वार्षिक प्रतिवेदन
Annual Report
2016-17

सिंचाई जल प्रबंधन पर अखिल भारतीय समन्वित अनुसंधान परियोजना

All India Coordinated Research Project on Irrigation Water Management

भाकृअनुप - भारतीय जल प्रबंधन संस्थान
भारतीय कृषि अनुसंधान परिषद

ICAR - Indian Institute of Water Management
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भारतीय जल प्रबंधन संस्थान
ICAR-IIWM

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AICRP-IWM Annual Report 2016-17

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PREFACE

I am privileged to present the Annual Report of All India Coordinated Research Project on Irrigation Water Management (AICRP-IWM) for the year 2016-17. The report covers research findings of twenty-six network centres working through five themes of the project. Since its inception, AICRP-IWM has been instrumental in developing region/location specific water management technologies in different agro-ecological regions of the country. The network centres have been carrying out on station and on farm experiments for development and standardization of replicable and cost effective technologies, which not only improved water productivity but also enhanced farmers' income and livelihoods. Apart from the farmers, a number of such technologies have been extended to line department personnel and policy makers of the central and state governments of the country. The scientists working under AICRP-IWM have contributed in implementation of flagship programmes on irrigation water management and contingency plans for different districts of the country. The network centres have taken up capacity building programme on irrigation water management for different levels of stakeholders across the country. Water management and transfer of technology have also been extensively carried out in the tribal areas of the country.

I take this opportunity to express my gratitude towards Dr. T. Mohapatra, Secretary DARE and Director General ICAR, Govt. of India for his constant support and encouragement. I sincerely express the gratitude to Dr. K. Alagusundaram, Deputy Director General (NRM) and Dr. S. K. Chaudhari, Assistant Director General (S&WM), ICAR for their valuable suggestions and timely cooperation during the report period. The consistent hard work of the scientists and their associates in the network centres to generate and extend technologies to the primary and secondary stakeholders deserves wholehearted appreciation. Their timely cooperation was crucial to run the project smoothly. I appreciate the team effort of Dr. Prabhakar Nanda, Dr. Shilabhadra Mohanty, Principal Scientist, ICAR-IIWM, ICAR-IIWM and Dr. Pragna Dasgupta, Research Associate, AICRP-IWM, ICAR-IIWM for compiling and editing the report. Translation of Executive Summary of the report in Hindi has been efficiently done by Dr. Om Prakash Verma. I also thank Dr. Krishna Gopal Mandal, Principal Scientist, ICAR-IIWM for giving his valuable comments and suggestions during revision of the report.

Bhubaneswar

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

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कार्यकारी सारांश

विषय 1. सतही जल एवं भूजल की उपलब्धता तथा गुणवत्ता का आकलन

श्रीगंगानगर (कृषि पारिस्थितिकी उप क्षेत्र 2.1) केंद्र पर रबी मौसम 2016 के दौरान इंदिरा गाँधी नहर परियोजना कमांड की खेतावली जल वितरणिका (डिस्ट्रीब्यूटरी) में सापेक्ष जल की आपूर्ति 0.5 थी जब यहाँ अधिकतम क्षेत्र को गेहूँ के बाद सरसों, जौ, चारा, ग्राम और सब्जियों की फसलों के तहत उगाया गाया। खरीफ मौसम 2016 के दौरान यह जल आपूर्ति 0.60 थी जब अधिकतम क्षेत्र को अमेरिकी कपास (*Gossypium hirsutum*) की फसल के बाद ग्वार और धान के तहत उगाया गया। चूँकि दोनों मौसमों में जल की आपूर्ति में कमी थी इसलिये वहाँ रबी के मौसम में गेहूँ की जगह कुछ क्षेत्र में सरसों या जौ की फसलों को उगाने का सुझाव दिया गया तथा खरीफ मौसम में अमेरिकी कपास के कुछ क्षेत्र में ग्वार और मूँग की फसलों के तहत बुआई का सुझाव दिया गया ताकि सभी फसलों की जल की आवश्यकता के साथ जल की आपूर्ति का मिलान किया जा सके।

