सिचाई जल प्रबंधन पर अखिल भारतीय समन्वित अनुसंधान परियोजना

All India Coordinated Research Project on Irrigation Water Management

वार्षिक प्रतिवेदन

ANNUAL REPORT 2022

भाकृअनुप-भारतीय जल प्रबंधन संस्थान

ICAR-Indian Institute of Water Management

Bhubaneswar, Odisha, India

भाकृअनुप

ICAR

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भाकृअनुप - भारतीय जल प्रबंधन संस्थान

भुवनेश्वर, ओडिशा, भारत

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PREFACE

The Annual Report of All India Coordinated Project on Irrigation Water Management (AICRP on IWM) contains the research findings of different coordinating centres for the year 2022 along with extension activities, human resource development programmes, publication, and recommendations of various centres. With the growing demand for water by different sectors, economic use of water is of paramount importance. I take this opportunity to present a consolidated report of the centres under different themes. Scientists have been engaged in carrying out research on improving water use efficiency in different crops and cropping sequences under different irrigation methods & regimes in various agro-climatic conditions of the Country. A few centres have started working on sensor based irrigation scheduling to further improve water use efficiency. Studies on groundwater, including recharge potential are being conducted extensively in various major and minor river basins of the Country. Formulation of State-wise water budget is currently under focus. Significant achievements have been made during the reporting year 2022. On-station and on-farm research endeavors of 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. These finding not only improved water productivity but also enhanced income and livelihood of farmers. The AICRP centres also carried out capacity building exercises for different stakeholders and implemented scheduled caste sub plan and tribal sub plan schemes for improving livelihoods of farmers at different places. Some of the pilot interventions contributed in rainwater harvesting and groundwater recharge in both high rainfall areas and rainfed areas of the Country.

I take this opportunity to express my gratitude to Dr. Himanshu Pathak, 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 my gratitude to Dr. S.K. Chaudhari, Deputy Director General (NRM) and Dr. A. Velmurugan, Assistant Director General (S&WM), ICAR for their valuable suggestions and timely cooperation. I express my heartfelt thanks to scientists of AICRP-IWM scheme working at different centres for their untiring efforts to improve irrigation water management scenario in 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. I appreciate the team work of Dr. S. Mohanty, Principal Scientist, Dr. P. Nanda, Principal Scientist, Dr. B. S. Satapathy, Sr. Scientist, Dr. D. Ghosh, Scientist, ICAR-IIWM and Dr. Pragna Dasgupta, Research Associate, AICRP-IWM for compiling the research outcomes and preparing the annual report.

Bhubaneswar, Odisha

(A. Sarangi)
Director, ICAR-IIWM

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कार्यकारी सारांश

वर्ष 2022 के दौरान 26 केन्द्रों के द्वारा जल की उपलब्धता का आकलन, भूजल पुन:भरण, क्षेत्रीय स्तर पर भूजल का उपयोग, दबाव युक्त सिंचाई प्रणालियों का मूल्यांकन, भूजल का आकलन एवं पुन:भरण, बागवानी एवं अधिक मूल्य वाली फसलों में जल प्रबंधन, मृदा-जल - पौधों के बीच संबंध और उनकी पारस्परिक क्रिया पर बुनियादी अध्ययन, नहर और भूमिगत खारे जल का संयुक्त उपयोग, जल उत्पादकता बढ़ाने के लिए जल निकासी का अध्ययन, जल के बहुआयामी उपयोग से उत्पादकता में वृद्धि, अधिक वर्षा वाले क्षेत्रों में वर्षा जल प्रबंधन के क्षेत्र में अनुसंधान एवं विस्तार कार्यों को कार्यान्वित किया गया। वर्ष 2022 की प्रमुख उपलब्धियां नीचे सूचीबद्ध की गई हैं, जो इस प्रकार से है।

सतही जल और भूजल उपलब्धता का आकलन

मुला राइट बैंक नहर के कमांड क्षेत्र की माइनर संख्या 2 से मृदा और जल के नमूने तथा मृदा और कुएं के जल की गुणवत्ता के विश्लेषण के आधार पर यह स्पष्ट हुआ कि मृदा और जल की गुणवत्ता खराब होती जा रही है यानि लवणता और अम्लता की ओर बढ़ती जा रही है। कमांड क्षेत्र में टिकाऊ कृषि के लिए फसलों की उत्पादकता, मृदा और जल की गुणवत्ता में सुधार हेतु निश्चित प्रबंधन रणनीतियों को अपनाने की आवश्यकता है। कुछ प्रबंधन रणनीतियाँ जो कि इस प्रकार से हैं (1) फलीदार फसलों के समावेश के साथ फसल चक्र को अपनाना और गन्ना जैसी वार्षिक फसलों को लगातार उगाने से बचना, (2) लवण सहिष्णु फसलें जैसे कपास, बरसीम, चुकंदर, गेहूं, ज्वार, मक्का, सूरजमुखी, पालक, पत्ता गोभी आदि को शामिल करना (3) सिंचाई के लिए अच्छी गुणवत्ता वाले जल के साथ मामूली रूप से खराब जल को कम मात्रा में मिलाना (4) दबाव युक्त सिंचाई प्रणाली को अपनाना (5) मृदा परीक्षण के मूल्यों के आधार पर उर्वरकों का प्रयोग करना (6) खराब मृदा के सुधार के लिए रासायनिक संशोधनों का उपयोग करना (7) जैविक खाद और हरी खाद वाली फसलों जैसे सनहेम्प, ढैंचा और ग्लारिसीडिया का उपयोग करना। (राहुरी केंद्र)

मध्य पंजाब भूजल दोहन के मामले में पंजाब राज्य का सबसे अधिक प्रभावित क्षेत्र है क्योंकि, इस क्षेत्र में सभी ब्लॉकों में भूजल का अत्यधिक दोहन किया जा चुका है। मध्य पंजाब में वर्ष 1998-2019 की अवधि के दौरान भूजल की कमी को प्रभावित करने वाले कारकों का विश्लेषण करने और स्थिरता के लिए उपयुक्त प्रबंधन रणनीतियों को तैयार करने के लिए यह अध्ययन किया गया। ट्रेंड विश्लेषण को नॉन-पैरामेट्रिक सेन के स्लोप के द्वारा परिमाणित किया गया और मान-केंडल परीक्षण के द्वारा इसके महत्व का आकलन किया गया। भूजल मॉडल को विकसित करने के लिए आर्टीफिसियल न्यूरल नेटवर्क (ANN) और मल्टीपल लीनियर रिग्रेसन (MLR) का मॉडलिंग उपकरण के रूप में उपयोग किया गया। समग्र भूजल स्थिरता सूचकांक (GSI) को एनालिटीकल हिरार्ची प्रोसेस (AHP) का उपयोग करके विकसित किया गया। मध्य पंजाब में वर्षा और न्यूनतम तापमान ने कोई ट्रेंड नहीं दिखाया। फतेहगढ़ साहिब, कपूरथला और पटियाला में अधिकतम तापमान के पैरामीटर में उल्लेखनीय वृद्धि देखी गई। पूरे मध्य पंजाब में भूजल स्तर घटता हुआ पाया गया जो 0.30-1.07 मीटर प्रति वर्ष के बीच था। मध्य पंजाब में भूजल के अत्यधिक दोहन के मामले में संगरूर जिला सबसे बुरी तरह से प्रभावित पाया गया। मध्य पंजाब में आर्टीफिसियल न्यूरल नेटवर्क ने मल्टीपल लीनियर रिग्रेसन की तुलना में बेहतर प्रदर्शन दिखाया। पहचान की गई संभावित प्रबंधन रणनीतियों में (i) धान के तहत क्षेत्र को अन्य फसलों में स्थानांतरित करना (ii) धान की लंबी अवधि की किस्मों के तहत क्षेत्र को कम अवधि की किस्मों के तहत स्थानांतरित करना (iii) समग्र भूजल स्थिरता सूचकांक में सुधार के लिए नहर सिंचित क्षेत्र को बढ़ावा देना आदि शामिल थी। सभी रणनीतियों में समग्र भूजल स्थिरता सूचकांक में सुधार के लिए धान के क्षेत्र का विविधीकरण अधिक प्रमुख था। (लुधियाना केंद्र)

पंजाब राज्य में कृषि क्षेत्र बिजली (33%) और जल (80-90%) का प्रमुख उपभोक्ता है। राज्य के कुछ क्षेत्रों में भूजल स्तर की गहराई में तेज गिरावट का सामना करना पड़ रहा है जबकि, कुछ क्षेत्र जल स्तर के बढ़ने की समस्याओं का सामना कर रहे हैं। इस प्रकार इसका प्रमुख उद्देश्य इस राज्य की कृषि में पम्पिंग ऊर्जा की दक्षता में सुधार के लिए स्पेसियल डीसीजन सपोर्ट सिस्टम (SDSS) को विकसित करना था। कृषि उत्पादन के लिए घटते भूजल स्तर के परिणामस्वरूप पम्पिंग ऊर्जा की खपत में वृद्धि होती है और यह इस क्षेत्र में जल-खाद्य-ऊर्जा नेक्सस की दिशा में योगदान देता है। इसके अलावा पंप के गलत आकार का चयन इस जल-खाद्य-ऊर्जा नेक्सस को जोड़ रहा है। इसका अध्ययन

भूजल के अनावश्यक दोहन को रोकने के लिए किया गया। पंजाब राज्य के कुल 12959 गांवों के लिए स्पेसियल डीसीजन सपोर्ट सिस्टम को विकसित किया गया। स्पेसियल डीसीजन सपोर्ट सिस्टम उपयोगकर्ताओं को उनके क्षेत्र की स्थिति, भूजल स्तर, हिस्टोरिकल वेदर डेटासेट तथा फसल पैटर्न की स्थानिक और अस्थायी स्थितियों के आधार पर उस क्षेत्र में वास्तविक पम्पिंग ऊर्जा की आवश्यकता के बारे में मार्गदर्शन करता है। डिजाइन किया गया यह सिस्टम पंजाब राज्य की पांच प्रमुख फसलों कपास, मक्का, धान, गन्ना और गेहूं से संबंधित है। यह स्पेसियल डीसीजन सपोर्ट सिस्टम नीति निर्माताओं/पंपिंग उद्योगों/किसानों और/या हितधारकों को इस क्षेत्र के लिए आवश्यक वास्तविक पंप की हॉर्सपावर और प्रतिदिन पंपिंग घंटे का अनुमान लगाने में सहायता करेगा। (लुधियाना केंद्र)

छत्तीसगढ़ के अरपा जलग्रहण क्षेत्र में हाइड्रोलॉजिकल मॉडलिंग के लिए सॉइल एंड वाटर असेसमेंट टूल (SWAT) सॉफ्टवेयर का उपयोग किया गया। इस मॉडल का उपयोग जल संतुलन घटकों जैसे कि वर्षा, अधिकतम तापमान, न्यूनतम तापमान, सतही अपवाह, परकोलेशन, वाष्पोत्सर्जन आदि पर जलवायु परिवर्तन के प्रभावों का अध्ययन करने के लिए किया गया। GCM जलवायु परिवर्तन परिदृश्य (SSP2-4.5 और SSP5-8.5) एवं तीन समयावधि स्लाइसेस 2030 (2021-2046), 2060 (2047-2073) और 2090 (2074-2121) का विश्लेषण किया गया। न्यूनतम और अधिकतम तापमान, सतही अपवाह, रिसाव, वाष्पीकरण, भूजल योगदान और जल की उपज के लिए आधार वर्ष (1985-2020) हेतु परिवर्तन विश्लेषण किया गया था। (रायपुर केंद्र)

भूजल का संभावित क्षेत्रीकरण और पुन:भरण

भौगोलिक सूचना प्रणाली (GIS), उप-वाटरशेड्स की प्राथमिकता और भूजल पुन:भरण के लिए संभावित स्थलों की पहचान जैसी तकनीकों का उपयोग करके भाखड़ा नदी वाटरशेड के मॉर्फोमेट्रिक मापदंडों की जांच के लिए एक अध्ययन किया गया। भाखड़ा नदी का वाटरशेड उत्तराखंड के उधम सिंह नगर जिले के तराई और भभर क्षेत्रों और नैनीताल जिले और उत्तर प्रदेश के रामपुर जिले के अंतर्गत आता है। यह क्षेत्र 216.725 किमी की परिधि के साथ 475.623 वर्ग किमी के क्षेत्र को कवर करता है। इस अध्ययन क्षेत्र की प्रमुख भूमि उपयोग व भूमि कवर इकाइयाँ कुल 260.932 वर्ग किमी (54.86% क्षेत्र) में फैले वन क्षेत्र के रूप में थी इसके बाद 183.46 वर्ग किमी (38.574% क्षेत्र) के कृषि भूमि के क्षेत्र में खेती की गई फसलें थीं। इस अध्ययन क्षेत्र की अधिकतम मृदा का प्रकार भबर है जो 235.246 वर्ग किमी के क्षेत्र को कवर करता है। तराई मृदा इस अध्ययन क्षेत्र के 207.420 वर्ग किमी को कवर करती है। अध्ययन क्षेत्र का एक छोटा सा भाग पहाड़ी मृदा और जलोढ़ मृदा से ढका हुआ है। निम्नतम कंपाउंड मूल्य के साथ तीन उप-वाटरशेड्स अर्थात निहाल, घुटवा और ढ़ीमरी अधिक प्राथमिकता वाले क्षेत्र के अंतर्गत आते हैं जहाँ पर मृदा और जल संरक्षण के उपायों के कार्यान्वयन के लिए तत्काल ध्यान देने की आवश्यकता है। जल संरक्षण संरचनाओं के निर्माण के लिए उपयुक्त स्थानों यानि 27 चेक बांधों और 55 तालाबों की पहचान की गई। ये संरचनाएं कृत्रिम भूजल पुन:भरण के संभावित स्थलों के रूप में कार्य करेंगी। ये संरचनाएं भाखड़ा नदी वाटरशेड क्षेत्र में विभिन्न गतिविधियों के लिए जल की उपलब्धता बढ़ाने में भी मदद कर सकती हैं। (पंतनगर केंद्र)

सिंचाई जल प्रबंधन क्षेत्रीय केंद्र बेलवातगी में एक भूजल पुन:भरण इकाई स्थापित की गई और इससे पुन:भरण का अनुमान लगाया गया। इस पुन:भरण इकाई की स्थापना के बाद से विगत तीन वर्षों में कुल 12.24 लाख लीटर भूजल का पुन:भरण हुआ है। भूजल के मूल्यांकन से पता चला कि भूमि के स्तर से लगभग 100 फीट से अधिक के नीचे भूजल स्तर में 26 फीट नीचे भूमि स्तर (BGL) तक भूजल में काफी वृद्धि हुई है। भूजल की विद्युत चालकता (EC) में 10 डेसी सिमन्स/मीटर से अधिक तक और औसत 1.59 डेसी सिमन्स/मीटर तक की भारी कमी प्राप्त हुई। नलकूपों की जल उपज 0.4 लीटर/घंटा से बढ़कर लगभग 2.5 लीटर/घंटा तक बढ़ गई। पुन:भरण यूनिट की स्थापना के बाद से केंद्र के घरेलू उपयोग के लिए लगभग 10.43 लाख लीटर नलकूप के जल को निकाला जा चुका है। (बेलावतगी केंद्र)

मध्य प्रदेश राज्य की सभी 12 नदी घाटियों के लिए भूजल संभावित क्षेत्रीकरण का कार्य शुरू किया गया और भूजल संभावित क्षेत्रों के मानचित्र विकसित किए गए। इन नक्शों को पांच अलग-अलग भूजल संभावित क्षेत्रों जैसे बहुत अच्छा, अच्छा, मध्यम, खराब और बहुत खराब में वर्गीकृत किया गया। परिणामों से पता चला कि सभी नदी घाटियों का बड़ा हिस्सा मध्यम क्षेत्र से अच्छे क्षेत्र की श्रेणी के अंतर्गत आता है जो क्रमशः लगभग 50-55% और 25-30% तक है। पूरे मध्य प्रदेश राज्य में विभिन्न भूजल संभावित क्षेत्रों को क्रमशः 6.20%, 28.73%, 51.43%, 13.05% और 0.59% को शामिल करते हुए बहुत अच्छे, अच्छे, मध्यम, खराब और बहुत खराब के रूप में वर्गीकृत किया गया है। (जबलपुर केंद्र)

राजस्थान के उदयपुर जिले में चयनित वर्षा जल संचयन संरचनाओं अर्थात शिश्वी-I, शिश्वी-II और कर्माल की भंडारण क्षमता

में वार्षिक हानि 2.36% से 3.57% तक के बीच है। भंडारण क्षमता में औसत वार्षिक हानि का मूल्यांकन 2.92% के रूप में किया गया। इस प्रकार हर 4 साल में डी-सिल्टेशन शेड्यूलिंग का सुझाव दिया गया जो इन संरचनाओं की भंडारण क्षमता को 10% तक अधिक बढ़ा सकता है। डी-सिल्टेशन के बाद शिश्री जल संचयन संरचनाओं की पुन:भरण दर 8.32 सेमी/दिन पाई गई जो कि पहले केवल 6.29 सेमी/दिन थी। डी-सिल्टेशन की क्रिया से पहले भूजल का पुन:भरण आयतन 18821 घनमीटर था जो डी-सिल्टेशन के बाद बढ़कर 38785 घन मीटर तक हो गया। (उदयपुर केंद्र)

सतही और दबाव युक्त सिंचाई प्रणालियों का उपयोग करके सिंचाई के समय का निर्धारण

स्प्रिंकलर सिंचाई विधि के माध्यम से विभिन्न सिंचाई कार्यक्रमों के तहत मूंगफली की उत्पादकता और जल उपयोग दक्षता के आकलन पर अनुसंधान किया गया। ओड़िशा राज्य के पश्चिमी मध्य टेबल भूमि क्षेत्र में 90% PE के सिंचाई स्तर पर सिंचाई करने से मूंगफली (किस्म-स्मृति) की फसल में अधिकतम फली उपज (2.01 टन/हेक्टर) का उत्पादन प्राप्त हुआ। शुद्ध लाभ ₹ 59,443.7/हेक्टर और लाभ-लागत अनुपात 2.35 प्राप्त हुआ। (चिपलिमा केंद्र)।

तीन वर्षों तक फूलगोभी में ड्रिप सिंचाई और फसल ज्यामिति के तहत अनुसंधान किया गया। ड्रिप सिंचाई के साथ फूलगोभी की उपज में 47.7 से 52.4 टन/हेक्टर तक वृद्धि हुई और ड्रिप सिंचाई के साथ अधिकतम उपज 1.0 के फसल वाष्पोत्सर्जन के सिंचाई स्तर पर दर्ज की गई। अधिक दूरी की तुलना में कम दूरी पर फूलगोभी की बुवाई से अधिक पैदावार प्राप्त होती है। ड्रिप सिंचाई के स्तर 0.6 फसल वाष्पोत्सर्जन पर सिंचाई से न्यूनतम जल उपयोग और अधिकतम जल खपत दक्षता प्राप्त हुई। (श्रीगंगानगर केंद्र)

तीन वर्षों तक गाजर की फसल के उत्पादन के लिए ड्रिप सिंचाई और फसल ज्यामिति के साथ एक अनुसंधान किया गया। सतही (Flood) सिंचाई (31.5 टन/हेक्टर) की तुलना में ड्रिप सिंचाई (39.3 से 43.6 टन/हेक्टर) से गाजर की फसल का अधिक उत्पादन प्राप्त हुआ। ड्रिप सिंचाई के साथ 0.8 फसल वाष्पोत्सर्जन के स्तर पर गाजर की सिंचाई की गई। अधिक दूरी की तुलना में कम दूरी पर गाजर की बुवाई से अधिक पैदावार प्राप्त हुई। ड्रिप सिंचाई के साथ 0.6 फसल वाष्पोत्सर्जन के स्तर पर सिंचाई से न्यूनतम जल उपयोग और अधिकतम जल खपत दक्षता प्राप्त हुई। (श्रीगंगानगर केंद्र)

धान-गेहूं फसल पद्धति के तहत गेहूं की फसल में विभिन्न बुवाई की विधियों और सिंचाई के समय-निर्धारण के साथ अनुसंधान किया गया। अधिक दाना उपज (4.73 टन/हेक्टर) और शुद्ध आय (₹ 59057/हेक्टर) प्राप्त करने के लिए हैप्पी सीडर के साथ गेहूं की बुवाई और क्रिटिकल रूट इनीसियसन, टिलरिंग, जोइंटिंग, दूध बनने और दाना भरने की अवस्थाओं में पाँच सिंचाइयाँ करने का सुझाव दिया गया। (अयोध्या केंद्र)

अलग-अलग ड्रिप सिंचाई शेड्यूल्स और उर्वरक के अलग-अलग स्तरों के साथ आंवला के बाग में पौधों के बीच खाली जगह पर लगातार तीन वर्षों तक हल्दी की फसल में प्रयोग किया गया। कुल 19.90 टन/हेक्टर की अधिकतम उपज, ₹ 494200/हेक्टर का अधिकतम शुद्ध लाभ और लाभ-लागत अनुपात (4.82) प्राप्त करने के लिए आंवला के बाग की खाली जगह में उगाई जाने वाली हल्दी में उर्वरकों की सुझाई गई 100% मात्रा के प्रयोग के साथ 80% PE पर ड्रिप सिंचाई का सुझाव दिया गया। (अयोध्या केंद्र)

फर्टिगेशन

गन्ने के खेत में ड्रिप फर्टिगेशन के तहत अनुसंधान किया गया। पश्चिमी महाराष्ट्र की मध्यम काली मृदा में अधिक उपज, वित्तीय लाभ और सिंचाई जल की बचत प्राप्त करने के लिए गोबर की खाद के साथ मृदा परीक्षण-आधारित उर्वरकों के प्रयोग के आधार पर 80% ETc पर सतही ड्रिप सिंचाई विधि के माध्यम से वैकल्पिक दिनों पर क्रमशः 36 और 32 साप्ताहिक विभाजन के रूप में फर्टिगेशन का उपयोग करने की सलाह दी गई। (राहुरी केंद्र)

धान-मूंग-ब्रोकली फसल पद्धति में ड्रिप फर्टिगेशन के तहत प्रयोग किया गया। सिंचाई के स्तर 1.20 ETc पर ड्रिप सिंचाई से सबसे अधिक धान की उपज प्राप्त हुई जबकि, 1.00 ETc पर ड्रिप सिंचाई से अधिकतम ब्रोकली हेड की उपज प्राप्त हुई। सिंचाई के स्तर 1.20 ETc पर ड्रिप सिंचाई के साथ अधिकतम फसल पद्धति की उपज की गणना की गई जो 1.00 ETc पर ड्रिप सिंचाई के बराबर थी। ड्रिप के माध्यम से उर्वरकों की सुझाई गई 100% मात्रा के प्रयोग से धान के अनाज की उपज, ब्रोकोली की उपज और फसल पद्धति की उपज में काफी अधिक वृद्धि हुई; जो ड्रिप सिंचाई के माध्यम से उर्वरकों की सुझाई गई 75% मात्रा के प्रयोग के बराबर थी। (जोरहाट केंद्र)

टमाटर-बैंगन फसल क्रम के साथ ड्रिप फर्टिगेशन का प्रयोग किया गया। जब फॉस्फोरस की सुझाई गई 75% मात्रा का बुवाई के समय प्रयोग तथा वृद्धि की विभिन्न अवस्थाओं पर नाइट्रोजन

एवं पोटेशियम की 75% मात्रा का फर्टिगेशन के माध्यम से प्रयोग किया तो टमाटर और बैंगन की फसलों से अधिकतम फल उपज एवं अधिक जल उपयोग दक्षता प्राप्त हुई और अधिक शुद्ध लाभ भी प्राप्त हुआ। (बठिंडा केंद्र)

सरसों की फसल के लिए नाइट्रोजन, फॉस्फोरस, पोटेशियम और सल्फर का उपयोग करते हुए ड्रिप फर्टिगेशन शेड्यूल का प्रयोग किया गया। इस अनुसंधान के तीन वर्षों (रबी 2019-20 से 2021-22) से पता चला कि 60% ETc पर ड्रिप सिंचाई शेड्यूल के कारण 2.08 टन/हेक्टर की अधिक दाना उपज एवं 14.73 किग्रा/हेक्टर-मिमी की जल उपयोग दक्षता प्राप्त हुई तथा ₹ 62,777/ हेक्टर का शुद्ध लाभ और 1.93 का लाभ-लागत अनुपात प्राप्त हुआ। ड्रिप सिंचाई के तहत फर्टिगेशन के माध्यम से उर्वरकों की सुझाई गई 75% मात्रा + 30 किग्रा/हेक्टर की दर से सल्फर के प्रयोग से अधिकतम दाना उपज (2.12 टन/हेक्टर), चारा उपज (4.91 टन/हे) एवं जल उपयोग दक्षता (15.04 किग्रा/हेक्टर-मिमी) प्राप्त हुई। नियंत्रण उपचार (मृदा में उर्वरकों की सुझाई गई 100% मात्रा का प्रयोग एवं बॉर्डर स्ट्रिप सिंचाई विधि) तथा उर्वरकों की सुझाई गई 75% मात्रा + 10 एवं 20 किग्रा/हेक्टर की दर से सल्फर के प्रयोग की तुलना में 75% NPK की मात्रा एवं 30 किग्रा सल्फर प्रयोग के कारण अधिक शुद्ध लाभ ₹ 62239/हेक्टर एवं लाभ-लागत अनुपात 1.77 प्राप्त हुआ। (बिलासपुर केंद्र)

गेंदा की फसल में अलग-अलग सिंचाई स्तरों के तहत अकार्बनिक और तरल कार्बनिक (वर्मीवाश) उर्वरकों का उपयोग करके सतही और उपसतही ड्रिप फर्टिगेशन पर अनुसंधान किया गया। सतही और उपसतही ड्रिप फर्टिगेशन के सभी स्तरों में से बुवाई के समय 25% NPK उर्वरकों का प्रयोग तथा ड्रिप फर्टिगेशन के माध्यम से 75% NPK उर्वरकों के प्रयोग के कारण अधिकतम फूलों की उपज (20.13 टन/हेक्टर) और जल उपयोग दक्षता (57.90 किग्रा/हेक्टर-मिमी) प्राप्त हुई। (पालमपुर केंद्र)

मृदा-जल - पौधों के बीच संबंध पर मूलभूत अध्ययन

मालाप्रभा कमांड क्षेत्र की काली मृदा में सिंचाई एवं उर्वरकों के विभिन्न स्तरों के तहत उपयुक्त फसल पद्धति का मूल्यांकन किया गया। अरहर + उड़द अंतरसस्य फसल पद्धति में सतही सिंचाई विधि के द्वारा 0.8 ETc के स्तर पर सिंचाई करने तथा उर्वरकों की सुझाई गई 100% मात्रा के प्रयोग करने पर अधिक मक्का समतुल्य उपज (6.89 टन/हेक्टर) प्राप्त हुई। इस सिंचाई एवं उर्वरक के स्तर के कारण अधिक शुद्ध लाभ (₹ 29018/हेक्टर) एवं लाभ-लागत अनुपात (1.95) प्राप्त हुआ। (बेलवातगी केंद्र)

खरीफ मौसम में संकर मक्का की किस्म डेका-1B 9144 की मेड़ एवं ऊंची क्यारी में बुवाई करने से समान मक्का भुट्टा उपज क्रमश: 7.97 एवं 7.98 टन/हेक्टर तथा जल उत्पादकता क्रमश: ₹ 1.84 and ₹ 1.82/मिमी प्राप्त हुई। इन बुवाई की विधियों से शुद्ध लाभ ₹ 1,03,524 एवं 1,03,815/हेक्टर तथा लाभ-लागत अनुपात 2.23 प्राप्त हुआ। जबकि, संकर मक्का की समतल क्यारियों में बुवाई करने से 7.34 टन/हेक्टर भुट्टा उपज एवं ₹ 1.14/मिमी जल उत्पादकता प्राप्त हुई; ₹ 88442/हेक्टर का शुद्ध लाभ एवं 1.77 लाभ लागत अनुपात प्राप्त हुआ। इसलिए, उत्तराखंड राज्य के तराई क्षेत्रों में संकर मक्का की मेड़ एवं ऊंची क्यारियों में बुवाई जल भराव एवं अपर्याप्त जल निकासी की समस्या का समाधान कर सकती है। (पंतनगर केंद्र)

मक्का (किस्म-शुगर 75) एवं मेंथा (किस्म – सीआईएम क्रांति) को 2 : 2 के अनुपात (50/100 सेमी की दूरी पर मक्का की 2 पंक्तियाँ तथा मक्का की 2 पंक्तियों के बीच मेंथा की 2 पंक्तियाँ) में अंतरसस्य के रूप में धान की पुआल की पलवार (6 टन/हेक्टर) के साथ उगाया गया। इससे अधिकतम मक्का समतुल्य उपज (29.18 टन/हेक्टर) एवं सिंचाई जल उत्पादकता (39.33 किग्रा/हेक्टर-मिमी) प्राप्त हुई। कुल ₹ 3,62,080/हेक्टर का शुद्ध लाभ एवं 3.6 लाभ लागत अनुपात प्राप्त हुआ। सिंचाई के समय के निर्धारण के स्तरों के बीच IW/CPE 1.2 (मक्का समतुल्य उपज : 23.45 टन/हेक्टर ऑइल उपज: 0.12 टन/हेक्टर) एवं 1 (मक्का समतुल्य उपज : 24.56 टन/हेक्टर ऑइल उपज: 0.13 टन/हेक्टर) के स्तरों पर सिंचाई करने पर समान उपज प्राप्त हुई। अत: यह निष्कर्ष निकाला जा सकता है कि उत्तराखंड राज्य के तराई क्षेत्रों में स्प्रिंग के मौसम में अधिक फसल एवं जल उत्पादकता प्राप्त करने के लिए धान की पुआल की पलवार (6 टन/हेक्टर) के साथ मक्का एवं मेंथा को अंतरसस्य पद्धति में IW/CPE 1.0 के स्तर पर सिंचाई के साथ उगाया जा सकता है। (पंतनगर केंद्र)

