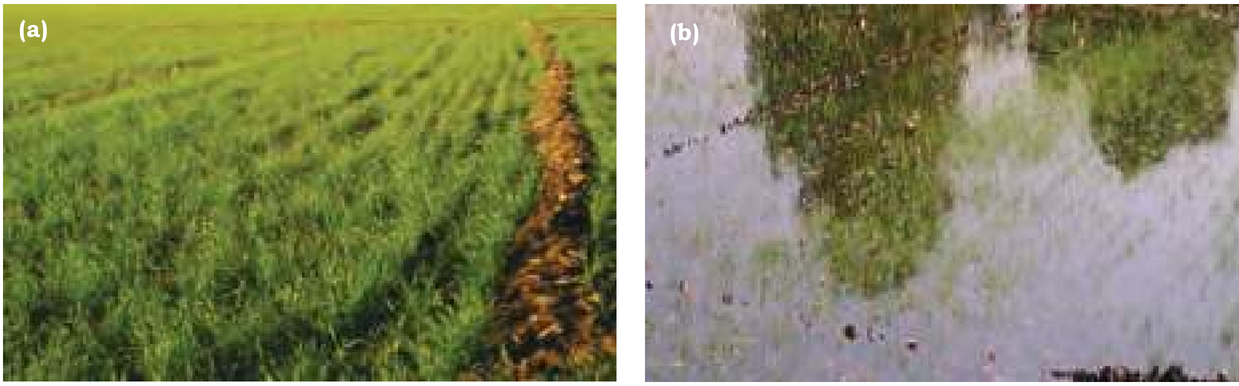
Table 51. Details of the demonstration area and yield of wheat at Andhed and Manasgaon distributaries

Location	Farmers	Area (ha)	Time of sowing	Time of harvest	Average grain yield (t ha^{-1})				Increase in yield (%)	
					Andhed		Manasgaon		Andhed	Manasgaon
					Test block (IWM)	Control block (WFI)	Test block (IWM)	Control block (WFI)		
Head reach	3	0.1	2nd week of Nov.	2nd week of April	5.53	5.01	5.61	5.09	10.38	10.21
Middle reach	3	0.1	3rd week of Nov.	2nd week of April	5.69	5.18	5.63	5.05	9.84	11.48
Tail reach	3	0.1	4th week of Nov.	2nd week of April	4.71	4.36	5.02	4.61	8.02	8.89
Mean	3	0.1	-	-	5.31	4.85	5.42	4.91	9.48	10.38

Note: IWM, improved water management; WFI, wild flood irrigation

Table 52. Performance of wheat under improved water management technology at Andhed and Manasgaon distributaries

S. No.	Particulars		*Rabi* 2019-20	
			Test block	Control block
1	Recommended irrigation practice		Four irrigations at CRI, late tillering, flowering and milk stage by border strip method (6 m × 50 m)	Farmers' practice (Flood irrigation)
2	No. of irrigations		4	4
3	Depth of irrigation applied (cm)		6	10
4	Total water applied (cm)		34	50
5	Saving of water over control (cm)		16	-
6	Grain yield (t ha^{-1})	(LMC) Andhed	5.31	4.85
		(RMC) Manasgaon	5.42	4.91
7	Increase in yield (%)	(LMC) Andhed	9.48	-
		(RMC) Manasgaon	10.38	-
8	Water expense efficiency (kg ha-mm^{-1})	(LMC) Andhed	15.62	9.70
		(RMC) Manasgaon	15.94	9.82

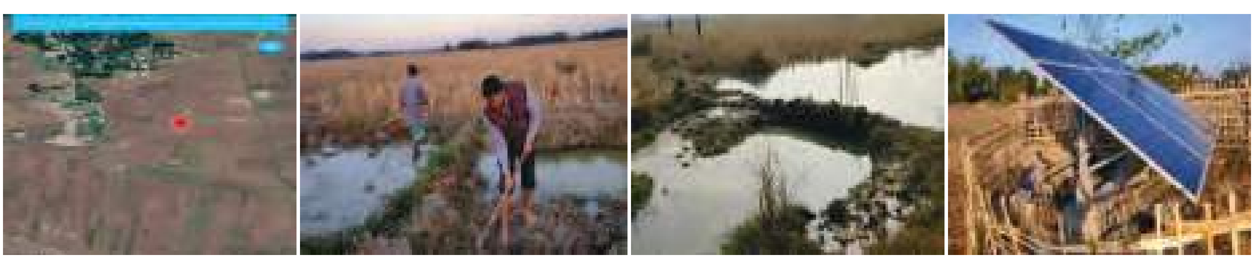


Wheat grown with (a) border strip method and (b) farmers' flood irrigation at farmer's field

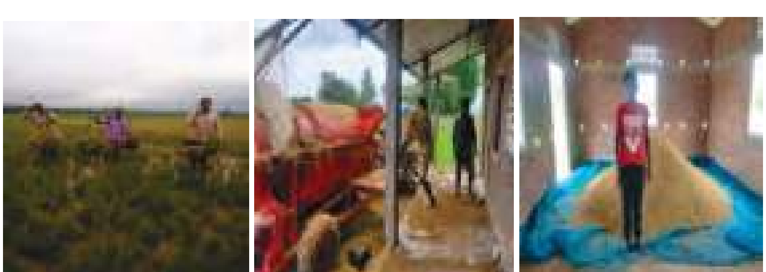
8.6. Jorhat

8.6.1. Effect of recommended water management practices on autumn rice in farmers' field

Cultivation of autumn (*ahu*) rice using diversion based irrigation water was done on 2.0 ha in Garmur village, Bokakhat, Golaghat district of Assam. The objectives were to demonstrate the effect of recommended water management practice on autumn rice in farmers' fields at multiple locations across Assam, to enhance irrigation water use efficiency of rice under recommended practice and save water on farm. Since the year of commencement i.e. 2000-01 various location have been covered under the demonstration. During 2019-20, autumn rice variety *Dishang* was taken up to demonstrate recommended irrigation practice i.e. 5 cm irrigation at 3 days after disappearance of ponded water. All other recommended agronomic practices for autumn rice were followed. Ten farm families were involved with the demonstration. Water from natural stream and deep tubewell was used conjunctively for irrigation. Water from natural stream was applied through diversion based irrigation. Total eight irrigations were given from the natural stream and three irrigations with groundwater from deep tubewell operated with solar pump. Results showed that rice grain yield was 4.60 t ha^{-1} with net return of ₹23,475.00 ha^{-1} and benefit-cost ratio 1.69. Total quantity of water used for irrigation was 550 mm ha^{-1} and irrigation water use efficiency was 8.36 kg ha-mm^{-1}.



Photographs showing google map location of natural stream at 26.6549° N 93.6396° E and diversion of stream water to crop field



Photographs showing harvest and post-harvest activities of autum rice

Media coverage on demonstration of improved irrigation at Garmur village, Golaghat district, Assam

8.6.2. Effect of recommended water management practices on summer rice in farmers' fields in shallow tubewell command

Summer (*boro*) rice variety *Kanaklata* was demonstrated to study the effect of recommended water management practice i.e. 5 cm irrigation at 3 days after disappearance of ponded water (DADPW) on rice productivity, water use efficiency and farmers' income. The demonstration was conducted covering 0.5 ha of farmers' field in Bokakhat, Golaghat district of Assam. Recommended improved water management practice was compared with farmers' practice, *i.e.*, continuous submergence. The demonstrations started in farmers' fields since 2000-01 to cover various locations and prove the efficacy of improved water management on summer rice in Assam. Crop was transplanted from 24.05.2020 to 25.01.2020 and harvested from 20.05.2020 to 24.05.2020. Biometric observations showed that grain yield was 5.50 t ha^{1} and water use efficiency was 6.47 kg ha-mm^{-1} with 5 cm water at 3 DADPW compared to yield of 4.2 t ha^{-1} andwater use efficiency of 3.40 kg ha-mm^{-1} with farmers' practice (Table 53).

Table 53. Effect of irrigation practices on summer rice at farmers' fields

Treatment	Grain yield (t ha^{1})	No. of irrigations	Total irrigation water applied (mm)	WUE (kg ha-mm^{-1})	Irrigation saving over farmers' practice
5 cm irrigation at 3 days after disappearance of ponded water	5.50	17	850	6.47	32.0
Farmers' practice (continuous submergence)	4.25	25	1250	3.40	-

8.6.3. Demonstration on irrigation management in tomato and brinjal in shallow tubewell command

Demonstrations were carried out at farmers' fields in different villages of Assam. This was 10th year of demonstration of improved irrigation practice on vegetable crops for improving yield and water use efficiency. Tomato and brinjal crops were grown in two *bigha* (0.26 ha) of land, one *bigha* was alloted for each crop. Improved irrigation practice i.e. 4 cm of irrigation was applied at 15-18 days interval on one half of the field, while farmers' conventional practice of irrigation, at 10 days interval, was applied in other half. Source of irrigation was groundwater through shallow tubewell.

In tomato, the demonstration was done at Ellengmara, Jorhat district, Assam. Hybrid tomato was planted from 16th to 20th December 2019 and harvested on 8th March 2020. All other recommended agronomic practices were followed. Results revealed that average fruit yield of tomato under improved irrigation practice was 24.50 t ha^{-1}, which was 19.51% higher than that of farmers practice (Table 54. The improved irrigation practice also saved 33.33% of irrigation water.

Table 54. Fruit yield and irrigation water use efficiency of tomato under demonstration at farmers' field in Neulgaon (Jorhat district), Assam

Treatment	Farmers' practice	Improved practice
Fruit yield (t ha^{-1})	20.50	24.50
Total irrigation water used (mm)	240.0	160.0
Irrigation water use efficiency (kg ha-mm^{-1})	85.42	153.13
	Increase in yield (%)	19.51
	Water saving (%)	33.33

In brinjal, demonstrations were carried out at farmers' fields in Neulgaon, Bokakhat district, Assam. Brinjal variety *Sangro* 33 was planted on 20th and 21st December 2019 and harvested on 14th March 2020. All other recommended agronomic practices were followed. Results revealed that average fruit yield of brinjal under improved irrigation practice was 24.50 t ha^{-1}, which was 32.43% higher than that of farmers practice (Table 55). The improved irrigation practice also saved 23.81% of irrigation water.

Table 55. Fruit yield and irrigation water use efficiency of brinjal under demonstration at farmers' field in Neulgaon (Jorhat district), Assam

Treatment	Farmers' practice	Improved practice
Fruit yield (t ha^{1})	18.50	24.50
Total irrigation water used (mm)	210	160
Irrigation water use efficiency (kg ha-mm^{-1})	88.10	153.13
	Increase in yield (%)	32.43
	Water saving (%)	23.81

8.7. Almora

8.7.1. Demonstration of microirrigation system

Microirrigation system was demonstrated at several farmers' fields to enhance water utilization efficiency by reducing conveyance and application losses. Drip system was installed over 5906.0 m^2 from the year 2012 to 2020. During 2020, drip system was installed on 100 m^2 in one farmer's field. The practical know-how was provided to the farmer including the maintenance of the drip system. The drip system was modified as per the farmer's suggestions and it is working very well.

8.7.2. Demonstration of LDPE film lined tank at farmers' field

The demonstration was conducted to motivate farmers of the hills to grow vegetables instead of cereal crops with appropriate water storage and efficient water utilization technologies. To meet the objective, micro-water recourses have been developed so far with total water capacity of 4127.9 m^3. During 2019-20, additional water capacity of 150 m^3 was developed in one farmer's field in Challar Mussauli village of Hawalbagh block, Almora district by harvesting water from a small stream (Table 56). Drip irrigation system was installed in 100 m^2 land of the farmer.

Table 56. Micro-water resource development at farmer's field

S.N.	Name of farmer	Village	Block	Volume of tank (m^3)	Remarks
1	Sri Mohan Singh (Matiyani)	Kasoon	Hawalbagh	50.0	Constructed under AICRP-IWM project
2	Nagar Palika (Almora site)	Near NTD	Hawalbagh	100.0	Constructed under AICRP-IWM project

Technical help by scientists of AICRP on IWM is being extended to farmers, state department officials, and other stake holders for the construction of tank. The technical help was extended to one of the farmers for repairing cement tank through poly cement tank technology. The cement tank was constructed in the year 2019-20 by utilizing assistance of fish department of state.

8.8. Morena

On farm irrigation water management experiments were conducted on the farmers' fields in Hadwansi, Santha, Sikraroda, Bhatpura, Silabata, Jatbarkapura, Baroli and Sirmiti villages of Morena district, Madhya Pradesh.