कोटा (कृषि पारिस्थितिकी उप क्षेत्र 5.2) केंद्र पर मानसगाँव जल वितरणिका का आकलन किया गया जिससे पता चला कि फरवरी 2016 के दौरान अधिकतम सापेक्ष जल आपूर्ति (0.66) के साथ रबी मौसम 2015-16 के दौरान औसत सापेक्ष जल की आपूर्ति 0.54 (नवम्बर 2015-फरवरी 2016) थी। खरीफ मौसम 2016 के दौरान अक्टूबर महीने में सापेक्ष जल की आपूर्ति केवल 0.06 ही थी। रबी एवं खरीफ मौसम के दौरान क्रमश: 90 एवं 6 दिनों तक नहर से फसलों की सिंचाई के लिये जल छोड़ा गया था। दोनों मौसम खरीफ एवं रबी के दौरान खेत स्तर पर औसत जल की उपलब्धता क्रमश: 197.83 एवं 6521.65 हेक्टेयर सेंटीमीटर थी। वहाँ पर खरीफ मौसम के दौरान 329.55 हेक्टेयर सेंटीमीटर के रूप में जल की अधिकता थी लेकिन रबी मौसम के दौरान 7754.18 हेक्टेयर सेंटीमीटर की मात्रा के साथ जल की कमी थी। और खरीफ एवं रबी मौसम के दौरान शुद्ध कमांड बुआई क्षेत्र क्रमश: 996.54 और 1056.32 हेक्टेयर था।

परभाणी केंद्र (कृषि पारिस्थितिकी उप क्षेत्र 6.2) पर जायकवाड़ी सिंचाई परियोजना का भूजल स्तर के उतार-चढ़ाव और इसकी गुणवत्ता के मूल्यांकन के लिये चयन किया गया। वर्ष 1985 से वर्ष 2017 के बीच कमांड क्षेत्र में वार्षिक भूजल स्तर में उतार-चढ़ाव 2.2 से 15.1 मीटर तक पाया गया तथा गैर-कमांड क्षेत्र में यह स्तर 3.8 से 15.1 मीटर तक पाया गया। नहरी जल के साथ पुन:भरण के कारण कमांड क्षेत्र में भूजल स्तर मार्च 2017 के दौरान सबसे ज्यादा था। कमांड और गैर कमांड क्षेत्रों से भूजल को दो श्रेणियों यानी अधिक (C_3S_1) और मध्यम (C_2S_1) लवणीय जल के रूप में वर्गीकृत किया गया। दोनों प्रकार की श्रेणियों में सोडियम तत्व का कोई खतरा नहीं था। इससे यह निष्कर्ष प्राप्त हुआ कि कमांड क्षेत्र के भूजल का अच्छी जल निकास की व्यवस्था के बिना किसी भी प्रकार की मृदा में उपयोग नहीं किया जा सकता।

कोयम्बटूर केंद्र (कृषि पारिस्थितिकी उप क्षेत्र 8.1) पर लोवर भवानी सिंचाई परियोजना के कमांड क्षेत्र की कूगलूर वितरणिका के ओड टर्न स्लूइस कमांड क्षेत्र में सिंचित शुष्क मौसम की फसलों के लिये औसत जल का निर्वहन 66.83 घन मीटर/सेकंड था। यहाँ जनवरी से अक्टूबर 2016 तक सापेक्ष जल की आपूर्ति 80.7% थी। ओड टर्न के लिये कुल 2011.55 हेक्टेयर कमांड क्षेत्र में से केवल 47.73% समेकित फसल क्षेत्र था। इवन टर्न के लिये कुल 1949.79 हेक्टेयर कमांड क्षेत्र में से 50.21% क्षेत्र को नहर से पुन:भरित जल के कारण अच्छी तरह से फसल क्षेत्र के तहत लाया गया।

जम्मू केंद्र (कृषि पारिस्थितिकी उप क्षेत्र 14.2) पर खरीफ मौसम में बासमती धान तथा रबी मौसम में गेहूँ एवं अन्य फसलों के लिये प्रदर्शन संकेतक मूल्यांकित किये गये जो यह दिखाते हैं कि तावी लिफ्ट नहरी कमांड क्षेत्र में अंतिम छोर पर सापेक्ष जल की आपूर्ति एवं सापेक्ष सिंचाई की आपूर्ति क्रमशः 65% और 70०% तक कम पायी गयी। इसके प्रदर्शन मानदंडो ने भी यह संकेत दिया कि नहर के हैड, मध्यम और अंतिम छोर में कृषि उत्पादन, जल की आपूर्ति और जल के उपयोग में महत्वपूर्ण अंतर प्राप्त होता है। इन संकेतकों में से एक सापेक्ष जल आपूर्ति ने दिखाया कि नहर के हैड, मध्यम और अंतिम छोर पर फसलों की जल माँग को पूरा करने के लिये सापेक्ष जल की आपूर्ति में क्रमश: 9%, 18% और 65% तक सुधार करने की जरूरत है।