सिंचाई की तीन विधियों (नाली, एकांतर नाली एवं फ्लड) तथा पलवार की चार परिस्थियों (धान के पुआल, काली पॉलीथीन, जूट का कपड़ा एवं मृदा की पलवार) के तहत मक्का की फसल के प्रदर्शन को आँका गया। तीन वर्षों के अनुसंधान के परिणामों ने दिखाया कि नाली सिंचाई विधि के साथ काली पॉलीथीन की पलवार के प्रयोग से मक्का की अधिकतम उपज प्राप्त हुई। यह उपज फ्लड सिंचाई विधि एवं काली पॉलीथीन की पलवार के प्रयोग से प्राप्त उपज (16.37 टन/हेक्टर) के बराबर थी। फ्लड सिंचाई विधि की तुलना में नाली सिंचाई विधि से 52.7% सिंचाई जल की बचत प्राप्त हुई। (गयेशपुर केंद्र)

गेहूं-मूंग के फसल क्रम में चार सिंचाई स्तरों (IW/CPE = 0.6, 0.8, 1.0 और किसानों की सिंचाई विधि (बाढ़ सिंचाई) के साथ-साथ जिंक उर्वरक के स्तरों (5 ,0 और 10 किग्रा $ZnSO_4$) की प्रतिक्रिया से पता चला कि सिंचाई के स्तर IW/CPE 1.0 के साथ गेहूं की दाना उपज (5.42 टन/हेक्टर) अधिक प्राप्त हुई। लेकिन, किसानों की पारंपरिक सिंचाई विधि से 5.32 टन/हेक्टर उपज प्राप्त हुई जो कि एक ही समान थी। मूंग की फसल में IW/CPE 1.0 के सिंचाई स्तर पर सिंचाई करने और 10 किग्रा/हेक्टर की दर से जिंक सल्फेट का प्रयोग करने से अधिकतम दाना उपज (1.23 टन/हेक्टर) प्राप्त हुई। किसानों की पारंपरिक सिंचाई विधि एवं 10 किग्रा/हेक्टर की दर से जिंक सल्फेट का प्रयोग के संयोजन के परिणामस्वरूप गेहूं के दाने और पुआल दोनों में N, P और K तत्वों का अधिक अपटेक हुआ। हालांकि, यह IW/CPE 1.0 के सिंचाई स्तर पर सिंचाई करने और 10 किग्रा/हेक्टर की दर से जिंक सल्फेट का प्रयोग के समान ही था। इसी तरह, IW/CPE 1.0 के सिंचाई स्तर पर सिंचाई करने और 10 किग्रा/हेक्टर की दर से जिंक सल्फेट के प्रयोग के संयोजन के परिणामस्वरूप मूंग की फसल द्वारा काफी अधिक पोषक तत्व ग्रहण किए गए। (गयेशपुर केंद्र)

असम राज्य के जोरहाट जिले की बलुई दोमट मृदा में प्याज (किस्म – एग्रीफाउंड लाइट रेड) की फसल के लिए ड्रिप सिंचाई विधि से सिंचाई के समय का निर्धारण किया गया। सिंचाई के 100%, 80%, 60% and 40% ET_c के स्तरों की तुलना में 120% ETc के स्तर पर सिंचाई करने से प्याज की अधिकतम उपज प्राप्त हुई। रेस्पोंस फेक्टर Ky का उपयोग करके प्याज की किस्म की जल उत्पादकता की गणना की गई। वर्ष 2021-22 के रबी के मौसम में प्याज की प्रारम्भिक एवं मध्य वृद्धि अवस्थाओं ने Ky के मान को 1 से अधिक दिखाया। इससे यह प्राप्त हुआ कि क्रॉप रेस्पोंस जल कि कमी के प्रति बहुत संवेदनशील होता है जब जल का उपयोग कम होता है तो वैसे ही उपज में भी कमी प्राप्त होती है। सिंचाई के 120% ETc के स्तर पर सिंचाई अधिकतम उपज को सही साबित करती है। (जोरहाट केंद्र)

ऊंची क्यारी के आयामों को मानकीकृत करने के लिए एक प्रयोग किया गया और फसलों की सघनता के माध्यम से इसकी उत्पादकता का मूल्यांकन किया गया। सिंचाई शेड्यूलिंग के स्तरों में अधिकतम बासमती धान समतुल्य उपज (7.13 टन/हेक्टर) 100% फील्ड केपेसिटी (I_1) पर सिंचाई के साथ प्राप्त हुई। जबकि, विभिन्न फसल क्रमों के बीच धान (लघु अवधि) - मेथी – शलजम - प्याज - लोबिया के फसल क्रम को ऊंची क्यारियों पर उगाने से 10.15 टन/हेक्टर की काफी अधिक बासमती धान समतुल्य उपज प्राप्त हुई तथा ₹ 2,88,113/हेक्टर का शुद्ध लाभ एवं 1.75 का लाभ-लागत अनुपात प्राप्त हुआ। इस फसल क्रम के साथ कुल ₹ 789/हेक्टर/दिन की लाभप्रदता प्राप्त हुई। मृदा में नमी के अध्ययन से पता चला कि 50% क्षेत्र में मृदा को 1 मीटर की ऊंचाई तक उठाकर ऊंची क्यारियां बनाई जा सकती हैं और अतिरिक्त जल को जमा करने के लिए शेष 50% क्षेत्र में 1.0 मीटर की गहराई वाली नीची क्यारियाँ बनाई जा सकती हैं। यह तकनीक जम्मू कश्मीर केंद्र शासित प्रदेश के रणबीर नहर के कमांड क्षेत्र (जिसका क्षेत्रफल लगभग 10000 हेक्टर है) के अंतर्गत जल भराव वाले क्षेत्रों तथा अन्य समान पारिस्थिकी तंत्र के लिए उपयोगी साबित हो सकती है। (जम्मू केंद्र)

परिचालन अनुसंधान परियोजना (ओआरपी)

अवानपुर डिस्ट्रीब्यूटरी के हेड, मिडिल और टेल रीच पर किसानों की विधि (खेत से खेत की बाढ़ सिंचाई के माध्यम से 8-10 सेमी जल) की तुलना में चेक बेसिन (5 मीटर × 10 मीटर) सिंचाई विधि से गेहूं की महत्वपूर्ण वृद्धि की अवस्थाओं (क्रिटिकल रूट इनिसियसन, लेट जोइंटिंग और मिल्किंग) में बेहतर जल प्रबंधन यानि 6 सेमी गहराई की सिंचाई के परिणामस्वरूप 27.34 से 31.12% तक अधिक गेहूं की औसत उपज तथा 103.8-112.71% अधिक जल उपयोग दक्षता प्राप्त हुई। (अयोध्या केंद्र)

अवानपुर डिस्ट्रीब्यूटरी के किसानों के खेत में नहर के जल की कम उपलब्धता के तहत रबी मौसम के दौरान फसलों के विविधीकरण पर अनुसंधान से पता चला कि चना और सरसों की अंतरफसल (4:1) पद्धति ने 4.79 टन/हेक्टर के अधिकतम गेहूं समतुल्य उपज के साथ सबसे अच्छा प्रदर्शन दिखाया। इसके बाद मसूर और सरसों की अंतर-फसल (4:1) पद्धति और चना की अकेली फसल ने क्रमशः 4.49 और 4.30 टन/हेक्टर के बराबर गेहूं की पैदावार उत्पन्न की। सरसों और चने की अंतरफसल से ₹ 66860 प्रति हेक्टर का अधिकतम शुद्ध लाभ प्राप्त हुआ और 2.52 का लाभ-लागत अनुपात भी दर्ज किया गया। (अयोध्या केंद्र)

किसानों द्वारा कपास की फसल में पारंपरिक रूप से अपनाई गई समतल बुवाई एवं चेक बेसिन सिंचाई विधि की तुलना में मेड़ पर बुवाई और नाली सिंचाई विधि के लाभों को दर्शाने के लिए खरीफ 2022 के दौरान पंजाब राज्य में बठिंडा जिले के मुअर, संगत, नथाना, बठिंडा और तलवंडी साबो ब्लॉकों में प्रत्येक गांव में पांच प्रदर्शन आयोजित किए गए। पाँच किसानों के खेतों में सिंचाई के जल को बचाने के लिए समतल बुवाई एवं चेक बेसिन सिंचाई विधि

की तुलना में मेड़ पर बुवाई और नाली सिंचाई विधि अधिक उपज और जल उत्पादकता के मामले में आशाजनक सुधार हेतु सही साबित हुई। इसके अलावा अन्य लाभ जैसे कि (i) मृदा की सतह के नीचे परत निर्माण की अनुपस्थिति ने अंकुरण को प्रतिबंधित नहीं किया और (ii) बारिश के तुरंत बाद खेत में जल भराव की अनुपस्थिति ने अंकुरण के प्रतिशत में वृद्धि आदि। किसान अपनी ही भूमि में प्रदर्शित परिणामों से संतुष्ट पाये गए। (बठिंडा केंद्र)

बठिंडा जिले के तीन ब्लॉकों में किसानों के खेतों पर पांच प्रदर्शन आयोजित किए गए। धान की किस्मों अर्थात पूसा बासमती 1718, पीआर 126 और पीआर 130 को किसानों की पद्धति (वृद्धि की अवधि के दौरान निरंतर जलमग्नता) और उन्नत तकनीक (2 सप्ताह तक लगातार जलमग्न + खेत में जल सूखने के 2 दिन बाद सिंचाई) के साथ उगाया गया। किसानों की विधि एवं उन्नत तकनीक के तहत प्रयोग किया गया सिंचाई का जल क्रमशः 100 और 72 सेमी था। इस प्रकार उन्नत तकनीक से 25-54% तक सिंचाई जल की बचत प्राप्त हुई लेकिन, किसानों की विधि की तुलना में उन्नत विधि से केवल 1.7 से 5.0% तक ही उपज में वृद्धि प्राप्त हुई। इस प्रकार किसानों को विश्वास दिलाया गया कि यद्यपि उन्नत तकनीक के साथ धान की उपज में वृद्धि महत्वपूर्ण नहीं हुई लेकिन, इस तकनीक को अपनाकर सिंचाई के जल की एक महत्वपूर्ण मात्रा को बचाया जा सकता है। (बठिंडा केंद्र)

खेत में मौजूद तालाब जल का एक अच्छा स्रोत होता है जिससे 15 किसानों के खेतों में ड्रिप सिंचाई प्रणाली को स्थापित किया गया। इसका मुख्य उदेश्य पंक्तियों में उगाई जाने वाली फसलों की पैदावार, सिंचाई जल की बचत, जल उत्पादकता और आर्थिक लाभ में सुधार का मूल्यांकन करना था। इसके अतिरिक्त, प्रदर्शन के लिए आईडबल्यूएमआरसी, बेलवातगी केंद्र द्वारा 24 एकड़ भूमि के लिए सेंसर आधारित ड्रिप सिंचाई स्वचालन प्रणाली स्थापित की गई और किसानों, छात्रों, अधिकारियों आदि के लिए फील्ड दिवसों के साथ-साथ प्रशिक्षण कार्यक्रमों का आयोजन भी किया गया । (बेलवातगी केंद्र)

चंबल नहर के कमांड क्षेत्र के लिए अत्यधिक उत्पादक और लाभदायक फसल पद्धति को स्थापित करने के लिए मध्य प्रदेश के मुरैना जिले के हड़वांसी, संथा, सिकरेरोदा, भाटपुरा, सिलबाटा, जाटबरकापुरा, बरौली और सिरमती गाँवों में किसानों के खेतों पर सिंचाई जल प्रबंधन के प्रयोग आयोजित किए गए। नहर के कमांड क्षेत्र के ऊपरी छोर के लिए अरहर-गेहूं फसल चक्र के बाद धान-गेहूं लाभकारी फसल चक्र होगा। मध्य छोर के लिए अरहर-गेहूं के बाद ग्वार-गेहूं तथा अंतिम छोर के लिए बाजरा-सरसों के बाद बाजरा - चना, और ग्वार-जौ फसल चक्र फायदेमंद रहेंगे। लेजर लेवलर यंत्र के द्वारा भूमि समतलन ने फसलों की उपज और जल उत्पादकता पर सकारात्मक प्रभाव दिखाया। धान को छोड़कर सभी फसलों के लिए नहर के कमांड क्षेत्र के ऊपरी, मध्य और अंतिम छोर पर उपज (16-22%), आर्थिक लाभ और जल उत्पादकता (11-52%) के मामले में चौड़ी क्यारी एवं नाली सिंचाई विधि सर्वोत्तम पाई गई । (मुरैना केंद्र)

केरल राज्य के विभिन्न जिलों में जल प्रबंधन पर अखिल भारतीय समन्वित अनुसंधान परियोजना के केंद्र चलाकुड़ी के द्वारा विभिन्न तकनीकों के बहु स्थानीय प्रयोग किए गए। थ्रिसुर, एरणाकुलम एवं पालकड़ जिलों के 3 किसानों के खेतों पर पारंपरिक एवं जल घुलनशील उर्वरकों का उपयोग करते हुए केला की प्रीसिसन खेती को दोहराया गया जिसको 6 किसानों द्वारा अपनाया गया। उपरोक्त जिलो में 5 किसानों के खेतो में सुपारी की फसल में पलवार एवं सिंचाई के प्रभाव को प्रदर्शित किया गया। थ्रिसुर जिले के दो किसानों के खेतों पर "एमोर्फोफैलस में सिंचाई शेड्यूलिंग और पलवार " नामक एक अन्य अध्ययन का प्रदर्शन किया गया। (चलाकुड़ी केंद्र)

जनजातीय उप योजना (TSP) और अनुसूचित जाति उप योजना (SCSP)

टीएसपी के तहत वर्ष 2022 के दौरान "कोंकण विजय भंडारा" नाम के चार और आठ प्लास्टिक अस्तरित चेक बांध क्रमशः जवाहर और विक्रमगढ़ तालुका में बनाए गए। इससे कुल 49 आदिवासी किसानों ने लाभ प्राप्त किया और सब्जियां, काजू, आम और चमेली उगाने के लिए 30.05 हेक्टर अतिरिक्त कृषि क्षेत्र का उपयोग किया। वर्ष 2021-22 के दौरान कुल 350 कोंकण जलकुंड का निर्माण किया गया। कुल 175 आदिवासी किसान लाभान्वित हुए और इनके द्वारा आम तथा काजू के पौधे उगाने के लिए 35 हेक्टर के अतिरिक्त क्षेत्र की सिंचाई की गई। महाराष्ट्र राज्य के पालघर जिले के मोखड़ा, जव्हार और विक्रमगढ़ तालुकों में आम और काजू के बागानों में चमेली की अंतरफसल की भी सिंचाई की गई। उत्तर कोंकण क्षेत्र में जलकुंड तकनीक के मूल्यांकन से पता चला कि आम और काजू की कलमों की उत्तरजीविता में क्रमश: 28.85 और 41.5% तक की वृद्धि दर्ज हुई। जलकुंड तकनीक के कार्यान्वयन के बाद खेती योग्य भूमि उपयोग सूचकांक 0.25 से बढ़कर 0.45 तक हो गया और पारंपरिक विधि के उपयोग की तुलना में प्रति हेक्टर ₹1,30,334 को बचाया गया। आम और काजू के बागानों में अंतर-फसल के रूप में वृक्षारोपण कर उगाई गई

चमेली की फसल से प्रति हेक्टर ₹ 1,29,324 का लाभ प्राप्त हुआ । (दापोली केंद्र)

अनुसूचित जाति उप योजना के तहत अप्रैल से दिसंबर 2022 तक गिम्हावणे और असोंड गांवों में वर्षा जल का संचयन, सब्जियों की खेती के लिए जल संसाधनों का उपयोग तथा जल की उत्पादकता को बढ़ाने के लिए 11 चेक बांधों का निर्माण किया गया। इनके परिणामस्वरूप गाँवों में सब्जियों का उत्पादन करने वाले क्षेत्रों की जल की उपलब्धता में वृद्धि हुई। कुल 17 अनुसूचित जाति के किसानों को खरीफ (वर्षा आधारित) के मौसम के दौरान मल्च की सहायता से धान की खेती और गर्मियों के दौरान धान में ड्रिप सिंचाई पर प्रशिक्षण और प्रदर्शन आयोजित किया गया । (दापोली केंद्र)

अनुसूचित जाति उप योजना के तहत असम राज्य के बोंगईगाँव एवं ढुबरी जिलों के उथले नलकूप वाले कमांड क्षेत्रों में कुल 2 हेक्टर भूमि में अनुसूचित जाति के 6 किसानों के खेतों पर गर्मियों के धान में उन्नत जल प्रबंधन पर प्रदर्शन आयोजित किया गया। जब खेत में भरे जल का स्तर भूमि के स्तर से 15 सेमी तक नीचे गिर गया तो एकांतर नम एवं सुखी सिंचाई विधि के द्वारा 5 सेमी की गहराई का सिंचाई जल प्रयोग किया गया। किसानों के खेतों पर 40 सेमी लंबे एवं 15 सेमी व्यास वाले छिद्रित पीवीसी पाइपों की सहायता से खेत में भरे जल की गहराई को मापा गय। (जोरहाट केंद्र)

जोरहाट जिला, बिश्वनाथ जिले के मरलगाँव, और सिबसागर जिले के दिखौमुख और गोलाघाट जिले के ऊपरी टेमेरा गाँवों के कुल 185 किसानों के लिए सूक्ष्म सिंचाई के साथ-साथ उन्नत सतही सिंचाई के साथ फसलों में जल प्रबंधन पर विभिन्न प्रशिक्षण कार्यक्रम आयोजित किए गए। (जोरहाट केंद्र)

अनुसूचित जाति उप योजना के तहत राजस्थान के कोटा जिले की डीगोद तहसील के सुहाना गांव में अनुसूचित जाति के किसानों के लिए सोयाबीन की फसल में स्प्रिंकलर सिंचाई के साथ आठ प्रदर्शन आयोजित किए गए। किसानों के खेतों में फ्लड सिंचाई विधि की तुलना में स्प्रिंकलर सिंचाई विधि के तहत 9.2% अधिक औसत उपज और 45.1% औसत जल उपयोग दक्षता प्राप्त हुई। इसके बाद कोटा जिले की दिगोद तहसील के सुहाना गांव और सुल्तानपुर तहसील के खंडगांव गांव में अनुसूचित जाति के किसानों के लिए सोयाबीन की फसल के साथ फव्वारा सिंचाई पर दो प्रशिक्षण कार्यक्रम आयोजित किए गए। (कोटा केंद्र)

टीएसपी और एससीएसपी कार्यक्रम के तहत छोटी जोत वाले अनुसूचित जन जाति के कुल 95 किसानों और अनुसूचित जाति के कुल आठ किसानों को 36 हेक्टर भूमि वाले विभिन्न गांवों के किसानों के 11 समूहों में ड्रिप सिंचाई प्रणाली वितरित की गई। डांग जिले के किसानों के खेतों में करेला, लौकी, तरबूज आदि फसलों में ड्रिप सिंचाई प्रणाली का सफल प्रदर्शन आयोजित किया गया और आसपास के कई किसानों ने आगे आकर बढ़-चढ़ कर सब्जियों वाली फसलों में ड्रिप सिंचाई विधि को अपनाने में अपनी रुचि दिखाई । (नवसारी केंद्र)

टीएसपी के तहत महाराष्ट्र राज्य के हिंगोली जिले के कलामनुरी तहसील के वाई गांव में स्प्रिंकलर और ड्रिप सिंचाई प्रणाली के तकनीकी परीक्षण और प्रदर्शन आयोजित किए गए। कुल 10 स्प्रिंकलर और ड्रिप सिंचाई प्रणाली के जोड़ों के खेत पर परीक्षणों से पता चला कि स्प्रिंकलर का परिचालन दबाव 2 से 2.5 किलोग्राम/वर्ग सेमी था तथा स्प्रिंकलर हेड का डिस्चार्ज स्प्रिंकलर नोजल की स्वीकृत सीमा के भीतर था। ड्रिप सिंचाई प्रणाली के जोड़ों ने भी स्वीकृत डिस्चार्ज को दिखाया और एकरूपता गुणांक 0.9 से अधिक पाया गया। इन उन्नत सिंचाई विधियों ने सभी किसानों के लिए उनकी पारंपरिक सिंचाई विधि की तुलना में 19.23 से 30.45% तक अधिक फसल का उत्पादन दिया और लगभग 30-40% तक सिंचाई जल की बचत भी की। इससे किसानों की आर्थिक स्थिति में काफी सुधार देखने को मिला। किसानों ने इन उन्नत सिंचाई प्रणालियों द्वारा ऊबड़-खाबड़ भूमि पर समान रूप से जल का उपयोग किया। वर्तमान में वे दबाव युक्त सिंचाई प्रणाली की मदद से सोयाबीन, अरहर और कपास की फसलों की सुरक्षात्मक सिंचाई कर सकते हैं और अतिरिक्त क्षेत्र को भी सिंचाई के तहत ला सकते हैं। वे सीमित जल संसाधनों के बावजूद गेहूँ और हल्दी की खेती कर सकते हैं और फसलों की अधिक पैदावार प्राप्त कर सकते हैं। (परभणी केंद्र)

Executive Summary

During the year 2022, 26 centres carried out research and extension work in the field of assessment of water availability, groundwater recharge, groundwater use at regional level, evaluation of pressurized irrigation system, groundwater assessment and recharge, water management in horticultural and high value crops, basic studies on soil, water, plant relationship and their interaction, conjunctive use of canal and underground saline water, drainage studies for enhancing water productivity, enhancing productivity by multiple use of water, rainwater management in high rainfall areas. Salient achievements of year 2022 are enlisted below.

Assessment of surface water and groundwater availability

On the basis of soil and water sampling from minor No. 2 of Mula Right Bank Canal Command area and with characterization of soil and well water quality, it is evident that the soil and water quality is getting deteriorated tending towards salinity and sodicity. Certain management strategies need to be followed to improve the soil and water quality and productivity of crops for sustainable agriculture in the command area. The management strategies are (1) crop rotation with inclusion of leguminous crops and avoid continuously growing of annual crops like sugarcane, (2) inclusion of salt tolerant crops like cotton, berseem, sugarbeet, wheat, jowar, maize, sunflower, spinach, cabbage, etc., (3) mixing moderately degraded water with good quality water for irrigation, (4) adoption of pressurized irrigation system, (5) fertilizer application based on soil test values, (6) use of chemical amendments for reclamations of degraded soils, and (7) use of organic manures and green manuring crops like sunhemp, *dhaincha* and glyricidia. (Rahuri centre)

Central Punjab is worst affected zone of Punjab in terms of groundwater exploitation because all the blocks are over-exploited in this zone. The study was carried out in Central Punjab to (i) analyze the factors affecting groundwater depletion during 1998-2019, and (ii) find suitable management strategies for sustainability. Trend analysis was quantified by non-parametric Sen's slope and their significances were assessed by Mann-Kendall test. Artificial neural network (ANN) and multiple linear regression (MLR) were used as modelling tools to develop groundwater model. The composite groundwater sustainability index (GSI) was developed using analytical hierarchy process (AHP). Rainfall and minimum temperatures did not show any trend in Central Punjab. The parameter of maximum temperature showed significantly increasing trend in Fatehgarh Sahib, Kapurthala and Patiala. Groundwater level was found to be decreasing all over Central Punjab, varying from 0.30–1.07 m year^{-1}. Sangrur was found to be worst affected in terms of groundwater over-exploitation in Central Punjab. ANN performed better compared to MLR in Central Punjab. Potential management strategies identified were (a) shifting area under paddy to other crops, (b) shifting area under long duration variety to area under short duration variety of paddy, and (c) increasing canal irrigated area for improving GSI. Among all the strategies, diversification of paddy area was more prominent in improving GSI. (Ludhiana centre)

Agriculture is the major consumer of electricity (33%) and water (80-90%) in Punjab. Some regions of the state are suffering from sharp decline in water table depth while some are facing the problems of rising water table. Thus the major aim was to develop a Spatial Decision Support System (SDSS) for improving pumping energy efficiency in agriculture in the state. The declining water table for agricultural production results in increase of pumping energy consumption, and contributes towards water-food-energy nexus in the region. Furthermore, the selection of wrong size of pump is adding to the nexus. The study was conducted to prevent unnecessary exploitation of groundwater. A SDSS was developed for 12959 villages of Punjab. The SDSS guides the user regarding actual pumping energy requirement depending on spatial and temporal conditions of his field location, groundwater level, historical weather dataset and cropping pattern in that area. The designed system deals with five major crops of Punjab, *viz.*, cotton, maize, rice, sugarcane and wheat. The developed SDSS will assist policy makers/pumping industries/farmers and/or stakeholders in estimating the actual pump horsepower and pumping hours per day required for a field. (Ludhiana centre)

SWAT software was used for hydrological modelling in Arpa catchment area of Chhattisgarh. The model was used to study the impact of climate change on water balance components in terms of precipitation, maximum temperature, minimum temperature, surface runoff, percolation, evapotranspiration, etc. GCM climate change scenarios (SSP2-4.5 and SSP5-8.5) representing three time period slices of 2030s (2021-2046), 2060s (2047-2073) and 2090s (2074-2121) were analyzed. Change analysis with reference to baseline year (1985-2020) was carried out for minimum and maximum temperature, surface runoff, percolation, evapotranspiration, groundwater contribution and water yield. (Raipur centre)

Groundwater potential zoning and recharge

A study was conducted to investigate morphometric parameters of Bhakra river watershed using GIS techniques, prioritization of sub-watersheds, and identification of potential sites for groundwater recharge. Bhakra river watershed falls under *Tarai* and *Bhabhar* regions of Udham Singh Nagar and Nainital districts of Uttarakhand and Rampur district of Uttar Pradesh. The regions cover an area of 475.623 km^2 with perimeter of 216.725 km. The dominant LULC units of the study area was forest area spreading over 260.932 km^2 (54.86% area) followed by cultivated cropland covering an area of 183.46 km^2 (38.574% area). Maximum soil type of the study area is *bhabar* soil covering an area of 235.246 km^2. *Tarai* soil covers 207.420 km^2 of study area. A small portion of the study area is covered by hill soil and alluvial soil. Three sub-watersheds *viz.*, Nihal, Ghutwa and Dhimri with lowest compound value were under high priority area, that required immediate attention for implementation of soil and water conservation measures. Suitable locations were identified for construction of water conservation structures, i.e. 27 check dams and 55 farm ponds. These will act as potential sites for artificial groundwater recharge. These could also help in enhancing water availability for various activities in Bhakra river watershed area. (Pantnagar centre)

A groundwater recharge unit was installed at IWMRC Belavatagi and estimation of recharge was done. Since installation of the recharge unit, total recharge in three years was 12.24 lakhs litres. Monitoring of groundwater revealed that there is considerable rise in water table from more than 100 feet below ground level (bgl) to about 26 feet bgl. There was drastic reduction in electrical conductivity (EC) of the groundwater from more than 10 dS m^{-1} to an average of 1.59 dS m^{-1}. Borewell yield increased significantly from 0.4 lps to around 2.5 lps. Since installation of the recharge unit, about 10.43 lakhs litres of tubewell water has been withdrawn for domestic uses of the centre. (Belavatagi centre)

Groundwater potential zoning of all 12 river basins of Madhya Pradesh was taken up and groundwater potential zones maps were developed. These maps were classified into five different groundwater potential zones such as very good, good, moderate, poor and very poor. Results revealed that major portion of all the river basins come under moderate zone to good zone, that is about 50-55% and 25-30% respectively. As a whole in the state of Madhya Pradesh, different groundwater potential zones are categorized into very good, good, moderate, poor, and very poor covering 6.20%, 28.73%, 51.43%, 13.05%, and 0.59% area respectively. (Jabalpur centre)

Annual loss in storage capacity of selected rainwater harvesting structures *viz.*, Shishvi-I, Shishvi-II and Karmal in Udaipur district of Rajasthan varied from 2.36% to 3.57%. The average annual loss in storage capacity was evaluated as 2.92%. Thus de-siltation scheduling is recommended every four years, which will enhance storage capacity of the structures by more than 10%. Recharge rate of the Shishvi water harvesting structures after de-siltation was found to be 8.32 cm day^{-1} which previously was only 6.29 cm day^{-1}. Recharge volume increased from 18821 m^3 before de-siltation to 38785 m^3 after de-siltation. (Udaipur centre)

Irrigation scheduling using surface and pressurized irrigation system

An experiment on “Assessment of productivity and WUE of groundnut under varied irrigation schedules through sprinkler” was carried out. Groundnut (cv. Smruti) produced significantly highest pod yield (2.01 t ha^{-1}) when irrigated with 90% PE through sprinkler system with net return of ₹ 59,443.7 ha^{-1} and B-C ratio of 2.35 in West Central Table Land zone of Odisha. (Chiplima centre)