8.8.1. Assessment of precision land levelling on different cropping systems at head reach of canal command

Pigeonpea-wheat: The on-farm trial was carried out at five locations in the head reach of canal command for evaluating traditional method of levelling with precision land levelling by laser leveller and irrigation through border strip method in canal command area for pigeonpea-wheat cropping system. Extra early maturity variety of pigeonpea (*Pusa* 992) was grown during *kharif* 2020 with recommended dose of fertilizer (20-60-40 kg N, P_2O_5, 40 K_2O ha^{-1}) applied as basal and irrigated with canal water and groundwater as per crop requirement. Results showed an increase in pigeonpea seed yield by 21.4% and additional net return of ₹20932 ha^{-1} with improved practice compared to farmers' practice. Thus, newly developed technology helped the farmers to increase the production and profit (Table 57). Succeeding wheat crop (var. GW-322) grown during *rabi* 2019-20 showed higher grain yield and water productivity by 17.7% and 1.54 kg m^{-3}, respectively in plot with precision land levelling compared to farmers' practice. Similarly, net profit and benefit-cost ratio was also higher under the improved practice compared to farmers' practice.

Table 57. Effect of precision laser land levelling on crop yield and water productivity in pigeonpea-wheat cropping system at head reach of canal command

Particulars	Traditional land levelling		Laser land levelling	
	Pigeonpea	Wheat	Pigeonpea	Wheat
Nutrient applied (N:P:K:Zn kg ha^{-1})	20:60:40	120:50:30	20:60:40	120:60:40:5
No. and source of irrigation	1 groundwater + 1 canal water	4 (canal water) + 1 (groundwater)	1 groundwater + 1 canal water	4 (canal water) + 1 (groundwater)
Effective rainfall (mm)	399	72	399	72
Total water applied (mm)	142	283	125	233
Method of irrigation	Border strip	Border strip	Border strip	Border strip
Seed/grain yield (t ha^{-1})	1.72	4.24	2.08	4.99
Straw/stover yield (t ha^{-1})	5.63	4.83	5.89	5.62
Cost of production (₹ ha^{-1})	29960	31422	31580	33880
Gross return (₹ ha^{-1})	114150	100924	136702	118554
Net profit (₹ ha^{-1})	84190	69502	105122	84674
Benefit-cost ratio	3.81	3.21	4.33	3.50
Total water use (m^{-3} ha^{-1})	5146	3791	4921	3238
Water productivity (kg m^{-3})	0.33	1.12	0.42	1.54

Rice-wheat: Similar set up of experiment was also conducted at five locations of head reach of canal command under rice-wheat cropping system. Rice (var. *Pusa*-1509) crop grown during *kharif* 2020 showed 16.2% higher yield with laser land levelling (recommended practice, RP) compared to farmers' practice (FP) of traditional land levelling. The water productivity, net income and benefit-cost ratio were also higher with the improved practice compared with farmers' practice (Table 58). After harvest of rice crop, wheat (var. GW-322) was sown by zero seed drill machine during *rabi* season. Three irrigations were applied through canal water and remaining through groundwater. Results of the trial indicated that wheat grain yield increased by 11.8% in the laser levelled field, crop sown with zero seed drill and border strip irrigation compared to farmers' practice of traditional land levelling broadcasting of seeds and flood irrigation. Water productivity, net profit and benefit-cost ratio were higher with improved recommended practice compared to farmers' practice. The additional net profit of ₹22367 ha^{-1} was obtained with the improved practices over farmers' practices.

Table 58. Effect of precision laser land levelling on crop yield and water productivity in rice-wheat cropping system at head reach of canal command

Particulars	Traditional land levelling (FP)		Laser land levelling (RP)	
	Rice (*kharif*)	Wheat (*rabi*)	Rice (*kharif*)	Wheat (*rabi*)
Nutrient applied (N:P:K:Zn kg ha^{-1})	100:50:40	120:50:30	120:60:40:5	120:60:40
No. and sources of irrigation	Canal water + Groundwater	4 (Canal water)	Canal water + Groundwater	4 (Canal water)
Effective rainfall (mm)	329	72	329	72
Total water applied (mm)	420	286	350	246
Soil moisture depletion (mm)	-	23	-	19
Method of irrigation	Border strip	Flooding	Border strip	Border strip
Grain yield (t ha^{-1})	4.43	4.37	5.15	4.89
Straw yield (t ha^{-1})	5.61	4.82	6.14	5.22
Total cost of production (₹ ha^{-1})	35800	33280	37480	28895
Gross return (₹ ha^{-1})	89288	103383	103376	121365
Net profit (₹ ha^{-1})	74032	70103	65896	92470
Benefit-cost ratio	3.19	3.11	2.76	4.20
Total water use (m^{-3} ha^{-1})	7490	3810	6790	3370
Water productivity (kg m^{-3})	0.59	1.15	0.76	1.45

8.8.2. Assessment of rice establishment methods under rice-mustard crop rotation at mid reach of canal command

The on-farm trial was carried out at five locations in the mid reach of canal command comparing traditional method of planting with direct seeding of rice by zero-till seed drill in rice-mustard cropping system. It was observed that transplanted rice gave 12.6% higher grain yield over direct seeding (Table 59). Due to high cost of cultivation under transplanted rice, higher benefit-cost ratio was recorded in direct seeding over the transplanted crop.

Table 59. Comparative performance of transplanted and direct seeded rice

Table 59. Comparative performance of transplanted and direct seeded rice

Particulars	Transplanted rice	Direct seeded rice
Name of variety	Pusa-1509	Pusa-1509
Nutrient applied (N:P:K:S:Zn kg ha^{-1})	120:60:40:30:5	120:60:40:30:5
Sources of irrigation	Canal water + Groundwater	Canal water + Groundwater
Effective rainfall (mm)	329	329
Total water applied (mm)	460	285
Method of irrigation (cm)	Flood	Check basin
Grain yield (t ha^{-1})	5.39	4.79
Straw yield (t ha^{-1})	5.89	5.46
Total cost of production (₹ ha^{-1})	39600	29720
Gross return (₹ ha^{-1})	107578	95801
Net profit (₹ ha^{-1})	67978	66081
Benefit-cost ratio	2.72	3.22
Total water use (m^3 ha^{-1})	7890	6140
Water productivity (kg m^{-3})	0.58	0.78

8.8.3. Assessment of various methods of irrigation method through sowing methods in pearl millet-chickpea in tail reach of canal

The on-farm trial was carried out at five locations in the tail reach of canal command. During *kharif* 2020, farmers' traditional method of planting for pearl millet was compared with intercultural operation and water conservation in ridge and furrow. Sowing of pearl millet was done on ridge to drain excess rainwater and conserve the water. Ridge furrow maker was used to make ridge and furrow at 20 days after sowing. Ridge and furrow also facilitated intercultural operations. Results showed that improved practice led to increase the seed yield and water productivity by 22.1 and 32.3%, respectively (Table 60). Gross return, net return, benefit-cost ratio and water productivity were also higher with improved practice compared to farmers' practice.

Table 60. Comparative performance of pearlmillet in tail reach

Particulars	Farmers' practice	Improved practice
Name of variety	Hybrid	Hybrid
Nutrient applied (N:P:K:S:Zn kg ha^{-1})	80:40:20	80:40:20
Sources of irrigation	Canal + Tubewell	Canal + Tubewell
Effective rainfall (mm)	329	329
Irrigation water applied (mm)	138	115
Soil moisture addition (mm)	38	45
Method of irrigation (cm)	Flooding	Ridge furrow
Seed yield (t ha^{-1})	2.67	3.26
Stover yield (t ha^{-1})	6.82	7.05
Total cost of production (₹ ha^{-1})	24350	26765
Gross returns (₹ ha^{-1})	67635	74725
Net profit (₹ ha^{-1})	43285	47996
Benefit-cost ratio	2.90	2.79
Total water use (m^3 ha^{-1})	4290	3990
Water productivity (kg m^{-3})	0.62	0.82

After harvestion of pearl millet, succeeding chickpea was grown during *rabi* 2019-20. Chickpea crop (var. *Jaki*-9218) was irrigated with broad bed and furrow method as improved practice and compared with border strip method as farmers' practice. Broad bed and furrow irrigation method resulted in increased seed yield by 37.8% along with enhanced profit and water productivity compared to farmers' practice (Table 61). Therefore, adoption of newly developed irrigation technology can fetch higher yields and additional profit for the farmers.

Table 61. Comparative performance of chickpea in tail reach

Particulars	Farmers' practice	Improved practice
Name of variety	*Jaki* 9218	*Jaki* 9218
Nutrient applied (N:P:K:S:Zn kg ha^{-1})	20:40:20	20:60:30
Source of irrigation	Irrigation-1(Canal)	Irrigation-1 (Canal)
Effective rainfall (mm)	33.3	33.3
Irrigation water applied (mm)	80	51
Soil moisture depletion (mm)	64	55
Method of irrigation (cm)	Border strip	Broad bed and furrow
Seed yield (t ha^{-1})	1.66	2.28
Straw yield (t ha^{-1})	2.38	2.56
Total cost of production (₹ ha^{-1})	25230	24280
Gross returns (₹ ha^{-1})	85431	94420
Net profit (₹ ha^{-1})	60201	69590
Benefit-cost ratio	3.38	3.80
Total water use (m^3 ha^{-1})	1773	1393
Water productivity (kg m^{-3})	0.93	1.64

Chapter 9

Tribal Sub Plan and Scheduled Caste Sub Plan

9.1. Rahuri

9.1.1. Distribution of microirrigation sets to tribal farmers

Akole tahsil of Ahmednagar district, Maharashtra was selected for implementation of tribal sub plan (TSP) programme of AICRP on Irrigation Water Management as per the guidelines of ICAR. Survey was conducted for the tribal villages in Akole tahsil. Discussions were done among the project scientists, state govt. officials and farmers regarding implementation of TSP programme. The farmers expressed their needs about micro irrigation and knowledge gap for operation and maintenance of microirrigation.

Distribution of drip and sprinkler irrigation sets

For the distribution of drip and sprinkler irrigation sets, 100 farmers from seven tribal villages (Shelad, Vagdari, Dhamanvan, Paithan, Ghoti, Pimpri and Khadki bk.) of Akole tahsil of Ahmednagar district of Maharashtra were selected. These Scheduled Tribe farmers had very poor economic and social status. The drip and sprinkler irrigation sets were distributed (50 each) among farmers for growing cereals, vegetables, fruits, flowers and cash crops during *kharif* and *rabi* seasons. Impact analysis was done on adoption of drip and sprinkler irrigation systems of 100 farmers of Akole tahsil. The adoption of micro irrigation system enhanced the yield of *rabi* season crops by 23-80% through drip irrigation and 18-75% through sprinkler irrigation system, over traditional irrigation practice (Table 62); which ultimately enhanced the farmers income.

Table 62. Impact of microirrigation adoption on *rabi* crops in Akole tehsil

Crop	Total area (ha)	Yield (t ha^{-1})		Yield increment (%)	Income (₹ ha^{-1})	
		Traditional	Microirrigation		Traditional	Microirrigation
Drip irrigation						
Potato	3.55	1.00-4.00	1.35-5.10	23-67	6500-26000	8775-33150
Rajma	5.45	0.50-4.00	0.70-5.10	23-80	6500-30000	8775-40000
Marigold	0.20	2.00	3.00	50	30000-40000	40000-60000
Sprinkler irrigation						
Tomato	0.55	3.00-3.50	3.60-4.50	20-29	15000-17500	18000-22500
Onion	0.80	4.50-5.00	6.00-7.00	33-40	22500-25000	30000-35000
Wheat	8.00	0.35-0.90	0.45-1.20	18-63	7000-18000	9000-24000
Chickpea	2.60	0.19-0.30	0.23-0.41	21-75	7600-12000	9200-16400
Fodder maize	0.20	5.00	6.30	26	5000	6300

9.2. Pusa

9.2.1. Irrigation facility to a group of tribal farmers

A solar tree based irrigation system was been installed in village- Pachbania, P.O.- Tardiha, P.S.- Madhepur, District- Madhubani, Bihar under TSP programme. The system consists of a solar tree of capacity 5.0 kW and a tubewell with 5.0 hp submersible pump. The system will provide irrigation to 18 tribal farmer beneficiaries round the year at no cost. The benefit can be extended to another group of about 12 farmers using flexible pipes.



Irrigation facility through solar tree to tribal farmers of village-Pachbania of Madhubani district, Bihar

9.3. Udaipur

9.3.1. Use of drip irrigation in turmeric crop at farmer's field to improve the water use efficiency

The study area falls under agro-climatic zone IVA of southern Rajasthan which is having hilly and undulating topography. The soil type of the area is sandy loam whereas average annual rainfall is 670 mm. The turmeric is one of the important crops of the region grown in tribal area by the farmers as medicinal crop. The result of the study revealed that application of irrigation scheduled at 90% of ET_c with black silver mulch in turmeric gave maximum and significantly higher tuber yield (18.20 t ha^{-1}), as compared to rest of the treatments (Table 63). The maximum water use efficiency (2.27 kg ha-mm^{-1}) was also recorded in irrigation scheduled at 90% of ET_c with black silver mulch followed by irrigation scheduled at 80% of ET_c with black silver mulch (2.06 kg ha-mm^{-1}). Whereas, the maximum water productivity (0.208 kg m^{-3}) was recorded in treatment where irrigation scheduled at 70% of ET_c with black silver mulch followed by irrigation scheduled at 80% of ET_c with black silver mulch (0.188 kg m^{-3}).