विषय 2. सतही एवं दबाव सिंचाई प्रणालियों का डिजाइन, विकास एवं रिफाइनमेंट

हिसार केंद्र (कृषि पारिस्थितिकी उप क्षेत्र 2.3) पर चौधरी चरण सिंह हिसार कृषि विश्व विद्यालय के अनुसंधान फार्म पर एक प्रयोग ने दिखाया कि कुंड सिंचित मेड़ एवं क्यारी प्रणाली (FIRBS) के साथ गेहूँ की जल उत्पादकता (3.58 किलोग्राम/घन मीटर) अधिकतम थी उसके बाद मिनी स्प्रिंकलर (2.99 किलोग्राम/घन मीटर) एवं परंपरागत सिंचाई प्रणाली (2.36 किलोग्राम/घन मीटर) के साथ थी।

हिसार केंद्र (कृषि पारिस्थितिकी उप क्षेत्र 2.3) पर गेहूँ की फसल में जल उत्पादकता में वृद्धि के लिये खेतों पर अपनाई गई वैज्ञानिक विधियों में से कुंड सिंचित मेड़ एवं क्यारी प्रणाली (FIRBS) से परंपरागत बुआई एवं सतही सिंचाई की तुलना में 6.4% तक अधिक दाना उपज (4.51 टन/हेक्टेयर) प्राप्त हुई। इस उन्नत विधि

से 3.1 सेमी (12.6%) तक सिंचाई जल की बचत भी प्राप्त हुई। परंपरागत प्रणाली की तुलना में कुंड सिंचित मेड़ एवं क्यारी प्रणाली से 3 6 .6 किलोग्राम/हेक्टेयर सेंटीमीटर तक जल उत्पादकता में वृद्धि हुई।

श्रीगंगानगर केंद्र (कृषि पारिस्थितिकी उप क्षेत्र 2.1) पर 30 मई को ड्रिप सिंचाई के तहत बीटी कपास के रोपण से 3.06 टन/हे की पैदावार प्राप्त हुई तथा 1.95 के लाभ लागत अनुपात के साथ रु. 86589/हे/मौसम की शुद्ध आय प्राप्त हुई। कपास में ड्रिप सिंचाई के साथ 3.65 किग्रा/हे-मिमी की जल खपत दक्षता दर्ज हुई। कपास में 30 मई को सिंचाई करने से और 15 मई को ड्रिप सिंचाई के साथ सीधी बुआई (नियंत्रित उपचार) करने पर भी समान परिणाम प्राप्त हुए (उपज-3.43 टन/हे, जल खपत दक्षता-3.69 किग्रा/हे- मिमी, शुद्ध आय- रु 100591/हे एवं लाभ लागत अनुपात-2.24)। इस प्रकार, जब नहर बंद होने के कारण समय पर बुवाई संभव नहीं हो पाती है तो कपास के पौधों की पोलिथीन थैलियों में रोपाई की जा सकती है और इन पौधों को उपज में बिना कोई हानि के खेतों में 30 मई तक प्रत्यारोपित किया जा सकता है।

जूनागढ़ केंद्र (कृषि पारिस्थितिकी उप क्षेत्र 5.1) द्वारा ऊजींग पाइप (22 मिमी बाहरी व्यास, 16 मिमी भीतरी व्यास) के माध्यम से सिंचाई करने का अध्ययन किया गया। इस अध्ययन से यह पता चला कि जब दबाव हैड को पाइपों की अलग अलग लंबाई के साथ बदला गया तो दबाव हैड में पाइप की प्रारंभिक 0-20 मीटर लंबाई तक गिरावट प्राप्त हुई। और उसके बाद दबाव में अंतर पाइपों की 30, 45 और 60 मीटर लंबाई तक बहुत कम था। ऊजींग पाइप की एमीटिंग विशेषताओं से पता चला कि एमीटिंग निर्वहन दर (लीटर/घंटा) इनलेट से दूरी के साथ घटती गई। प्रेशर हेड में व्यापक विविधता के कारण इस प्रणाली ने एमीटिंग दर की एकरूपता के संबंध में खराब प्रदर्शन दिखाया।