An experiment was conducted under drip irrigation and crop geometry in cauliflower for three years. Cauliflower yield with drip irrigation varied from 47.7 to 52.4 t ha^{-1} and maximum yield was recorded with drip irrigation scheduled at 1.0 ET$_c$. Narrow spacing produced higher yield of cauliflower than wider spacing. Minimal water use and maximum water expense efficiency were recorded with drip irrigation at 0.6 ET$_c$. (Sriganganagar centre)

An experiment was carried out with drip irrigation and crop geometry in carrot for three years. Higher carrot yield was recorded with drip irrigation (39.3 to 43.6 t ha^{-1}) as compared to flood irrigation (31.5 t ha^{-1}). Maximum carrot yield was recorded with drip irrigation at 0.8 ET_c. Narrow spacing produced higher yield of carrot than wider spacing. Minimal water use and maximum water expense efficiency were recorded with drip irrigation at 0.6 ET_c. (Sriganganagar centre)

An experiment was carried out with different sowing methods and irrigation scheduling in wheat under rice-wheat cropping system. Sowing with happy seeder and applying five irrigations at CRI, tillering, late jointing, milking and dough stage may be recommended for higher grain yield of wheat (4.73 t ha^{-1}) and higher net income (₹ 59057 ha^{-1}), followed by sowing with happy seeder and applying four irrigations at CRI, tillering, late jointing and milking stage. (Ayodhya centre)

An experiment was conducted in turmeric for three consecutive years in the alley of Aonla orchard with different drip irrigation schedules and varying levels of fertilizer. Drip irrigation at 80% PE with 100% RDF in turmeric grown in the alley of Aonla may be recommended to obtain highest yield of 19.90 t ha^{-1}, maximum net return of ₹ 494200 ha^{-1} and B-C ratio of 4.82. (Ayodhya centre)

Fertigation

An experiment was conducted in sugarcane under drip fertigation under Western Maharashtra condition. Preseasonal sugarcane planting is advised using alternate day irrigation through surface drip scheduled at 80% ET_c and fertigation with 36 and 32 weekly splits for plant cane and ratoon, respectively, based on recommended soil test-based fertilizer application as per the following recommended yield target equation with FYM for achieving higher yield, financial returns, and water conservation in medium black soils of western Maharashtra. (Rahuri centre)

An experiment was conducted on rice–greengram–broccoli cropping system under drip fertigation. Drip irrigation at 1.20 ET_c recorded highest rice grain yield, whereas drip irrigation at 1.00 ET_c produced maximum broccoli head yield. Maximum system yield was computed with drip irrigation at 1.20 ET_c, which was at par with drip irrigation at 1.00 ET_c. Application of 100% RDF through drip recorded significantly higher rice grain yield, head yield of broccoli, and system yield; which was at par with 75% RDF through drip. (Jorhat centre)

A drip fertigation experiment was conducted with a tomato-brinjal crop sequence. Highest fruit yield, water use efficiency and net profit from tomato and brinjal crops were achieved under drip irrigation when 75% of recommended dose of P was applied as a basal dose and 75% of the recommended doses of N & K were applied through fertigation at various growth stages of crops. (Bathinda centre)

An experiment was conducted to develop drip fertigation schedule using NPK and Sulphur for mustard crop. Three years of (*Rabi* 2019-20 to 2021-22) of experiment revealed that drip irrigation schedule at 60% ET_c led to highest seed yield of 2.08 t ha^{-1}, water use efficiency (WUE) of 14.73 kg ha-mm^{-1}, net return of ₹ 62777 ha^{-1} and benefit-cost ratio (B:C) of 1.93. Application of 75% RDF+Sulphur @ 30 kg ha^{-1} through fertigation resulted in highest seed yield of 2.12 t ha^{-1}, stover yield of 4.91 t ha^{-1}, WUE of 15.04 kg ha-mm^{-1}, net return of ₹ 62239 ha^{-1} and B:C ratio of 1.77 over 10 and 20 kg ha^{-1} sulphur with 75% RDF and the Control (Soil application of 100% RDF and border strip irrigation). (Bilaspur centre)

A study was conducted on surface and subsurface drip fertigation using inorganic and liquid organic (vermiwash) fertilizers under varying irrigation schedules in marigold crop. Marketable flower yield (20.13 t ha^{-1}) was significantly higher and water use efficiency (57.90 kg ha-mm^{-1}) was maximum with application of 25% NPK as basal and sub-surface drip fertigation of 75% NPK among all the surface and subsurface fertigation treatments. (Palampur centre)

Basic studies on soil-plant-water-environment relationship

Evaluation of suitable cropping system under different irrigation and nutrients levels in *Vertisols* of Malaprabha command showed that surface irrigation at 0.8 ET_c in Redgram+Blackgram intercrop and application of 100% recommended dose of fertilizers resulted in significantly higher maize equivalent yield of 6.89 t ha^{-1}, net return of ₹ 29,018 ha^{-1} and benefit-cost ratio of 1.95. (Belavatagi centre)

Ridge sowing and bed sowing of *kharif* hybrid maize var. Decalb 9144 showed statistically similar cob yields of 7.97 and 7.98 t ha^{-1}, economic water productivities of ₹ 1.84 and 1.82 mm^{-1}, net returns of ₹ 1,03,524 and 1,03,815 ha^{-1}, and benefit-cost ratios of 2.23 each compared to flat sowing of the hybrid maize that gave yield of 7.34 t ha^{-1}, economic water productivity of ₹ 1.14 mm^{-1}, net return of ₹ 88442 ha^{-1} and benefit-cost ratio of 1.77. Thus ridge or bed planting of maize can resolve the water stagnation and inadequate drainage issue during *kharif* season in *Tarai* region of Uttarakhand (Pantnagar centre)

Sweet corn (var. Sugar-75) and mentha (var. CIM Kranti) grown as an intercrop in the ratio 2:2 (2 rows of maize at 50/100 cm and 2 rows of mentha between two pairs of maize) with rice straw mulch @ 6 t ha^{-1} resulted in highest maize equivalent yield (MEY) of 29.18 t ha^{-1}, irrigation water productivity of 39.33 kg ha-mm^{-1}, net return of ₹ 3,62,080 ha^{-1} and B:C ratio of 3.6. Between the irrigation scheduling treatments, maize equivalent yields (MEYs) and mentha oil yields under IW/CPE 1.2 (MEY: 23.45 t ha^{-1}, Oil: 0.12 t ha^{-1}) and IW/CPE 1.0 (MEY: 24.56 t ha^{-1}, Oil: 0.13 t ha^{-1}) were at par. It was concluded that maize and mentha can be grown as intercrops in the ratio of 2:2 with rice straw mulching in maize and irrigation at IW:CPE 1.0 to fetch higher crop and water productivities during spring season (February-June) in *Tarai* region of Uttarakhand. (Pantnagar centre)

Performance of sweet corn was assessed under three irrigation methods (furrow, alternate furrow and flood irrigation methods) and four mulch conditions (rice straw, black polythene, jute textile and soil mulch). Average result of three years of trial showed that maximum yield (17.17 t ha^{-1}) of sweet corn was obtained with furrow irrigation coupled with black polythene mulching (BPM) which was statistically at par yield (16.37 t ha^{-1}) with flood irrigation and BPM. Furrow also led to 52.7% water saving over flood irrigation. (Gayeshpur centre)

Response of four irrigation levels (IW/CPE=0.6, 0.8, 1.0 and flood irrigation as farmers' practice) coupled with zinc fertilization treatments (0, 5 and 10 kg ha^{-1} $ZnSO_4$) in wheat-greengram cropping sequence revealed that grain yield of wheat was highest (5.42 t ha^{-1}) with irrigation at IW/CPE 1.0, but the yield was at par with farmers' practice (5.32 t ha^{-1}). Greengram recorded maximum yield (1.23 t ha^{-1}) with irrigation at IW/CPE 1.0 and $ZnSO_4$ @ 10 kg ha^{-1}. A combination of farmers' practice and $ZnSO_4$ @ 10 kg ha^{-1} resulted in highest uptake of N, P and K in both wheat grain and straw, although it was at par with IW/CPE 1.0 and $ZnSO_4$ @ 10 kg ha^{-1}. Similarly, a combination of IW/CPE 1.0 and $ZnSO_4$ @ 10 kg ha^{-1} resulted in significantly higher nutrient uptake by greengram. (Gayeshpur centre)

Drip irrigation scheduling for onion var. Agrifound Light Red was done in sandy loam soil of Jorhat district, Assam. Bulb yield was significantly higher with irrigation scheduled at 120% ET_c over irrigation at 100%, 80%, 60% and 40% ET_c. Water applied under 120% ET_c was 3.84 L m^{-2} day^{-1}. Water productivity behaviour of the onion variety was estimated using yield response factor Ky. During *rabi* 2021-22, the crop showed Ky>1 for Initial and Mid stages. This inferred that crop response was very sensitive to water deficit with proportionally larger yield reductions when water use was reduced. This justified the highest yield obtained with irrigation at 120% ET_c .(Jorhat centre)

An experiment was conducted to standardize the dimensions of raised bed and evaluate its productivity through crop intensification under raised-sunken bed technology. Among irrigation scheduling treatments, highest basmati equivalent yield (7.13 t ha^{-1}) was obtained with irrigation at 100% field capacity (I_1). Among different crop sequences, rice (short duration) - fenugreek - knolkhol - green onion - cowpea on raised beds recorded significantly higher basmati rice equivalent yield of 10.15 t ha^{-1}, highest net return of ₹ 2,88,113 ha^{-1}, benefit-cost ratio of 1.75 and sequence profitability of ₹ 789 ha^{-1} day^{-1}. Moisture study showed that raised beds can be formed by raising soil upto a height of 1.0 m in 50% area and sunken beds of depth of 1.0 m can be formed in remaining 50% area to store excess water. The technology is suitable for waterlogged area in Ranbir canal command which is about 10000 ha in UT of Jammu and Kashmir, as well as areas with similar ecologies. (Jammu centre)

Operational Research Project (ORP)

Improved water management practice i.e. 6 cm water per irrigation at critical growth stages (CRI, late jointing and milking) of wheat in check basin (5 m × 10 m) resulted in 27.34 to 31.12% higher average wheat grain yield, and 103.8-112.71% higher water use efficiency over farmers' practice (8-10 cm water through field to field flood irrigation) at head, middle and tail reaches of Awanpur distributory. (Ayodhya centre)

Trial on diversification of crops during *rabi* season under poor availability of canal water in farmers' field of Awanpur distributory showed that intercrop of chickpea and mustard (4:1) performed best with highest equivalent wheat yield of 4.79 t ha^{-1}. This was followed by intercrop of lentil and mustard (4:1) and sole crop of chickpea that gave equivalent wheat yields of 4.49 and 4.30 t ha^{-1}, respectively. Intercropping of mustard and chickpea also recorded maximum net profit of ₹ 66860 per hectare and benefit-cost ratio of 2.52. (Ayodhya centre)

During *kharif* 2022, five demonstrations were conducted in one village in each of Muar, Sangat, Nathana, Bathinda and Talwandi Sabo blocks of Bathinda district (Punjab) to show the benefits of ridge sowing & furrow irrigation over flat sowing & check basin irrigation practiced by farmers in cotton. Ridge sowing & furrow irrigation proved to be more promising in saving irrigation water and improving yield and WUE over flat sowing & check basin irrigation in all five farmers' fields. Additional benefits were (i) absence of crust formation below soil surface did not restrict germination, and (ii) absence of water stagnation in field just after rain increased germination percentage. The farmers were convinced with the results demonstrated in their own land. (Bathinda centre)

Five demonstrations were conducted at farmers' fields in three blocks of Bathinda district. Rice varieties *viz*., Pusa Basmati 1718, PR 126 and PR 130 were grown with farmers' practice (continuous submergence throughout the growth period) and recommended technology (continuous submergence for 2 weeks + irrigation after 2 days after the disappearance of ponded water). Irrigation water applied under farmers' practice and recommended technology was 100 and 72 cm, respectively. Recommended technology led to 25-54% water saving, but only 1.7 to 5.0% higher yield compared to farmers' practice. Thus, the farmers were convinced that although increase in rice yield was not significant with the recommended technology, a significant amount of irrigation water can be saved by adopting the technology. (Bathinda centre)

Drip irrigation system was installed in 15 farmers' fields getting good source of water from farm ponds. Goal was to evaluate improvement in crop yield, water saving, water productivity, and economic feasibility in row crops. Additionally, sensor based drip irrigation automation system was installed for 24 acre land in IWMRC Belavatagi for demonstration, and organization of field days as well as training programmes for farmers, students, officials, etc. (Balavatagi centre)

On farm irrigation water management trials were conducted on farmers' fields in Hadwansi, Santha, Sikraroda, Bhatpura, Silabata, Jatbarkapura, Baroli and Sirmiti villages of Morena district of Madhya Pradesh to establish highly productive and remunerative cropping systems for Chambal canal command area. For head reach of the canal command, beneficial crop rotation would be pigeonpea-wheat followed by rice-wheat. For mid reach, pigeonpea–wheat followed by clusterbean-wheat, and for tail reach pearlmillet–mustard followed by pearlmillet–chickpea, and clusterbean–barley would be beneficial. Laser land levelling showed positive impact on crop yield and water productivity. Broad bed and furrow irrigation was found to be best in terms of yield (16-22%), economic benefits and water productivity (11-52%) in head, mid and tail reaches of the canal command area for all crops, except rice. (Morena centre)

Multi-locational field trials of different technologies developed by AICRP on IWM Chalakudy centre were conducted in different districts of Kerala. "Open field precision farming in banana using conventional, water soluble fertilizers" was replicated in three farmers' fields in Thrissur, Ernakulam and Palakkad districts, that resulted in adoption of the technology by six farmers. "Effect of mulching and drip irrigation in nutmeg" was demonstrated on five farmers' fields in Thrissur, Ernakulam and Palakkad districts. Another study "Irrigation scheduling and mulching in Amorphophallus" was demonstrated in two farmers' fields in Thrissur district. (Chalakudy centre)

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

During 2022, four and eight plastic lined check dams named *Konkan Vijay Bandhara* were constructed in Jawhar and Vikramgad taluka, respectively. It benefitted 49 tribal farmers and commanded additional area of 30.05 ha to grow vegetables, cashew, mango and jasmine. Total 350 *Konkan Jalkunds* were constructed during the year. Total 175 tribal farmers got benefitted, and additional area of 35 ha was irrigated to grow mango and cashew saplings; jasmine intercrop in mango & cashew plantations was also irrigated in Mokhada, Jawhar and Vikramgad talukas of Palghar district (Maharashtra). Assessment of *Jalkund* technology in north Konkan region showed that survival of mango and cashew grafts increased by 28.85% and 41.5%, respectively. Cultivated land utilization index increased from 0.25 to 0.45 after implementation of *Jalkund* technology. A profit of ₹ 1,29,324 per hectare was fetched from jasmine crop grown as an intercrop in mango and cashew plantations. (Dapoli centre)

Under SCSP, 11 check dams were constructed for rainwater harvesting, utilization of water resource for vegetable cultivation, and increasing water productivity in Gimhawane and Asond villages during the period April to December 2022. This has resulted in increased water availability in the villages and area under vegetable production. Total 17 SC farmers were given training and demonstration on mulch rice cultivation during *kharif* (rainfed) and drip irrigation in rice during summer. (Dapoli centre)

Under SCSP, improved irrigation water management in summer rice was demonstrated in six SC farmers' fields covering 2.0 hectare land in shallow tubewell (STW) command areas of Bongaigaon and Dhubri districts of Assam. Alternate wetting and drying technique was employed, in which 5 cm irrigation water was applied when ponded water dropped to 15 cm below ground level. The ponded water depth was monitored in 40 cm long and 15 cm diameter PVC pipes with perforations installed in the farmers' fields. (Jorhat centre)

Under SCSP, different training programmes were carried out on water management in crops with reference to improved surface irrigation as well as micro irrigation for total 185 farmers at Jorhat district, Maralgaon village of Biswanath district, and Dikhoumukh village of Sibsagar district, and Upper Temera village of Golaghat district of Assam. (Jorhat centre)

Under SCSP, eight demonstrations with sprinkler irrigation in soybean crop were conducted for scheduled caste farmers at Suhana village, Digod tehsil, Kota district ofRajasthan. There was 9.2% higher average yield and 45.1% average water use efficiency in farmers' field under sprinkler irrigation compared to those under farmers' practice of flood irrigation. This was followed by two training programmes on sprinkler irrigation to soybean crop for SC farmers at Suhana village of Digod tehsil, and Khandgavn village of Sultanpur tehsil of Kota district. (Kota centre)

Drip irrigation system was distributed to 95 ST farmers having small land holdings and eight SC farmers under TSP and SCSP programme, respectively in 11 groups of farmers from different villages covering about 36 ha land. Successful demonstration of drip irrigation in crops like bittergourd, littlegourd, watermelon, etc. on farmers' fields of Dangs district was done. Many farmers from surrounding areas came forward and showed interest in adopting drip irrigation in vegetable crops. (Navsari centre)

Technical tests and demonstration of sprinkler and drip irrigation systems were carried out in Wai village, Kalamnuri taluka, Hingoli district (Maharashtra). Field tests of 10 sprinkler and drip irrigation sets showed that discharge of sprinkler head was within permissible limit of sprinkler nozzle, drip irrigation sets also recorded permissible discharge and showed uniformity coefficient greater than 0.9. For all the farmers there was 19.23 to 30.45% higher crop yield, 30-40% water saving compared to their conventional practice. Economic status of the farmers also improved. Farmers pointed out that the advanced irrigation systems applied water uniformly over undulating land. They could apply protective irrigation to soybean, redgram and cotton with the help of pressurized irrigation, and bring additional area under irrigation. They could cultivate wheat and turmeric despite limited water resources and observed higher crop yields. (Parbhani centre)

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 (DSS) 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. Centres and their controlling universities

S.No.	Location of Centre	Controlling University/ICAR Institute
1	Almora	VPKAS, Almora
2	Bathinda, Ludhiana	PAU, Ludhiana
3	Belavatagi	UAS, Dharwad
4	Bhavanisagar, Madurai, Coimbatore	TNAU, Coimbatore
5	Bilaspur, Raipur	IGKVV, Raipur
6	Chalakudy	KAU, Thrissur
7	Chiplima	OUAT, Bhubaneswar
8	Dapoli	DBSKKV, Dapoli
9	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	-	-	-
		4.4	Madhya Bharat Plateau and Bundelkhand uplands, hot, moist semi-arid ESR with deep loamy and clayey mixed red and black soils, medium to high AWC and LGP 120-150 days	Chambal	Morena	RVSKVV, Gwalior

	5. Central Highlands (Malwa) Gujarat plain and Kathiawar Peninsula, semi-arid eco-region	5.1	Central Kathiawar Peninsula, hot dry Semi-arid ESR with shallow and medium loamy to clayey black soils (deep black soils as inclusion), medium AWC and LGP 90-120 days	-	Junagadh	JAU, Junagadh
		5.2	Madhya Bharat plateau, Western Malwa plateau, eastern Gujarat plain, Vindhyan and Satpura range and Narmada valley hot moist semi-arid ESR with medium and deep, clayey black soils (shallow black soils as inclusions), medium to high AWC and LGP 120-150 days	Chambal	Kota	AU, Kota
		5.3	Coastal Kathiwar Peninsula, hot moist semi-arid ESR with deep loamy coastal alluvium-derived soils (saline phases inclusion), low to medium AWC and LGP 120-150 days	-	-	-
	6. Deccan plateau, hot semi-arid eco-region	6.1	South-western Maharashtra and North Karnataka Plateau, hot dry semi-arid ESR with shallow and medium loamy black soils (deep clayey black soils as inclusion) medium to high AWC and LGP 90-120 days	-	-	-
		6.2	Central and western Maharashtra plateau and north Karnataka plateau and north western Telangana plateau, hot moist semi-arid ESR with shallow and medium loamy to clayey black soils (medium and deep clayey black soils as inclusion) medium to high AWC and LGP 120-150 days	Jayakwadi Mula	Parbhani Rahuri	VNMKV, Parbhani MPKV, Rahuri
		6.3	Eastern Maharashtra plateau, hot moist semi-arid ESR with medium and deep clayey black soils (shallow loamy, to clayey black soils as inclusion), medium to high AWC and LGP 120-150 days	-	-	-
		6.4	Moderately to gently sloping North Sahyadris and western Karnataka plateau, hot dry sub-humid ESR with shallow and medium loamy and clayey black soils (deep clayey black soils as inclusion), medium to high AWC and LGP 150-180 days	Malaprabha	Belavatagi	UAS, Dharwad
	7. Deccan plateau (Telengana) and Eastern Ghats, hot semi-arid eco-region	7.1	South Telengana Plateau (Rayalsema) and Eastern Ghat, hot dry semi-arid ESR with deep loamy to clayey mixed red and black soils, medium AWC and LGP 90-120 days	-	-	-
		7.2	North Telangana plateau, hot moist semi-arid ESR with deep loamy and clayey mixed red and black soils, medium to very high AWC and LGP 120-150 days	-	-	-
		7.3	Eastern ghat (south), hot moist semi-arid/dry subhumid ESR with medium to deep loamy to clayey mixed red and black soils, medium AWC and LGP 150-180 days	-	-	-
	8. Eastern Ghats and Tamil Nadu uplands and Deccan (Karnataka) plateau, hot semi-arid eco-region	8.1	Tamil Nadu uplands and leeward flanks of south Sahyadris, hot dry semi-arid eco-subregion with moderately deep to deep, loamy to clayey, mixed red and black soils medium AWC and LGP 90-120 days	Periyar Vaigai Periyar Vaigai	Coimbatore Madurai	TNAU, Coimbatore
		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
		10.1	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

	10. Central Highlands (Malwa and Bundelkhand), hot subhumid (dry) eco-region	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
	12. Eastern plateau (Chhotanagpur) and Eastern Ghats, hot subhumid eco-region	12.1	Garjat Hills, Dandakaranya and Eastern Ghats, hot moist subhumid ESR with deep loamy red and lateritic soils, low to medium AWC and LGP 180-210 days	Hirakud	Chiplima	OUAT, Bhubaneswar
		12.2	Eastern Ghats, hot moist subhumid ESR with medium to deep loamy red and lateritic soils, medium AWC and LGP 180-210 days	-	-	-
	13. Eastern plain, hot subhumid (moist) eco-region	13.1	North Bihar and Avadh plains, hot dry to moist subhumid ESR with deep, loamy alluvium derived soils, low to medium AWC and LGP 180-210 days	Gandak	Pusa	RAU, Samastipur
		13.2	Foothills of central Himalayas, warm to hot moist subhumid ESR with deep loamy to clayey Tarai soils, high AWC and LGP 180-210 days	-	-	-
	14. Western Himalayas, warm subhumid (to humid with inclusion of perhumid) eco-region	14.1	South Kashmir and Punjab Himalayas, cold and warm dry semi-arid/dry subhumid ESR with shallow to medium deep loamy brown forest and Podzolic soils, low to medium AWC and LGP 90-120 days	-	-	-
		14.2	South Kashmir and Kumaun Himalayas, warm moist to dry subhumid transitional ESR with medium to deep loamy to clayey brown forest and podzolic soils, medium AWC and LGP 150-210 days	Yamuna Ravi and Tawi	Almora Jammu	VPKAS, Almora SKUAST, Jammu
		14.3	Punjab Himalayas warm humid to perhumid transitional ESR with shallow to medium deep loamy brown forest and podzolic soils, low to medium AWC and LGP 270-300 + days	-	Palampur	HPKVV, Palampur
		14.4	Kumaun Himalayas, warm humid to perhumid transitional ESR with shallow to medium deep loamy red and yellow soils, low AWC and LGP 270-300 + days	-	-	-
		14.5	Foothills of Kumaun Himalayas (subdued), warm humid/perhumid ESR with medium to deep, loamy Tarai sols, medium AWC and LGP 270-300 + days	-	Pantnagar	GBPUAT, Pantnagar
HUMID-PER-HUMID ECO-SYSTEM	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	-	-	-
COASTAL ECO-SYSTEM	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	-	-	-
	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 ECO-SYSTEM	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; 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	Dugwell 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 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* pond
Sriganganagar	Loam to silty clay loam	> 10 m	276	Canal Tubewell
Udaipur	Sandy loam	12-18 m	670	Canal Tubewell

Chapter 1

Assessment of Surface Water and Groundwater Availability

1.1. Rahuri

1.1.1. Development of soil and water quality management strategies under special reference to GIS and remote sensing in minor of Mula right bank canal command area

The minor No. 2 of Mula Right Bank Canal (MRBC) command of Mula reservoir of Maharashtra state was selected for assessment of major, secondary and micronutrients status of soil with delineation of areas of nutrient deficiency or sufficiency and suggesting soil and water management strategies along with suitable cropping pattern. Study was conducted in an area of about 540 ha covering 4 villages *viz;* Sade, Pimpri Avghad, Tamnar Akhada and Desvandi. The soil and adjacent well or borewell water samples were collected at every 100 m × 500 m on grid basis as per GPS locations in Minor no. 2 of Mula right bank canal command. Soil texture is clayey, medium deep to deep dark brown to grayish brown colour having the average bulk density of 1.33 g cm^{-3} and porosity of 49.75%. The majority area of the Mula Right Bank Canal Command of Mula reservoir was found to be under agricultural land (90.76%), whereas 5.43% area was under built up land. The water bodies such as river, open water, lakes, pond and reservoirs cover 3.81% of the area.

Total 152 soil samples and 90 water samples were collected from the Minor no.2 of MRBC command. The soil and water sample locations in the study area and LULC map are depicted in Figure 1.

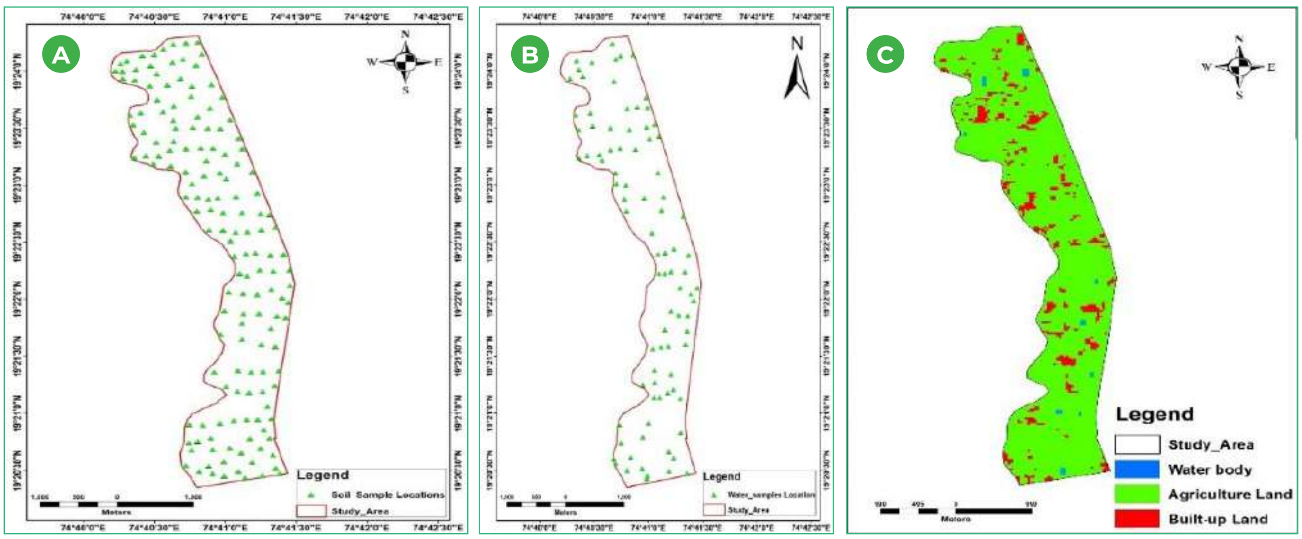


Figure 1. Study area of Mula right bank canal command: (a) Soil sample's location of study, (b) Water sample's location of study, and (c) LULC map

From the soil and water analyses, it was observed that most of the area is having moderately alkaline pH (90.13%) with normal EC (77.63%), moderate organic carbon (34.86%) and high in calcium carbonate (53.28%). The average soil available N, P and K was observed 134.91 kg ha^{-1}, 18.77 kg ha^{-1} and 459.46 kg ha^{-1}, respectively i.e. the available N and P are low, however, available K is very high. The soil is sufficient in Mn, Zn and Cu while deficient in Fe content. Average calcium (Ca^{2+}) content was 4.36 me L^{-1}, magnesium (Mg^{2+}) content was 3.10 me L^{-1}, potassium (K^{+}) content was 0.17 me L^{-1}. Average carbonate (CO_3^{2-}) content was 0.63 me L^{-1}, bicarbonate (HCO_3^{-}) content was 3.02 me L^{-1}, chloride (Cl^{-}) was 8.29 me L^{-1} and sulphate was 8.82 me L^{-1}. From the above observed data, it is concluded that soils are alkaline with increased soluble salts being saline in nature. The cations are in the order of $Na^{+} > Ca^{2+} > Mg^{2+} > K^{+}$ while anions are in the order of $SO_4^{2-} > Cl^{-} > HCO_3^{-} > CO_3^{2-}$. The average sodium adsorption ratio (SAR) was 5 and residual sodium carbonate (RSC) was 3.92 me L^{-1} while ESP was 14.85%. From the above soil analysis, it is concluded that the MRBC command area of minor no.2 is tending towards salinity wherein the soil is getting deteriorated.