Table 63. Effect of irrigation schedule and mulch on crop yield, water use efficiency (WUE), water productivity (WP) of turmeric crop

Treatment	Turmeric yield (t ha^{-1})				WUE (kg ha-mm^{-1})	WP (kg m^{-3})
	2018	2019	2020	Pooled		
Irrigation at 70% ET_c black silver mulch	15.6	16.3	16.1	16.00	2.00	0.208
Irrigation at 80% ET_c with black silver mulch	16.4	16.6	16.6	16.53	2.06	0.188
Irrigation at 90% ET_c with black silver mulch	17.5	18.6	18.5	18.20	2.27	0.182
Irrigation at 70% ET_c without mulch	14.4	14.2	14.3	14.30	1.78	0.186
Irrigation at 80% ET_c without mulch	14.7	14.3	14.6	14.53	1.81	0.165
Irrigation at 90% ET_c without mulch	14.8	14.6	15.1	14.83	1.85	0.148
Farmers' practice	15.7	16.3	16.5	16.17	2.02	0.147


Drip irrigation with black silver mulch in turmeric

9.4. Morena

9.4.1. Demonstration of improved water management practice in tribal farmers' fields

Demonstrations of improved water management practices in clusterbean, pigeonpea and greengram during *kharif* season and wheat, mustard and chickpea during *rabi* season were successfully conducted on scheduled tribal farmers' fields of Dangpura village. Improved package of practices of crops including irrigation scheduling as per recommendations of AICRP-IWM, RVSKVV-ZARS, Morena were compared to farmers' practice. The improved water management practices increased the yield of various crops grown in *kharif* and *rabi* season and farmers' income over their traditional irrigation practice (Table 64).

Table 64. Performance of crops with improved water management practice during *kharif* 2020 and *rabi* 2019-20

Technology	Crop	No. of beneficiary	Yield (t ha^{-1})		Cost of cultivation (₹ ha^{-1})	Net return (₹ ha^{-1})	B-C ratio
			Seed/ Grain	Straw			
Farmers' practice	Clusterbean	12	1.26	3.28	20630	31160	2.51
Improved practice			1.52	4.10	22980	39340	2.71
Farmers' practice	Pigeonpea	15	1.42	4.35	28960	64940	3.24
Improved practice			1.93	5.38	30560	96000	4.11
Farmers' practice	Greengram	22	0.48	1.28	18950	16871	1.89
Improved practice			0.69	1.45	19310	31792	2.65
Farmers' practice	Wheat	20	3.64	4.23	30320	60905	3.01
Improved practice			4.26	4.80	33260	67945	3.04
Farmers' practice	Mustard	25	1.41	3.86	23580	4263	2.81
Improved practice			1.83	4.64	25660	59958	3.34
Farmers' practice	Chickpea	25	1.32	1.68	25650	43060	2.64
Improved practice			1.79	1.90	26990	64073	3.37

Note: IP, improved package of practices including irrigation scheduling as per recommendations; FP, farmers' practice; Sale price of clusterbean seed was ₹ 3850 q^{-1} and stover ₹ 100 q^{-1} in local market; Minimum support price (MSP) for pigeonpea was ₹ 6000 q^{-1} and stover ₹ 200 q^{-1} in local market; MSP for greengram seed was ₹ 7196 q^{-1} and stover ₹ 100 q^{-1} in local market; MSP for wheat grain ₹ 1925 q^{-1} and straw ₹ 400 q^{-1} in local market; MSP for mustard seed ₹ 4,425 q^{-1} and stover ₹ 100 q^{-1} in local market; MSP for chickpea seed ₹ 4875 q^{-1} and stover ₹ 200 q^{-1} in local market

Demonstrations at farmers' field under TSP

9.4.2. Capacity building and extension activities

Extension activities were conducted by scientists of AICRP on IWM centre in TSP villages for enhancing water productivities (Table 65).

Table 65. List of extension activities carried out in TSP village during 2020

S. No.	Date	Title	Village	Participant
1.	1/06/2020	Irrigation water management methods	Shishpura	118
2.	19/08/2020	Irrigation water management in *kharif* crops	Dangpura	54
3.	1/10/2020	Irrigation water management in *rabi* crops	Chetikheda	59
4.	8/3/2020	Irrigation water management in *zaid* crops	Dangpura	109

9.5. Navsari

9.5.1. Distribution of irrigation pipes to tribal farmers of south Gujarat

The Navsari centre is representing south Gujarat, heavy rainfall agroclimatic zone of Gujarat. The eastern and southern boundaries of this zone have hilly terrains predominantly tribal belt. This area is distributed in some talukas of Navsari, Valsad and Dangs districts. During the current year (2020-21), Adada village in Navsari taluka of Navsari district was selected for demonstration. The selected farmers belonged to scheduled caste (SC) category having small land holding of 1.0 to 1.5 ha. Crops grown by the farmers are vegetables, sugarcane and rice and source of irrigation is borewell. Farmers convey irrigation water to their fields through open channels due to which there is conveyance loss of water as well as increase in labour requirement. In order to overcome this situation, meeting was held with a group of farmers and *Sarpanch* to convince to use irrigation pipes and adopt drip irrigation systems to save water. Eight farmers were selected for the demonstration, and irrigation pipes were provided for conveying water to their fields. Every farmer was provided with 12 irrigation pipes (diameter: 3 inch) of length 6 m and three bends. These irrigation pipes are adequate to cover 0.75 ha of land per farmer, thereby covering total 6.0 ha with irrigation pipeline. Survey will be conducted to study the impact of this irrigation system on conveyance losses and crop conditions. Farmers will be encouraged to adopt drip/sprinkler systems of irrigation using the irrigation pipes.

Distribution of irrigation pipes to farmers in Adada village, Navsari

9.6. Dapoli

9.6.1. Impact assessment of water management interventions in tribal areas of Konkan region using physical indicators

Impact assessment was done to create awareness of water management practices among tribal farmers of Konkan region. Objectives were to i) evaluate the impact of water management interventions in tribal areas of Konkan region using different physical indicators and ii) improve water use efficiency and water productivity of crops using harvested rainwater. As per the TSP program in these talukas, water management interventions like construction of *Jalkund* and plastic lined bandhara (*Konkan Vijay Bandhara*), sunken dyke for rainwater harvesting and low pressure drip irrigation system for precise utilization of water were done in these areas as per the suitability of location as well as farmers' need for interventions.

During 2019-20, tribal farmers were interviewed through the questionnaire and the results and success stories were presented for the approval of recommendation on *Jalkund* intervention study. Total 100 *Jalkund* were constructed that benefitted 100 tribal farmers commanding 10 ha area under mango and cashew in Jawhar taluka. Total 10 *Konkan Vijay Bandhara* were constructed benefitting 39 tribal farmers and commanding total area of 11.9 ha under vegetables, cashew, mango and jasmine cultivation in Vikramgad taluka (Table 66). Total 15 low pressure drip irrigation sets were planned for installation for jasmine crop on 15 farmers' fields in Vikramgad taluka during the year 2019-20.

Table 66. Water management interventions in tribal area during 2019-20

S. No.	Name of village	Number of units constructed	Number of beneficiaries (farmers)	Area commanded (ha)
Konkan Jalkund				
1.	Wadoli	12	12	1.20
2.	Pimpura	10	10	1.00
3.	Khambala	18	18	1.80
4.	Talasari	20	20	2.00
5.	Dabhosa	20	20	2.00
6.	Sakharshet	20	20	2.00
Total		**100**	**100**	**10.00**
Konkan Vijay Bandhara				
S. No.	**Name of village**	**Number of units constructed**	**Number of beneficiaries (farmers)**	**Area commanded (ha)**
1.	Kegawa Nandanpada	01	07	3.63
2.	Kegawa Barafpada	04	12	4.45
3.	Balapur Patilpada	01	04	1.61
4.	Sawarai	03	12	1.40
5.	Kasa Budruk	01	04	0.80
Total		**10**	**39**	**11.89**

The status of water management interventions in tribal areas of Konkan region from 2012-13 to 2019-20 are presented in Table 67 and 68. Total 759 Jalkund were constructed in Mahad taluka of Raigad district and Jawhar, Vikramgad & Mokhada talukas of Palghar district. Total 429 farmers were benefitted from this intervention during last eight years. Thus, total 75.9 ha was brought under irrigation through this rainwater harvesting technology. Total 34 *Konkan Vijay Bandhara* were constructed in 15 villages of Mandangad taluka of Ratnagiri district, Mahad taluka of Raigad district, and Jawhar, Vikramgad & Mokhada talukas of Palghar district. Irrigation facility was created for *rabi* crops on 139.2 ha benefitting more than 198 farmers during last seven years. Most of the farmers are growing seasonal vegetables, jasmine, cashew and mango.

Table 67. Details of *Jalkund* construction, beneficiaries and area commanded from year 2013-14 to 2019-20

Location	Jalkund constructed during last 6 years			
	Villages covered (No.)	Jalkund (No.)	Beneficiaries (No.)	Area commanded (ha)
Mahad taluka, Dist. Raigad	06	180	90	18.0
Jawhar taluka, Dist. Palghar	14	265	182	26.5
Vikramgad taluka, Dist. Palghar	20	172	86	17.2
Mokhada taluka, Dist. Palghar	18	142	71	14.2
Grand Total	**58**	**759**	**429**	**75.9**

Table 68. Details of *Konkan Vijay Bandhara* construction, beneficiaries and area commanded from year 2012-13 to 2019-2020

Location	*Konkan Vijay Bandhara* constructed during last 7 years			
	Villages covered (No.)	Bandhara (No.)	Beneficiaries (No.)	Area commanded (ha)
Mandangad taluka, Dist. Ratnagiri	02	04	28	29.0
Mahad taluka, Dist. Raigad	01	02	05	2.0
Jawhar taluka, Dist. Palghar	06	16	70	20.0
Vikramgad taluka, Dist. Palghar	04	08	55	50.2
Mokhada taluka, Dist. Palghar	02	04	40	38.0
Grand total	**15**	**34**	**198**	**139.2**

9.7. Palampur

9.7.1. Distribution of microirrigation kits and construction of water harvesting tank

Tribal Sub Plan: During 2019-20, twenty-five drip irrigation kits were distributed and installed for demonstrations in tribal farmers' fields. About 250 m^2 area was covered under every kit.

Scheduled Caste Sub Plan: A polyline water harvesting tank with drip irrigation system was established. Monsoon rainwater was harvested, and used for field demonstration of various crops.

9.8. Parbhani

9.8.1. Distribution of microirrigation kits and construction of water harvesting tank

Need based agricultural interventions for enhancing crop productivity on scheduled caste farmers' field: The intervention was carried out to enhance crop productivity and sustainable livelihood security of scheduled caste farmers. The Manwat taluka of Parbhani district experiences drought like situation once in three years. Protective irrigation in *kharif* and judicious use of available water for irrigation through advanced irrigation technology is necessary. Therefore, Bhosa village of Manwat taluka, Parbhani was selected with consultation of agricultural scientists of VNMKV, Parbhani to demonstrate the benefits of sprinkler irrigation under rainfed condition for sustainable crop production. The selected village Bhosa is a medium size village. The participatory rural appraisal survey conducted at the village revealed that the scheduled caste farmers are not using the existing advanced irrigation systems due to poverty and lack of knowledge. In accordance with this, it was decided to provide the sprinkler irrigation set for efficient use of water resources for sustainable crop production.

Distribution of sprinkler irrigation system: Sprinkler irrigation sets were distributed to the scheduled caste farmers of Bhosa village. On this occasion, six sprinkler irrigation sets were distributed by the Honourable Vice Chancellor and Director of Research, VNMKV, Parbhani. On this occasion *kisan mela* was also organized to guide the farmers regarding operation of sprinkler irrigation system.

9.9. Kota

9.9.1. Distribution of sprinkler irrigation sets and demonstration of sprinkler irrigation on wheat

It was done in two villages namely, Karvarikhurd and Gordhanpura from Kishannganj tehsil, Baran district, Rajasthan. Total 37 ST farmers of Saharia tribe were selected as beneficiaries, out of which 14 farmers were given sprinkler irrigation sets and 23 farmers were given HDPE pipeline for enhancing crop and water productivity of wheat.

During *rabi* 2019-20, total 57 demonstrations on wheat crop were conducted to show the impact of improved water management technologies using conveyance and lifting of water by using HDPE pipelines and applying sprinkler irrigation. Out of these, 20 demonstrations were on method of irrigation and irrigation at critical stages of wheat crop in Garda command and non-command areas; 23 demonstrations were on wheat crop on conveyance and lifting of water by using HDPE pipeline for irrigation at critical stages for enhancing crop and water productivity and 14 demonstrations on wheat under sprinkler irrigation for enhancing crop and water productivity in tribal villages of Karvarikhurd and Govardhanpura.