परभाणी केंद्र (कृषि पारिस्थितिकी उप क्षेत्र 6.2) पर युग्मित पंक्ति रोपण के साथ 1.5 मीटर चौड़ाई की ऊँची क्यारियों पर हल्दी की खेती की गयी और एक दिन छोड़कर एक दिन के बाद 80% PE के सिंचाई स्तर का निर्धारण इनलाइन ड्रिप सिंचाई प्रणाली के तहत किया गया। इस सिंचाई स्तर के कारण अन्य सिंचाई स्तरों की तुलना से 32.91 टन/हे तक राइजोम उपज एवं 33.18 किग्रा/हे-मिमी तक जल उपयोग दक्षता प्राप्त हुई तथा अधिक शुद्ध लाभ (रु. 3,54,090/हे) और लाभ लागत अनुपात (3.34) भी प्राप्त हुआ। उर्वरकों की सुझाई गई मात्रा यानि 120% (200: 100: 100 किग्रा नाइट्रोजन, फॉस्फोरस व पोटासियम) के फर्टिगेसन से काफी अधिक ताजा राइजोम उपज (34.04 टन/हे) का उत्पादन हुआ जिसके परिणामस्वरूप अधिक जल उपयोग दक्षता (3 2.1 2 किग्रा/हे-मिमी) प्राप्त हुई।

परभाणी केंद्र (कृषि पारिस्थितिकी उप क्षेत्र 6.2) पर सोयाबीन-चना फसल पद्धति में फव्वारा सिंचाई प्रणाली से सिंचाई (3 सिंचाइयाँ प्रत्येक को अधिकतम वृद्धि, फूल बनने और फली बनने की अवस्थाओं पर) करने से चना उपज (दाना उपज-2.17 टन/हे) का अधिक उत्पादन प्राप्त हुआ। इस सिंचाई पद्धति के कारण चना की फसल से अधिक शुद्ध लाभ (रु. 62,121/हे) एवं लाभ लागत अनुपात (3.58) भी प्राप्त हुआ। फव्वारा सिंचाई प्रणाली के तहत इस फसल में फली बनने की अवस्था पर एक सिंचाई देने पर सबसे अधिक जल उपयोग दक्षता (13.95 किग्रा/हे-मिमी) प्राप्त हुई जबकि सबसे कम जल उपयोग दक्षता (7.30 किग्रा/हे-मिमी) सतही विधि द्वारा तीन सिंचाइयों (प्रत्येक को अधिकतम वृद्धि, फूल बनने और फली बनने की अवस्थाओं पर) के साथ प्राप्त हुई।

फैजाबाद केंद्र (कृषि पारिस्थितिकी उप क्षेत्र 9.2) पर राजमा की फसल में ड्रिप सिंचाई पद्धति के तहत 60% PE के स्तर पर सिंचाई देने एवं 100% नाइट्रोजन उर्वरक की मात्रा का प्रयोग करने पर सतही (0.8 IW/CPE) एवं अन्य ड्रिप सिंचाई उपचारों की तुलना में काफी अधिक दाना उपज (13.05 टन/हे) प्राप्त हुई। लेकिन यह उपज 60०% PE के स्तर पर ड्रिप सिंचाई के साथ 75% नाइट्रोजन (12.71 टन/हेक्टेयर) के प्रयोग और 80% PE स्तर पर सिंचाई तथा 100% नाइट्रोजन (12.56 टन/हे) के प्रयोग के साथ लगभग बराबर थी। ड्रिप सिंचाई के तहत 60% PE के स्तर पर सिंचाई और 100% नाइट्रोजन उर्वरक के प्रयोग से 106.4 किग्रा/हे-मिमी की जल उपयोग दक्षता प्राप्त हुई और उसके बाद 60% PE (99.39 किग्रा/हे-मिमी) के स्तर पर ड्रिप सिंचाई के साथ 75% नाइट्रोजन के प्रयोग से प्राप्त हुई। ड्रिप सिंचाई के 60% PE के स्तर में केवल 132 मिमी ही सिंचाई जल का उपयोग हुआ जिससे सतह सिंचाई (415 मिमी) की तुलना में 68.2% जल की बचत प्राप्त हुई।