From the soil and water samples analysis, it was concluded that most of well waters are moderate to unsuitable for irrigation and Na concentration was high in well water and soil, indicating the need of soil management against leaching problems and the use of amendments and reclamation. Most of the water samples showed higher SSP values. The soils are having very good potential for intensive cropping system under integrated nutrient management and pressurized irrigation system for judicious use of water. Therefore, careful management practices including drainage facilities are vital for these areas while applying this water for irrigation purpose. In general, it was concluded that the soils and bore/well waters in the area of MRBC are getting deteriorated to a great extent that soils may become saline sodic to sodic in nature.

Recommendation

On the basis of remote sensing and GIS mapping and characterization of soil and well water quality from minor No. 2 of Mula Right Bank Canal Command, it is evident that the soil and water quality is getting deteriorated tending towards salinity and sodicity which require the following recommended management strategies to be followed for improving the soil and water quality and productivity of crops for sustainable agriculture in command areas.

Management strategies

- Crop rotation with inclusion of leguminous crops and avoiding continuously growing of annual crops like sugarcane.
- Inclusion of salt tolerant crops like cotton, berseem, sugarbeet, wheat, jowar, maize, sunflower, spinach, cabbage, etc.
- Sowing of vegetable/ row crops on ridges and furrow method to avoid salt injuries.
- Use of mixing of moderately degraded water with good quality water for irrigation.
- Adoption of pressurized irrigation system.
- Cultivation of short duration crops with minimum water requirement.
- Fertilizer application should be based on soil test values.
- Use of chemical amendments for reclamations of saline sodic to sodic soil.
- Use of organic manures and green manuring crops like sunhemp, dhaincha and glyricidia.
- Use of subsurface drainage system, wherever possible.

1.2. Ludhiana

1.2.1. Development of groundwater indices for water resources management in Central Punjab

Punjab occupies about 1.5% of the total geographical area of India. It falls under semi-arid climate having a cropping intensity of 206%. Paddy-wheat is the pre-dominant cropping pattern in the state. Water requirement of crops cannot be met by rainfall and surface water collectively. Therefore, there is a lot of stress on groundwater. Analysis of 150 blocks in Punjab revealed that 117 blocks are overexploited, 6 are critical, 10 are semi-critical and only 17 are safe blocks. There is significant increase in area under high water consuming crop i.e. paddy. This has increased tubewell density and resulted in exploitation of groundwater. In the recent years, due to erratic rainfall patterns and increasing temperatures, the stress on groundwater has increased further. So, need was felt to analyze the parameters that are influencing groundwater depth. Trend analysis of both supply (rainfall, canal water) and demand indicators is necessary for efficient water management strategies. Sustainable use of water resources can be made for agriculture by knowing the demand and availability of water resources.

Unrestricted use of a groundwater resource can adversely impact sustainability of the region. For sustainability of agriculture, there is a need to identify critical indicators which are responsible for diminishing/depletion of natural resources. Response indicators can be defined as measures in the form of actions needed for sustainability in response to varying state of environment. So, there is need to evaluate response indicators for restricting water consumption by reducing groundwater stress on sustainable basis. Central Punjab was selected for the present study as it is worst affected zone of Punjab in terms of groundwater exploitation. All the blocks are over-exploited in this zone. It comprises of 10 districts namely Amritsar, Barnala, Fatehgarh Sahib, Jalandhar, Kapurthala, Ludhiana, Moga, Patiala, Sangrur and Tarn Taran.

Trend analysis of supply side and demand side indicators was carried out using non-parametric tests Mann-Kendall and Sen's slope. Homogeneity tests was applied using Pettitt's test to see any abrupt change in time series analysis for the study period. Artificial neural network (ANN) and multiple linear regression (MLR) were used as modeling tool to develop groundwater model. Both the techniques were developed using python language. The sensitivity analysis was done to identify the most important input parameters. A composite groundwater sustainability index (GSI) was developed using analytical hierarchy process (AHP) with Saaty score for central Punjab (Figure 2). Rainfall, canal irrigated area and non-paddy area were taken as positive indicators. Paddy area (Rice and Basmati), tubewell density and sugarcane area were taken as negative indicators. For improving GSI, different management strategies such as shifting area under paddy to non-paddy crops, shifting area under long duration variety to area under short duration variety of paddy and increasing canal irrigated area were adopted.

Based on the results of the present study, the following specific conclusions have been drawn.

1. No trend was observed in minimum temperature in the study period in all the districts. Rainfall data also showed no trend except Moga district, where significant increasing trend was observed. However, the maximum temperature showed significant increasing trend only in Fatehgarh Sahib, Patiala and Kapurthala districts.
2. Potential evapotranspiration exhibited significantly increasing trend in all the districts.
3. Water table depth and groundwater draft exhibited increasing trend in all the districts. Maximum increase in draft was recorded at Sangrur district and lowest increase in Tarn Taran district.
4. Area under paddy showed significant increasing trend in all districts except Patiala district where significant decreasing trend was detected.
5. ANN performed better as compared with the MLR statistically in the present study.
6. Presently, global sustainability index (GSI) was found to be poorly sustainable (Level III).
7. The GSI improved from poorly sustainable (Level III) to moderately sustainable (Level II) in a single year by adopting 10% of management strategy-I (MS-I) only, 90% of MS-II and by increasing canal irrigated area by 100%.
8. GSI can be upgraded to Level II in 3 years, if each year 3% area is diversified in conjunction with 5% area under short duration annually.
9. GSI can also be upgraded to Level II in 2 years, if each year 4% area is diversified in addition with 5% area under short duration annually.

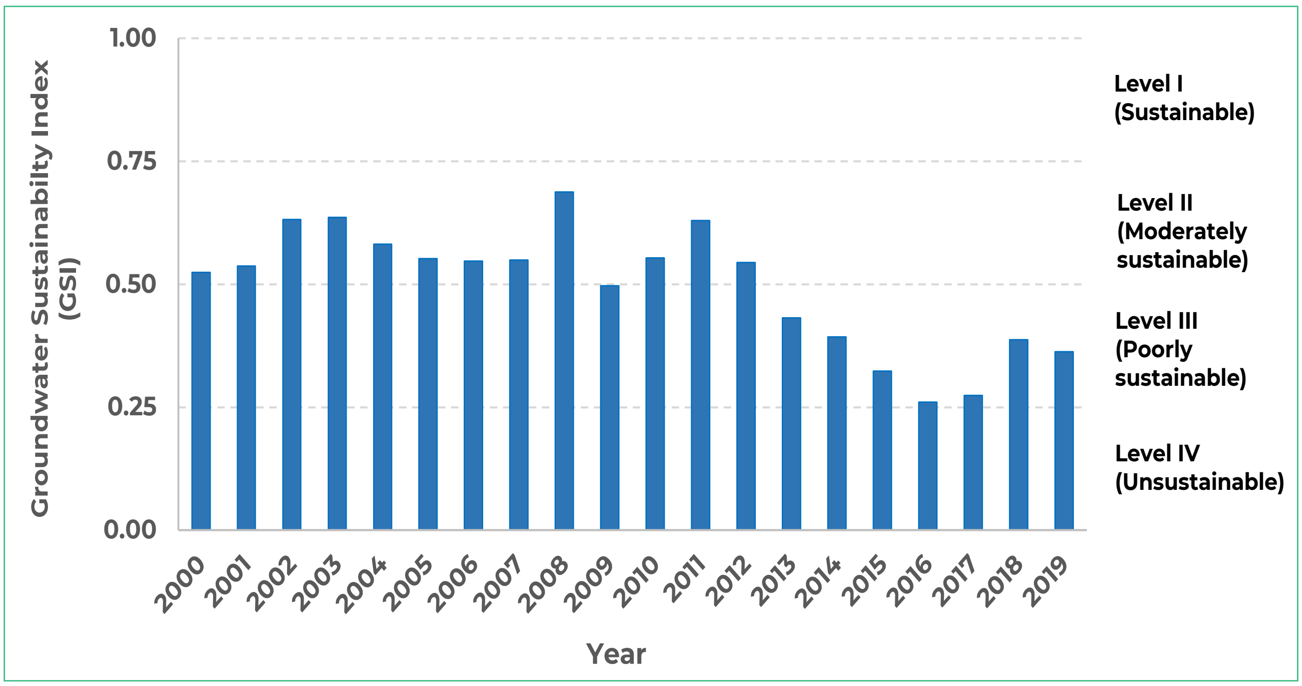


Figure 2. Groundwater sustainability index in Central Punjab (2000-2019)

1.2.2. Spatial Decision Support System for optimum energy supply for agriculture pump sets in Punjab

Agriculture is the major consumer of electricity (33%) and water (80-90%) in Punjab. Some regions of the state are suffering with sharp decline in water table depths while some are facing the problems of rising water table. The aim of the study was to develop a Spatial Decision Support System (SDSS) for improving the pumping energy efficiency in agriculture. The declining water table results in increase in pumping energy consumption, contributing in unbalanced water-food-energy nexus in the region. Furthermore, the selection of wrong size of pump is adding to the nexus. In order to prevent over-exploitation of groundwater, this study was conducted as a result of which a SDSS was developed using Python language for 12959 villages of Punjab. This system guides the user with actual pumping energy requirement based upon spatial and temporal conditions of field's locations, groundwater level, historical weather dataset and cropping pattern. The designed system deals with five major crops of Punjab, i.e., cotton, maize, paddy, sugarcane and wheat.

Research was conducted to address this issue that involves the use of remote sensing techniques, ArcGIS and python broadly. Analysis of past 12 years (2007-2018) data on daily basis was performed to understand the mechanics of actual field conditions.

Groundwater level maps from 2007-2018 explain the increasing depths of the groundwater shown in home screen of SDSS in an easy format; hence, helping farmers, stakeholders and policy makers in arranging copping pattern with respect to groundwater and irrigation water requirements. The developed SDSS will assist policy makers/pumping industries/farmers and/or stakeholders in estimating the actual amount of pump horsepower and pumping hours per day required for fields. This study takes into account historical weather conditions, groundwater behaviour and actual irrigation water requirements. Hence, this system minimizes the chances of over and under irrigation by showing effective results of pump capacity (hp) and pumping hours required in a range of mean and maximum values.

Geographical Information System (GIS) helped in integrating, managing and analyzing data at spatial and temporal scale. With the analysis of spatial location and organization of layers of information into visualizations using maps, this system reveals deeper insights in data, and help users make smarter decisions. These applications of GIS provide beneficial contributions in the SDSS. The GIS not only helped in building water table depth maps, but also aided in development of irrigation water requirement data of whole Punjab state and also helped in making future predictions of the groundwater table on the village basis by estimating the rise/fall rates of groundwater per year. A screenshot of the SDSS is shown in Figure 3.

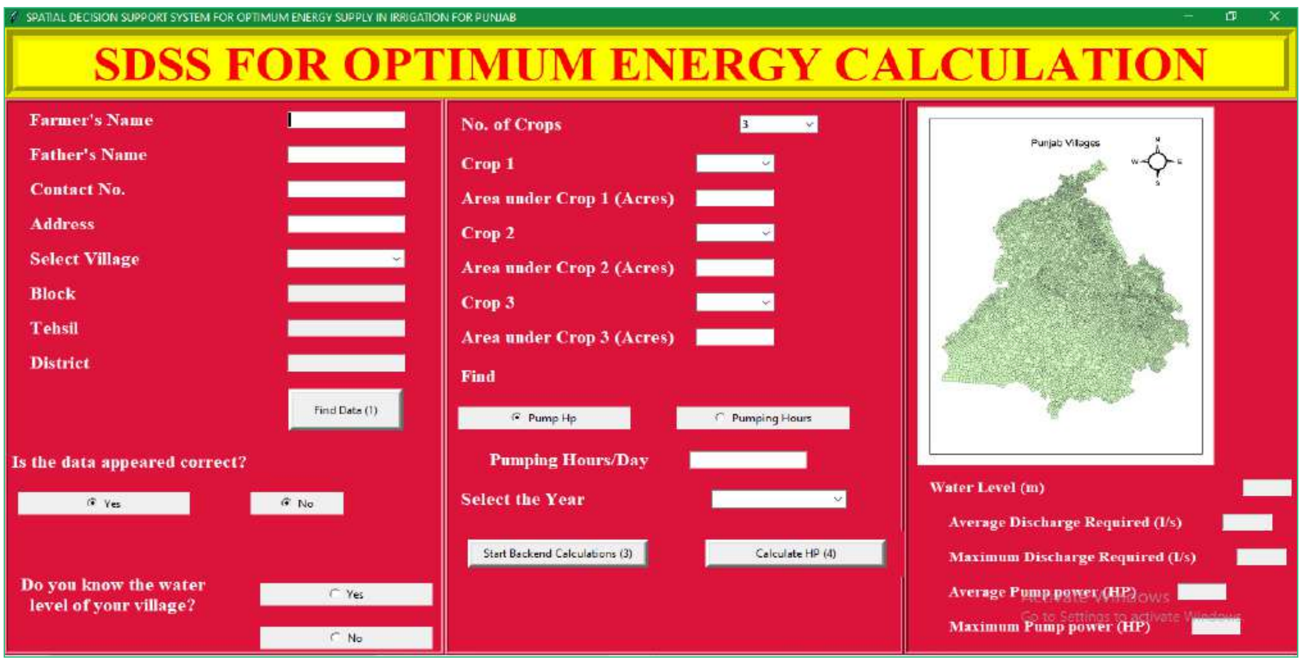


Figure 3. Screenshot of input form of spatial decision support system for calculation of pump power

Following are the conclusions of the present study:

- Area under groundwater table depth 3-10 m decreased from 1.948 Mha (38.68%) to 1.067 Mha (21.19%) whereas area with groundwater level depth beyond 10 m increased from 3.378 Mha (67.07%) to 3.538 Mha (70.25%) in 2007 to 2018. Also, area under groundwater depth with more than 30 m increased from nil (0%) to 0.53 Mha (10.52%) from 2007 to 2018. Hence, the data revealed that the entire state is facing the challenges of groundwater depletion.
- The SDSS will be beneficial for farmers for deciding the cropping pattern and area under cultivation depending upon the availability of electricity (hours) and pump capacity.
- Henceforth, this system will provide guidelines to policy maker for supply of electric energy (hours) based upon desired crop planning for a particular area depending upon its groundwater status.

1.3. Raipur

1.3.1. Hydrological modelling for impact assessment of land use variability on water yield of Arpa

Hydrological modeling of Arpa Catchment area was done by using SWAT software. The calibrated model was used to study the impact of climate change on the water balance components in terms of precipitation, maximum temperature, minimum temperature, surface runoff, percolation, evapotranspiration, groundwater contribution to streamflow and water yield. GCM climate change scenarios (SSP2-4.5 and SSP5-8.5) representing three time period slices of 2030s (2021-2046), 2060s (2047-2073) and 2090s (2074-2121) were introduced in the model one by one, and their impact on the water resources was analysed with reference to baseline (1985-2020). Based on the different GCM scenarios, a range of probable changes in water balance components was analyzed.

The SSP2-4.5 and SSP5-8.5 scenarios indicated increasing trends in annual precipitation in the 2030s, 2060s and 2090s. Regarding the 2030s, SSP2-4.5 and SSP5-8.5 predicted increase in rainfall by 19.35% (229.62 mm) and 18.33% (217.57 mm), respectively compared to the baseline (1186.80 mm). For the 2060s, it predicted increase in rainfall by 26.90% (319.25 mm) and 29.94%. (355.33 mm). For 2090s, both scenarios indicated an increase, ranging between 40.63% (482.15 mm) and 62.01% (735.94 mm) relative to the baseline. In both scenarios, there is a decrease in precipitation in March, April, May and June. Percentage change in precipitation in GCM Scenario SSP2-4.5 and SSP5-8.5 compared to baseline given in Table 1 and Table 2, respectively.

Similar change analysis was carried out for minimum and maximum temperatures, surface runoff, percolation, evapotranspiration, groundwater contribution and water yield.

Table 1. Change in precipitation in GCM Scenario SSP2-4.5 compared to baseline

Month	Precipitation (mm)				Change (%)		
	Baseline (1985-2020)	2030s	2060s	2090s	2030s	2060s	2090s
Jan	26.46	36.78	38.86	41.48	38.99	46.85	56.77
Feb	22.95	29.39	33.43	32.34	28.05	45.67	40.91
Mar	41.40	17.29	22.91	18.03	-58.22	-44.67	-56.46
Apr	48.26	10.03	18.67	13.74	-79.22	-61.32	-71.53
May	62.18	13.77	26.99	24.28	-77.85	-56.59	-60.95
Jun	157.90	99.38	97.24	122.68	-37.06	-38.41	-22.30
Jul	303.15	443.63	423.81	436.08	46.34	39.80	43.85
Aug	267.14	410.23	452.43	510.41	53.56	69.36	91.06
Sep	159.73	218.24	228.65	294.14	36.63	43.15	84.15
Oct	59.38	73.56	109.44	107.67	23.88	84.32	81.34
Nov	20.77	37.64	30.46	30.15	81.22	46.67	45.18
Dec	17.49	26.49	23.16	37.94	51.48	32.47	117.00
Annual	1186.80	1416.42	1506.05	1668.95	19.35	26.90	40.63

Table 2. Change in precipitation in GCM Scenario SSP5-8.5 compared to baseline

Month	Precipitation (mm)				Change (%)		
	Baseline (1985-2020)	2030s	2060s	2090s	2030s	2060s	2090s
Jan	26.46	43.22	52.83	44.79	63.36	99.65	69.29
Feb	22.95	28.85	25.40	35.29	25.70	10.67	53.77
Mar	41.40	22.17	18.98	24.11	-46.46	-54.16	-41.75
Apr	48.26	10.20	16.31	11.82	-78.86	-66.20	-75.51
May	62.18	15.25	35.01	18.21	-75.47	-43.69	-70.70
Jun	157.90	107.10	145.73	144.86	-32.17	-7.71	-8.26
Jul	303.15	448.26	385.98	513.67	47.87	27.32	69.44
Aug	267.14	376.06	425.91	577.08	40.77	59.43	116.02
Sep	159.73	204.66	237.57	333.15	28.13	48.73	108.57
Oct	59.38	73.44	108.22	131.81	23.68	82.27	121.99
Nov	20.77	38.59	44.59	51.63	85.80	114.70	148.61
Dec	17.49	36.58	45.61	36.31	109.20	160.83	107.65
Annual	1186.80	1404.37	1542.13	1922.74	18.33	29.94	62.01

Chapter 2

Groundwater Potential Zoning and Recharge

2.1. Pantnagar

2.1.1. Identification of potential groundwater recharge zones in river basins of Uttarakhand - Bhakra river

Morphometric analysis of Bhakra river watershed was accomplished through measurement of linear, aerial, and relief aspects of Bhakra river basin of Uttarakhand. The watershed was found to be of 4th order as per Strahler's stream ordering technique. The dendritic drainage pattern with very coarse drainage texture was observed in the watershed. High bifurcation value implied higher flash flood potential of watershed. The value of form factor and elongation ratio suggested that the basin was elongated with lower runoff peak of longer duration. The Bhakra river watershed had 172 streams. The number of streams under I, II, III, and IV order were found to be 99, 50, 22, and 1, respectively. Sub-watershed Nihal (SWS3) had the highest number of streams (34) while sub-watershed Khairlya (SWS7) had the lowest number of streams (7). The total lengths of stream segments of I, II, III, and IV were 230.825, 116.572, 44.212 and 52.223 km, respectively. The sub-watershed SWS7 had the minimum stream length (L_u =16.8 km) while sub-watershed SWS3 had the maximum stream length (L_u = 85.763 km).

Four different types of soil were identified in the study area on the basis of Indian soil classification, namely: hill soil, *Bhabar* soil, *Tarai* soil, and alluvial soil. Five major categories of land use land cover (LULC) units, namely, woody shrubs, cropland, urban area, wetland, and forest area was identified in Bhakra river watershed. Most of the study area (54.86% of the total watershed area) was under forest. Dominant soil type of the study area was *Bhabar* soil covering an area of 235.246 km^2 followed by *Tarai* soil covering 207.42 km^2 of study area, and small portion of the study area was covered by hill soil and alluvial soil. There was 0-5% slope in maximum area (330.56 km^2) of the watershed.

Based on morphometric parameters, prioritization of sub-watershed was carried out using compound priority method. Three sub-watersheds *i.e.*, Nihal (SWS3), Ghutwa (SWS8) and Dhimri (SWS11) with lowest compound values were under high priority which required immediate attention for soil and water conservation measures and six sub-watersheds *i.e.*, Khani (SWS1), Paniyali (SWS2), Rakashiya (SWS5), Khairlya (SWS7), Kagarsen (SWS9), and Kurna (SWS10) were under medium priority while two sub-watersheds *i.e.*, Basi (SWS4) and Bhadwara (SWS6) were under low priority group.

Thematic maps of DEM, soil, slope, drainage, and land use land cover were overlaid in ArcGIS software. Possible potential sites were visualized according to the priority set for location identification. The proposed recharge sites were grouped into two water recharging structures, farm ponds and check dams, based on the conditions and guidelines.

Decision rules for construction of artificial groundwater recharge structures were as follows:

i. **Farm pond:** This structure could be constructed on the first order stream, having a 0-5% land slope.

ii. **Check dam:** This could be constructed on first to fourth order stream having a land slope of >15%.

Based on the above conditions and guidelines, suitable locations of 55 farm ponds and 27 check dams were identified as potential sites for artificial groundwater recharge, respectively as shown in Figure 4 and Figure 5. These could help in enhancing water availability for various activities in Bhakra river watershed. Areas suitable for construction of farm ponds and check dams are presented in Table 3.

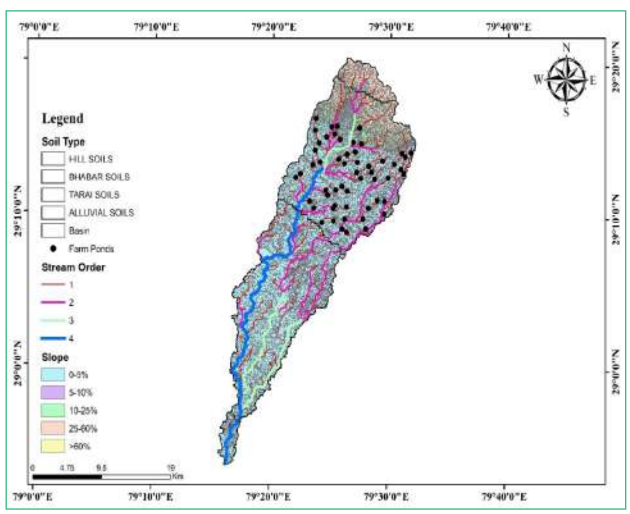


Figure 4. Potential sites of farm ponds in Bhakra river watershed

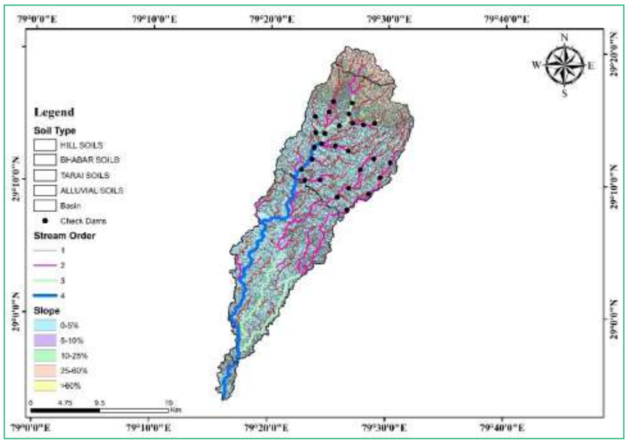


Figure 5. Potential sites of check dams in Bhakra river watershed

Table 3. Area suitable for farm ponds and check dams in Bhakra river watershed

Type of structure	Slope (%)	Area (km^2)	No. of potential sites
Farm pond	0-5	330.57	55
Check dam	<15	416.27	27

2.2. Belavatagi

2.2.1. Assessment of influence of groundwater recharge on groundwater yield, quality & fluctuations

The study was conducted to explore indigenous groundwater recharge technique for an existing tubewell and assess the impact of groundwater recharge structure on groundwater quality. Recharge pit with double ring technique around the existing tubewell was constructed during March 2020. Excess rainwater through runoff from the adjoining fields was diverted to the tubewell. Runoff water collected through rainwater harvesting in nearby farm ponds was transferred to double ring as a point recharge. Afterwards, weekly observations of groundwater quality and fluctuation in water yield and water levels were noted. Later monthly/ seasonal variations in tubewell water level, quality and discharge were observed. The effect of rainwater harvesting for groundwater recharge with respect to monthly average water level, water quality and well yield and monthly withdrawal are presented in Table 4.

The monthly average results from point recharge through rainwater harvesting revealed that there has been considerable rise in the water table from more than 100 feet below ground level (bgl) to around 26 feet bgl, drastic reduction in electrical conductivity (EC) of groundwater from more than 10 dS m^{-1} to an average EC of 1.59 dS m^{-1}. Borewell yield has significantly increased from 0.4 litre per second (lps) to around 2.5 lps. About 10.44 lakhs litres of tubewell water has been withdrawn for domestic uses in Balavatagi center during March 2020 to September 2022.

Table 4. Details of the impact of rainwater harvesting for tubewell recharge and withdrawal of water from tubewell for domestic use

Month(s)	Water table (feet bgl)	Well yield (lps)	Water EC (dS m^{-1})	Water withdrawal (lakh litre)
Before installation of groundwater recharge unit during March 2020				
	100	0.77	10.22	--
After installation of groundwater recharge unit with rainfall / recharge events				
Impact of rainwater harvesting during year 2020				
Average (Jan-Dec 2020)	22.5	2.37	1.76	2.16
Impact of rainwater harvesting during year 2021				
Average (Jan-Dec 2021)	24	2.60	1.03	4.64
Impact of rainwater harvesting during year 2022				
Average (Jan-Dec 2022)	31	2.48	2.15	3.63
Monthly average so far	26	2.52	1.59	**10.44**

2.3. Jabalpur

2.3.1. Groundwater potential zoning in all river basins of Madhya Pradesh using geoinformatics technique

The study was done to delineate groundwater potential zones of all the river basins located in Madhya Pradesh, India. In Madhya Pradesh there are 12 river basins; Betwa, Chambal, Dhasan, Ken, Mahanadi, Mahi, Narmada, Sindh, Sone, Tapi, Tons, and Wainganga covering total 3.28 lakh km^2 (Figure 6). The study utilized a combination of geographic information system and analytical hierarchical process techniques (AHP) for delineation of groundwater potential zone boundaries. A total of eight thematic maps including Geology, Geomorphology, Land Use Land Cover, Lineament density, Drainage Density, Rainfall, Soil, and Slope were prepared and analyzed for assessment of groundwater potential zones. The AHP method was utilized to assign weights to each class in all thematic maps. The output accuracy was cross validated with data on the region's groundwater prospects. Very high, high, moderate, poor and very poor classifications were applied to the resulting map of groundwater potential zones (Figure 7) of the State.

Different Basin maps of Madhya Pradesh were collected from MPWRD website and manually digitized on a scale of 1:500000. For preparation of different theme layers, data were taken from different agencies and rectified/ reclassified/ digitized/ computed, a summary of which is presented in Table 5.

Table 5. Summary of data used in the study

S. No.	Layer	Data (Scale/ Resolution) & Agency	Work done on available data
1.	Geology	Digitized Vector File on a scale of 1:50000 (Bhukosh Portal) Map Sheets from GSI (1:250000) (Hard Copy)	Rectified Digitized
2.	Geomorphology	Digitized Vector File on a scale of 1:250000 (Bhukosh Portal)	Used directly
3.	Lineament Density	Lineament WMS Link Map on a scale of 1:50000 (Bhuvan Geo-Portal)	Digitized
4.	Land Use Land Cover	Sentinel-2 (10 m) LULC Raster File (ESRI & Microsoft Portal) 2021	Classes reclassified
5.	Soil Texture	Soil map sheets on a scale of 1:250000 (NBSS&LUP Nagpur)	Scanned and digitized
6.	Slope	SRTM 30 m DEM (USGS Earth Explorer)	Used directly
7.	Drainage Density	SRTM 30 m DEM (USGS Earth Explorer)	Used directly
8.	Rainfall	Rainfall data (0.25 degree × 0.25 degree) IMD Grided Data	Normalised (30 years)
9.	Validation	Ground Water Prospects Map (Well Yield Data) on scale of 1:50000 (Bhujal-Bhuvan Portal)	Used directly

It was found from the analysis that major portion of all the river basins come under Moderate zone to Good zone of groundwater potential which are about 50-55% and 25-30%, respectively. Total 19116 km^2 area is found under Very Good zone in the Madhya Pradesh out of which 55.36% of area lies in Narmada Basin followed by Sindh Basin (19.55%). About 88,558 km^2 area is categorized under Good zone. Out of this, Narmada and Chambal share equal percentage (about 25%) followed by Sone basin (13.39%). Total 1,58,528 km^2 area is found in Moderate zone in Madhya Pradesh out of which 27.25% of area lies in the Narmada Basin followed by Chambal Basin (19.55%). Narmada and Sindh basins majorly contribute 27.60% and 17.84% of the Poor zone (40,212 km^2). Only 1830 km^2 area is in Very Poor zone which mostly falls under Sindh, Narmada, and Dhasan basins. As a whole in the state of Madhya Pradesh, the different groundwater potential zones are categorized into Very Good, Good, Moderate, Poor, and Very Poor comprising 6.20%, 28.73%, 51.43%, 13.05%, and 0.59% area, respectively (Figure 6). Highest validation accuracy (84%) was observed in Sindh Basin of Madhya Pradesh. Lowest validation accuracy was found in Sone (70.43%) and Tapi (70.25%) Basins, respectively. The average validation accuracy of groundwater potential map of Madhya Pradesh has been estimated to be 78%.