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. In demonstration block, three irrigations were applied at CRI, late tillering and milking stages by border strip method (5 m × 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}, respectively) and weed management (metsulfuron methyl @ 4 g ai ha^{-1}) for wheat. In control block, irrigations were applied by flooding method without considering critical growth stages and recommended practices of nutrient and weed management. It is evident from Table 69 that mean grain yield of wheat was 9.97% higher in demonstration block (4.63 t ha^{-1}) than that (4.21 t ha^{-1}) in block under farmers' practice at tribal belt of Baran district village Karvari Khurd under TSP programme. Water expense efficiency (16.53 kg ha-mm^{-1}) was also higher in the test block compared to the control block (10.52 kg ha-mm^{-1}).

Table 69. Effect of improved water management practices on performance of wheat in Garda command

Particulars	*Rabi* 2019-20	
	Demonstration block	Control block
Recommended irrigation practices	POP and improved water management	Farmers' practice
No. of irrigations	3	3
Total water applied (cm)	28	40
Grain yield (t ha^{-1})	4.63	4.21
Increase in yield (%)	9.97	-
WEE (kg ha-mm^{-1})	16.53	10.52

Note: Grain yield is average value of 10 demonstrations; POP, package of practices; WEE, water expense efficiency

Demonstration of border strip method of irrigation for wheat in Garda command area

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 the Saharia tribal belt. Source of irrigations was tubewell. In demonstrations block, three irrigations were applied by border strip method at CRI, flowering and milking stages using 6 cm depth along with recommended practices of nutrient (N_{120}, P_{60} & K_{40} kg ha^{-1}, respectively) and weed management (metsulfuron methyl @ 4 g ai ha^{-1}). Farmers of tribal belt applied irrigations @ 8 cm depth without consideration of critical stages. Table 70 shows that improved water management practice produced 10.94% higher yield compared to farmers' practice (4.02 t ha^{-1}). Water expense efficiency (15.66 kg ha-mm^{-1}) was also higher in the demonstration block compared to the control block (11.92 kg ha-mm^{-1}).

Demonstration of improved water management for wheat in non-command area

Table 70. Effect of improved water management practice on performance of wheat in non-command area

Particulars	*Rabi* 2019-20	
	Demonstration block	Control block
Recommended irrigation practices	Recommended POP & improved water management practices	Farmers' practices
No. of irrigations	3	3
Total water applied (cm)	28	34
Grain yield (t ha^{-1})	4.46	4.02
Increase in yield (%)	10.94	-
Water expense efficiency (kg ha-mm^{-1})	15.92	11.82

Note: Grain yield is average value of 10 demonstrations; POP, package of practices

3. Demonstrations on wheat for improving water productivity by using HDPE pipeline

In demonstrations block, three irrigations were applied using border strip method at CRI, flowering and milk stage by carrying water through pipeline from local river. Farmers of tribal belt faced problem of scarcity of water and they were paying irrigation charges at ₹4150 ha^{-1} irrigation from the neighbour farmer having tubewell. In this connection, HDPE pipe line was provided to the farmers on co-operative basis for increasing crop as well as water productivity. Data shown in Table 71 revealed that an improved water management practice gave grain yield of 4.51 t ha^{-1} and net return of ₹74893 ha^{-1} under demonstrations block which were 9.20 and 37.79% higher as compared to control block (farmers' practice), respectively. Water productivity was also found higher in test block (₹26.7 m^{-3}) as compared to control block (₹13.59 m^{-3}).

Table 71. Effect of improved water management practices on grain yield and water productivity of wheat in tribal area

Particulars	*Rabi* 2019-20	
	Demonstration block	Control block
Recommended irrigation practices	T_1: Water carrying from the local river and irrigation at critical stages	T_2: Farmers' practice
No. of irrigations	3	3
Grain yield (t ha^{-1})	4.51	4.13
Increase in yield (%)	9.20	-
Net return (₹ ha^{-1})	74893	54353
Net water productivity (₹ m^{-3})	26.74	13.59

Note: Grain yield is average 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) was ₹ 24900 ha^{-1} @ ₹ 825 ha^{-1} per irrigation for water lifting and ₹ 650 ha^{-1} per irrigation for labour and ₹ 3000 as fixed cost; Treatment cost (T_2) was ₹ 35200 ha^{-1} @ ₹ 4150 ha^{-1} per irrigation paid by farmer and ₹ 650 ha^{-1} per irrigation for labour

Irrigation water carried through pipelines from local river

4. Demonstration on wheat under sprinkler irrigation in tribal area

Fourteen sprinkler irrigation demonstrations on wheat crop were conducted in tribal villages of Karvarikhurd and Gordhanpura during *rabi* 2019-20 to evaluate performance of sprinkler irrigation in wheat. In the demonstration (test) block irrigations, sprinkler irrigation was applied with recommended package of practices (N_{120},P_{60},K_{40} kg ha^{-1}) whereas in control block irrigations were applied by flooding taking water from neighbouring fields @ ₹4150 ha^{-1} without implementing recommended package of practices. One year data (Table 72) revealed that mean grain yield (4.92 t ha^{-1}), net return (₹81760 ha^{-1}) and water productivity (₹29.20 m^{-3}) observed under the test block were higher as compared to control block.

Sprinkler irrigation demonstration of wheat in Saharia tribal area

Table 72. Effect of sprinkler irrigation on grain yield and water productivity of wheat

Particulars	*Rabi* 2019-20	
	Demonstration block	Control block
Recommended irrigation practice	T_1: Performance of sprinkler irrigation system	T_2: Farmers' practice
No. of irrigations	3	3
Grain yield (t ha^{-1})	4.92*	4.49*
Increase in grain yield (%)	9.57	-
Net return (₹ ha^{-1})	81760	62783
Net water productivity (₹ m^{-3})	29.20	15.70

Note: Grain yield is average value of 14 demonstrations; Common cost of cultivation = ₹ 16000 ha^{-1}; Sale price of wheat = ₹ 18.40 kg^{-1} and straw ₹ 2.50 kg^{-1}; Treatment cost (T_1) is ₹ 24200 ha^{-1} @ electricity charge of ₹ 650 ha^{-1} per irrigation and ₹ 650 ha^{-1} per irrigation for labour and ₹ 3000 as fixed cost; Treatment cost (T_2) is ₹ 35200 ha^{-1} @ ₹ 4150 ha^{-1} per irrigation

Therefore, the scientific interventions for improving wheat crop and water productivities at villages Karvarikhud and Gordhanpura of Kishanganj tehsil of Baran district under Garda command during 2019-20 is summarized in Table 73.

Table 73. Achievements from field demonstration during 2019-20 (up to June 2020)

S. No.	Block/ Village	Location specific technologies	Name/ No. of farmers	Total area demonstrated (ha)	Benefitted area (ha)
1	Gordhanpura	Recommended POP for wheat and improved water management technology in Garda command	10	1.0	3.5
2	Gordhanpura	Recommended package of practices for wheat in non-command area of Baran district	10	1.0	3.5
3	KarvariKhurd	Water lifting device from local river	23	2.5	5.0
4	KarvariKhurd	Introduction of sprinkler irrigation	6	0.6	1.2
5	Gordhanpura	Introduction of sprinkler irrigation	8	0.8	1.6

9.10. Coimbatore

9.10.1. Demonstration and training on microirrgation system and acid treatment of soils

Scientists of AICRP on IWM Coimbatore centre conducted field demonstrations and trainings to scheduled caste farmers of Pethikuttai (Coimbatore), Chittampatti and Ayyanarpuram (Madurai), and Bhavanisagar under scheduled caste sub plan (SCSP) programme on various aspects like drip and sprinkler irrigation systems, acid treatment of soils in farmers' fields before cultivating crops.

Training and demonstration conducted under SCSP programme

Chapter 10

Technology Assessed, Refined and Transferred

10.1. Pusa

10.1.1. Design and evaluation of drainage cum recharge structure under north Bihar condition

The alluvial plains of Bihar have potential aquifers with ample source of water for groundwater recharge. But these plains are facing accelerated groundwater draft over the last couple of decades. Besides this, groundwater decline, waterlogging and lack of drainage facility delays sowing of *rabi* crop leading to poor performance of crops. Groundwater recharge can be done using surplus runoff water available during the monsoons. A drainage cum recharge structure was developed for farmers of south Bihar as well as farmers of *Taal* and *Chaur* lands facing the above issues.

In 2020, six drainage-cum-recharge units have been constructed in university campus of DrRPCAU, Pusa. One recharge unit was installed at KVK, Piprakothi, East Champaran and tested for three years. Five more recharge units will be tested in the coming year. The technology of groundwater recharge unit was released on 11.06.2020 by the 8th research council of DrRPCAU, Pusa. More than three recharge units are being constructed in the farmers' fields at different places. In this technology, the second aquifer is the target aquifer, recharge capacity of 22000-24000 lph, solid removal efficiency of 80-82%, recharging depth of 45-55 m and annual groundwater recharge potential of 2.0-2.5 ha-m. Major components of the structure are stilling basin, siltation tank, recharge filter and boring.

The major scope of this technology includes effective drainage from waterlogged area of agricultural fields during monsoon season; early vacating of field for timely sowing of *rabi* crops; augmentation of groundwater resources; and development of water positive zone.


Drainage cum groundwater recharge unit

Farmers' experience: Sukhet village is located in Jhanjharpur tehsil of Madhubani district, Bihar. The village has a geographical area of 503.4 ha with population of 5,792. This region is known for its recurrent floods due to its river system and bowl-shaped depression, so the water gets stagnated in the region for longer time. Flood starts in July and many fields remain submerged till March. Rice is harvested in a waterlogged condition. The sowing of *rabi* crops is limited to very small area due to waterlogging. There is no wheat sowing in most parts and late sowing in some parts of the village. Drainage cum recharge unit was installed in a farmer's field of Sukhet village. This intervention resulted in timely drainage of stagnated water through the structure and the land was vacated in the last week of November making it available for timely sowing of *rabi* crops after many years.

10.1.2. Irrigation through community tubewells

Bihar state is facing severe challenges in climatic events like flood, drought, extreme temperature and terminal heat for *rabi* crops from last several decades, impacting agricultural production and the socio-economic condition. The major food demand of the state is met through the rice-wheat cropping system contributing about 77.37% of the total food grain production from around 70% of the gross cropped area but unfortunately, the productivity of both the crops is far below the national average, reason being climatic stresses. The average productivity of rice in Bihar is just 2.5 t ha^{-1}, that too, with a decreasing compound agricultural growth rate of -3.61% owing to erratic rainfall, increased frequency and duration of dry spells and early withdrawal of monsoon. The major source of irrigation is groundwater extracted by diesel pump set. Rural electrification has peaked up in the state, but the quality of power supply (in terms of stable voltage) is still an issue. Due to unstable power supply, 3-phase electric pumps could not be utilized by the farmers and still they are dependent on the diesel pumping sets. High cost of irrigation coupled with late onset of monsoon are the major factors that compel the farmers for late sowing and late transplanting, thereby impacting different phenological events. Not only this, the delay in sowing of rice affects succeeding wheat crop and it has been found that when wheat is sown beyond November, it is affected by terminal heat during its flowering-milking stage when temperature goes above maximum threshold of 27^{0}C. At the same time, the late sown wheat crop is generally affected by strong hailstorms in the month of April which has become very common in the state during past few years due to recent climatic changes. Thus, the concept of single phase 3 hp submersible pump took shape which extracted water at affordable cost with existing electricity supply conditions. The submersible pumps are considered to be the most efficient pumping systems as far irrigation is concerned. Switching from high capacity 3-phase submersible pumps which could not be operated due to fluctuation of voltage in one or the other phase, the single phase pumps were promoted which are available with maximum power rating of 3 hp.

After successful trials of this concept in university farms, it has been taken to farmers' field at 17 locations through an innovative community irrigation approach. With the financial support of Climate Resilient Agriculture Programme of the State of Bihar, 17 tubewells (100 mm diameter) equipped with 3-hp single phase submersible pumps each costing around 1.6 lakhs, were installed in 17 adopted villages in 11 districts, each having a command area of 12-15 acre. The detailed information related to installation of tubewells is presented in Table 74. A group of 10 to 20 farmers from each village was formed with an agreement that all participating farmers will have an equal right and equal opportunity to avail the irrigation facility as and when needed by the crop. The team of scientists of AICRP on Irrigation Water Management and the Centre of Excellence on Water Management of DrRPCAU is contributing and supervising the community irrigation tubewell programme with the help of Krishi Vigyan Kendra of the district.