बिलासपुर केंद्र (कृषि पारिस्थितिकी उप क्षेत्र 11.0) पर गेहूँ की फसल में 12 मिमी कुमुलेटिव पैन वाष्पीकरण (CPE) के बाद फव्वारा सिंचाई से 30, 24 और 18 मिमी CPE के बाद सिंचाई स्तरों की तुलना में 2.94 टन/हे की अधिक उपज प्राप्त हुई और 0.79 लाभ लागत अनुपात के साथ रु. 22649/हेक्टेयर का शुद्ध लाभ प्राप्त हुआ। 12 मिमी CPE के सिंचाई उपचार के साथ जल खपत दक्षता 74.69 किग्रा/हे-सेमी थी। जैव नियंत्रक अथार्थ ट्राइकोंटिनोल के प्रयोग से पोटासियम क्लोराइड (0.2%) एवं केल्सियम क्लोराइड (0.1%) की तुलना में 2.84 टन/हे की अधिक दाना उपज और 93.70 कि.ग्रा/हे-सेमी की जल खपत दक्षता प्राप्त हुई।

चिप्लीमा केंद्र (कृषि पारिस्थितिकी उप क्षेत्र 12.1) द्वारा पश्चिमी ओडिशा में महीन बनावट वाली मृदा में तीन वर्षों तक किये गये अनुसंधान प्रयोग से पता चला कि केला की फसल में किसानों को इष्टतम फल उत्पादन (38.7 टन/हे) प्राप्त करने के लिये धान के पुआल की पलवार के प्रयोग के साथ 100% PE के स्तर पर सिंचाई

की जानी चाहिये। प्लास्टिक पलवार एवं बिना पलवार के साथ 100% PE के सिंचाई स्तर पर ड्रिप प्रणाली द्वारा सिंचाई करने से 60% PE एवं 80% PE के सिंचाई स्तरों की तुलना में अधिक शुद्ध लाभ (रु. 1,59,138/हे) और लाभ लागत अनुपात (3.33) प्राप्त हुआ।

पुसा समस्तीपुर केंद्र (कृषि पारिस्थितिकी उप क्षेत्र 13.1) पर आयोजित किये गये तीन वर्षों के अनुसंधान प्रयोग से पता चला कि पपीता की फसल में पलवार के साथ 100% PE के सिंचाई स्तर पर ड्रिप प्रणाली द्वारा सिंचाई करने के कारण अन्य सिंचाई उपचारों की तुलना में काफी अधिक फल उपज (168.62 टन/हे) एवं जल उपयोग दक्षता (8.16 टन/हे-सेमी) प्राप्त हुई। इसी उपचार के कारण अधिक शुद्ध लाभ (रु. 23,51,491/हे) एवं लाभ लागत अनुपात (13.2:1) भी प्राप्त हुआ।

ग्यासपुर केंद्र (कृषि पारिस्थितिकी उप क्षेत्र 15.1) पर सतह सिंचाई (50 मिमी) एवं 1.0 ETc स्तर पर ड्रिप सिंचाई से मक्का भुट्टा की उपज (6.91 टन/हे) अन्य ड्रिप सिंचाई स्तरों जैसे 0.8 ETc और 0.6 ETc से प्राप्त पैदावार से काफी अधिक थी। मक्का भुट्टा में शर्करा (6.42%), कुल चीनी (20.7%) और टीएसएस (7.4%) जैसे गुणों में भी 1.0 ETc के ड्रिप सिंचाई स्तर के साथ अन्य उपचारों की तुलना में महत्वपूर्ण वृद्धि पायी गई। वर्मीकंपोस्ट के रूप में 75% अकार्बनिक नाइट्रोजन+ 25% कार्बनिक नाइट्रोजन के प्रयोग से मुक्का भुट्टा में अधिकतम टीएसएस (7.31%) प्राप्त हुआ साथ ही अधिक भुट्टा उपज (6.96 टन/हे) एवं जल उपयोग दक्षता (29.90 किग्रा/हे-मिमी) भी प्राप्त हुई। ड्रिप सिंचाई (1.0 ETc स्तर के साथ 3 दिन के अंतराल पर 21 सिंचाइयाँ) के कारण सतही सिंचाई (10 दिन के अंतराल पर 5 सिंचाइयाँ) से प्राप्त जल उत्पादकता (20.19 किग्रा/हे-मिमी) की तुलना में 43.2% सिंचाई जल की बचत (जल उत्पादकता -28.15 किग्रा/हे-मिमी) प्राप्त हुई।