A comprehensive approach that includes assessment, monitoring, conservation, education, and diversification of water sources, as well as policies and regulations, is necessary for sustainable management of poor groundwater potential zones in river basins.

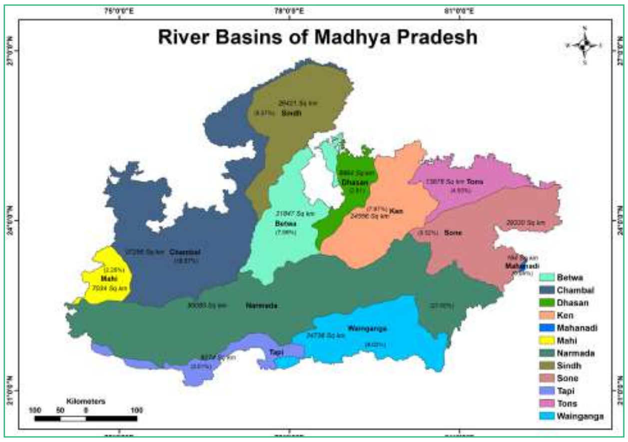


Figure 6. Major River Basins in Madhya Pradesh

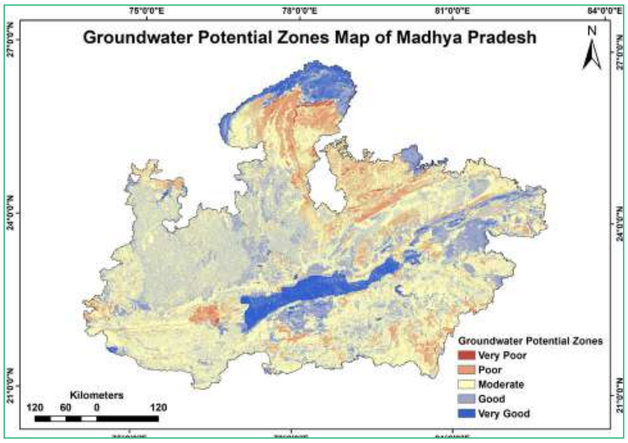


Figure 7. Groundwater Potential Zones map of Madhya Pradesh

2.4. Udaipur

2.4.1. Effect of de-silting of water harvesting structures on augmentation of groundwater recharge

The study was conducted at Girwa block of Udaipur district of Rajasthan with three rainwater harvesting structures named as Shishvi-I, Shishvi-II and Karmal having catchment area of 10 ha, 80 ha and 150 ha, respectively. Shishvi-I structure is constructed using dry stone masonry. Shishvi-II and Karmal structures are constructed using cement masonry. Locations of the structures are shown in Figure 8.

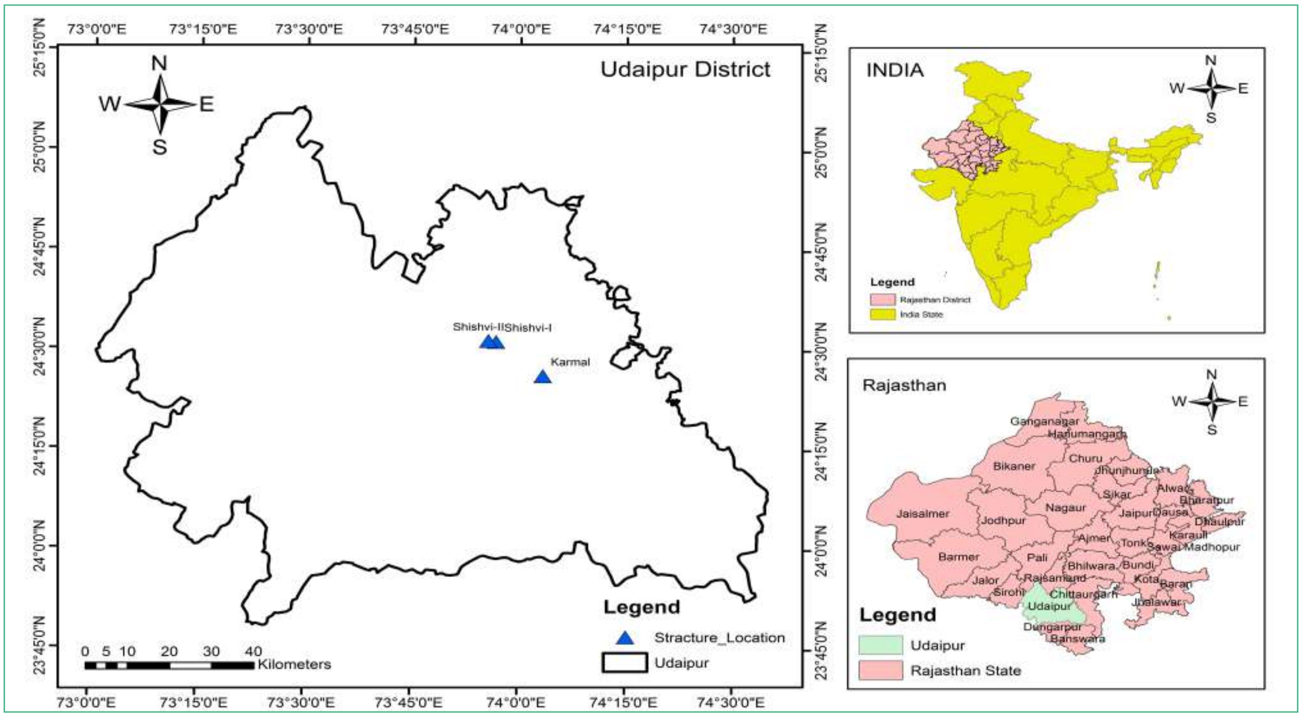


Figure 8. Location of the study area

Submergence areas of all the three structure was found out with the help of contour survey of the structures. Submergence area was 3431.07 m^2, 6922.00 m^2 and 8138.72 m^2 for Shishvi-I, Shishvi-II and Karmal WHS, respectively. Storage capacity was 2744.86 m^3, 5537.60 m^3 and 6510.00 m^3 for Shishvi-I, Shishvi-II and Karmal WHS, respectively. Siltation depth in each WHS was found out by pit method. The whole submergence area was divided into systematic square grids of the submergence area of the structure. From each grid, siltation sample through dugout pit was taken at the center point and was considered as average depth of siltation of that particular grid. Annual siltation rates of Shishvi-I, Shishvi-II and Karmal are 64.75 m^3, 157.22 m^3 and 232.62 m^3, respectively. Table 6 shows the details of structure name, quantity of siltation, number of years and annual siltation rate. Annual loss in storage capacity of the selected rainwater harvesting structures varies from 2.36% to 3.57%. Average annual loss in storage capacity was evaluated as 2.92%. The storage capacity lost over a period of 4 years is approximately 12% of the total capacity. Thus, de-siltation of the structures is recommended at four years interval.

Table 6. Details of capacity reduced at selected WHS

S. No.	Structure name	Storage capacity (m^3)	Volume of siltation (m^3)	No. of years	Reduced capacity in given year (%)	Volume of silt per year (m^3)	Reduced capacity per year (%)
1	Shishvi-I	2744.86	841.715	13	30.66	64.75	2.36
2	Shishvi-II	5537.60	1415.290	9	25.55	157.22	2.83
3	Karmal	6510.00	1861.000	8	28.58	232.62	3.57

The impact of de-siltation on groundwater recharging at Shishvi-I village was evaluated in terms of recharge rate and recharge volume. Rainfall and pond water level were monitored on daily basis during monsoon months to find out the recharge rate and volume. In 2022, after de-siltation the recharge volume and rate were estimated to be 38,785 m^3 and 8.32 cm per day, respectively. Before de-siltation, recharge volume and recharge rate were 18,821 m^3 and 6.29 cm per day, respectively. Evaluation of the structures clearly shows that the groundwater recharge rate has increased due to de-siltation of the structures.

Chapter 3

Irrigation Scheduling using Surface and Pressurized Irrigation Systems

3.1. Chiplima

3.1.1. Assessment of productivity and WUE of groundnut under varied irrigation schedules through sprinkler

During the *rabi* season of 2019–2021, an experiment using seven alternative irrigation regimes under sprinkler irrigation and farmers' practice (Table 7) was carried out with the following goals i) to study the yield and economics of the groundnut (var. *Smruti)* cultivation under micro irrigation system and ii) to study best possible irrigation schedule to enhance the irrigation water use efficiency (IWUE). The irrigation practice, I_6 (0.9 PE) was found to have significantly higher yields than the other seven irrigation schedules in terms of the number of pods per plant (15.2), seeds per pod (2.1), pod weight per plant (34.2 g), 100 kernel weight (44.7 g), pod yield (2.01 t ha^{-1}), and haulm yield (1.15 t ha^{-1}). The lowest pod yield of 1.48 t ha^{-1} and haulm yield of 0.91 t ha^{-1} were observed in the irrigation practice of I_1 (0.4 PE). As a result, treatment I_6 (0.9 PE) recorded higher net returns of ₹ 59,443.7 ha^{-1} with B-C ratio of 2.35. The lowest net return of ₹ 38,439.5 ha^{-1} and lowest B-C ratio of 1.60 was observed in the irrigation practice I_1 (0.4 PE). The highest water productivity of 947.4 g m^{-3} was observed with irrigation practice I_1 (0.4 PE) and I_8 (Farmers' practice). Sprinkler irrigation with 0.9 PE recorded 29.17% higher yield, 40.91% more profit, and 65.23% higher water productivity in comparison to farmers' practice.

Groundnut cultivation under sprinkler irrigation

Table 7. Effect of different irrigation practices on growth and yield attributes and economics of summer groundnut (Pooled results of three years)

Treatment	Pod yield (t ha^{-1})	Haulm yield (t ha^{-1})	Water used (mm)	Water productivity (g m^{-3})	Net return (₹ ha^{-1})	B:C
I_1: 0.4 PE	1.48	0.91	158	0.978	38440	1.60
I_2: 0.5 PE	1.60	1.01	202	0.825	43206	1.78
I_3: 0.6 PE	1.64	1.01	249	0.683	44559	1.81
I_4: 0.7 PE	1.79	1.01	292	0.638	50349	2.02
I_5: 0.8 PE	1.98	1.14	335	0.614	58083	2.32
I_6: 0.9 PE	2.01	1.16	391	0.537	59444	2.35
I_7: 1.0 PE	1.94	1.14	435	0.465	56045	2.20
I_8: Farmers' practice	1.56	0.96	500	0.325	42189	1.80
CD (p=0.05)	0.02	0.06	-	-	-	-

3.2. Sriganganagar

3.2.1. Studies on optimum irrigation schedule for cauliflower through drip under different crop geometries

An experiment was conducted to optimize the drip irrigation schedule under varied crop geometry of cauliflower during *rabi* 2019-20 to 2021-22. Based on three years of testing, it was revealed that irrigation and crop geometry had a substantial impact on the production of cauliflower (var. *Empire*). With irrigation scheduled at 1.0 ET_c, the greatest fruit output of cauliflower (52.4 t ha^{-1}) was observed (Table 8). It was at par with the yield achieved at 0.8 ET_c and much greater than the yield obtained at 0.6 ET_c. The total water use under drip irrigation at 0.6, 0.8 and 1.0 ETc was 226, 255 and 283 mm, respectively as against 654 mm in surface irrigation. The water expense efficiency of the respective treatment was 203 and 58.3 kg ha-mm^{-1}, respectively. The yield of cauliflower significantly increased with increasing plant population. Narrow spacing (45 cm single row or 30×60 cm paired planting) resulted in a much better yield of cauliflower than wider spacing (60 cm single or 40×80 cm paired planting). Economic benefits obtained from different treatments of the experiment is listed in Table 9.

Table 8. Effect of different irrigation and crop geometry on plant population, flower number, flower weight, and yield of cauliflower (Pooled over three years)

Treatment	Plant population (000 ha^{-1})	No. of flowers (000 ha^{-1})	Flower weight (kg $flower^{-1}$)	Yield (t ha^{-1})
Irrigation schedule				
I_1 : 0.6 ET_c	72.0	70.7	0.675	47.7
I_2 : 0.8 ET_c	72.5	71.1	0.725	51.6
I_3 : 1.0 ET_c	72.6	71.4	0.734	52.4
Flood irrigation	79.6	76.6	0.498	38.1
CD (p=0.05)	1.7	2.0	0.050	3.2
Crop geometry				
G_1 : 45 cm	84.2	82.5	0.679	56.2
G_2 : 60 cm	60.5	59.6	0.738	44.2
G_3 : 30 x 60 cm	83.4	81.9	0.693	56.9
G_4 : 40 x 80 cm	61.5	60.4	0.736	45.0
CD (p=0.05)	1.3	1.5	0.050	2.4

Table 9. Effect of different irrigation treatments on water use, water expense efficiency, and economics (Pooled over three years)

Irrigation schedule	Irrigation water applied (mm)	Total water use (mm)	WEE (kg ha-mm^{-1})	Cost of production (₹)	Net return/ mm of water (₹)	Net seasonal income (₹)	B:C
0.6 ET_c	186	226	211	313632	1628	1064385	4.39
0.8 ET_c	215	255	203	278460	1600	1046086	4.76
1.0 ET_c	243	283	185	250390	1468	959929	4.83
Surface irrigation	614	654	58	68000	479	312910	5.60

Note: Pre-sowing irrigation applied is 100 mm in all the treatments

Cauliflower under drip irrigation

3.2.2. Response of carrot to irrigation scheduling through drip under different land configuration

Cotton-vegetables is the most common and profitable cropping system in the peri-urban parts of Rajasthan's North West Plain Zone. Tuber crops such as carrot may be a suitable crop following cotton using the same drip system architecture used in the raised bed planting approach. An experiment was carried out from *rabi* 2019-20 to 2021-22 to optimize the drip irrigation schedule in carrot (var. *Jyoti*) of a cotton-carrot system under varied land configurations. On the yield of carrots, it was revealed that irrigation and crop shape had a considerable impact (Table 10). Carrot yield peaked at 43.6 t ha^{-1} measured at 0.8 ET_c and it was statistically on par with the yield attained at 0.6 ET_c and much better than treatments at 1.0 ET_c. Irrigation scheduled at 0.8 ET_c gave 33.5% higher yield and saved 64.6% irrigation water as compared with flood irrigation. Water expanse efficiency was also highest with 0.8 ET_c (231 kg ha-mm^{-1}), while in case of surface irrigation, it was 62.53 kg ha-mm^{-1}. Increases in plant population had a major impact on carrot output, and narrow spacing (20 cm), whether on a flat or raised bed, produced much more carrots than wider spacing (30 cm). Economic benefits obtained from different treatments of the experiment is listed in Table 11.

Table 10. Effect of different irrigation and crop geometry on length, girth and yield of carrot (Pooled over three years)

Treatment	Length (cm)	Girth (cm)	Yield (t ha^{-1})
Irrigation schedule			
I_1 : 0.6 ET_c	23.8	3.34	42.0
I_2 : 0.8 ET_c	24.3	3.24	43.6
I_3 : 1.0 ET_c	24.2	3.30	39.3
Flood irrigation	22.0	3.20	31.5
CD (p=0.05)	1.5	0.20	3.2
Crop geometry			
G_1 : 20 cm rows	22.9	3.28	45.5
G_2 : 30 cm rows	23.0	3.34	37.7
G_3 : Three rows of 20 cm on raised bed of 50 cm	25.0	3.29	45.3
G_4 : Three rows of 30 cm on raised bed of 70 cm	25.5	3.28	38.1
CD (p=0.05)	1.1	0.15	2.4

Table 11. Effect of different irrigation treatments on water use, water expense efficiency, and economics (Pooled over three years)

Irrigation schedule	Irrigation water applied (mm)	Total water use (mm)	WEE (kg ha-mm^{-1})	Cost of production (₹)	Net seasonal income (₹)	B:C	Net return/ mm of water
0.6 ET_c	187	238	231	278029	670352	3.41	999
0.8 ET_c	220	270	215	244354	621170	3.54	926
1.0 ET_c	250	300	178	220009	482018	3.19	719
Surface irrigation	620	671	63	58000	193688	4.34	289

Note: Pre-sowing irrigation applied is 100 mm in all the treatments

Carrot under drip irrigation

3.3. Ayodhya

3.3.1. Effect of irrigation scheduling and *in situ* residue management of combine harvested rice on performance of wheat and nutrients' availability under rice-wheat cropping system

Rice-wheat is the major cropping system of eastern India. Residue management of combine harvested rice is very difficult. Use of happy seeder for sowing of wheat may be quite effective for *in situ* management of residues as well as reducing the cost of field preparation, number of irrigations and also advancement in date of sowing. Keeping in view the above facts into consideration, an experiment was conducted from *rabi* 2019-20 to 2021-22. It was observed that sowing of wheat crop (var. NW-5054) with happy seeder (M_2) resulted in a significantly higher yield of 4.54 t ha^{-1} with WUE of 15.84 kg ha-mm^{-1} over conventional method of sowing (M_1) being at par with sowing of wheat after residue incorporation (M_3) in which the yield was 4.37 t ha^{-1} with WUE 15.15 kg ha-mm^{-1} (Table 12). The higher yield recorded under happy seeder treatment may be because of early sowing (10 days) of the crop than other treatments. Irrigation at five crop growth stages i.e. crown root initiation (CRI), tillering, late jointing, milking and dough stage recorded a significantly higher yield of wheat 4.54 t ha^{-1} with WUE 13.71 kg ha-mm^{-1} over irrigation schedule at three crop growth stages (3 irrigation at CRI, late jointing and milking stage) being at par with irrigation schedule at four crop growth stages (CRI, tillering, late jointing and milking stage) in which the yield was 4.32 t ha^{-1} with WUE 15.36. The maximum net return was obtained when wheat was sown with a happy seeder (M_2) and five irrigations (I_3) were used.

Table 12. Effect of irrigation scheduling and *in situ* residue management practices on performance of wheat crop (Pooled over three years)

Treatment	Yield (t ha^{-1})	WUE (kg ha-mm^{-1})	Cost of cultivation (₹ ha^{-1})	Net return (₹ ha^{-1})	B : C
Sowing method					
M_1: Conventional sowing (after cleaning of residue)	3.99	13.89	34467	43683	1.27
M_2: Sowing with happy seeder	4.54	15.84	32267	57050	1.77
M_3: Sowing after residue incorporation	4.37	15.15	33700	50891	1.51
CD (p=0.05)	0.31	-	-	-	-
Irrigation scheduling					
I_1: 3 irrigations (at CRI, LJ and milking stage)	4.03	16.67	32567	49314	1.52
I_2: 4 irrigations (at CRI, tillering, late jointing (LJ) and milking stage)	4.32	15.36	33300	50570	1.52
I_3: 5 irrigations (at CRI, tillering, LJ, milking and dough stage)	4.54	13.71	34567	51741	1.50
CD (p=0.05)	0.24	-	-	-	-

Note: Depth of irrigation=60 mm; LJ- late jointing; CRI- crown root initiation

3.3.2. Evaluation of drip irrigation in turmeric under Aonla based alternate land use system

The Aonla is a hardy fruit crop and has tremendous medicinal values. Open barren alleys pose the problem of excess weed infestation in Aonla orchards which unnecessarily enhance the maintenance cost of the orchards. An alternate land use system through turmeric cultivation in the alleys of existing Aonla orchards shall be quite helpful in increasing the production and productivity of the Aonla growers of eastern Uttar Pradesh. Drip irrigation system may be quite effective in moving the salt away from the root zone, particularly in salt-affected soil and also save water which is a precious scarce resource. The experiment was performed in turmeric (var. *Narendra Turmeric*-1) for three consecutive years (2019 to 2022) in the alley of Aonla orchard. The yield data clearly showed that all the drip irrigation treatments recorded significantly higher yield of turmeric in comparison to surface irrigation treatment (Table 13). Drip irrigation treatment at 80% PE with 100% recommended dose of fertilizer (RDF) produced significantly higher yield of turmeric 19.9 t ha^{-1} with WUE of 24.05 kg ha-mm^{-1} which was at par with drip irrigation at 80% PE with 75% RDF (I_5), and drip irrigation at 80% PE during summer & 60% PE during winter with 100% RDF (I_2) treatments in which the yield was 19.4 and 19.3 t ha^{-1} with WUE of 23.51 and 25.62 kg ha-mm^{-1}, respectively. The fertilizer dose 100% and 75% RDF had not any significant impact on turmeric yield under different drip irrigation treatments. The surface irrigation (0.8 IW/CPE with 100% RDF) gave the lowest yield of turmeric 15.0 t ha^{-1}. The irrigation practice I_4 (drip irrigation at 80% PE with 100% RDF) recorded the highest net income of ₹4,94,200 ha^{-1} with benefit-cost ratio of 4.82 followed by ₹4,82,700 ha^{-1} and 4.80 under I_5 (drip irrigation at 80% PE with 75% RDF).

Table 13. Effect of different drip and surface irrigation on performance of turmeric under alleys of aonla plantation (Pooled over three years)

Treatment combination	Yield (t ha^{-1})	WUE (kg ha-mm^{-1})	Cost of cultivation (₹ ha^{-1})	Net return (₹ ha^{-1})	B:C
I_1 : Surface irrigation at 0.8 IW/CPE + 100% RDF	15.0	14.93	110500	340790	3.08
I_2 : Drip irrigation at 80% PE during summer & 60% PE during winter + 100% RDF	19.4	25.62	105500	474460	4.49
I_3 : Drip irrigation at 80% PE during summer & 60% PE during winter + 75% RDF	18.7	24.79	104500	456740	4.37
I_4 : Drip irrigation at 80% PE + 100% RDF	19.9	24.05	102500	494200	4.82
I_5 : Drip irrigation at 80% PE + 75% RDF	19.4	23.51	100500	482700	4.80
I_6 : Drip irrigation at 60% PE + 100% RDF	17.6	23.76	99500	427390	4.29
I_7 : Drip irrigation at 60% PE + 75% RDF	16.8	22.88	98500	405140	4.11
CD (p=0.05)	1.1	-	-	-	-

Note: RDF- recommended dose of fertilizer


Turmeric crop grown in the alleys of Aonla under drip irrigation

Chapter 4

Fertigation

4.1. Rahuri

4.1.1. Suitability of irrigation methods and yield targeting approach through fertigation in *preseasonal* sugarcane in Vertisol

Use of surface drip and subsurface drip irrigation systems in sugarcane is becoming more common. Irrigation and fertigation management are critical in drip irrigated sugarcane cultivation. Therefore, it is necessary to investigate the influence of NPK fertigation with Soil Test Crop Response (STCR) equation on sugarcane production under different irrigation practices. An experiment was conducted from November 2017 to February 2021 in sugarcane (var. MS-10001) under split-plot design. It was observed that maximum number of internodes, girth of internodes, and sugarcane yield were recoded with drip irrigation on alternate day at 80% ET_c (I_1). Whereas, fertilizer treatment F_5 i.e. yield target of 250 MT ha^{-1} with FYM produced significantly higher number of internodes, girth of internodes, and sugarcane yield; which was at par with F_4 and significantly superior over F_3, F_2, and F_1. The brix value was not varied with different fertigation practice. However, the commercial cane sugar was maximum in the fertilizer treatment F_5 (22.9 t ha^{-1}) which was at par with F_4 (20.4 t ha^{-1}) and significantly superior over F_1 and F_3. Maximum water use efficiency and water saving were computed with drip and sub-surface drip irrigation practices. Highest gross and net monetary returns and B-C ratio were obtained with treatments I_1F_5 i.e. drip irrigation at 80 % ET_c and fertilizer treatment of target yield of 250 MT ha^{-1} with FYM. The influence of irrigation methods over soil pH, EC and organic carbon was non-significant. Effect of irrigation methods on soil pH, EC, organic carbon and available nutrients showed significant results except for available K; whereas the effect of fertilizer treatments showed significant results. Significantly highest available nitrogen (179 kg ha^{-1}) was recorded in the treatment F_5. Similar results were found with respect to available phosphorus (17.8 kg ha^{-1}) and available potassium (445.3 kg ha^{-1}).

Table 14. Effect of different irrigation methods and fertilization practice on growth, yield, and quality of sugarcane (Pooled over three years)

Treatment	Yield (t ha^{-1})	Brix (%)	Commercial cane sugar (t ha^{-1})	Water applied (cm)	Total water used (cm)	Water use efficiency (kg ha-cm^{-1})
Irrigation method (I)						
I_1: Drip irrigation on alternate day with 80% ET_c	117	21.2	17.2	104	123	964
I_2: Subsurface drip on alternate day with 80% ET_c	114	21.0	16.7	104	123	942
I_3: Surface irrigation at 75 mm CPE	109	21.3	15.8	194	209	522
CD (p=0.05)	NS	NS	NS	-	-	-
Fertilizer treatment (F)						
F_1: Drip irrigation with no fertilizers (Control)	61	21.5	8.7	134	152	403
F_2: GRDF (340:170:170 kg ha^{-1}) N, P_2O_5, K_2O, FYM 20 t ha^{-1}	104	21.2	14.7	134	152	683
F_3: Yield target of 150 MT ha^{-1} with FYM	112	20.7	16.2	134	152	736

F_4: Yield target of 200 MT ha^{-1} with FYM	136	21.6	20.4	134	152	899
F_5: Yield target of 250 MT ha^{-1} with FYM	155	20.8	22.9	134	152	1021
CD (p=0.05)	19	NS	3.7	-	-	-
Interaction I × F						
CD (p=0.05)	NS	NS	NS	-	-	-

Note: NS, non-sigificant; CPE, cumulative pan evaporation; FYM, farmyard manure

4.2. Bathinda

4.2.1. Optimizing N, P, and K through various fertigation combinations for improved yield of tomato and brinjal (Coordinated trial)

An experiment was conducted during 2020-22 under drip fertigation to optimize the fertilizer requirement of tomato-brinjal crop sequence for higher productivity. In tomato (var. *Punjab Ratta*), among N, P and K application, treatments with no basal dose (T_3 = 100% $NPK_{Fertigation}$ & T_7 = 75% $NPK_{Fertigation}$) gave significantly lower fruit yield as compared to T_2 (100% $NK_{Fertigation}$ + 100% P_{Basal}) & T_6 (75% $NK_{Fertigation}$ + 75% P_{Basal}). However, these treatments gave significantly higher fruit yield than control (T_9) and absolute control (T_{10}) treatments (Table 15). A similar observation was also recorded in case of brinjal (var. PBHR 42 hybrid). Treatments with no basal dose (T_3 = 100% $NPK_{Fertigation}$ & T_7 = 75% $NPK_{Fertigation}$) gave significantly lower fruit yield of brinjal as compared to T_2 (100% $NK_{Fertigation}$ + 100% P_{Basal}) & T_6 (75% $NK_{Fertigation}$ + 75% P_{Basal}). However, these treatments gave significantly higher fruit yield than control (T_9) and absolute control (T_{10}) treatments. The treatments with 100% N & K through fertigation with 100% P applied as basal dose (T_2 & T_6) gave significantly higher fruit yield, water use efficiency (WUE), and B-C ratio of tomato and brinjal as compared to other treatments (Table 15). After harvest, maximum available N and P in soil were observed with treatment T_3, and maximum K was recorded with treatment T_9 (Table 16).