Table 74. Detailed information of community tubewells installed at different locations of north Bihar

S. No.	District	Village	Number of beneficiaries	Area (acre)
1	Gopalganj	Vill: Sipaya, Block: Kuchaikote	15	15
		Vill: Baraipatti, Block: Gopalganj	20	20
2	Begusarai	Village: Badkurwa, Post- Vikrampur, Cheriya Bariyarpur	30	20
3	Muzaffarpur	Vill: Dwarikanathpur, Post–Karja, Block-Madwan	75	50
		Vill: + P.O. Patsara	20	25
4	West Champaran	Vill: Mirjapur, Madhopur	15	15
		Vill: Samhuta, Narkatiaganj	15	15
5	Sitamarhi	Vill: Chainpura	56	72
6	Madhubani	Vill: Bisaul, Post–Sukhet, Block-Jhanjharpur	23	20
7	East Champaran	Vill: Bhatoli, Parsauni	30	25
		Vill: Belwatiya, Block- Piprakothi	14	14
8	Saran	Vill: Majhwalia, Block- Jalalpur	09	15
		Vill: Dharhara, Block- Manjhi	15	20
9	Sheohar	Vill: Khairwadaro, Katsari Road	15	15
		Vill: Lalgarh, Madhuban Tariyani Road	20	20
10	Darbhanga	Vill+Post- Ratanpur, PS-Kamtaul	20	20
		Sundar Das, Vill+Post- Ratanpur, PS-Kamtaul	15	15
11	Siwan	Kaladumra, Goreakothi	15	15
		Maharajganj, Siwan	50	40
		Bhopatpur Bhartiya, Lakrinabiganj	25	25
	Total		**497**	**476**

Village-Sikatiya, Dist. Siwan

Village- Kaladumra, Dist. Siwan

Village- Bisaul, Sukhet, Dist.- Madhubani

Village- Chainpura, Dist. Sitamarhi

Glimpses of the 3 hp single phase tubewells installed at different locations in farmers' field

10.2. Kota

10.2.1. Impact assessment of recommended package of practices on *rabi* crops at left and right main canal sites of Chambal command

Under ORP, impact assessment study was conducted for the *rabi* crops grown at both left main canal (LMC) and right main canal (RMC) sites of Chambal command area. Survey was done on 100 farmers' fields during 2019-20 as summarized in Table 75. In *rabi* season, major crops grown are wheat, mustard, chickpea and coriander while soybean, urdbean, rice and maize are grown during *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 applying inputs in excess as per the recommendation. The percentage of adoption of recommended package of practices especially with respect to cultural practices i.e. proper planting geometry and seed rate are not in use by the farmers' whereas, depth of irrigation water applied, method of irrigation, application of zinc and potash, use of herbicide in wheat and rice and 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, regarding application of nitrogeneous fertilizer, more than 63.1% farmers have adopted recommendations in all the crops except soybean where the adoption is only 11.3-12.1% (Table 75). In wheat, mustard and rice, 41.8 to 76.3% farmers are using recommended number of irrigations but in soybean only about 13.1-14.4% farmers are using recommended number. Due to availability of canal water only 18.4-30.4% farmers are following the recommended depth of irrigation and 29.9-34.4% are following recommended method of irrigation. However, farmers have started using border strip method of irrigation due to worthy results of improved water management technology.

Table 75. Adoption rate of recommended package of practices for different crops in ORP area under left main canal (LMC) and right main canal (RMC) during 2019-20

Package	Adoption (%)							
	Rabi season 2019-20							
	Wheat		Mustard		Chickpea		Coriander	
	RMC	LMC	RMC	LMC	RMC	LMC	RMC	LMC
Improved seed & seed rate								
Variety	71.2	70.4	87.2	84.6	65.6	46.2	72.3	72.4
Seed rate	36.2	38.41	45.2	42.1	38.9	41.4	48.9	46.5
Organic manure & fertilizers								
Organic manure	9.8	9.1	-	-	-	-	-	-
Nitrogen	68.9	66.4	68.2	67.8	24.5	23.4	74.2	69.5
Phosphorus	62.5	63.4	58.3	59.4	38.9	36.5	66.8	69.7
Potash	9.6	8.4	-	-	-	-	-	-
Sulphur	3.5	4.2	38.4	37.6	-	-	62.4	65.4
Zinc	8.9	9.4	-	-	-	-	11.2	10.8
No. of irrigations at critical stages, depth (50-60 mm) and method (border strip method)								
No. of irrigations	64.2	63.2	42.5	40.8	16.2	18.4	34.5	36.7
Depth of irrigation	25.7	28.6	31.2	28.6	18.4	19.2	31.2	30.8
Method of irrigation	36.4	34.5	28.6	32.6	24.6	25.3	38.7	36.9
Weed management (Post-emergence in wheat and pre-emergence in mustard, chickpea & coriander)								
Herbicide weed control	32.6	33.4	11.4	13.5	10.8	12.6	16.8	18.2

Extension activities and transfer of technologies in farmers' field: 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. Eighteen field demonstrations on wheat crop were conducted out of which 6 at head, 6 at middle and 6 at tail reaches of the selected distributaries of Andhed and Manasgaon. The project scientists regularly give advice to the Govt. officers for improved and innovative water management technologies. In addition to this, the scientists have delivered lectures on soil, water and new irrigation methods to line department field staff. The project scientists also participated in agriculture technology fairs and disseminated improved water management technologies through All India Radio School. Technologies undertaken by AICRP on IWM scientists of Kota center is listed in Table 76.

Table 76. Technologies undertaken for dissemination at farmers' fields

Crop	Technologies
Wheat, mustard, chickpea and coriander	Border strip method of irrigation (5 m x 50 m) with 80% cut- off ratio
Wheat, mustard, chickpea and coriander	Irrigation at critical stages: Wheat: CRI, late tillering, flowering & milking Mustard: branching, flowering & pod development Chickpea: flowering and pod development Coriander: late vegetative stage and umbel formation
Rice	Irrigation of 5-7 cm depth of irrigation at 1-3 days after disappearance of ponding water
Rice	System of Rice Intensification (SRI): Saturated condition by intermittent light irrigation upto panicle initiations and then shallow standing water
Wheat, chickpea, coriander	Sprinkler and mini-sprinkler irrigation
Garlic, onion	Mini-sprinkler irrigation

10.3. Chalakudy

10.3.1. Technology accepted in the package of practices recommendation of KAU

Study on open field precision farming in Nendran banana has revealed that common fertilizer and high priced water-soluble fertilizer performed similar. Water-soluble cheaper source of fertilizer can be recommended in place of high priced fertilizer. In fertigation fertilizer quantity can be reduced to 75%. 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 plant^{-1} instead of the present 115 g plant^{-1}. Reducing the level of P below 75% reduced the yield considerably.

Farm trials: Results of the experiment conducted for three years were presented in the Zonal Research Extension Advisory Committee of the Kerala Agricultural University (Table 77). They proposed to conduct multi location field trials. Three farmers were identified and field trials were conducted in three different districts *viz.*, Thrissur, Ernakulam and Palakkad. The modified soil test based recommendation gave the highest banana yield in Palakkad, whereas maximum yield of banana was found in recommended package of practice and modified recommendation at Thrissur and Eranakulam, respectively. These results of the farm trial were presented in the Zonal Research Extension Advisory Committee of the Kerala Agricultural University.

Multi-location farm trials of banana

Table 77. Banana yield (t ha^{-1}) obtained from different farm trials in three districts of Kerala

Treatment	Palakkad	Palakkad	Thrissur	Ernakulam
Recommended package of practice	9.23	10.13	11.96	12.1
Modified recommendation	9.77	10.67	11.68	15.1
Soil test based recommendation	9.5	10.23	10.68	13.7
Modified soil test based recommendation	11.16	11	11.10	13.97

10.3.2. Standardization of open field precision farming in banana (revalidation)

Study was conducted to standardise the level of irrigation and fertilizer doses under open field precision farming in banana using common water soluble fertilizers such as urea, ammonium phosphate sulphate and muriate of potash. The treatments included three levels of drip irrigation at 60% , 80% and 100% PE, three doses of fertilizers at 75%, 100% and 125% RDF, with and without plastic mulching (Table 78). Observations on yield parameters were recorded. It was noticed that, irrigation at 100% PE and fertilizer application at 125% RDF without plastic mulching showed significant higher crop yield.

Table 78. Effect of drip irrigation, fertilizer and mulching treatments on yield and yield parameters of banana

Treatment	Bunch yield per plant (t ha^{-1})	Fingers per bunch	Yield (t ha^{-1})
Drip irrigation level			
I_1 (60% PE)	15.1	66.26	37.82
I_2 (80% PE)	15.6	67.60	38.99
I_3 (100% PE)	16.8	70.84	41.92
CD (p=0.05)	1.06	3.41	2.65
Dose of fertilizer			
D_1 (75% RDF)	15.59	67.21	38.98
D_2 (100% RDF)	15.81	67.45	39.53
D_3 (125% RDF)	16.09	70.04	40.23
CD (p=0.05)	NS	NS	NS
Mulching			
M_0 (without mulch)	16.80	69.67	42.00
M_1 (plastic mulch)	14.86	66.79	37.16
CD (p=0.05)	0.87	2.78	2.16

Note: PE, pan evaporation; RDF, recommended dose of fertilizer

Field view of the experiment along with banana produce

10.3.3. Irrigation kits for kitchen garden

Kitchen gardening is gaining popularity in the urban and peri urban areas. In order to improve the water use efficiency and as a time saving technique, irrigation kits using KAU-microsprinkler and drip was developed. The kits have been approved by the Director of Research, Kerala Agricultural University for distribution to farmers.

KAU microsprinkler kit

KAU microsprinkler, developed at Agronomic Research Station, Chalakudy, is a farmer friendly water saving technique. A household irrigation kit named KAU microsprinkler kit (Figure 18) was designed and developed with KAU- microsprinkler for irrigating kitchen garden. Performance of the system was evaluated and found good. Demonstration of the installation of the kit has been established in the Research Station for the benefit of the farmers.

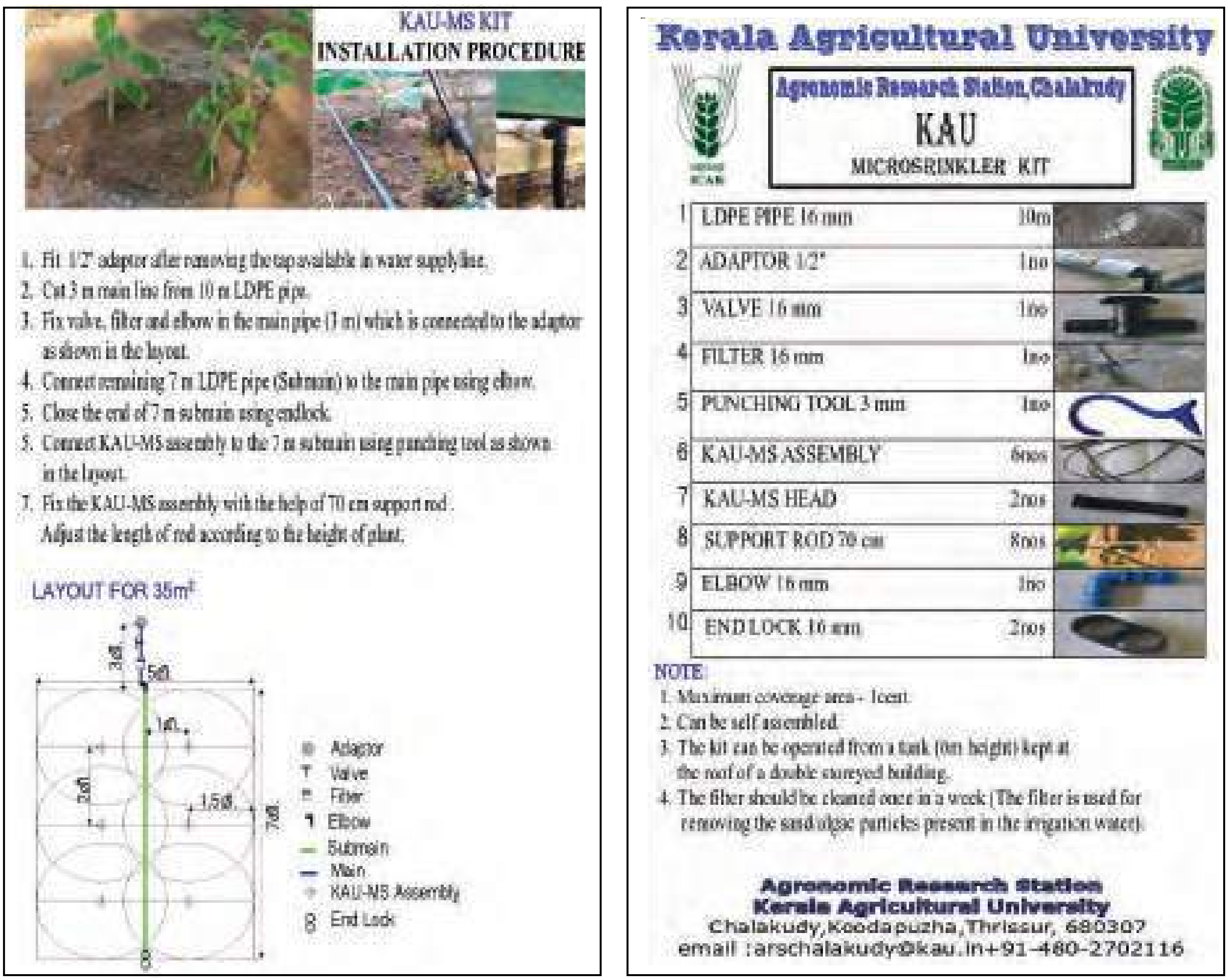


Figure 18. Leaflet of KAU microsprinkler kit

Drip irrigation kit

Drip irrigation kit (Figure 19) was designed and developed for irrigating 50 grow bags using arrow drippers after evaluating the performance. Demonstration of the installation of the kit has been established in the research station for the benefit of the farmers. The kits have been made available to farmers through different stations of university at fixed price.