जोरहाट केंद्र (कृषि पारिस्थितिकी उप क्षेत्र 15.4) द्वारा असम में नींबू के पौधों के बगीचे के लिये छिद्रित पीवीसी पाइपों के साथ उपसतह जल निकासी का अध्ययन किया गया जिनको भूमि सतह से 45 सेंटीमीटर की गहराई पर स्थापित किया गया था। इस जल निकास पद्धति ने नींबू के पौधों के लिये 1: 100 अनुपात के ढ़लान के साथ वर्षा के मौसम के दौरान जड़ क्षेत्र के नीचे जल स्तर को सफलतापूर्वक कम किया। इन पाइपों का उपयोग गुरुत्वाकर्षण बल के माध्यम से जल की आपूर्ति करके 0.8 प्रभावी वर्षा के स्तर पर उपसतह सिंचाई प्रदान करने के लिये भी किया गया। इस तकनीक का लाभ लागत अनुपात 2.62 था।

नवसारी केंद्र (कृषि पारिस्थितिकी उप क्षेत्र 19.1) पर आम की फसल में जब उप सतह ड्रिप सिंचाई प्रणाली (एक दिन छोड़कर 0.6 PE) के तहत भूमि की सतह के 50 सेमी नीचे सिंचाई करने पर बहुत अधिक फल वजन (215 ग्राम) प्राप्त हुआ। जबकि सतही ड्रिप सिंचाई से 177 ग्राम फल वजन प्राप्त हुआ। हालांकि, भूमि की सतह से 30, 40 एवं 60 सेमी नीचे ड्रिप सिंचाई के स्तरों में यह परिणाम सांख्यिकीय रूप से समान थे। उपसतही ड्रिप सिंचाई के साथ जल उपयोग दक्षता (43.6 किग्रा/हे-मिमी) अधिकतम पायी गई जबकि न्यनतम जल उपयोग दक्षता (30.2 किग्रा/हे-मिमी) सतही ड्रिप सिंचाई के साथ प्राप्त हुई।

विषय 3. भूजल पुन:भरण तकनीकों का विकास एवं मूल्यांकन तथा वर्षा जल प्रबंधन

लुधियाना केंद्र (कृषि पारिस्थितिकी उप क्षेत्र 4.1) पर खरीफ धान की खेती में कृषि जल उपयोग (सिंचाई व परकोलेशन) का भूजल स्तर पर प्रभाव का अध्ययन सेरेस-राइस मॉडल की सहायता से किया गया। कुल 16 वर्षों (1998 से 2014) के आँकड़ों से प्राप्त जल संतुलन कारकों के सिमुलेशन ने दर्शाया कि मृदा की बनावट के साथ जल निकास में कमी हुई। प्रयोगात्मक स्थल एवं लुधियाना जिले में पिछले 16 वर्षों के दौरान भूजल स्तर में उतार-चढ़ाव क्रमश: -0.07 से 1.70 मीटर और -0.28 से 1.62 मीटर के बीच परिवर्तित हुआ। प्रायोगिक स्थल और लुधियाना जिले दोनों के लिये धान की फसल से प्राप्त लाभ प्रवाह कुल सिंचाई जल के प्रयोग (वर्षा + सिंचाई) का लगभग 66% था।

लुधियाना केंद्र (कृषि पारिस्थितिकी उप क्षेत्र 4.1) पर चार पदार्थों की परतों जैसे, ईंट फ्लेक्स (B), बजरी (G), मोटी रेत (CS) और दानेदार सक्रिय चारकोल (C) के साथ एक समानान्तर मिश्रित फिल्टर विकसित किया गया। इस फिल्टर से छनित जल के गुणवत्ता गुणों जैसे विद्युत चालकता, पीएच, कुल घुलनशील लवण, अवशोषित सोडियम कार्बोनेट और नाइट्रेट आदि के लिये इसका परीक्षण किया गया। परतों में पदार्थों की मोटाई से पता चला कि बजरी (सिल्ट) निष्कासन दक्षता, फिल्टर सामग्री की बढ़ती संख्या के साथ बढ़ी है। यह निष्कासन दक्षता 15 सेमी मोटी ईंट फ्लेक्स परतों (B15) के लिए 7.71% से लेकर बजरी+मोटी रेत+चारकोल के संयोजन के लिये 72.7% तक बढ़ी। परीक्षण के बाद, B30:G:CS:C and B15:G:CS:C संयोजनों के लिये नाइट्रेट निष्कासन दक्षता क्रमश: 24.33 और 24.45% पायी गयी।