Table 15. Effect of drip fertigation on yield attributes and yield of tomato and brinjal (Pooled over two years)

Treatments	Tomato				Brinjal			
	Fruit length (mm)	Fruit breadth (mm)	No. of fruits per plant	Fruit yield (t ha^{-1})	Fruit length (cm)	Fruit breadth (cm)	Fruit weight (g)	Fruit yield (t ha^{-1})
T_1: 100% $N_{Fertigation}$ + 100% PK_{Basal}	42.5	42.6	97.3	59.4	9.90	7.80	222	55.8
T_2: 100% NK_{Ferg} + 100% P_{Bas}	42.9	42.6	109.1	66.4	10.30	8.00	252	73.0
T_3: 100% NPK_{Ferg} + $Zero_{Bas}$	42.0	42.1	88.7	53.9	10.00	7.80	226	58.2
T_4: 75% NPK_{Ferg} + 25% NPK_{Bas}	42.6	42.9	100.8	61.3	10.50	8.20	253	74.4
T_5: 75% N_{Ferg} + 75% PK_{Bas}	43.0	42.9	96.9	58.9	9.70	7.60	220	53.0
T_6: 75% NK_{Ferg} + 75% P_{Bas}	43.6	42.5	108.5	66.3	10.10	7.90	248	72.2
T_7: 75% NPK_{Ferg} + $Zero_{Bas}$	41.7	42.1	87.3	53.3	9.90	7.70	224	57.1
T_8: 25% of 75% NPK_{Bas} & remaining NPK_{Ferg}	42.8	42.6	100.2	62.0	10.20	7.90	248	71.3
T_9: 100% NPK – Control	39.8	40.7	67.9	41.5	9.50	7.40	196	43.7
T_{10} : Absolute Control	37.7	38.5	52.4	31.7	9.20	7.20	175	29.4
CD (p=0.05)	NS	NS	5.9	3.4	0.50	0.40	17	5.9

Table 16. Effect of drip fertigation on water use efficiency, economics and nutrient status of soil

Treatment	Tomato		Brinjal		Soil after harvest		
	WUE (kg ha-mm^{-1})	B:C	WUE (kg ha-mm^{-1})	B:C	Available N (kg ha^{-1})	Available P (kg ha^{-1})	Available K (kg ha^{-1})
T_1 : 100% N_{Ferg} + 100% PK_{Bas}	260	2.20	472	4.65	68.2	24.2	329
T_2 : 100% NK_{Ferg} + 100% P_{Bas}	291	2.41	614	5.79	71.7	22.7	322
T_3 : 100% NPK_{Ferg} + $Zero_{Bas}$	236	1.94	491	4.54	74.4	25.6	327
T_4 : 75% NPK_{Ferg} + 25% NPK_{Bas}	269	2.19	628	5.64	73.2	20.4	325
T_5 : 75% N_{Ferg} + 75% PK_{Bas}	258	2.21	448	4.54	69.0	21.0	327
T_6 : 75% NK_{Ferg} + 75% P_{Bas}	291	2.44	603	5.85	73.2	21.5	323
T_7 : 75% NPK_{Ferg} + $Zero_{Bas}$	234	1.96	476	4.62	73.7	23.2	325
T_8 : 25% of 75% NPK_{Bas} & remaining NPK_{Ferg}	272	2.25	600	5.60	70.5	19.7	324
T_9 : 100% NPK – Control	109	1.69	220	4.04	69.8	23.6	331
T_{10} : Absolute Control	83	1.39	149	3.12	50.1	12.8	318

Drip fertigation in tomato and brinjal

4.3. Jorhat

4.3.1. Effect of varying drip irrigation level and NPK fertigation on rice (autumn)- greengram–broccoli cropping system in Assam

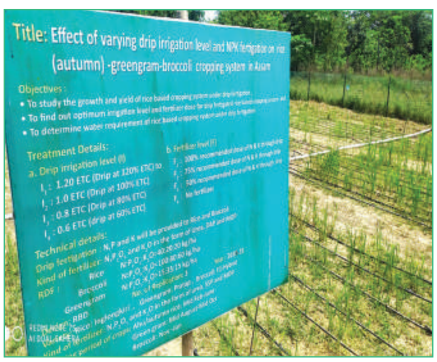
An experiment was conducted with varying drip irrigation levels and NPK fertigation in rice–greengram–broccoli cropping system during 2019-2022 with the following objectives i) to study the growth and yield of direct seeded autumn rice (var. *Inglongkiri*) under drip irrigation and ii) to find out optimum irrigation and fertilizer dose for drip fertigated direct seeded autumn rice. Treatments were not imposed in greengram grown during rainy season. Different irrigation regimes influenced the grain yield of autumn rice significantly. Drip irrigation at 1.20 ET_c (I_1) treatment recorded the highest grain yield of rice followed by drip irrigation at 1.00 ET_c (I_2) which was at par with I_1. Greengram variety (var. *Pratap*) was grown duirng *kharif* season; so application of drip irigation was not possible.In case of broccoli (var. *Fiesta*), head yield and rice equivalent yield of I_2 treatment recorded the highest yield but was at par with I_3 (drip at 0.8 ET_c). The system yield was in similar trend to that of rice yield i.e. I_1 recorded the highest grain yield but was at par with I_2 (Table 17). The requirement for irrigation water was reduced with the reduction in drip irrigation level from 1.20 ET_c to 0.6 ET_c. Irrigation water requirement for broccoli crop was less than that of rice crop. Water productivity for rice and broccoli increased with the decrease in irrigation level through drip. With drip irrigation at 0.6 ET_c, the maximum water productivity of 2.09 kg m^{-3} and 18.30 kg m^{-3} for rice and broccoli, respectively, was computed (Table 18). Different fertilizer levels significantly influenced all the parameters studied. F_1 treatment i.e. 100% recommended dose of N, P & K through drip recorded significantly higher grain yield of rice, head yield of broccoli and system yield; which was at par with F_2 (75% through drip).

Table 17. Effect of different levels of drip fertigation on rice, broccoli, and system yields (Pooled over three years)

Treatment	Rice grain yield (t ha^{-1})	Rice equivalent broccoli yield (t ha^{-1})	System yield (t ha^{-1})
Drip irrigation level (I)			
I_1: 1.20 ET_c	3.59	15.6	2.24
I_2: 1.0 ET_c	3.43	15.9	2.15
I_3: 0.8 ET_c	3.18	14.8	2.01
I_4: 0.6 ET_c	2.63	12.4	1.44
CD (p=0.05)	0.31	1.5	0.20
Fertilizer level: Drip fertigation (F)			
F_1: 100% RDF	3.90	16.5	2.26
F_2: 75% RDF	3.68	15.8	2.16
F_3: 50% RDF	3.37	14.7	1.99
F_4: No fertilizer	1.88	9.9	1.31
CD (p=0.05)	0.31	1.5	0.20

Table 18. Irrigation water use and water productivity in rice and broccoli under varied levels of drip irrigation (Pooled over three years)

Treatment	Irrigation water use (mm)		Water productivity (kg m^{-3})	
	Rice	Broccoli	Rice	Broccoli
Drip irrigation level				
I_1: 1.2 ET_c	252	80.8	1.42	11.6
I_2: 1.0 ET_c	210	67.4	1.63	14.2
I_3: 0.8 ET_c	168	53.9	1.89	16.4
I_4: 0.6 ET_c	126	40.4	2.09	18.3




Drip fertigation in autumn rice and broccoli

4.4. Bilaspur

4.4.1. To study the effect of moisture regimes and sulphur on yield of mustard under drip environment

Indian mustard (*Brassica juncea*) crop is cultivated in 47,000 hectare land in Chhattisgarh. But crop productivity is very low in the state i.e. 1.18 t ha^{-1}. Water shortage and nutrient deficiency are two major constraints drastically affecting mustard production; in which sulphur deficiency is a major cause. Hence, a drip fertigation experiment was conducted with mustard variety *Chhattisgarh Sarson*-1 for three consecutive years (*Rabi* 2019-20 to 2021-22) incorporating sulphur application with drip. Treatments comprised of irrigation schedules *viz.*, 80, 60 and 40% ET_c, and fertigation schedules *viz.*, 75% RDF + S @ 30 kg ha^{-1}, 75% RDF + S @ 20 kg ha^{-1}, 75% RDF + S @ 10 kg ha^{-1}. Control comprised of border strip irrigation and soil application of 100% RDF (100:60:40 kg NPK per ha through Urea, SSP, MOP; 45 kg Sulphur ha^{-1} supplied through SSP.

Results showed that irrigation and fertigation levels significantly influenced the grain and stover yields of mustard. Irrigation scheduling at 60% ET_c (I_2) recorded significantly higher seed yield (2.08 t ha^{-1}) and stover yield (4.99 t ha^{-1}) compared to irrigation scheduled at 40% ET_c (I_3), but at par with yield under 80% ET_c (Table 19). The Control also produced higher seed and stover yields over 40% ET_c. Application of 75% RDF+Sulphur @ 30 kg ha^{-1} through fertigation (F_1) recorded significantly higher seed yield (2.12 t ha^{-1}) and stover yield (4.91 t ha^{-1}) in comparison to application of 75% RDF + Sulphur @ 10 kg ha^{-1} (F_3) and 100% RDF through soil application (Control), but at par with F_2 (75% RDF + Sulphur @ 20 kg ha^{-1}). Water use efficiency (14.73 kg ha-mm^{-1}), net return (₹ 62777 ha^{-1}) and benefit-cost ratio (1.93) were also highest under 60% ET_c among all drip irrigation treatments and the Control.

Table 19. Performance of mustard under drip fertigation

Treatment	Grain yield (t ha^{-1})	Stover yield (t ha^{-1})	Water use efficiency (kg ha-mm^{-1})	Net income (₹ ha^{-1})	B : C ratio
Drip irrigation schedule					
I_1 (80% ET_c)	1.83	4.33	10.82	15246	1.57
I_2 (60% ET_c)	2.08	4.99	14.73	62777	1.93
I_3 (40% ET_c)	1.48	3.73	13.20	35468	1.08
Fertigation schedule					
F_1 (75% RDF + S @ 30 kg ha^{-1})	2.12	4.91	15.04	62239	1.77
F_2 (75% RDF + S @ 20 kg ha^{-1})	1.89	4.47	13.38	52768	1.57
F_3 (75% RDF + S @ 10 kg ha^{-1})	1.49	3.85	10.62	36102	1.11
F_4 (100% RDF soil application)	1.68	4.18	11.95	50254	1.77
Control (Border strip irrigation and soil application of 100% RDF)	1.64	4.33	6.39	48334	1.66

4.5. Palampur

4.5.1. Effect of drip fertigation, irrigation and drip line - FYM placement on productivity of marigold under protected conditions

An experiment was conducted with marigold crop (var. *Pusa Narangi Gainda*) on silty clay loam soil in summer season of 2021 and 2022 under protected condition of polyhouse. Objective was to study the effects of surface and subsurface drip fertigation using inorganic & liquid organic (vermiwash) fertilizers under varying irrigation schedules on crop performance. Total 12 fertigation treatment combinations were employed, with six under surface drip irrigation @ 0.8 PE and remaining six under sub surface drip irrigation @ 0.6 PE. Sixth and twelfth treatment combination involved application of 100% NPK using conventional method with surface drip and sub surface drip irrigation systems, respectively. Every treatment combination had different basal dose and varying weekly fertigation. The weekly fertigation was given in 10 splits in each treatment combination. The treatment combinations and fertigation schedules are presented in tabular form (Table 20 & 21). Randomized block design was adopted for the experiment with three replications for each treatment combination. Plot size of every treatment combination was 3.0 m × 0.5 m. Recommended fertilizer dose for marigold crop is N:P_2O_5:K_2O kg ha^{-1} 100:75:75. Initial fertility status of experimental field showed low available N, higher available P and medium available K.

Table 20. Fertigation treatment combinations for marigold crop under protected condition

Treatment combination	Basal	Weekly fertigation in 10 splits	Drip irrigation system
T_1	100% PK	100% N	Surface drip at 0.8 PE
T_2	25% NPK	75% NPK	Surface drip at 0.8 PE
T_3	50% NPK	50% NPK	Surface drip at 0.8 PE
T_4	100% PK	100% N + Vermiwash @ 75 mL m^{-2}	Surface drip at 0.8 PE
T_5	25% NPK	25% NPK + Vermiwash @ 75 mL m^{-2}	Surface drip at 0.8 PE
T_6	100% NPK conventional method + Vermiwash @ 75 mL m^{-2} at weekly intervals in 10 splits		Surface drip at 0.8 PE
T_7	100% PK	100% N	Sub surface drip at 0.6 PE
T_8	25% NPK	75% NPK	Sub surface drip at 0.6 PE
T_9	50% NPK	50% NPK	Sub surface drip at 0.6 PE
T_{10}	100% PK	100% N + Vermiwash @ 75 mL m^{-2}	Sub surface drip at 0.6 PE
T_{11}	25% NPK	25% NPK + Vermiwash @ 75 mL m^{-2}	Sub surface drip at 0.6 PE
T_{12}	100% NPK conventional method + Vermiwash @ 75 mL m^{-2} at weekly intervals in 10 splits		Sub surface drip at 0.6 PE

Table 21. Fertigation schedule for marigold crop under protected condition

Treatment combination	Fertigation schedule
T_1	SSP 45 g MOP 12 g + 1.5 g urea / split weekly for 15 fertigations
T_2	Urea 6 g SSP 12 g MOP 3 g + 3 g 19:19:19 + urea 0.5 g / split weekly for 10 fertigations
T_3	Urea 12 g SSP 24 g MOP 6 g + 2 g 19:19:19 + urea 0.3 g / split weekly for 10 fertigations
T_4	SSP 45 g MOP 12 g + 0.25 g urea / split weekly + 75 mL Vermiwash for 10 fertigations
T_5	Urea 6 g SSP 12 g MOP 3 g + 1 g 19:19:19 + urea 0.2 g / split weekly + 75 mL Vermiwash for 10 fertigations
T_6	Urea 12 g SSP 45 g MOP 12 g + 75 mL Vermiwash for 10 fertigations

Results of the experiment showed that different fertigation schedules or nutrient management treatments significantly increased the marketable yield of marigold (Table 22). Average flower yield of 20.13 t ha^{-1} was significantly higher under 25% NPK basal + 75% NPK fertigation with sub surface drip irrigation at 0.6 PE (T_8). The next best treatment combination was 25% NPK basal + 75% NPK fertigation with surface drip irrigation at 0.8 PE (T_2) showing marketable flower yield of 18.23 t ha^{-1}, followed by T_9 with yield of 16.83 t ha^{-1}. Water use efficiency (WUE) of 57.90 kg ha-mm^{-1} was highest under T_8, followed by 48.61 kg ha-mm^{-1} under T_9.

Table 22. Performance of marigold crop under different fertigation schedules in protected condition

Treatment combination	Marketable yield ($t\ ha^{-1}$)		Average yield ($t\ ha^{-1}$)	Water use efficiency ($kg\ ha\text{-}mm^{-1}$)		Average WUE ($kg\ ha\text{-}mm^{-1}$)
	2021	2022		2021	2022	
T_1	14.96	15.97	15.46	33.23	34.49	33.86
T_2	18.18	18.29	18.23	40.39	39.50	39.95
T_3	16.00	15.78	15.89	35.55	34.08	34.82
T_4	16.49	14.18	15.33	36.32	30.62	33.47
T_5	13.87	14.02	13.95	30.81	30.29	30.55
T_6	16.87	14.60	15.73	37.15	32.16	34.66
T_7	14.84	15.38	15.11	43.59	43.68	43.64
T_8	21.47	18.80	20.13	62.40	53.40	57.90
T_9	17.07	16.58	16.83	50.11	47.11	48.61
T_{10}	14.71	14.96	14.83	43.20	42.49	42.85
T_{11}	12.87	13.87	13.37	37.78	39.39	38.59
T_{12}	15.29	14.73	15.01	44.89	43.26	44.08
CD (p=0.05)	0.29	0.23	0.26	0.77	0.51	0.64

Note: Total water use for 0.8 PE and 0.6 PE was 454 and 346 mm, respectively in 2021; Total water use for 0.8 PE and 0.6 PE was 463 & 352 mm, respectively 2022. WUE, water use efficiency

Marigold crop under protected conditions

Chapter 5

Basic Studies on Soil-Plant-Water-Environment Relationship

5.1. Belavatagi

5.1.1. Evaluating suitable cropping system under different irrigation and nutrient levels in *Vertisol* of Malaprabha Command Area

Field experiment was conducted to evaluate the productivity and profitability of different cropping systems under different irrigation schedules and nutrient levels in Vertisols of Malaprabha command area during 2019-21. The treatments consist of two irrigation levels in main plot (M_1 = 0.8 ET_c, M_2 = 0.6 ET_c), four cropping systems in sub plot (C_1: Pigeon-pea +Blackgram intercrop C_2: Fingermillet-Chickpea system, C_3: Groundnut-Chickpea system and Single control: Maize-Chickpea system), and two nutrient levels in sub sub plot (N_1: 100% RDF in *kharif* & *rabi*, N_2: 125% RDF in *kharif*, 100% RDF in *rabi*) in Factorial RCBD and replicated thrice.

The experimental results revealed that maize equivalent yield (MEY), chickpea yield, and system productivity and B:C ratio were significantly high at irrigation level of 0.8 ET_c than irrigation level (0.6 ET_c). Among different *kharif* crops, higher MEY was recorded in C_1- Pigeonpea+Blackgram (6.03 t ha^{-1}). Groundnut-Chickpea cropping system recorded significantly higher system productivity and B:C ratio compared to other cropping systems. Among the nutrients levels, significantly higher MEY, chickpea yield, system productivity and B:C ratio was recorded with 125% RDF compared to 100% RDF. The data on cropping system productivity revealed that significantly higher system productivity was observed under single control (Maize-Chickpea) than Groundnut-chickpea (Table 23).

Table 23. Effect of irrigation and nutrient levels on cropping system performance

Treatment	Pooled maize equivalent yield (t ha^{-1})	Pooled chickpea yield (t ha^{-1})	Cropping system productivity (t ha^{-1})	Gross return (₹ ha^{-1})	Net return (₹ ha^{-1})	B : C
Main plot: Irrigation level						
M_1: 0.8 ET_c	4.83	0.88	4.88	60549	29780	2.04
M_2: 0.6 ET_c	4.49	0.96	5.41	55632	28002	1.99
CD (*p*=0.05)	0.19	NS	0.23	335	303	0.01
Sub plot: Cropping system						
C_1: Pigeonpea + Blackgram intercrop	6.03	-	5.11	60986	33476	1.82
C_2: Fingermillet-Chickpea system	3.28	1.52	4.20	50817	28699	1.77
C_3: Groundnut-Chickpea system	4.64	1.29	5.36	59597	28303	2.11
CD (*p*=0.05)	0.3	0.16	0.34	469	441	0.03
Sub-sub plot: Nutrient level						
N_1: 100% RDF (*kharif* & *rabi*)	4.52	0.95	4.91	55387	28347	1.95
N_2: 125% RDF in *kharif* & 100% RDF in *rabi*	4.73	0.58	5.28	58825	31657	1.86
CD (*p*=0.05)	0.17	0.12	0.22	308	299	0.01
Single Control Maize-chickpea	5.47	1.0	5.96	63754	34951	1.83

Cropping system evaluation in Malaprabha command area

5.2. Pantnagar

5.2.1. Improvising *kharif* maize performance through land configurations and nitrogen scheduling

Field experiment was conducted at *tarai* region of Uttarakhand during *kharif* 2022 to develop the best crop establishment method and nitrogen scheduling for higher grain yield of maize (var. Decalb 9144) and higher water use efficiency under irrigated ecology. The treatments consisted of three crop establishment methods (flat, ridge and bed sowings) and three nitrogen (N) schedules (N_1- 1/3rd N at basal+1/3rd at knee-high+1/3rd at tasseling stage, N_2- 1/4th basal+1/4th N prior to knee- high+1/4th N at knee-high+1/4th N at tasseling and N_3- N_1+foliar spray of 2% urea at prior to knee-high stage and prior to tasseling stage and replicated thrice in a split plot design. The experimental findings revealed that bed sowing of *kharif* maize resulted in significantly higher net return (₹ 1,03,815) and B:C ratio (2.23) as compared to flat sowing (Table 24). Application of recommended doses of nitrogen in four split doses produced higher grain yield (8.12 t ha^{-1}), net return (₹ 1,05,648 ha^{-1}), B:C ratio (2.24) and economic water productivity (₹ 1.71 mm^{-1}).

Table 24. Performance of *kharif* maize as influenced by crop establishment methods and nitrogen scheduling (mean of 3 years)

Treatment	Cob yield (t ha^{-1})	Cost of production (₹ ha^{-1})	Economic water productivity (₹ mm^{-1})	Net return (₹ ha^{-1})	B:C ratio
Crop establishment method					
Flat sowing	7.34	50442	1.140	88442	1.77
Ridge sowing	7.97	47305	1.838	103524	2.23
Bed sowing	7.98	47305	1.823	103815	2.23
CD (*p*=0.05)	0.31	-	133.3	5847	0.13
Nitrogen management practices					
N_1: 3 splits of N	7.38	47737	1.491	92033	1.97
N_2: 4 splits of N	8.12	48086	1.713	105648	2.24
N_3: N_1+ foliar spray of 2% urea at prior to knee high and prior to tasseling stage	7.78	49230	1.598	98100	2.03
CD (*p*=0.05)	0.31	-	-	5847	0.13

Water stagnation in flat bed maize

Ridge planted maize

5.2.2. Mitigating heat stress in spring sweet corn through irrigation optimization, mulch and companion cropping

Experiment was conducted during 2020-21 at *Tarai,* spring season (Feb-June) to study the effect of irrigation schedule and mulching on crop yield, economics and water productivity of Sweetcorn + Mentha cropping system. Sweetcorn variety Sugar-75 and mentha variety CIM Kranti were taken for the experiment. The treatments consisted of two irrigation schedules *viz.*, IW: CPE 1.0 (6 cm irrigation depth) and IW:CPE 1.2, four cropping systems *viz.*, Sweetcorn + Mentha (1:1) (one row of mentha between two rows of sweetcorn at 75 cm distance), Sweetcorn + Mentha (2:2) (2 rows of maize at 50/100 cm and 2 rows of mentha between two pairs of sweetcorn), Sole sweetcorn crop (75 cm × 20 cm), Sole mentha crop (50 cm), and two mulching treatments *viz.*, no mulch, and rice straw mulch @ 6.0 t ha^{-1} at knee high stage in factorial RBD and replicated thrice. Uniform irrigation was given for proper establishment of the crops and after that irrigation were scheduled as per the ratios. Crops were irrigated when cumulative pan evaporation (CPE) values were reached at 50 and 60 mm in IW:CPE 1.2 and 1.0, respectively.

Experimental results indicated that scheduling of irrigation at IW:CPE 1.2 significantly produced higher system yield in terms of sweetcorn equivalent yield in sweetcorn + mentha cropping system but water productivity was significantly higher at IW:CPE 1.0. Intensification of sweetcorn with intercropping of mentha at 2:2 significantly increased the system yield, net return, B:C ratio than the sole sweetcorn crop. Intensification of sweetcorn with mentha (intercrop) had no significant effect on water productivity compared to sole sweetcorn crop. Application of rice straw mulching at knee-height stage of sweetcorn + mentha cropping system significantly increased the system yield, net return and water productivity compared to no mulch condition (Table 25).

Table 25. Effect of different treatments on yields of maize and mentha crops

Treatment	Maize cob yield with husk (t ha^{-1})	Mentha oil yield (t ha^{-1})	System yield (Maize equivalent yield) (t ha^{-1})	Water productivity (t ha-mm^{-1})	Net return (₹ ha^{-1})	B:C
Irrigation schedule						
IW:CPE 1.0	21.40	0.12	23.45	30.29	277870	3.02
IW:CPE 1.2	22.30	0.13	24.56	26.15	291092	3.04
CD (*p*=0.05)	0.72	NS	0.77	0.863	11119	NS
Cropping system						
Maize + Mentha (1:1)	21.01	0.06	26.28	28.58	318935	3.23
Maize + Mentha (2:2)	22.97	0.08	29.18	31.86	362080	3.60
Sole maize crop	21.53	-	21.53	31.54	269803	3.41
Sole mentha crop	-	0.24	19.14	20.91	187106	1.87
CD (*p*=0.05)	0.88	0.01	1.09	1.22	15725	0.16
Mulching						
No mulch	20.90	0.12	22.89	26.92	271645	3.02
Rice straw mulch @ 6 t ha^{-1}	22.81	0.13	25.12	29.53	297317	3.04
CD (*p*=0.05)	0.72	0.01	0.77	0.86	11119	NS

Mentha+Maize (2:2)

Mentha after maize harvest in Maize+Mentha (2:2)

5.3. Gayeshpur

5.3.1. Management of different irrigation methods and mulch conditions in sweet corn for higher crop and water productivity

Field experiments were conducted at research farm of Gayeshpur, Nadia, West Bengal to study the effect of different irrigation schedules and mulching on growth, yield, economics of sweetcorn (var. Sugar-75) performance of growth, yield attributes and yield of sweet corn. The treatments consisted of three irrigation methods (furrow, alternate furrow and flood irrigation) and four mulch conditions (rice straw mulch, black polythene mulch, jute textile mulch and soil mulch) in split plot design and replicated thrice. Results of the study showed that maximum growth, yield attributes and yield (16.45 t ha^{-1}) of sweet corn was obtained with furrow irrigation coupled with black polythene mulch (BPM) which was statistically at par with flood irrigation using BPM with cob yield of 15.57 t ha^{-1}. Highest WUE (9.77 kg ha-cm^{-1}) (Table 26) was obtained with alternate furrow irrigation method and BPM (I_2M_2), whereas minimum WUE (4.33 kg ha-cm^{-1}) was recorded with flood irrigation and soil mulching (I_3M_4).

Table 26. Cob yield and water use efficiency (WUE) of sweet corn as influenced by different irrigation methods and mulching

Treatment (I × M)	Soil profile contribution (mm)	Effective rainfall (mm)	Irrigation water applied (mm)	Total water use (mm)	Cob yield (t ha^{-1})	WUE (kg ha-cm^{-1})
I_1M_1	22.10	28.40	140.60	191.10	15.32	8.02
I_1M_2	27.20	28.40	140.60	196.20	16.45	8.38
I_1M_3	18.10	28.40	140.60	187.10	14.47	7.73
I_1M_4	15.40	28.40	140.60	184.40	13.35	7.24
I_2M_1	26.30	28.40	96.40	151.10	13.42	8.88
I_2M_2	21.50	28.40	96.40	146.30	14.31	9.77
I_2M_3	23.40	28.40	96.40	148.20	12.99	8.76
I_2M_4	16.70	28.40	96.40	141.50	11.90	8.41
I_3M_1	23.30	28.40	240.60	292.30	14.51	4.96
I_3M_2	20.30	28.40	240.60	289.30	15.57	5.38
I_3M_3	20.80	28.40	240.60	289.80	14.15	4.88
I_3M_4	18.50	28.40	240.60	287.50	12.44	4.33

Note: I_1: Furrow irrigation; I_2: Alternate furrow irrigation; I_3: Flood irrigation; M_1: Rice straw mulch; M_2: Black polythene mulch; M_3: Jute textile mulch; M_4: Soil mulch

Sweet corn crop under different irrigation & mulching treatments

5.3.2. Irrigation and zinc fertilization on crop and water productivity in wheat-greengram cropping sequence

Field experiment was conducted at research farm of Gayeshpur, Nadia, West Bengal to study the effect of different irrigation schedules and zinc fertilization on growth, yield, economics and water use efficiency of wheat (var. PBW 343) and greengram (var. IPM-02-03). The treatments consisted of four irrigation levels (IW/CPE=0.6; IW/CPE=0.8; IW/CPE=1.0 and flood irrigation i.e. farmers' practice) coupled with three levels of zinc fertilization ($ZnSO_4$ @ 0, 5 and 10 kg ha^{-1}) in split plot design and replicated thrice. Results of the experiments revealed that grain yield of wheat was highest (5.42 t ha^{-1}) with irrigation at IW/CPE=1.0 and 10 kg ha^{-1} $ZnSO_4$. Minimum water use (154.00 mm) was observed with irrigation at IW/CPE=0.6. Highest water use efficiency (32.23 kg ha-mm^{-1}) was recorded with irrigation at IW/CPE=0.6, whereas lowest WUE (16.13 kg ha-mm^{-1}) was obtained with farmers' practice. Similarly, highest greengram yield was recorded with irrigation at IW/CPE=1.0 and $ZnSO_4$ @ 10 kg ha^{-1}. However, highest water use efficiency of 7.33 kg ha-mm^{-1} was registered with irrigation scheduling at IW/CPE=0.8 and $ZnSO_4$ @ 10 kg ha^{-1} (Table 27).

Table 27. Crop yield and water use efficiency of wheat and greengram under different irrigation schedules and Zinc fertilization

Treatment	Wheat			Greengram		
	Total water use (mm)	Grain yield (t ha^{-1})	WUE (kg ha-mm^{-1})	Total water use (mm)	Grain yield (t ha^{-1})	WUE (kg ha-mm^{-1})
I_1Zn_0	154.00	3.98	25.86	155.40	0.88	5.65
I_1Zn_5	153.40	4.72	30.76	155.00	0.97	6.25
I_1Zn_{10}	152.20	4.91	32.23	153.80	1.05	6.81
I_2Zn_0	201.40	4.64	23.04	150.00	0.95	6.30
I_2Zn_5	202.30	4.94	24.39	148.90	1.04	7.00
I_2Zn_{10}	201.30	5.21	25.86	148.40	1.09	7.33
I_3Zn_0	249.20	4.84	19.42	197.50	0.99	5.02
I_3Zn_5	251.00	5.21	20.72	196.80	1.08	5.50
I_3Zn_{10}	251.50	5.42	21.56	196.70	1.23	6.26
I_4Zn_0	299.08	4.82	16.13	244.68	0.96	3.92
I_4Zn_5	298.44	5.18	17.35	244.04	1.02	4.19
I_4Zn_{10}	299.02	5.32	17.79	244.62	1.16	4.73

Greengram crop under wheat-greengram sequence

5.4. Jorhat

5.4.1. Estimation of yield response factor (Ky) to soil water for onion (*Allium cepa* L.) under various irrigation regimes

Field experiment was conducted at research farm of Assam Agricultural University, Jorhat during 2019-22 to develop irrigation schedules for maximization of onion bulb yield and to assess the effect of limited water supply on production of onion (var. *Agrifound Light Red*). The treatments consist of five irrigation management practices i.e. drip irrigation at 120% ETc, 100% ETc, 80% ETc, 60% ETc and 40% ETc in a randomised block design with four replications. Irrigation was applied at two alternate days intervals. It was observed that highest yield (16.52 t ha^{-1}) and B:C ratio was found in treatment T_1, i.e. 120% ET_c applying 3.84 L m^{-2} day^{-1} through drip irrigation system (Table 28). The yield response factor K_y for all the growth stages of onion *viz.*, Initial, Mid, Development and Late was found out. In the year 2019-20, K_y value was greater than 1 for Initial stage only. Also in the year 2021-22, K_y value for Initial and Mid stages were greater than 1, which means crop response is very sensitive to water deficit with proportional larger yield reductions when water use is reduced.