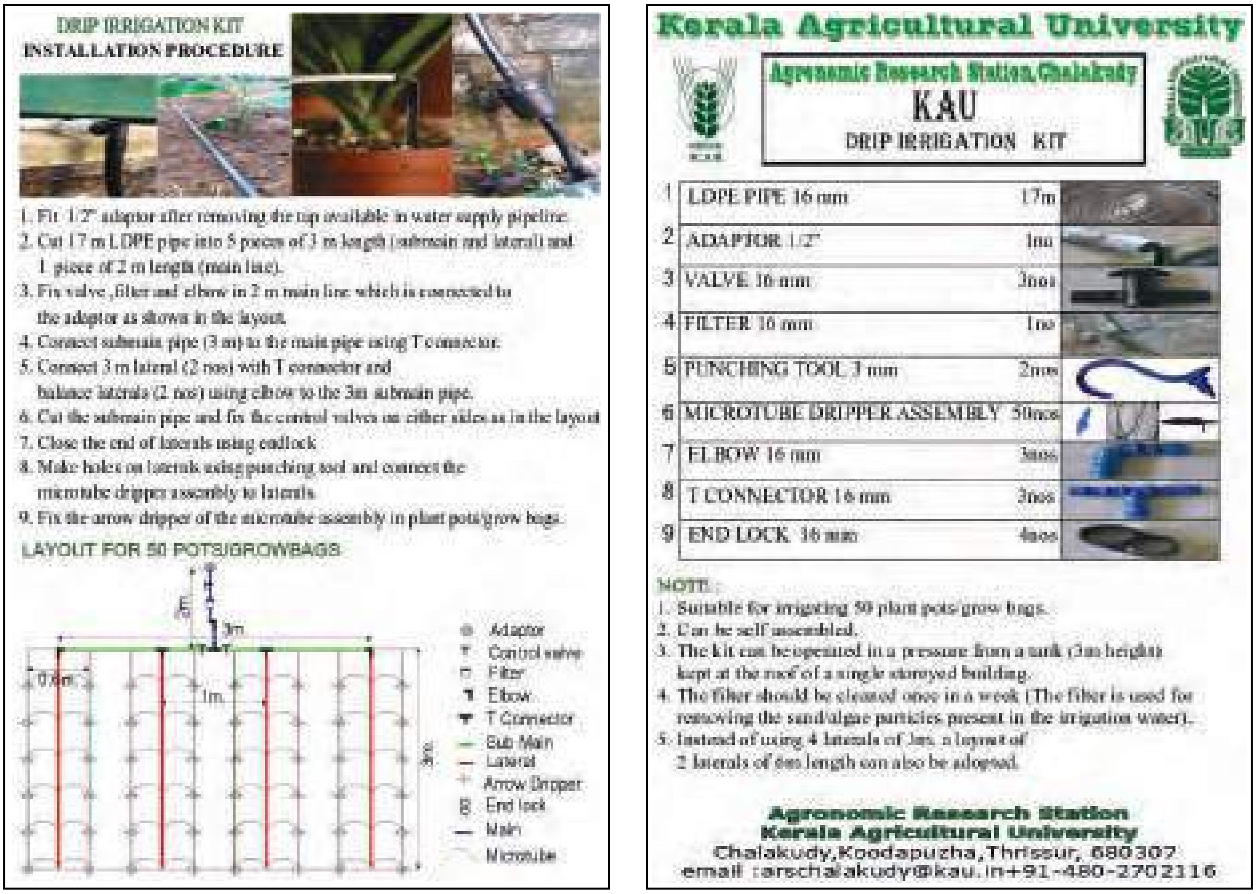


Figure 19. Leaflet of drip irrigation kit

10. 4. Almora

10.4.1. Extension activities and transfer of technology

The multiple water use model developed by Almora centre has various components. Some of the components have specifically been popularized among the hill farmers so that they can get extra benefits by taking up each component as an individual enterprise. One such component is Azolla cultivation which has been demonstrated and popularized among the farmers. Azolla reduces evaporation from ponds and has several other advantages. It makes good compost, can be used as fodder for cattle, and feed for fish and poultry. Therefore, Azolla cultivation can result in reducing input cost and obtain good yield of milk from cattle, eggs form poultry, etc. Azolla absorbs carbon from the atmosphere, reduces evaporation from an open tank or pond, reduces weed problem and mosquito breeding in ponds. Seeing so many benefits, around 12 farmers have purchased Azolla from ICAR-VPKAS, whereas it was provided free of cost to around five poor farmers to cultivate on their fields. About 25 kg Azolla was sold to farmers and different organizations. One poly cement tank was constructed at a farmer's field to store water for irrigation and fish farming. The same farmer also constructed polyline tank for azolla cultivation. The farmer is also establishing multiple water use model to enhance water productivity. The hill farmers were advised to grow vegetable crops like onion, garlic in *rabi* season and okra in *kharif* season. The farmers got convinced to grow these crops because they found that the crops are hardy in nature and profitable with low input. Farmers were also advised to plant hybrid napier on their field risers and use it as feed for cattle.

10.5. Ludhiana

10.5.1. Extension activities through promotions and demonstrations to farmers

Two videos were created on *Apni Kheti* channel in YouTube on developed technologies i) safe rainwater recharging technique by PAU, ii) open well water recharging technique. The farmers were trained about different techniques like precision technologies for water saving and its recharging, rainwater harvesting for groundwater recharge, and water resource management for sustainable agriculture. The skill development was also done on roofwater harvesting structure. The centre popularized the innovative water saving technologies among the farmers through demonstration, publications, radio and TV talks, etc.

Field visit on bed planted cotton

Chapter 11

Recommendations

The network centres of AICRP on Irrigation Water Management have proposed recommendations from replicated field experiments which have been concluded with statistically significant findings. These recommendations may be considered for extension to farmers, line departments, KVKs, governmental and non-governmental organizations. The recommendations have been listed as below.

Dapoli

- It is recommended to grow sweet potato-sweet corn crops in sequence under lateritic soils of Konkan region with drip irrigation system and irrigation should be scheduled on alternate day at 100% crop evapotranspiration (total water applied 132.44 and 311.81 mm, respectively) and 100% RDF through water soluble fertilizers (FYM at 10 t ha^{-1} + 75:50:75 and 200:60:60 kg $N:P_2O_5:K_2O$ ha^{-1} for sweet potato and sweet corn, respectively) for obtaining higher system production and economic returns.

Parbhani

- For higher seed yield and net monetary returns of pigeonpea in Marathwada region, it was recommended to schedule alternate day drip irrigation at 80% crop evapotranspiration for crop sown at a spacing of 150 × 30 cm through inline lateral laid 150 cm apart and drip fertigation of 20:40:20 kg $N:P_2O_5:K_2O$ ha^{-1} should be applied in ten splits through water soluble fertilizers out of which 20% N and 40% P in two splits at 0-30 DAS, 30% N, P and 25% K in three splits at 31-60 DAS, 30% N, P and 40% K in three splits at 61-90 DAS, and 20% N and 35% K in two splits at 91-120 DAS.
- For higher bulb yield and net monetary returns of onion grown in summer season in Marathwada region, it was recommended to schedule alternate day drip irrigation at 60% crop evapotranspiration through inline lateral laid at the centre of raised bed having six rows of onion planted at a spacing of 15 cm × 7.5 cm and drip fertigation of 80:40:40 kg N, $N:P_2O_5:K_2O$ ha^{-1} with N and K_2O in 10 equal splits at 8 kg and 4 kg, respectively and P_2O_5 in 5 equal splits at 8 kg ha^{-1} at an interval of 7 days from transplanting to 70 days after transplanting.

Jorhat

- State level recommendation of irrigation at 15 cm depletion of water from soil surface for autumn rice crop was approved for inclusion in the state package of practices of crops.

Sriganganagar

- It was recommended to apply three post sowing irrigations to cotton crop at 35 DAS, square formation stage/boll initiation stage and boll development stage for higher crop yield. The depth of each irrigation should be 60 mm to save irrigation water by 10%.

Chiplima

- It was recommended to grow baby corn crop with surface irrigation at IW/CPE 0.8 and IW/CPE 0.7, with 5 cm irrigation depth in West Central Table Land Zone of Odisha to obtain higher yield, profit and benefit-cost ratio.
- Raised and sunken bed farming system developed by Chiplima centre was recommended for rice-cowpea cropping system during *kharif* season in the lowlands of canal command area of Hirakud dam having elevation difference of 60 cm for higher rice equivalent yield, higher profit and benefit-cost ratio.

Coimbatore

- Application of irrigation to rice crop after formation of hair line crack through alternate wetting and drying was recommended to save irrigation water, enhance water use efficiency while maintaining and/or improving grain yield of rice.

Jabalpur

- To enhance water productivity of rice–wheat cropping system in Madhya Pradesh, it was recommended to apply one cut-off irrigation at 10 days before harvesting of *kharif* rice crop and apply one irrigation after sowing in the subsequent *rabi* wheat crop in zero tillage condition to fetch higher net return and benefit-cost ratio.

Rahuri

- Planting of two eye bud *suru* sugarcane at distance of 30 cm in 5 feet long furrows under sub surface drip fertigation scheduled at 80% crop evapotranspiration every alternate day with 80% RDF (200:136:136, $N:P_2O_5:K_2O$ kg ha^{-1}) through water soluble fertilizers in 30 weekly splits is recommended for medium deep black soil of western Maharashtra for obtaining higher monetary returns.

Junagadh

- It was recommended to farmers, NGOs and government line departments that the total groundwater recharge should be at least 50% of rainfall to manage Uben basin for sustainable water resources to balance the inflow-outflow in almost all the zones. Bhesan region is suitable for low water requirement crops like coriander, cumin, etc. while high water requirement crops like wheat, vegetables, garlic, onion and horticultural crops may be adopted in Junagadh and Vanthali regions.
- Recommendations were made for farmers, government departments and NGOs on five groundwater recharging techniques namely, on stream check dam, recharge basin, roof water harvesting, open well recharging and connector well recharging techniques developed and evaluated by Junagadh centre.

▪ On-stream check dam groundwater recharge technique as a cost-effective recharge technique that results in groundwater recharge of 0.15 m^3 m^{-2} of catchment area at a cost of ₹1.02 m^{-3} as per prevailing cost.

▪ Recharge basin as a cost-effective recharge technique, which can result in recharge of about 0.13 m^3 m^{-2} of catchment area at a cost of ₹0.27 m^{-3} inJunagadh region.

▪ Roof water harvesting as an effective groundwater recharge technique because it can result in groundwater recharge of 0.22 m^3 out of potential runoff of 0.73 m^3 m^{-2} of roof area. Recharge of 0.22 m^3 may be done through tubewell and remaining 0.51 m^3 may be stored in a sump with a cost of ₹34 m^{-3}. The annual runoff coefficient of 0.71 for roof top was recommended for designing the roof water harvesting system.

▪ Open well technique effective for recharging shallow aquifer in Junagadh region which may recharge groundwater about 0.12 m^3 m^{-2} of bottom area of open well with recharge cost of ₹1.94 m^{-3}. Tubewell is effective for deep aquifer recharge, which may recharge 44473 m^3 groundwater per year with recharge costs of ₹0.45 and 0.28 m^{-3} including and excluding tubewell cost, respectively.