उदयपुर केंद्र (कृषि पारिस्थितिकी उप क्षेत्र 4.2) पर राजस्थान के अर्ध-शुष्क क्षेत्रों विशेष रूप से कठोर चट्टानी क्षेत्रों में भूजल के स्तर में प्रभावी वृद्धि के लिये कम लागत वाली भूजल पुन:भरण संरचनाएं बनाई गई। यह संरचनाएं तीनों जिलों उदयपुर, बांसवाड़ा और डुंगरपुर के डूँगरी पड़ा, झांनपा और पुंजपुर गाँवों में विकसित की गयी। इसी तीनों जगह पर इन संरचनाओं की कुल भूजल भंडारण क्षमता क्रमश: 260 से 3493, 450 से 8966 और 1145 घन मीटर दर्ज की गयी। इन गाँवों में इन संरचनाओं का उपयोग वर्षा जल संग्रहण तथा खरीफ फसलों (0.70 हेक्टेयर) व रबी फसलों जैसे गेहूँ

और चना (7 हेक्टेयर) में लंबे समय तक सूखे की अवधि पड़ने पर जीवन-रक्षक सिंचाई प्रदान करने के लिये किया गया। इन सभी पुन:भरण संरचनाओं के निर्माण से उस क्षेत्र के आदिवासी किसानों के सामाजिक एवं आर्थिक स्तर को सुधारने में भी काफी मदद मिली।

जूनागढ़ केंद्र (कृषि पारिस्थितिकी उप क्षेत्र 5.1) द्वारा नदी धारा पर चैक बाँध का मूल्यांकन किया गया जिसकी कुल भंडारण क्षमता 4539 घन मीटर थी। इस चैक बाँध से जूनागढ़ क्षेत्र में कुल 11,092 घन मीटर भूजल को रु. 4.07/घन मीटर पुन:भरण की लागत पर पुन:भरित किया गया। पुन:भरित बेसिन में कुल 3281 घन मीटर की भंडारण क्षमता थी। कुल 98600 वर्ग मीटर जल जलग्रहण क्षेत्र से 12906 घन मीटर भूजल पुन:भरित हुआ जिसमें लागत रु 0.17/घन मीटर भूजल पुन:भरण ही आई। छत से अपवाहित वर्षा प्रवाह की अनुमानित लागत रु 42 से 88/ वर्ग मीटर छत क्षेत्र प्राप्त हुई। जूनागढ़ क्षेत्र में छत से अपवाहित जल की मात्रा 0.73 घन मीटर/ वर्ग मीटर छत के क्षेत्रफल के बराबर थी। इस संग्रहीत जल से ट्यूबवेल और सम्प को पुन:भरित किया गया।

बेलवातगी केंद्र (कृषि पारिस्थितिकी उप क्षेत्र 6.4) पर 3 वर्षों (2014-15 to 2016-17) के आँकड़ों के विशेषण ने संकेत दिया कि सूरजमुखी की फसल में वर्षा आधारित स्थिति से प्राप्त उपज (1.44 टन/हे) की तुलना में यदि इसमें 0.8 IW/CPE स्तर पर सिंचाई की गई तो काफी अधिक दाना उपज (1.71 टन/हे) प्राप्त हुई। विभिन्न इन सीटू नमी सरंक्षण विधियों में से ढ़ेचाँ की हरी खाद के साथ चौड़ी क्यारी एवं कुंड विधि के कारण काफी अधिक दाना उपज (1.71 टन/हे), डंठल उपज (4.72 टन/हे) एवं जल उपयोग दक्षता (5.17 किग्रा/हे-मिमी) प्राप्त हुई।

कोयंबटूर केंद्र (कृषि पारिस्थितिकी उप क्षेत्र 8.1) द्वारा अमरावती नदी बेसिन (अति दोहित श्रेणी) के दक्षिण में स्थित अपर ओडई वाटरशेड में भूजल संसाधनों के संवर्धन के लिये कृत्रिम पुन:भरण पर एक अनुसंधान प्रयोग आयोजित किया गया। यहाँ वर्षा से 8-19% तक प्राकृतिक पुन:भरण होने का आकलन किया गया। कुल भूजल पुन:भरण 806.5 हेक्टेयर मीटर था जिसमें से मौजूदा वर्षा जल संचयन संरचनाओं के माध्यम से कृत्रिम पुन:भरण केवल 36.4 हेक्टेयर मीटर ही हुआ। इस अध्ययन क्षेत्र में कुल वर्षा अपवाह 1343.9 हेक्टेयर मीटर था और फसलों की जल माँग 327.8 हेक्टेयर मीटर थी। यहाँ पर रिमोट सेंसिंग और जीआईएस तकनीक का उपयोग करके संभावित पुन:भरण क्षेत्रों तथा उपयुक्त पुन:भरण संरचनाओं की पहचान की गई। इससे यह प्राप्त हुआ कि अध्ययन क्षेत्र का 15.7% क्षेत्र 'बहुत ही अच्छे' व 'अच्छे' पुन:भरण, 61.7% मध्यम पुन:भरण क्षेत्र और 22.62% 'खराब' व 'बहुत खराब' पुन:भरण क्षेत्र के अंतर्गत था।