Table 28. Bulb yield, Irrigation water use and water use efficiency as influenced by different irrigation schedules

Treatment	Bulb yield (t ha^{-1})				Irrigation water (mm)				Irrigation WUE (kg ha-mm^{-1})		
	2019	2020	2021	Pooled	2019	2020	2021	Pooled	2019	2020	2021
T_1	2.16	1.9	0.8961	1.65	20.00	18.22	31.06	23.09	11.85	10.43	2.88
T_2	1.83	1.72	0.8241	1.46	16.67	15.18	25.89	19.24	10.97	11.33	3.18
T_3	1.64	1.6	0.5529	1.26	13.33	12.14	20.71	15.39	13.51	13.18	2.66
T_4	1.56	1.49	0.2958	1.12	9.95	9.10	15.59	11.54	15.68	16.37	1.89
T_5	0.83	1.24	0.3145	0.79	6.67	6.07	10.39	7.71	12.44	20.42	3.03
CD (p=0.01)	0.07	0.06	0.14	-	-	-	-	-	-	-	-

Note: No. of irrigations in each treatment is 14

Drip irrigated onion crop

5.5. Jammu

5.5.1. Standardization and productivity enhancement of raised beds under raised-sunken bed technology for waterlogged areas of Jammu

Study was conducted to standardize width of raised beds based on moisture dynamics of the adjacent sunken beds so that crop intensification and water productivity of raised beds can be upscaled. Water budget and relative economics of the crop intensification was also worked out. The trials were conducted in Multiple Water Use Model in SKUAST Jammu from *kharif* 2020 to *zaid* 2022. Strip plot design was adopted with irrigation in main plot and crop intensification in sub-plot; every treatment being replicated thrice. Irrigation treatments comprised of I_1- Irrigation at field capacity (15 cm depth), I_2- Irrigation at 80% field capacity (15 cm depth), I_3- Irrigation at 60% field capacity (15 cm depth). Crop intensification treatments comprised of cropping sequences *viz*., S_1: Basmati rice-Wheat (Control), S_2: Okra-Cauliflower-Tomato, S_3: Maize-Marigold-Radish-Mixed fodder, S_4: Blackgram-Potato-French bean (Rajma)-Mixed fodder, S_5: Blackgram-KnolKhol-KnolKhol-Radish-Cowpea, S_6: Blackgram-KnolKhol-KnolKhol-Radish-Greengram, S_7: Rice (SD)-Fenugreek-KnolKhol-Green onion-Cowpea. Irrigation was applied taking into account field capacity of 0-15 cm depth, except rice. For rice crop water was applied during puddling operation and establishment phase *i.e.* 15 days after transplanting. Duration of the cropping sequences S_1, S_2, S_3, S_4, S_5, S_6 and S_7 are 257, 326, 347, 350, 351, 351 and 349 days, respectively.

Results showed that irrigation scheduled at field capacity for different cropping sequences gave significantly higher yield (7.13 t ha^{-1}), that was at par with yield (6.73 t ha^{-1}) obtained under irrigation at 80% of field capacity. Likewise, among the different crop sequences, S_7 *i.e.* rice (short duration) - fenugreek - knolkhol - green onion - cowpea on raised bed recorded significantly higher basmati rice equivalent yield (10.15 t ha^{-1}) than the other crop sequences (Table 29). Lowest basmati rice equivalent yield (3.36 t ha^{-1}) was recorded with S_1 *i.e.* conventional traditional basmati rice - wheat sequence on raised beds. Among the irrigation schedules , water use efficiency was highest (4.15 kg ha-mm^{-1}) with irrigation at field capacity, whereas S_7 recorded highest WUE of 4.79 kg ha-mm^{-1} among the cropping sequences. S_7 also fetched highest net return of ₹ 2,88,113 ha^{-1} and benefit-cost ratio of 1.75 (Table 30).

Moisture study showed that raised beds can be formed by raising soil up to a height of 1.0 m in 50% area and sunken beds of depth of 1.0 m can be formed in remaining 50% area to store excess water. The width of raised beds was standardized as 6.0-9.0 m. It was concluded that cropping sequence of short duration rice - fenugreek - knolkhol - green onion - cowpea on raised beds should be taken up for maximum system yield, system water productivity and profit in waterlogged ecosystem of Ranbir canal command.

Table 29. Effect of raised-sunken bed land configuration on crop performance

Irrigation schedule	Grain yield (t ha^{-1})	Irrigation (mm)	Rainfall (mm)	Total water use (mm)	WUE (kg ha-mm^{-1})
I_1: Irrigation at field capacity (FC)	7.13	542	1173	1715	4.15
I_2: Irrigation at 80% FC	6.73	470	1173	1643	4.09
I_3: Irrigation at 60% FC	6.22	385	1173	1558	3.99
CD (p=0.05)	0.41	-	-	-	-
S_1: Basmati rice-Wheat (Control)	3.36	560	992	1552	2.16
S_2: Okra-Cauliflower-Tomato	8.89	600	1090	1690	5.26
S_3: Maize-Marigold-Radish-Mixed fodder	5.57	300	1190	1490	3.73
S_4: Blackgram- Potato-Frenchbean-Mixed fodder	4.37	200	1240	1440	3.03
S_5: Blackgram-Knolkhol-Knolkhol-Radish-Cowpea	7.35	350	1240	1590	4.62

S_6: Blackgram-Knolk-hol-Knolkhol-Radish-Green-gram	7.18	350	1240	1590	4.51
S_7: Rice (SD)-Fenu-greek-Knolkhol-Green onion-Cowpea	10.15	900	1216	2116	4.79
CD (p=0.05)	0.37	-	-	-	-

Note: FC- field capacity, SD- short duration, WUE- water use efficiency

Table 30. Wate use and economics with different cropping sequences in raised beds under raised-sunder bed system

Crop sequence	Total irrigation water use (m^3 ha^{-1})	Sequence water use (m^3 ha^{-1})	Sequence water productivity (kg m^{-3})	Sequence profitability (₹ ha^{-1} day^{-1})	Net return (₹ ha^{-1})	B : C ratio
S_1	5600	15520	0.22	168	61416	0.69
S_2	6000	16900	0.53	627	228982	1.70
S_3	3000	14900	0.37	186	68071	0.43
S_4	2000	14400	0.30	119	43479	0.32
S_5	3500	15900	0.46	423	154651	1.05
S_6	3500	15900	0.45	395	144181	0.98
S_7	9000	21160	0.48	789	288113	1.75

Crops on raised bed under raised - sunken bed system for waterlogged ecosystem

Chapter 6

Operational Research Project (ORP)

6.1. Ayodhya

6.1.1. Studies on improved water management practices in wheat at head, middle and tail ends of Awanpur distributory

On-farm research study was conducted during *kharif* 2022 in Madhupur village at head end, Panapur and Narayanpur villages at middle end, and Alwalpur village at tail end of Awanpur distributory. Objective was to assess improved and farmers' water management practices for rice varieties *viz.*, BPT-5204 and *Sarjoo*-52 during *kharif* season and wheat variety PBW-154 during *rabi* season. Improved water management (T_1) in rice included application of 7 cm water at 1-4 days after disappearance of ponded water (DADPW) applied through check basin (10 m × 10 m). Farmers' practice (T_2) included application of 10-12 cm water by flooding/field to field irrigation. For wheat crop, improved water management was application of 6 cm irrigation at critical growth stages (CRI, late jointing, milking stage) through check basin (5 m × 10 m) method of irrigation (T_1) against farmers' practice of applying 8-10 cm irrigation by flooding / field to field irrigation (T_2). For both the crops, 15 farmers' fields were selected each at head, middle and tail end of the distributory. Area of demonstration was 1000 m^2 land for rice and 1000^2 for wheat for each farmer.

Rice: Results of the trial indicated that improved water management led to higher grain yields of 5.17, 4.84 and 4.80 t ha^{-1} compared to 4.05, 3.96 and 3.82 t ha^{-1} with farmers' practice, respectively at head, middle and tail ends of Awanpur distributory (Table 31). Water use efficiency (WUE) of 68.48 kg ha-mm^{-1} was maximum at the head end followed by 66.06 kg ha-mm^{-1} at the middle and 62.98 kg ha-mm^{-1} at the tail end (Table 31). WUE was lowest with farmers' practice *i.e.* 37.82, 36.52 and 35.82 kg ha-mm^{-1} at head, middle and tail end, respectively. Thus, improved water management led to 22.5 to 27.0% higher rice yield and 75.8 to 81.1% higher WUE over flood irrigation.

Wheat: Results of the trial showed that improved water management practice resulted in higher average grain yield of wheat i.e. 4.21, 4.20 and 4.11 t ha^{-1} at head, middle and tail ends, respectively of Awanpur distributory compared to 3.24 at head, 3.30 at middle and 3.13 t ha^{-1}, respectively at tail end with farmers' practice (Table 32). Thus, yield increased in the range of 27.3 to 31.1% under improved water management practice; WUE being 103.8-112.7% higher over farmers' practice.

Table 31. Performance of rice crop with improved water management at farmers' fields in Awanpur distributory during *kharif* 2022

Treatment	Head end		Middle end		Tail end	
	Yield (t ha^{-1})	WEE (kg ha-mm^{-1})	Yield (t ha^{-1})	WEE (kg ha-mm^{-1})	Yield (t ha^{-1})	WEE (kg ha-mm^{-1})
T_1	5.17	68.48	4.84	66.06	4.80	62.98
T_2	4.05	37.82	3.96	36.52	3.82	35.82
Increase in T_1 w.r.t. T_2 (%)	27.03	81.07	22.45	80.9	25.52	75.82

Table 32. Performance of wheat crop with improved water management at farmers' fields in Awanpur distributory during *rabi* 2021-22

Treatment	Head end		Middle end		Tail end	
	Yield (t ha^{-1})	WEE (kg ha-mm^{-1})	Yield (t ha^{-1})	WEE (kg ha-mm^{-1})	Yield (t ha^{-1})	WEE (kg ha-mm^{-1})
T_1	42.13	24.19	42.01	23.07	41.08	23.59
T_2	32.36	11.52	32.99	11.32	31.33	11.09
Increase in T_1 w.r.t. T_2 (%)	30.19	109.98	27.34	103.80	31.12	112.71

Rice

Wheat

Rice and wheat crop at farmers' field in Awanpur distributory

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

Middle and tail ends of Awanpur distributory often face shortage of canal water supply during *rabi* season. Demonstration of alternate crops and cropping systems were conducted in 10 farmers' fields in middle and tail ends to showcase improved crop yield and net return for the farmers to shift from conventional rice-wheat system. During *rabi* 2021-22, 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). Plot size of 1000 m^2 was taken for the trials in every farmer's field.

Results envisaged that equivalent wheat yield (4.79 t ha^{-1}) under intercropping of mustard and chickpea was highest followed by mustard+lentil intercrop (4.49 t ha^{-1}), and sole chickpea crop (4.30 t ha^{-1}). Economics of different crops and cropping systems (Table 33) indicated that mustard+chickpea intercrop accrued maximum net return of ₹ 66,860 ha^{-1} and highest benefit-cost ratio of 2.52 followed by mustard+lentil intercrop fetching net profit of ₹ 61,080 ha^{-1} with benefit-cost ratio of 2.30 (Table 33).

Table 33. Performance of diversified cropping system at tail end of Awanpur distributory during *rabi* 2021-22

Cropping system	Crop yield (t ha^{-1})		Wheat equivalent yield (t ha^{-1})		Net return (₹ ha^{-1})	B : C
	Improved practice	Farmers' practice	Improved practice	Farmers' practice		
Mustard	1.71	1.45	3.69	3.12	48404	2.06
Chickpea	1.91	1.56	4.30	3.52	57408	2.17
Lentil	1.87	1.54	4.13	3.40	53996	2.04
Pea	1.80	1.43	3.23	2.57	36500	1.38
Wheat	4.02	3.36	4.02	3.36	44890	1.34
Chickpea+mustard	1.53+0.62	1.12+0.52	4.79	3.65	66860	2.52
Lentil+mustard	1.48+0.57	1.15+0.47	4.49	3.55	61080	2.30
Pea+mustard	1.25+0.66	0.96+0.56	3.67	3.15	44970	1.70
Wheat+mustard	3.64+0.25	3.02+0.22	4.18	3.49	47980	1.43

Note: Unit price of wheat, mustard, chickpea, lentil and pea was ₹ 1950, 4200, 4400, 4300 and 3500, respectively.

Mustard+Chickpea at tail end

Mustard+Wheat at tail end

6.2. Bathinda

6.2.1. Popularization of ridge sowing for improving water use efficiency in cotton at farmers' fields in south-western Punjab

Demonstration trial was conducted in five farmers' fields in south-west districts of Punjab with the objectives of (i) showing benefits of ridge sowing over flat sowing of cotton, and (ii) enhance crop productivity and water use efficiency of cotton in canal command area. Two treatments were taken *viz.*, T_1- Flat sowing and check basin method of irrigation (Conventional practice by farmers), and T_2- Ridge sowing and furrow irrigation method (Recommended technology). Out of nine blocks of Bathinda district, the demonstrations were carried out in five blocks *viz.*, Bathinda, Talwandi Sabo, Nathana, Sangat and Maur. Under T_1, 10 cm pre-sowing irrigation was given for ensuring proper germination and establishment of cotton seedlings. Thereafter, 7.5 cm irrigation was applied in the check basins. On the other hand, dry sowing was done in ridges for T_2, followed by 6 cm irrigation through furrow irrigation method. Thus 4 cm irrigation water was saved during sowing time in case of ridge sowing and furrow irrigation were applied (T_2) compared to flat sowing and check basin irrigation (T_1).

At Ramgarh Bundar village (Block- Maur), six irrigations and one pre-sowing irrigation was given under flat sowing (T_1), whereas eight irrigations including one irrigation at the time of sowing under T_2. But irrigation water applied was less under ridge sowing (48.0 cm) than in flat sowing (55.0 cm) due to varied depths of irrigation. Numbers of irrigations under ridge sowing were more due to frequent irrigations. Seed cotton yield was higher in T_2 i.e. 2.85 t ha^{-1} (ridge sowing) than in T_1 (2.69 t ha^{-1}). Water use efficiency was also higher under ridge sowing over flat sowing as shown in Table 34.

In the village Gurusar Sehnewala (Block- Sangat), groundwater is of poor quality and good quality water is scarce. Results of trial in this village were similar to that of Ramgarh Bundar village i.e. higher seed cotton yield and WUE were observed with ridge sowing and furrow irrigation (2.8 t ha^{-1}, 66.7 kg ha-cm^{-1}) over flat sowing and check basin irrigation (2.73 t ha^{-1}, 57.5 kg ha-cm^{-1}).

In Kalyan Sukha village (Block- Nathana), seven irrigations including, one pre-sowing irrigation (10 cm) were given in flat sown cotton. While eight irrigations were given in cotton grown on ridges. Yet irrigation water applied (IWA) was higher under flat sowing (55 cm) than ridge planting (48 cm). Table 34 shows that seed cotton yield and WUE were also higher with ridge sowing (2.84 t ha^{-1}, 59.2 kg ha-cm^{-1}) than flat sowing (2.68 t ha^{-1}, 48.7 kg ha-cm^{-1}).

The village Deon (Block- Bathinda) and Lehri (Block- Talwandi Sabo) also illustrated similar results for yield and WUE (Table 34). IWA was 47.5 cm and 40.0 cm under flat sown cotton at Deon and Lehri villages, respectively. Whereas, under ridge sowing, 42.0 cm and 36.0 cm irrigation water was applied at Deon and Lehri, respectively.

Conclusion was derived from all the trials at farmers' fields ridge sowing method and furrow irrigation proved to be more promising in saving irrigation water and improving yield and WUE over flat sowing and check basin method of irrigation during *kharif* 2022. The farmers were convinced with the results demonstrated in their own land. Additional benefit with ridge sowing was that after seed sowing there was no crust formation, so germination was not hampered. Also, there was no water stagnation, in case of a rainfall event just after sowing, that led to increase in germination percentage.

Table 34. Performance of cotton under different sowing and irrigation methods in farmers' fields in Bathinda district

S. No.	Name of farmer and address	Variety/ Hybrid	Treatment	SCY (t ha^{-1})	IWA (cm)	WUE (kg ha-cm^{-1})
1	Lakhvir Singh, VPO – Ramgarh Bhundar, Block – Maur, Dist. Bathinda	BIOSEED 105	T_1	2.69	55.0	48.9
			T_2	2.85	48.0	59.4
2	Sehajdeep Singh, VPO – Gurusar Sehnewala, Block – Sangat, Dist. – Bathinda	RCH 605	T_1	2.73	47.5	57.5
			T_2	2.80	42.0	66.7
3	Deedar Singh, VPO – Kalyan Sukha, Block – Nathana, Dist. – Bathinda	RCH 776	T_1	2.68	55.0	48.7
			T_2	2.84	48.0	59.2
4	Baljinder Singh, VPO – Deon, Block & Dist. – Bathinda	RCH 773	T_1	2.65	47.5	55.8
			T_2	2.88	42.0	68.5
5	Gurpair Singh, VPO – Lehri, Block – Talwandi Sabo, Dist. – Bathinda	ACH 177-2	T_1	2830	40.0	70.8
			T_2	2900	36.0	80.6

Note: SCY : seed cotton yield, IWA: Irrigation water applied, Depth of irrigation (Flat sowing) = 7.5 cm, Ridge planting = 6.0 cm


Cotton demonstration plots at farmers' fields in different blocks of Bathinda district

6.2.2. Scaling of water productivity with intermittent irrigations in rice through farmer's participatory mode

Five demonstrations on judicious use of irrigation water in rice at farmers' fields were undertaken in three blocks namely Bathinda, Phul and Rampura of Bathinda district. Two treatments were taken *viz.*, T_1- Farmers' practice i.e. continuous submergence throughout the growth period, and T_2- Recommended technology i.e. continuous submergence for two weeks, thereafter irrigation at two days after the disappearance of ponded water (DADPW). In T_1, irrigation depth of about 5 cm was maintained in paddy fields. Approximately 20-22 irrigations were given by farmers as they continuously submerge the fields throughout the growing season of rice.

At village Nehian Wala (Block- Bathinda), 15 irrigations were given in basmati rice (Pusa Basmati 1718) under farmers' practice and 12 irrigations under recommended technology. Higher IWA (75.0 cm) was applied under T_1 and lower (60.0 cm) under T_2. Results showed that higher grain yield and WUE were recorded with recommended technology (Table 35). Short duration rice variety PR 126 was grown in farmers' fields of Mehma Sarja village (Bathinda block), Jaid village (Rampura block) and Burj Tharod village (Phul block). Recommended technology resulted in higher grain yield and WUE in all the villages (Table 35). Rice variety PR 130 grown in Burj Rajgarh village also demonstrated higher grain yield and WUE with irrigation 2DADPW compared to continuous submergence. The recommended technology led to 25%, 31-47% and 54% water saving with Pusa Basmati 1718, PR 126 and PR 130 over farmers' practice, respectively. Thus, it was evident to the farmers that although the increase in rice yield was 1.7 to 5.0% with the recommended technology, a significant amount of irrigation water can be saved by adopting the recommended technology.

Table 35. Performance of rice crop with intermittent irrigations at various locations of Bathinda district

SN	Name of farmer and address	Variety/ hybrid	Treatment	Grain yield (t ha^{-1})	IWA (cm)	WUE (kg ha-cm^{-1})
1	Gurmail Singh S/O Buggar Singh, VPO – Nehian Wala, Block & Dist. – Bathinda	Pusa Bas-mati 1718	T_1	4.25	75	56.7
			T_2	4.38	60	72.9
2	Jagtar Singh S/O Harmail Singh VPO – Mehma Sarja, Block & Dist. – Bathinda	PR 126	T_1	7.00	105	66.7
			T_2	7.15	80	89.4
3	Prem Singh S/O Darshan Singh, VPO – Jaid, Block – Rampura, Dist. – Bathinda	PR 126	T_1	7.40	110	67.3
			T_2	7.53	75	100.3
4	Jagpal Singh S/O Sukhmandar Singh, VPO – Burj Rajgarh, Block – Phul, Dist. – Bathinda,	PR 130	T_1	7.38	100	73.8
			T_2	7.50	65	115.4
5	Jagdev Singh S/O Chand Singh, VPO – Burj Tharod, Block – Phul, Dist. – Bathinda	PR 126	T_1	7.00	110	63.6
			T_2	7.35	80	91.9

Note: Depth of irrigation = 5.0 cm


Visit to the various paddy demonstrations at farmers' fields in different blocks of Bathinda district

6.3. Belavatagi

6.3.1. Extension of improved irrigation technologies in farmers' field

The following activities have been performed in farmers' field by scientists of AICRP on IWM Belavatagi centre.

- Drip irrigation system has been installed in 15 farmers' fields having good source of water with farm ponds to evaluate increase in crop yield, water saving and water productivity and its economic feasibility in row crops.
- Sensor based drip irrigation automation system was installed for 24 acre land in IWMRC Belavatagi for demonstration, organizing field days and training programmes for farmers, students, officials, etc.
- Four trainings and field demonstrations have been organized for farmers, farm women and school and college students of this region. Benefits of micro irrigation have been briefed during the events.

One day training and demonstration on 'automation of drip irrigation system' for farmers of Naragund and Ron talukas of Gadag district on 24.3.2022

6.4. Morena

6.4.1. Assessment of soil water conservation techniques and cropping systems at head, mid and tail reaches of selected distributary on farmers' field (ORP) for increasing yield and water productivity of Chambal canal command area

On farm irrigation water management (OFIWM) trials were conducted on farmers' fields in Hadwansi, Santha, Sikraroda, Bhatpura, Silabata, Jatbarkapura, Baroli and Sirmiti villages of Morena district, Madhya Pradesh. Rice, greengram, chickpea, pigeonpea, pearlmillet and clusterbean were taken during *kharif* and mustard, wheat and chickpea in *rabi* season. Objectives of the trials were demonstration of the effects of land levelling, methods of sowing, methods of irrigation on crop & water productivities; establish suitable cropping systems for head, mid and tail reaches of Chambal canal command. Cropping systems put under trial for head reach are paddy–wheat and soybean/ maize/pigeonpea–wheat. Cropping systems put under trial for middle reach are soybean–mustard, pigeonpea–wheat and clusterbean–wheat/barley. Cropping systems put under trial for end reach are pearlmillet–chickpea/mustard and pearlmillet/ blackgram/sesame–barley/mustard/chickpea. The trials done on farmers' fields during *rabi* 2021-22 and *kharif* 2022 are elaborated below.

Laser land levelling

Pigeonpea-wheat

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 maturing variety of pigeonpea (*Pusa* 992) was grown during *kharif* 2022 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 18.42% and additional net return of ₹ 19,925 ha^{-1} with improved practice compared to farmers' practice. Thus, newly developed technology helped the farmers to increase the production and profit (Table 36).

Succeeding wheat crop (var. GW-322) grown during *rabi* 2020-21 showed higher grain yield and water productivity by 14.38% and 1.79 kg m^{-3}, respectively in plot with precision land levelling compared to farmers' practice. Similarly, net profit (₹ 1,04,470 ha^{-1}) and benefit-cost ratio (1.79) was also higher under the improved practice compared to farmers' practice.

Table 36. Effect of precision laser land levelling on crop yield and water productivity in pigeonpea-wheat cropping system at head reach of canal command

Particulars	Pigeonpea		Wheat	
	Traditional land levelling	Laser land levelling	Traditional land levelling	Laser land levelling
No. of locations	5	5	5	5
Name of variety	Pusa 992	Pusa 992	HI-8759 (Pusa Tejas)	HI-8759 (Pusa Tejas)
Nutrient applied (N:P:K:Zn kg ha^{-1})	20:60:40	20:60:40	120:60:40:5	120:60:40:5
No. and source of irrigation	1 GW	1 GW	3 CW + 1 GW	3 CW + 1 GW
Effective rainfall (mm)	985	985	52	52
Total water applied (mm)	70	50	260	223
Method of irrigation	Border strip	Border strip	Border strip	Border strip
Seed/grain yield (t ha^{-1})	1.71	2.03	4.31	4.93
Straw/stover yield (t ha^{-1})	5.66	5.99	4.93	5.54
Total cost of production (₹ ha^{-1})	31810	33500	34590	37230
Gross return (₹ ha^{-1})	127010	148625	124400	141700
Net profit (₹ ha^{-1})	95200	115125	89810	104470
B-C ratio	3.99	4.43	3.59	3.80
Total water use (m^3 ha^{-1})	10550	10350	3120	2750
Water productivity (kg m^{-3})	0.16	0.19	1.38	1.79

Rice: MSP @ ₹ 6600 q^{-1} seed & straw @ ₹ 250 q^{-1}; Wheat: Dist. Mandi @ ₹ 2200 q^{-1} seed & stover @ ₹ 600 q^{-1}

Pigeonpea

Wheat

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 Basmati 1718) crop grown during *kharif* 2022 showed 15.5% higher yield with laser land levelling compared to farmers' practice of traditional levelling. The water productivity, net income and benefit-cost ratio were also higher with the improved practice compared with farmers' practice (Table 37). After harvest of rice crop, wheat (var. HI-8759) was sown by zero seed drill machine during *rabi* 2021-22. Five farmers were selected to adopt improved water management practice with border strip width 4 to 5 m for wheat crop. Four irrigations were applied through canal water. Results of the trial indicated that wheat grain yield increased by 3.28% in the laser levelled field, crop sown with zero seed drill and border strip irrigation compared to farmers' practice of traditional field 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 ₹ 9610 ha^{-1} was obtained with the improved technology over farmers' practice.

Table 37. Effect of precision laser land levelling on crop yield and water productivity in rice-wheat cropping system at head reach of canal command

Particulars	Rice (*kharif*)		Wheat (*rabi*)	
	Traditional land levelling (FP)	Laser land levelling (RP)	Traditional land levelling (FP)	Laser land levelling (RP)
No of location	5	5	5	5
Name of variety	Pusa Basmati 1718	Pusa Basmati 1718	HI-8759 (Pusa Tejas)	HI-8759 (Pusa Tejas)
Nutrient applied (N:P:K:Zn kg ha^{-1})	100:50:30:5	120:50:30:5	120:60:30	120:60:30
No. and sources of irrigation	Canal water + Groundwater	Canal water + Groundwater	4 (Canal water)	4 (Canal water)
Effective rainfall (mm)	693	693	52	52
Total water applied (mm)	80	80	260	260
Method of irrigation	Border strip	Border strip	Flooding	Border strip
Grain yield (t ha^{-1})	4.58	5.29	4.57	4.72
Straw yield (t ha^{-1})	5.66	6.31	5.86	5.92
Total cost of production (₹ ha^{-1})	39280	41045	35850	29900
Gross return (₹ ha^{-1})	148718	171290	135700	139360
Net profit (₹ ha^{-1})	109438	130245	99850	109460
B-C ratio	3.78	4.17	3.78	4.66
Total water use (m^3 ha^{-1})	7730	7430	3120	2520
Water productivity (kg m^{-3})	0.59	0.71	1.46	1.87

Dist. Mandi @ ₹ 3000 q^{-1} seed and stover @ ₹ 200 q^{-1} in local market; Dist. Mandi @ ₹ 2200 q^{-1} seed and stover in local market @ ₹ 600 q^{-1}

Rice

Wheat

6.4.2. Assessment effect of method irrigation method through sowing methods in pearlmillet-chickpea in tail reach of canal

The on-farm trial was carried out at five farmers' fields in the tail reach of Chambal canal command during *kharif* 2022. Two treatments were *viz.*, farmers' practice i.e. traditional method of planting for pearlmillet, and improved practice i.e. intercultural operation and water conservation in ridge and furrow. Sowing of pearlmillet was done on ridges to drain excess rainwater and conserve water in case of low rainfall condition. Ridge furrow maker was used to make ridges and furrows 20 days after seed sowing. Ridges and furrows also facilitated intercultural operations. Results showed that both seed yield and water productivity were higher by 22.58% compared to results under farmers' practice (Table 38). Gross return, net return, benefit-cost ratio and water productivity were also higher with improved practice compared to farmers' practice.

After harvest of pearlmillet, succeeding chickpea was grown during *rabi* 2021-22. As part of improved practice, chickpea crop (var. RVG 202) was planted on broad bed and furrow irrigation was applied. This was compared with border strip method of irrigation practiced by farmers. Improved practice demonstrated 37.8, 52.3, 30.0% higher yield, water productivity, and profit, respectively compared to farmers' practice (Table 38).