▪ Steady state recharge model for Junagadh region was recommended to the scientific community for recharging connector well:

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

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

Jammu

- Recommendations on technical details for developing multipurpose Ujh irrigation project were provided to the stakeholders of Jammu division i.e. Ravi Tawi Irrigation Complex in reconciling figures on parameters like effective rainfall, consumptive use of basmati rice and percolation rate of soil. These projected figures along with other technical details provided by the scientists of AICRP on IWM Jammu centre will be useful for determining dam height and designing the canal network for 22000 ha from river Ujh for districts Kathua and Samba. Based on the recommendations, canal has been approved by Govt. of India during 2019-20.
- Under the objective of PMKSY i.e. "more crop per drop", study was done to scale up water productivity through low-cost water harvesting and modern irrigation technologies for fruit orchards. Based on this, recommendation was provided to Directorate of Horticulture, Jammu on construction of polylined water harvesting tanks lined with silpaulin sheets (250 gsm) layered with cement sand blocks of ratio (1:7:2) as water storage/ harvesting structures at a cost of ₹ 1-1.25 per litre of different capacities ranging between 50-250 m^3 and less than 50 m^3. Apart from this, costs for on-line drip irrigation in 1.0 ha and 0.5 ha fruit orchards spaced at 10 m × 10 m, 6 m × 6 m and 5 m × 5 m as well as cost of fertigation equipments were provided which ranged between ₹35000-85000 excluding the cost of pump.

Gayeshpur

- It was recommended to grow broccoli and cauliflower crops with conjunctive use of arsenic contaminated groundwater and safe surface (pond) water in the ratio of 1:1 in high arsenic prone groundwater areas as a measure to mitigate arsenic contamination in crops by reducing accumulation of arsenic in edible parts.
- It was recommended to apply irrigation to rice crop in high arsenic prone groundwater areas using alternate wetting and drying method as a water management intervention for arsenic de-loading in rice grain.

Navsari

- The farmers of south Gujarat heavy rainfall agro-climatic zone following *rabi* sorghum-vegetable cowpea (summer) cropping system were recommended to irrigate the crops with drip irrigation system at 0.6 pan evaporation fraction (PEF) and apply N at 8 kg ha^{-1} and P_2O_5 at 40 kg ha^{-1} as basal and remaining 72 kg N in six equal splits at weekly interval starting from 20 DAS through fertigation to *rabi* sorghum and P_2O_5 at 40 kg ha^{-1} as basal and N at 20 kg ha^{-1} to cowpea in three equal splits at weekly interval for securing higher yield and economic benefit.
- The farmers of heavy rainfall agro-climatic zone of south Gujarat following *rabi* Indian bean (vegetable) - sweet corn (summer) cropping system were recommended to irrigate the crops through drip irrigation with dripper discharge rate of 8 lph and laying laterals at spacing of 1.60 m for four rows of Indian bean at 30 cm row spacing and three rows of sweet corn at 53 cm row spacing for getting higher crop yields and net return. Further, they are also advised to apply P_2O_5 at 40 kg ha^{-1} as basal and N at 20 kg ha^{-1} to Indian bean and P_2O_5 at 60 kg ha^{-1} as basal, N at 140 kg ha^{-1} and K_2O at 40 kg ha^{-1} to sweet corn in six equal splits at weekly interval starting from 20 DAS through fertigation for getting higher crop yield and economic return.

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BUDGET ALLOCATION 2020-21

Revised Estimate (Grant-in-aid Salary) for 2020-21 under AICRP on IWM Project

Council has allotted an amount of ₹180763000 as revised estomate (RE) for the financial year 2020-21 under Grant-in-aid Salary in respect of AICRP on Irrigation Water Management (IWM). Centre-wise proposal for RE 2020-21 under salary head has been submitted for kind approval of Director, ICAR-IIWM.

RE 2020-21 (Salary)

Sl. No.	Centre Name	Amount allotted (₹)
1	PAU, Ludhiana	15000000
2	UAS, Dharward	3500000
3	TNAU, Coimbatore	15400000
4	IGKV, Raipur	12000000
5	KAU, Thrissur	4280000
6	OUAT, Bhubaneswar	3680000
7	BSKKV, Dapoli	8500000
8	NDUAT, Faizabad	8000000
9	BCKV, Kalyani (Nadia)	7000000
10	CCSHAU, Hisar	4180000
11	SKUAST, Jammu	8720000
12	MPUAT, Udaipur	8220000
13	AU, Kota	8220000
14	JAU, Junagadh	7300000
15	RVSKVV, Morena	6220000
16	NAU, Navsari	3720000
17	CSKHPKV, Palampur	4000000
18	GBPUAT, Pantnagar	15500000
19	VNMKV, Parbhani	4000000
20	JNKVV, Jabalpur	7000000
21	MPAU, Rahuri	15403000
22	SKRAU, Bikaner	3920000
23	AAU, Jorhat	7000000
	Sub Total	**180763000**

Revised Estimate (Grant-in-aid General) other than Salary for 2020-21 under AICRP on IWM Project

Council has allotted an amount of ₹31990000 under Grant-in-aid General (except Salary) as RE in respect of AICRP on IWM for financial year 2020-21. Head-wise and centre-wise proposal for RE (Other than Salary) 2020-21 is submitted for kind approval of Director, ICAR-IIWM.

(₹)

	AICRP-IWM (RE 2020-21) GRANT IN AID GENERAL (Other than Salary)												
S.N	Centre Name	Grant-in-aid General			Total General	Grant-in-aid Capital		Total Capital	SCSP			Total SCSP	Grand Total
		Research	Operational	TA		Equipment	IT		Research	Operational	Capital (Eqipment)		
1	PAU, Ludhiana	700000	200000	30000	930000	400000	60000	460000	-	-	-		**1390000**
2	UAS, Dharward	640000	200000	30000	870000	400000	-	400000	-	-	-		**1270000**
3	TNAU, Coimbatore	800000	200000	30000	1030000	400000	-	400000	50000	80000	-	130000	**1560000**
4	IGKV, Raipur	700000	200000	30000	930000	400000	-	400000	50000	80000	-	130000	**1460000**
5	KAU, Thrissur	500000	200000	30000	730000	400000	60000	460000	-	-	-		**1190000**
6	OUAT, Bhubaneswar	400000	150000	30000	580000	400000	-	400000	-	-	-		**980000**
7	BSKKV, Dapoli	500000	200000	30000	730000	400000	-	400000	50000	80000	-	130000	**1260000**
8	NDUAT, Faizabad	500000	200000	30000	730000	400000	30000	430000	-	-	-		**1160000**
9	BCKV, Kalyani (Nadia)	500000	200000	30000	730000	400000	30000	430000	-	-	-		**1160000**
10	CCSHAU, Hissar	500000	200000	30000	730000	400000	-	400000	-	-	-		**1130000**
11	SKUAST, Jammu	500000	200000	30000	730000	400000	-	400000	-	-	-		**1130000**
12	MPUAT, Udaipur	500000	200000	30000	730000	400000	85000	485000	-	-	-		**1215000**
13	AU, Kota	500000	200000	30000	730000	400000	-	400000	50000	80000	-	130000	**1260000**
14	JAU, Junagadh	500000	200000	30000	730000	400000	-	400000	-	-	127000	127000	**1257000**
15	RVSKVV, Morena	500000	200000	30000	730000	400000	-	400000	-	-	-		**1130000**
16	NAU, Navsari	500000	200000	30000	730000	400000	-	400000	-	-	-		**1130000**
17	CSKHPKV, Palampur	500000	200000	35000	735000	400000	75000	475000	-	-	-		**1210000**
18	GBPUAT, Pantnagar	700000	200000	40000	940000	400000	30000	430000	-	-	-		**1370000**
19	VNMKV, Parbhani	500000	200000	38000	738000	400000	-	400000	50000	80000	-	130000	**1268000**
20	JNKVV, Jabalpur	500000	200000	38000	738000	400000	-	400000	-	-	-		**1138000**
21	MPAU, Rahuri	600000	200000	40000	840000	400000	-	400000	50000	92000	-	142000	**1382000**
22	SKRAU, Bikaner	500000	200000	40000	740000	400000	-	400000	-	-	-		**1140000**
23	AAU, Jorhat	500000	200000	40000	740000	400000	30000	430000	50000	-	-	50000	**1220000**
24	Dr.RPCAU, Pusa	300000	250000	40000	590000	-	-	0	-	-	-		**590000**
25	ICAR-RC-NEH, Umiam	300000	200000	40000	540000	-	-	0	-	-	-		**540000**
26	VPKAS, Almora	300000	200000	40000	540000	-	-	0	-	-	-		**540000**
27	IIWM(PCU)	40000	1450000	20000	1510000	400000	-	400000	-	-	-		**1910000**
	Sub Total	13480000	6650000	891000	**21021000**	9600000	400000	**10000000**	350000	492000	127000	**969000**	**31990000**

STAFF POSITION 2020

Almora	
Chief Scientist	Dr. S.C. Panday
Soil Physicist	Dr Manoj Parihar
Agril. Engineer	Er Shyamnath
Jr. Agronomist	Dr. D. Mahanta
Belavatagi	
Chief Scientist	Dr. P. S. Kanannavar
Soil Physicist	Dr. Vijayakumar. C
Agril. Engineer	Dr. P. S. Kanannavar
Coimbatore + Madurai + Bhavanisagar	
Chief Scientist	Dr. V. Ravikumar
Associate Professor	Dr. A. Valliammai
Assistant Professor	Dr. G. Thiyagarajan
Soil Physicist	Dr. R. Indirani
Jr. Agronomist	Dr. K. Kalaichelvi
Chalakudy	
Chief Scientist	Dr. Mini Abraham
S & WE	Dr. Shyla Joseph
Soil Physicist	Dr. Bhindhu P. S.
Chiplima	
Chief Scientist	Dr. A.K. Mohanty
Agril. Engineer	Dr. S. N. Bansude
Dapoli	
Chief Scientist	Dr. R.T. Thokal
Agril. Engineer	Dr. B.L. Ayare
Jr. Agronomist	Dr. M.S. Jadhav
Ayodhya	
Chief Scientist	Vacant
Agril. Engineer	Er. R.C. Tiwari
Jr. Agronomist	Dr. B.N. Singh
Gayeshpur	
Chief Scientist	Dr. S.K. Patra
Agril. Engineer	Er. S. Saha
Jr. Agronomist	Mr. R. Poddar
Hisar	
Chief Scientist	Dr. Manoj K. Sharma
Agril. Engineer	Sushil Kumar Singh
Soil Physics	Muli Devi Parihar
Jammu	
Chief Scientist	Dr. Abhijit Samanta
Jr. Agronomist	Dr. Vijay Bharti
Powarkheda + Jabalpur	
Chief Scientist	Dr. M.K. Awasthi
Scientist SWCE	Dr. Y.K. Tiwari
Soil Physicist	Vacant
Agril. Engineer	Vacant
Jr. Agronomist	Vacant
Irrigation Engineer	Vacant
Jorhat	
Chief Scientist	Dr. R.K. Thakuria
Soil Physicist	Dr. Bipul Deka
Agril. Engineer	Er. Kabyshree Choudhury
Junagadh	
Chief Scientist	Dr. H.D. Rank
Agril. Engineer	Prof. P.B. Vekariya
Agril. Engineer	Prof. R. J. patel
Agronomist	Vacant
Kota	
Chief Scientist	Dr. Rajendra Kumar Yadav
Agronomist	Dr. Baldev Ram
Agril. Engineer	Er. I.N. Mathur
Ludhiana + Bathinda	
Chief Scientist	Dr. Rajan Aggarwal
Asst. Res. Engineer	Dr. Sanjay Satpute
Soil Physicist	Dr. K.S. Sekhon
Asst. Agronomist	Dr. Anureet Kaur
Asst. Agril. Engineer	Dr. Anurag Malik
Morena	
Chief Scientist	Dr. Y.P. Singh
Agronomist	Dr. Sandeep S. Tomar

Agril. Engineer	Er. S.K. Tiwari
Navsari	
Chief Scientist	Dr. J.M. Patel
Soil Physicist	Dr. V.P. Usadadiya
Agril. Engg	Er. N.G. Savani
Palampur	
Chief Scientist	Dr Anil Kumar
Agronomist	Dr. S.K. Sandal
Pantnagar	
Chief Scientist	Dr. Yogendra Kumar
Soil Physicist	Dr. Harish Chandra
Agril. Engineer	Dr. Vinod Kumar
Agronomist	Dr. Gurvinder Singh
Agril Engineer	Dr. U.C. Lohni
Parbhani	
Chief Scientist	Dr. Madan Pendke (Additional charge)
Agril. Engineer	Dr. A.S. Kadale
Agronomist	Prof. G.D. Gadade
Pusa	
Chief Scientist	Dr. S.K. Jain
Agril. Engg	Dr. S.P. Gupta
Soil Chemist	Dr. A.K. Singh
Agril. Engineer	Dr. Ravish Chandra
Agronomist	Dr. Rajan Kumar
Rahuri	
Chief Scientist	Dr. A.V. Solanke
Research Engineer	Dr. S.D. Dahiwalkar
Agronomist	Prof. S.S. Tuwar
Asst. Res. Engineer	Er. S.A. Kadam
Soil Science	Dr. V.S. Patil
Raipur + Bilaspur	
Chief Scientist	Dr. M. P. Tripathi
Sr. Scientist (SWE)	Dr. Dhiraj Khalkho
Sr. Scientist (SWE)	Dr. Devesh Pandey
Agronomist	Dr. Geet Sharma
Soil Physicist	Sh. P.K. Keshry
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	Dr. R.P.S. Chauhan
Soil physicist	Vacant
Agronomist	Vacant
Agril. Engineer	Vacant
Jr. Agronomist	Vacant
Udaipur	
Chief Scientist	Dr. P.K. Singh
Soil Physicist	Dr. K.K. Yadav

Abbreviations

AICRP	All Indian Coordinating Research Project
AHP	Analytical Hierarchy Process
ArcGIS	Aeronautical Reconnaissance Coverage Geographic Information System
As	Arsenic
@	at the rate
B-C or B:C	Benefit-cost ratio
Bt	*Bacillus thuringiensis*
Ca^{2+}	Calcium ion
CD	Critical difference
CO_3^{2-}	Carbonate ion
CRI	Crown root initiation
CW	Canal water
DAS	Days after sowing
DAT	Days after transplanting
DEM	Digital elevation model
DFY	Dry fodder yield
DSR	Direct seeded rice
DSS	Decision Support System
EC	Electrical conductivity
E_p	Potential soil evaporation
ET_c	Crop evapotranspiration
fb	*followed by*
FP	Farmers' practice
FYM	Farmyard manure
GFY	Green fodder yield
GIS	Geographic information system
HCO_3^-	Bicarbonate ion
HDPE	High density polyethylene
HW	hand weeding
i.e.	That is
IFS	Integrated Farming System
IP	Improved practice
IW/CPE	Ratio of irrigation water and cumulative pan evaporation
IWM	Irrigation Water Management
IWMRC	Irrigation Water Management Research Center
K	Potassium
K^+	Potassium ion
K_2O	Potassium oxide (Potash)
K_{40}	40 kg K per hectare (dose)
K_c	Crop coefficient
LBP	Lower Bhavani Project
LDPE	Low density polyethylene
LMC	Left main canal
LULC	Land use land cover
MCDA	Multi-criteria decision analysis
Mg^{2+}	Magnesium ion
MGNREGA	Mahatma Gandhi National Rural Employment Guarantee Act
MODFLOW	Modular Three-Dimensional Finite-Difference Groundwater Flow Model
MPKV	Mahatma Phule Krishi Vidyapeeth
MSL	Mean sea level
N	Nitrogen
N_{120}	120 kg N per hectare (dose)
Na^+	Sodium ion
NGO	Non-governmental organization
NPK	Nitrogen, Phosphorus, Potassium
NS	Non-significant
P	Phosphorus
P_2O_5	Phosphorus pentoxide (Phosphoric acid)
P_{60}	60 kg P per hectare (dose)
PCU	Project coordinating unit
PE	Potential evaporation
PET	Potential evapotranspiration
PMKSY	Pradhan Mantri Krishi Sinchayee Yojana
POP	Package of practices
PVC	Polyvinyl chloride
RC-NEH	Research Complex for North Eastern Hill Region
RDF	Recommended dose of fertilizer
RMC	Right main canal
RSC	Residual sodium carbonate
RSC	Residual sodium carbonate
RVSKVV-ZARS	Rajmata Vijayaraje Scindia Krishi Vishwa Vidyalaya-Zonal Agricultural Research Station
SAR	Sodium adsorption ratio
SC	Scheduled caste
SCSP	Scheduled Caste Sub Plan
SRTM	Shuttle Radar Topography Mission
ST	Scheduled tribe
SWAT	Soil and Water Assessment Tool
Tp	Potential transpiration
TPR	Transplanted
TSP	Tribal Sub Plan
TW	Tubewell water
Vill.	Village
viz.	namely
WEE	Water expense efficiency
WSF	Water soluble fertilizer
WTD	Water table depth
WUE	Water use efficiency

Units

cm	centimetre
cm $year^{-1}$	centimetre per year
dS m^{-1}	deciSiemens per metre
g ai ha^{-1}	gram active ingredient per hectare
g kg^{-1}	gram per kilogram
gsm	grams per square metre
ha	hectare
ha^{-1}	per hectare
ha-m	hectare metre
hp	horsepower
kg	kilogram
kg cm^{-2}	kilogram per centimetre
kg cm^{-2}	kilogram per square centimetre
kg ha^{-1}	kilogram per hectare
kg ha-cm^{-1}	kilogram per hectare per centimetre
kg ha-kg^{-1}	kilogram per hectare per kilogram
kg ha-mm^{-1}	kilogram per hectare per millimetre
kg m^{-3}	kilogram per cubic metre
kg seed m^{-3}	kilogram seed per cubic metre
km^2	square kilometre
kW	kiloWatt
L	litre
L day^{-1}	litre per day
L ha^{-1}	litre per hectare
L ha^{-1} day^{-1}	litre per hectare per day
L kg^{-1}	litre per kilogram
lph	litre per hectare
lps	litre per second
LSD	least significant difference
m	metre
m s^{-1}	metre per second
m^{-1}	per metre
m^2	square metre
m^3	cubic metre
m^{-3}	per cubic metre
m^{-3} ha^{-1}	cubic metre per hectare
m^3 m^{-2}	cubic metre per square metre
MCM	million cubic metre
meq L^{-1}	milliequivalent per litre
mg kg^{-1}	milligram per kilogram
mm	millimetre
mm ha^{-1}	millimetre per hectare
ppm	parts per million
q^{-1}	per quintal
₹ ha^{-1}	rupees per hectare
₹ ha^{-1} $year^{-1}$	rupees per hectare per year
₹ kg^{-1}	rupees per kilogram
₹ L^{-1}	rupees per litre
₹ m^{-3}	rupees per cubic metre
₹ q^{-1}	rupees per quintal
t ha^{-1}	tonne per hectare
t ha-cm^{-1}	tonne per hectare per centimetre
μmhos cm^{-1}	micromhos per centimetre

राष्ट्रदूत 28 फरवरी 2021

मृदा एवं जल संसाधन प्रबंधन पर मंथन

उदयपुर, (कासं)। महाराणा प्रताप कृषि एवं प्रौद्योगिकी विश्वविद्यालय के संघटक प्रौद्योगिकी एवं अभियांत्रिकी महाविद्यालय में मृदा एवं जल संसाधन प्रबंधन विषय पर दो दिवसीय अंतरराष्ट्रीय अधिवेशन का आयोजन किया गया। इस अधिवेशन में 11 देशों के मृदा एवं जल विशेषज्ञों ने भाग लिया। उद्घाटन एवं समापन सत्रों के अलावा छह तकनीकी सत्रों में 50 से अधिक अनुसंधान पत्रों का वाचन किया गया साथ ही हरेक सत्र में एक एक कीनोट लेक्चर हुआ।

मुख्य अतिथि डॉ. नरेंद्र सिंह राठौड़, कुलपति, महाराणा प्रताप कृषि एवं प्रौद्योगिकी विश्वविद्यालय ने कहा कि जल एवं मृदा संसाधनों के प्रबंधन का सीधा संबंध फसलों की उत्पादकता के साथ किसानों और आमजन के जीवन स्तर से जुड़ा हुआ है। डॉ. उदयभान सिंह ने कीनोट लेक्चर दिया जो कि अमेरिका के मिसिसिपी स्टेट के जल संसाधन निदेशक हैं। उसके बाद जवाहर लाल नेहरू विश्वविद्यालय, नई दिल्ली के प्रोफेसर मिलाप पुनिया ने रिमोट सेंसिंग और जी आई एस तकनीक की मृदा एवं जल संसाधन प्रबंधन में उपयोगिता पर भाषण दिया।

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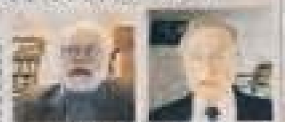
फसल उत्पादकता के साथ जल उत्पादकता बढ़ाएं

राजस्थान पत्रिका 28 फरवरी 2021

11 देशों के मृदा एवं जल विशेषज्ञों ने जल प्रबंधन पर किया मंथन

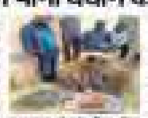


ਧਰਤੀ ਹੇਠਲੇ ਪਾਣੀ ਨੂੰ ਵਧਾਉਣ ਲਈ ਸੁਰੱਖਿਅਤ ਰੀਚਾਰਜਿੰਗ ਤਕਨੀਕਾਂ

ਅਜੀਤ

दैनिक भास्कर लुधियाना भास्कर 11-11-2020

एफपो लुधियाना 14 स्कूलों में पानी बचाने को करेगा काम



நீர் பாதுகாப்பு, மேலாண்மை பயிலரங்கு

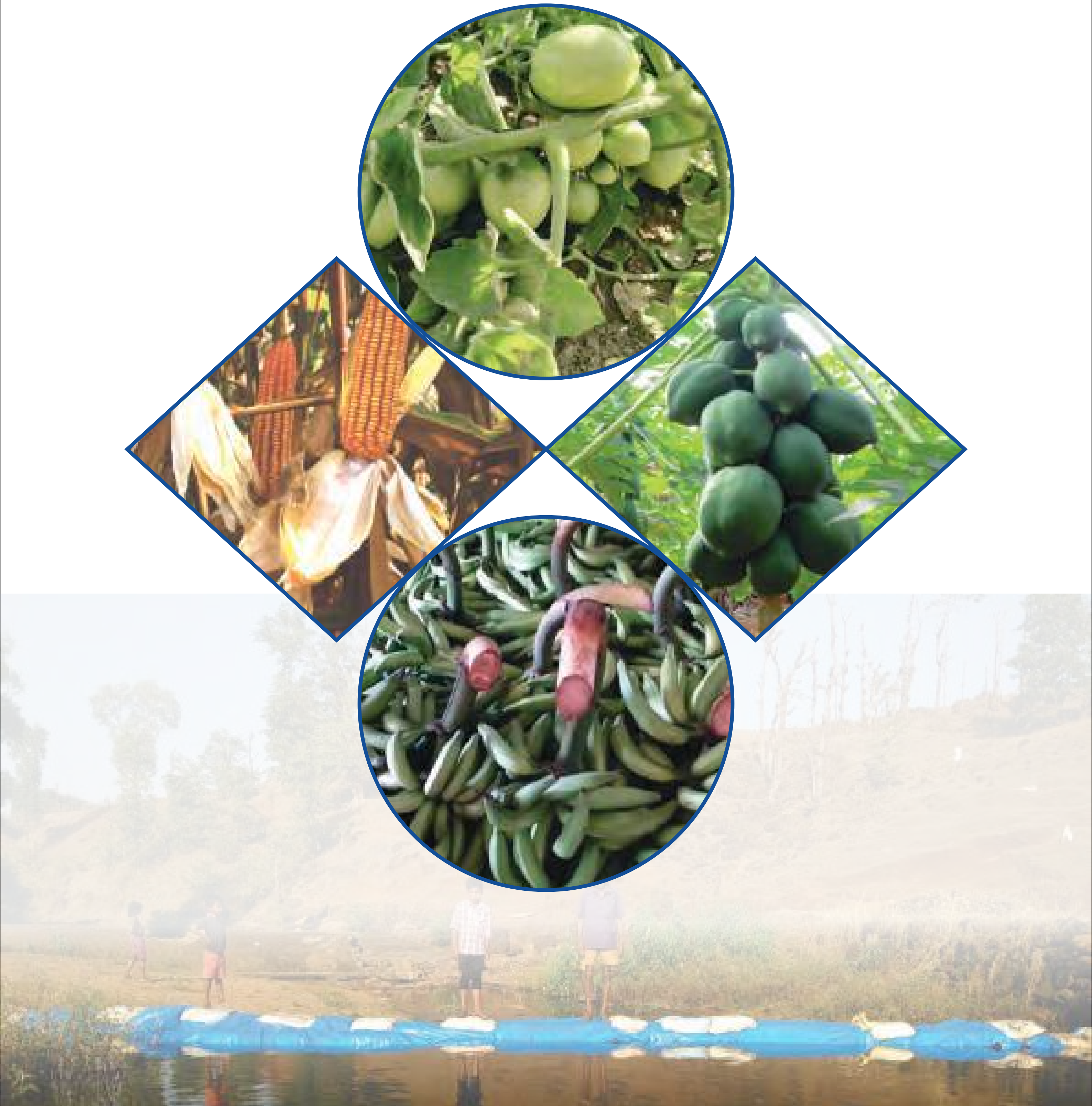
कारोबार के साथ भूजल स्तर उठाने को प्रयासरत हितेश

Dr Jitendra chairs meeting to clear decks for Ujh Multipurpose Project

Excelsior Correspondent

NEW DELHI, Feb 3: Union Minister of State (Independent Charge) Development of North Eastern Region (DoNER), MoS PMO, Personnel, Public Grievances, Pensions, Atomic Energy and Space, Dr Jitendra Singh today chaired a high - level meeting to clear the decks for the prestigious Ujh Multipurpose (National) Project in district Kathua of Jammu & Kashmir.

NOTES



भाकृअनुप-भारतीय जल प्रबंधन संस्थान

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