Table 38. Comparative performance of pearlmillet in tail reach

Particulars	Pearlmillet		Chickpea	
	Farmers' practice	Improved practice	Farmers' practice	Improved practice
No. of location	5	5	5	5
Name of variety	Hybrid	Hybrid	RVG 202	RVG 202
Nutrient applied (N:P:K:S:Zn kg ha^{-1})	100:40:40	100:40:40	20:50	20:50
Sources of irrigation	Canal + Tube-well water	Canal + Tube-well water	Irrigation-1 (Canal)	Irrigation-1 (Canal)
Effective rainfall (mm)	693	693	52	52
Irrigation water applied (mm)	-	-	70	45
Method of irrigation (cm)	Flooding	Ridge furrow	Border Strip	Broad bed and furrow
Yield (t ha^{-1})	2.17	2.66	1850	2250
Stover yield (t ha^{-1})	6.81	6.85	2520	2640
Total cost of production (₹ ha^{-1})	26000	28500	28025	26970

Gross returns (₹ ha^{-1})	71425	82825	100650	121350
Net profit (₹ ha^{-1})	45425	54325	72625	94380
Benefit-cost ratio (B:C)	2.74	2.90	3.59	4.49
Total water use (m^3 ha^{-1})	6930	6930	1220	970
Water productivity (kg m^{-3})	0.31	0.38	1.51	2.30

Pearlmillet: MSP @ ₹ 2350 q^{-1} seed and stover @ ₹ 300 q^{-1}; Chickpea: MSP @ ₹ 5100 q^{-1} seed and stover @ ₹ 250 q^{-1}

Ridge & Furrow making

Pearlmillet

Chickpea

6.5. Chalakudy

6.5.1. Multilocational field trials at different districts of Kerala

Different studies successfully conducted by AICRP on IWM Chalakudy centre were presented in the meeting of Zonal Research Extension Advisory Committee of the Kerala Agricultural University. The committee suggested to conduct multi-locational field trials at different districts of the state. One such study "Open field precision farming in banana using conventional, water soluble fertilizers" was replicated in three farmers' field in three the districts of Thrissur, Ernakulam and Palakkad. Six farmers adopted the technology. Another study "Effect of mulching and drip irrigation in nutmeg" was demonstrated on five farmers' fields in the districts of Thrissur, Ernakulam and Palakkad. The study "Irrigation scheduling and mulching in Amorphophallus" was demonstrated on two farmers' fields in Thrissur district.

Multilocational field trials

Chapter 7

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

7.1. Dapoli

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

TSP

Tribal Sub Plan (TSP) program was first implemented in a small area of Ratnagiri district. Later it was extended on a larger scale to Palghar district. The program was also conducted in Mahad taluka of Raigad district and Vikramgad, Mokahda and Jawhar talukas of Palghar districts. As per the TSP program in these talukas, water management interventions like construction of *jalkund* and plastic lined *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' needs.

During the year 2021-22, total 350 *Konkan Jalkund* were constructed storing 14 lakh litre rainwater, commanding 35 ha area, and benefitting 175 tribal farmers growing mango and cashew in Mokhada, Jawhar and Vikramgad talukas (Table 39). During 2021-22, total four *Konkan Vijay Bandhara* was constructed in Sakharshet and Wadoli villages of Jawhar taluka storing 6300 m^3 rainfall runoff, commanding 7.84 ha land, and benefitting 16 tribal farmers growing vegetables, cashew, mango, jasmine and maize. Similarly, eight *bandhara* was constructed in Vikramgad taluka, that stored 13120 m^3 of rainfall runoff and irrigated a command area of 21.80 ha under mango, cashew, clusterbean, cowpea and jasmine cultivation (Table 40). The *bandhara* water benefitted 31 tribal farmers from six villages in Vikramgad taluka. During 2021-22, low pressure drip irrigation system was installed for jasmine crop on 20 tribal farmers' fields in seven villages of Vikramgad taluka, and 2.0 ha land was irrigated.

Konkan Vijay Bandhara was effective in recharging wells at the downstream and enhanced the period for water availability after withdrawal of the monsoons. *Bandhara* water was used as drinking water for animals and for domestic purposes. Local people reported that water table in the nearby wells has increased. On the demand of farmers from nearby areas of Dapoli and Wakawali, eight *bandhara* was constructed in Asond and three *bandhara* was constructed in Gimhawane village. Farmers are utilizing the stored water for seed production of vegetables for *rabi* season as well as commercial seed production. Irrigation facility was created for about 4.0 ha land; many farmers are growing vegetables, sweetcorn and other crops.

Table 39. Water management interventions through *Konkan Jalkund* technology in Mokhada, Jawhar and Vikramgad talukas during 2021-22

S. No.	Name of village	Number of Jalkund constructed during 2021-22	Number of beneficiaries (Tribal farmers)	Area commanded (ha)
Mokhada taluka				
1.	Adoshi	06	03	0.60
2.	Sakhari	04	02	0.40
3.	Dhamanshet	02	01	0.20
4.	Dolhara	06	03	0.60
5.	Washala	10	05	1.00
Jawhar taluka				
6.	Dabhose	20	10	2.00
7.	Wadoli	24	12	2.40
8.	Sakharshet	18	09	1.80
9.	Wanwasi Nyahale	34	17	3.40
10.	Dharampur	08	04	0.80
Vikramgad taluka				
11.	Pochade Sakhara	128	64	12.80

12.	Sakhare Jambhe	36	18	3.60
13.	Pochade Jambhe	10	05	1.00
14.	Tembholi Sakhare	44	22	4.40
Total		**350**	**175**	**35.00**

Table 40. Water management interventions through *Konkan Vijay Bandhara* technology in Jawhar and Vikramgad talukas during 2021-22

S. No.	Name of village	Number of Konkan Vijay Bandhara constructed during 2021-22	Number of beneficiaries (Tribal farmers)	Area commanded (ha)
1.	Sakharshet, Jawhar	02	08	4.80
2.	Wadoshi, Jawhar	02	08	3.00
3.	Vehelpada, Vikramgad	01	04	3.35
4.	Balapur, Vikramgad	03	13	9.25
5.	Kangwa, Vikramgad	03	13	8.40
6.	Gadandhe, Vikramgad	01	01	0.80
Total		**12**	**47**	**29.60**

Since the beginning of *jalkund* technology in 2013-14, total 1309 *Jalkund* were constructed and 704 farmers have been benefitted from this intervention during last eight years (2013-14 to 2021-22). Total 130.9 ha land has been brought under irrigation through this rainwater harvesting technology. From 2013-14 to 2021-2022, total 67 *bandhara* was constructed in 29 villages creating irrigation facility for *rabi* crops on 190.3 ha land. Twenty-nine villlages have been covered and 313 tribal farmers have benefitted. From 2014-15 to 2021-22, total 30 low-pressure drip irrigation systems have been installed in 15 villages in Jawhar, Vikramgad and Mokhada talukas of Palghar district, and 30 farmers have benefitted to grow crop in 2.49 hectare area.

SCSP

From April to December 2022, 17 SC farmers of Gimhawane and Asond villages were given training and demonstration on mulching in rice cultivation during *kharif* (rainfed) and drip irrigation in rice during summer. Total 11 check dams were constructed for rainwater harvesting, utilization of water resources for vegetable cultivation, and increasing water productivity. This has resulted in increased water availability in the villages and areas under vegetable production.

Konkan Jalkund

Konkan Vijay Bandhara

7.2. Jorhat

7.2.1. Irrigation water management in summer rice in shallow tubewell command

Demonstration of improved water management technology, training on micro irrigation system, and distribution of pumpsets were done under Scheduled Caste Sub Plan (SCSP). Objectives of the SCSP programme were (i) to demonstrate and transfer water management technology in the farmers' fields, (ii) to enhance water use efficiency in summer rice in selected major STW command areas, (iii) to find out the extent of saving of irrigation water with optimum water management practices, (iv) to improve the knowledge base of farmers on efficient utilization of irrigation water, and (v) to increase cropping intensity at farm level.

Demonstration

Demonstrations were conducted on irrigation water management in summer rice through irrigation scheduling by alternate wetting and drying for shallow tubewell (STW) command areas of Bongaigaon and Dhubri districts of Assam through farmers' participatory approach in collaboration with KVK. The alternate wetting and drying involves application of 5 cm irrigation water when ponded water dropped to 15 cm below the ground level. In order to measure water level, a PVC pipe of length 40 cm and diameter 15 cm with perforations on all sides was installed in the farmer's field. The demonstrations covered six SC farmers' having 2.0 ha area.

Training

Six training programmes were conducted for SC farmers of Jorhat, Golaghat, Biswanath, Nalbari and Sibsagar districts of Assam for enhancing water productivity through efficient utilization of water resources.

1. Training was conducted on "Water management in crops with special reference to micro irrigation" on the occasion of International Workshop at Assam Agricultural University on 11th March, 2022. Venue for the training was AICRP on IWM, Jorhat centre where 35 SC farmers attended the programme. Scientists from AICRP on IWM were resource persons in the training programme.

2. A training under SCSP programme on "Irrigation water management in crops" was conducted by AICRP on IWM, Jorhat centre on 29th March, 2022 at Maralgaon of Biswanath district where 40 SC farmers went through the training. Scientists from AICRP on IWM and AICRP on Dryland Agriculture were the resource persons in the programme.

3. A training under SCSP programme on "Water management in field crops" was conducted by AICRP on IWM, Jorhat centre on 30th March, 2022 at BNCA of Biswanath district where 40 SC farmers attended the training. Scientists from AICRP on IWM and Biswanath College of Agriculture participated as resource persons.

4. A day long training programme under SCSP programme on "Water Management in *kharif* crops" was organized on 19th April 2022 at Solmara, Nalbari district. Altogether 40 trainees (SC farmers) attended the training, where scientists from AICRP on IWM Jorhat centre, Assam Agriculture University, and KVK Nalbari imparted training to the farmers as resource persons.

5. A day long training programme under SCSP programme on "Water Management in rice-based cropping system" was organized on 12th May, 2022 at Dikhoumukh, Sibsagar district. Total 30 SC farmers attended the training programme. Scientists from AICRP on IWM, Jorhat centre and Assam Agriculture University, were the resource persons in the training

6. A day long SCSP training programme on "Enhancing water poductivity through efficient utilization of water" was organized by AICRP on IWM in collaboration with KVK Golaghat on 22nd December, 2022 at Upper Temera village, Golaghat district. Total 35 SC farmers attended the training where scientists from AICRP on IWM, Jorhat centre and KVK, Golaghat were the resource persons.

Distribution

Five pump sets were distributed among SC farmers of Jorhat district for increasing cropping intensity in their farm through efficient utilization of water resources.

7.3. Kota

7.3.1. Demonstration on package of practices of soybean and improved water management practices at Suhana village (sprinkler irrigation at critical growth stage)

Eight demonstrations on soybean crop were conducted for scheduled caste farmers at Suhana village, Digod tehsil, Kota district. Demonstration block involved sprinkler irrigation at critical growth stage, whereas the Control block involved farmers' practice of flood irrigation. One irrigation through sprinkler (30 mm) and one flood irrigation (40 mm) were applied at critical growth stage of the crop in September in both demonstration and control blocks. The results of the trial were evaluated as average data obtained from eight farmers' fields. An average yield of 1.30 t ha^{-1} and water use efficiency (WUE) of 43.16 kg ha-mm^{-1} was observed in demonstration block, whereas yield of 1.19 t ha^{-1} and WUE of 29.75 kg ha-mm^{-1} in control block. Other standard package of practices were same for both the blocks. There was 9.2% higher average yield and 45.1% higher average WUE in the fields under sprinkler irrigation compared to fields under farmers' practice.

The successful demonstration of sprinkler irrigation to soybean crop in SC farmers' fields was followed by two training programmes. Two trainings were conducted, one at Suhana village, Digod tehsil, Kota district from 27-28 February 2022 and another training was at Khandgavn village, Sultanpur, Kota district from 01-02 March 2022 to discuss with beneficiaries the performance of sprinkler irrigation and other management practices in soybean crop.



Farmers' training at Suhana and Khandgavn villages (Kota district) under SCSP

7.4. Navsari

7.4.1. Distribution of micro irrigation sets and guidance to scheduled caste and scheduled tribe farmers

AICRP on IWM Navsari centre represents heavy rainfall agroclimatic zone of south Gujarat. Eastern and southern boundaries of this zone having hilly terrains is predominantly tribal belt. The area is distributed in some talukas of Navsari, Valsad and The Dangs districts.

Scientists of AICRP on IWM Navsari centre provided drip irrigation system to 95 tribal farmers having small land holdings and eight scheduled caste farmers under TSP and SCSP programme in 11 farmers' groups from different villages covering about 36 ha land under TSP. The scientists periodically visited farmers' field to encourage and provide on spot guidance to the farmers regarding adoption of drip/sprinkler systems for irrigating their crops. As a result of earlier demonstration on farmers' field on drip irrigation in crops like bittergourd, littlegourd, watermelon *etc*., many farmers from surrounding areas came forward and showed interest in adopting drip irrigation in vegetable crops.



Demonstrations of drip irrigation in different crops on farmers' fields and farmers' training

7.5. Parbhani

7.5.1. Evaluation of sprinkler and drip irrigation systems on tribal farmers' field

Demonstration on sprinkler and drip irrigation systems were carried out in Wai village, Kalamnuri taluka, Hingoli district. It was aimed to record the following observations: i) available operating pressure for sprinkler and drip irrigation systems, ii) measurement of dripper discharge and sprinkler nozzle discharge, iii) measurement of uniformity coefficient of sprinkler and drip irrigation system, iv) monitoring the yield of sprinkler and drip irrigated crops, and v) economic status of farmers. Field tests of 10 sprinkler and drip irrigation sets were taken for monitoring. It was observed that operating pressure of sprinkler was 2.0 - 2.5 kg cm^{-2}, whereas discharge of sprinkler head was within the permissible limit of sprinkler nozzle at all the observation stations. The drip irrigation sets also recorded permissible discharge and showed uniformity coefficient greater than 0.9. For all the farmers, crop yield increased from 19.23 to 30.45% compared to the situation before adoption of pressurized irrigation systems. Economic status of the farmers was also improved due adoption of new irrigation technology along with the use of fertilizers. As a result, socio-economic status of the farmers improved.

Feedback of the farmers was collected after *kharif* and *rabi* season 2022 to evaluate and analyze the impact of sprinkler irrigation system at Wai village. Farmers opined that operation of sprinkler irrigation system saved time, labour and energy. They experienced 30-40% water saving. The farmers pointed out that the advanced irrigation systems applied water uniformly over the field even on undulating land. They could apply protective irrigation to soybean, redgram and cotton with the help of pressurized irrigation. Farmers also experienced increase in yield with sprinkler irrigation system. Additional area could be brought under irrigation with the water resources available in the village. Although there is very limited water resource in the village, but with the introduction of sprinkler and drip irrigation systems farmers could cultivate crops like wheat and turmeric. The farmers experienced that sprinkler irrigation system was beneficial in ensuring sustainable livelihood security through judicious use of water. Turmeric yield (dry rhizome) increased from 2.5 to 4.5 t ha^{-1}. Yields of other crops also increased with the use of pressurized irrigation.

7.5.2. Need based agricultural interventions for enhancing crop productivity on scheduled caste farmers' field

Bhosa village under Manwat taluka, Parbhani district, Maharashtra was taken up to demonstrate the benefits of sprinkler irrigation under rainfed condition for sustainable crop production. The village has population of 1683, out of which 456 are scheduled caste (27.09%) as per Population Census 2011. Average annual rainfall in Manwat is 816.7 mm, but experiences drought like situation once in three years due to erratic nature of monsoon, untimely arrival of monsoon, frequent occurrences of dry spell in July and August, and early withdrawal of monsoon. This hampers dryland agriculture that faces problem of moisture availability for optimum crop production. Therefore, protective irrigation in *kharif* and judicious use of available water for irrigation through advanced irrigation technology is the need of hour in the poor scheduled caste farming community. It was decided to provide sprinkler irrigation sets for efficient use of available water resource (open well/borewell) and sustainable crop production.

Initially six farmers were identified for providing sprinkler irrigation sets based on their aadhaar card, availability of land on 7/12 record, availability of water resource in the field with water lifting device and electricity supply, and farmer's name being approved as a beneficiary by the Gram Sabha. Six SC farmers and 11 SC farmers were given sprinkler irrigation sets in a distribution programme organized on 19.03.2021 and 25.3.2022, respectively at Bhosa village. Data pertaining to cropping patterns and their outcome before and after adoption of sprinkler system was collected from the beneficiary farmers. Six farmers fetched gross income of ₹ 50,000 to 80,000 from turmeric & soybean crops after intervention compared to gross income of ₹ 26,000 to 50,000 from cotton, soybean and greengram crops before intervention during *kharif* season. Similarly, six farmers growing soybean-chickpea, groundnut and wheat after intervention fetched gross income of ₹ 23,000 to 55,000 compared to gross income of ₹ 20,000 to 45,000 fetched from sorghum, soybean-chickpea and groundnut before intervention.

Evaluation of micro irrigation systems in farmers' fields under TSP and SCSP programmes

Chapter 8

Recommendations

Ayodhya

Sowing of wheat (var. NW-5054) with happy seeder and application of five irrigations (at crown root initiation, tillering, late jointing, milking & dough stages) or four irrigations (at CRI, tillering, late jointing & milking stages) was recommended for higher crop yield and profit under rice-wheat cropping system of eastern Uttar Pradesh.

Drip irrigation at 80% PE along with 100% recommended dose of fertilizer to turmeric crop grown in alleys of aonla trees was recommended to obtain highest yield and economic returns from turmeric.

Bathinda

It was recommended to apply whole of P as basal and N & K through fertigation in 20 splits with variable doses at different growth stages (starting from three weeks after sowing @ 2%, 4%, 6%, 8% and 5% in four splits each at weekly interval) of 75% of the recommended dose of fertilizer (N = 187.5; P2O5 = 62.5; K2O = 47.0 kg ha-1) to maximize fruit yield, water use efficiency and net profit of tomato on loamy sand soil using drip irrigation system.

It was recommended to apply whole of P as basal, and N & K through fertigation in 14 splits with variable doses at different growth stages of brinjal (starting from three weeks after sowing @ 5%, 7.5% and 10% in 4 equal splits each, and 5% in two equal splits each at weekly interval) of 75% of the recommended dose of fertilizer (N = 156.25; P2O5 = 62.5; K2O = 22.5 kg ha-1) to maximize fruit yield, water use efficiency and net profit of brinjal on loamy sand soil using drip irrigation system.

Alternate application of good quality canal water and saline sodic tubewell water in the ratio 1:1 using surface drip with 80% recommended dose of nitrogen was suggested for cotton crop on sandy loam soil to sustain seed cotton yield with a minimal adverse effect on soil quality, thus providing sustainability in the long run in south-west Punjab.

Chiplima

In West Central Table Land zone of Odisha, it was recommended to grow groundnut crop (cv. *Smruti*) with 90% PE through sprinkler irrigation to obtain higher pod yield and economic return.

Coimbatore

Application of 25% NPK as basal + 25% NPK through fertigation + 25% NPK as manure + 25% NPK as Panchagavya through fertigation was recommended in chilli to obtain higher plant height, more number of branches per plant and higher fruit yield per plant.

Crop coefficient (K_c) was recommended for Kadhali banana and Red banana. In Kadhali banana K_c was 0.83-0.89, 0.98-1.04, 1.09-1.25 and 1.19-1.14 at initial, developmental, middle and end stages respectively. Whereas, in Red banana it was 0.82-0.90, 0.90-1.06, 1.12-1.22 and 1.20-1.18 at initial, developmental, middle and end stages respectively.

Jammu

Under waterlogged situation in Ranbir canal command, raised beds having width of 6.0-9.0 m and height of 1.0 m were recommended for crop intensification with 500% cropping intensity, by growing a sequence of rice (short duration) - fenugreek - knolkhol - green onion - cowpea to obtain highest yields, net returns and benefit-cost ratio as compared to conventional basmati rice-wheat sequence on flat bed.

Kota

Application of 100% NPK through fertigation and drip irrigation at 75% PE was recommended for higher productivity of tomato var. *Arka Rakshak* in clay loam soil of Rajasthan.

Pusa

Application of boron 1.0 kg ha^{-1} in combination of 50% grey water and 50% fresh water was recommended for higher tomato yield in boron stressed calcareous soil of Bihar, without developing any toxicity of boron in soil and crop.

Rahuri

On the basis of soil test-based fertiliser application as per yield target equation with FYM, it was recommended to plant preseasonal sugarcane and apply drip irrigation at 80% ETc and fertigation with 36 and 32 weekly splits for plant cane and ratoon crop, respectively, for achieving higher yield, monetary returns, and water savings in medium black soils of western Maharashtra.

Yield Target Equation of plant cane	Yield Target Equation of ratoon
FN = (4.03 × T) - (1.43 × SN) - (3.81 × FYM) FP_2O_5 = (1.23 × T) - (2.44 × SP) - (1.83 × FYM) FK_2O = (2.26 × T) - (0.55 × SK) - (1.40 × FYM)	FN = (4.4 × T) - (1.08 × SN) FP_2O_5 = (1.56 × T) - (2.32 × SP) FK_2O = (3.37 × T)- (0.64 × SK)

Rahuri

Crop coefficient (K_c) values listed in the following table were recommended for the estimation of water requirement of fodder maize and sunflower crops in deep black clayey soil.

Week after planting	K_c for fodder maize	K_c for sunflower
1	0.34	0.33
2	0.47	0.44
3	0.63	0.56
4	0.81	0.69
5	0.99	0.82
6	1.13	0.94
7	1.23	1.04
8	1.25	1.12
9	1.18	1.17
10	1.00	1.19
11	0.69	1.15
12	0.38	1.07
13	-	0.92
14	-	0.71
15	-	0.42

Alternatively, the following equation was recommended for estimating daily values of crop coefficient during crop growth period of fodder maize.

$$\boldsymbol{K_{ct}} = -5.2633\left(\frac{t}{T}\right)^3 + 4.4781\left(\frac{t}{T}\right)^2 + 0.8085\left(\frac{t}{T}\right) + 0.2832$$

Similarly, the following equation was recommended for estimation of daily values of crop coefficient during crop growth period of sunflower crop

$$\boldsymbol{K_{ct}} = -4.101\left(\frac{t}{T}\right)^3 + 2.760\left(\frac{t}{T}\right)^2 + 1.3377\left(\frac{t}{T}\right) + 0.2734$$

where, K_{ct} is the crop coefficient of crop on t^{th} day; t is number of days after sowing and T is total crop growth period (in days).

Udaipur

The Shishvi-I, Shishvi-II and Karmal rainwater harvesting structures located in Shishvi and Karmal villages in Girwa block, Udaipur district, Rajasthan were constructed 8 to 13 years back with maximum storage capacity of 2744.86, 5537.60 and 6510.00 m^3, respectively. It was recommended that de-siltation of the structures should be done every four years to check the annual loss (2-3%) in storage capacity as well as increase recharge rate and recharge volume of the structures.

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STAFF POSITION 2022

Almora	
Chief Scientist	Dr. S. C. Panday
Agril. Chemistry	Dr. Tilak Mondal
Jr. Agril. Engineer	Er. Shyamnath
Belavatagi	
Chief Scientist	Dr. V. S. Kubsad
Agril. Engineer	Dr. P. S. Kanannavar
Soil Physicist	Dr. Vijaya Kumar C.
Coimbatore + Madurai + Bhavanisagar	
Chief Scientist	Dr. V. Ravikumar
Asso. Professor	Dr. S. Selvakumar
Asso. Professor	Dr. K. Arunadevi
Soil Physicist	Dr. B. B. Saliha
Jr. Agronomist	Dr. R. Veeraputhiran
Chalakudy	
Chief Scientist	Dr. Mini Abraham
Soil & Water Engineer	Dr. Shyla Joseph
Soil Physicist	Dr. Mariya Dainy M.S.
Chiplima	
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	Dr. H. C. Singh
Agril. Engineer	Er. R. C. Tiwari

Gayeshpur	
Chief Scientist	Prof. P. K. Bandyopadhyay
Agronomist	Dr. R. Poddar
Hisar	
Chief Scientist	Dr. Manoj K. Sharma
Agril. Engineer	Sushil Kumar Singh
Soil Physicist	Muli Devi Parihar
Jammu	
Chief Scientist	Dr. A. K. Sharma
Soil Scientist	Dr. Abhijit Samanta
Agronomist	Dr. Vijay Bharti
Jabalpur + Powarkheda	
Chief Scientist	Dr. M. K. Awasthi
SWC Engineer	Dr. Y. K. Tiwari
Agronomist	Dr. Vijay Agrawal
Jorhat	
Chief Scientist	Dr. Chinmoy Kr. Sarma
Soil Physicist	Dr. Bipul Deka
Agril. Engineer	Er. K. Choudhury
Junagadh	
Chief Scientist	Dr. H. D. Rank
Agril. Engineer	Prof. P. B. Vekariya
Agril. Engineer	Prof. R. J. Patel
Kota	
Agronomist	Dr. Baldev Ram
Soil Scientist	Dr. Rajendra Kumar Yadav

Ludhiana + Bathinda	
Chief Scientist	Dr. Rajan Aggarwal
Asst. Res. Engineer	Dr. Sanjay Satpute
Soil Physicist	Dr. K. S. Sekhon
Agril. Engineer	Dr. Anurag Malik
Agronomist	Dr. Anureet Kaur
Morena	
Chief Scientist	Dr. Bharat Singh
Agronomist	Dr. Sandeep S. Tomar
Agril. Engineer	Dr. S. P. Shrivastava
Navsari	
Chief Scientist	Dr. J. M. Patel
Soil Scientist	Dr. S. L. Pawar
Agril. Engineer	Er. N. G. Savani
Palampur	
Chief Scientist	Dr. Anil Kumar
Soil Physicist	Dr. S.K. Sandal
Pantnagar	
Chief Scientist	Dr. Yogendra Kumar
Asso. Professor	Dr. Harish Chandra
Agril. Engineer	Dr. Vinod Kumar
Agronomist	Dr. Gurvinder Singh
Agril. Engineer	Dr. U. C. Lohni

Parbhani	
Agril. Engineer	Dr. H. W. Awari (Additional charge CS)
Agronomist	Dr. M. P. Jagtap
Soil Scientist	Dr. G. K. Gaikwad
Pusa	
Chief Scientist	Dr. S. P. Gupta
Agril. Engineer	Dr. S. K. Jain
Soil Chemist	Dr. A. K. Singh
Agril. Engineer	Dr. Ravish Chandra
Agronomist	Dr. Rajan Kumar
Rahuri	
Chief Scientist	Dr. A. V. Solanke
Soil Scientist	Dr. C. R. Palwe
Scientist (IDE)	Dr. P. G. Popale
Raipur + Bilaspur	
Chief Scientist	Dr. Dhiraj Khalkho
Agronomist	Dr. Geet Sharma
Soil Scientist	Dr. P. K. Keshry
Shillong	
Chief Scientist	Dr. B. U. Choudhury
Sriganganagar	
Chief Scientist	Dr. Raghuvir Singh Meena

BUDGET ALLOCATION 2022-23

Figures in ₹

S.N	Centre Name	Grant-in-Aid Salary	Grant-in-Aid General			Total General	Grant-in-Aid Capital		Total Capital	SCSP				G. Total
			Res.	Operational	TA		Equip.	IT		Res.	Opr.	Capital (Eqip.)	Total	
1	PAU, Ludhiana	9700000	50000	100000	15000	165000			0				0	9865000
2	UAS, Dharward	9500000	50000	50000	15000	115000		60000	60000				0	9675000
3	TNAU, Coimbatore	15600000	50000	75000	15000	140000			0	40000		250000	290000	16030000
4	IGKV, Raipur	10600000	50000	115000	15000	180000			0				0	10780000
5	KAU, Thrissur	7300000	50000	75000	21000	146000		60000	60000				0	7506000
6	OUAT, Bhubaneswar	3500000	50000	70000	15000	135000		60000	60000				0	3695000
7	BSKKV, Dapoli	8000000	50000	90000	15000	155000			0				0	8155000
8	NDUAT, Faizabad	8000000	50000	50000	15000	115000		60000	60000				0	8175000
9	BCKV, Kalyani Nadia	3100000	50000	70000	15000	135000			0				0	3235000
10	CCSHAU, Hissar	6000000	50000	50000	15000	115000			0				0	6115000
11	SKUAST, Jammu	10900000	50000	50000	15000	115000			0				0	11015000
12	MPUAT, Udaipur	8600000	50000	50000	15000	115000		60000	60000				0	8775000
13	AU, Kota(Raj.)	6100000	50000	50000	15000	115000			0				0	6215000
14	JAU, Junagadh	7300000	50000	50000	15000	115000		60000	60000				0	7475000
15	RVSKVV, Morena	5500000	50000	50000	15000	115000			0	40000		75000	115000	5730000
16	NAU, Navsari	7900000	50000	50000	15000	115000		60000	60000				0	8075000
17	CSKHPKV, Palampur	6000000	50000	50000	15000	115000			0				0	6115000
18	GBPUAT, Pantnagar	15000000	50000	50000	15000	115000		60000	60000				0	15175000
19	VNMKV, Parbhani	5200000	50000	90000	15000	155000		60000	60000				0	5415000
20	JNKVV, Jabalpur	11200000	50000	50000	15000	115000			0				0	11315000
21	MPAU, Rahuri	13200000	50000	50000	15000	115000			0				0	13315000
22	SKRAU, Bikaner	2800000	50000	50000	15000	115000			0				0	2915000
23	AAU, Jorhat	7000000	50000	90000	15000	155000		60000	60000	50000		75000	125000	7340000
24	Dr.RPCAU, Pusa		40000	50000	15000	105000			0	44000		150000	194000	299000
25	ICAR-RC-NEH, Umiam		46000	50000	15000	111000			0	45000		150000	195000	306000
26	VPKAS, Almora		40000	70000	15000	125000			0				0	125000
27	IIWM(PCU)			1030000	9000	1039000		0	0				0	1039000
	Sub Total	**188000000**	**1276000**	**2675000**	**405000**	**4356000**	**0**	**600000**	**600000**	**219000**	**0**	**700000**	**919000**	**193875000**

भारतीय जल प्रबंधन संस्थान

ICAR-IIWM

भाकृअनुप - भारतीय जल प्रबंधन संस्थान

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