मदुरै केंद्र (कृषि पारिस्थितिकी उप क्षेत्र 8.1) पर एक तालाब (आयाम-53 x 17 x 1.5 मीटर) में वर्षा जल एवं वर्षा अपवाहित जल का संग्रहण किया गया। बाद में इस संग्रहीत जल का जल तनाव या कमी की अवधि के दौरान कुल 5 एकड़ भूमि पर उगाई गई धान की खेती में महत्वपूर्ण वृद्धि अवस्थाओं पर सिंचाई के लिये पुन:उपयोग किया गया। इसके परिणामस्वरूप वर्षा में 61% कमी होने के बावजूद भी धान का उत्पादन 3.9 टन/हे प्राप्त हुआ तथा रु.122740/हे की अतिरिक्त आय प्राप्त हुई। मिनी पोर्टेबल स्पिंक्लर सिंचाई प्रणाली के साथ इस जल का उपयोग करके धान परती क्षेत्रों में मूँगफली की बुआई से 1.3 टन/हे की पैदावार हुई एवं रु. 3000/हे की अतिरिक्त आय भी प्राप्त हुई। पतले दानों सहित अधिक उपज देने वाली धान की किस्मों जैसे एडीटी-43 व CO-51 आदि को वहाँ किसानों द्वारा अपनाया गया। इन दोनों किस्मों की धान गहनता पद्धति के तहत खेती की गयी जिससे क्रमशः 4.4 और 4.8 टन/हे की पैदावार प्राप्त हुई जो किसानों की परंपरागत बुआई विधि से प्राप्त उपज 3.7 टन/हे से 17.3% अधिक थी। एकीकृत खेती पद्धति के तहत रोहू, कटला, मृगाल एवं कॉमन कार्प मछलियों का 1000 प्रति टैंक की दर से पालन किया गया जिससे 2 तालाबों से रु. 41,500/हे की अतिरिक्त आय प्राप्त हुई। प्रत्येक तालाब के ऊपर 20 पक्षियों का पालन किया गया जिससे अधिक आर्थिक लाभ (दूसरे व तीसरे वर्ष के अध्ययन के दौरान रु 16000) प्राप्त हुआ। इन पक्षियों की खाद को तालाब में फिंगरलिंग के लिये खाद्य सामग्री के रूप में उपयोग किया गया जिससे मछलियों की खाद्य लागत 20-30% तक कम हो गई। इस प्रकार, प्रभावी रूप से जल संग्रहण और बाद में इसके दक्ष पुन:उपयोग के जरिये किसानों को रु.72,840 का अतिरिक्त कुल सकल लाभ हुआ।

जबलपुर केंद्र (कृषि पारिस्थितिकी उप क्षेत्र 10.1) पर पिछले 15 वर्षों की अवधि (2000-2015) के बदलते जलवायु परिदृश्य के तहत भूजल पुन:भरण उपयोग के लिये ठोस योजना बनाई गई। रिमोट सेंसिंग के आँकड़ों और स्वाट (SWAT) मॉडल का उपयोग स्थानिक और समय के अनुसार भूजल पुन:भरण का अनुमान लगाने के लिये किया गया। सिम्युलेटेड भूजल पुन:भरण ने वास्तविक पुन:भरण के साथ अच्छा संबंध दिखाया जिसमें जल की उतार-चढ़ाव विधि से केवल 5% विचलन प्राप्त हुआ। स्वाट (SWAT) मॉडल ने यह भी बताया कि जबलपुर जिले के सात ब्लॉकों में लगभग 17% वर्षा या तो प्रत्यक्ष इन्फिल्ट्रेसन या पुन:भरण टैंक, जलाशय, चैक बाँध आदि द्वारा भूजल पुन:भरण में योगदान देती है।

अल्मोड़ा केंद्र (कृषि पारिस्थितिकी उप क्षेत्र 14.2) द्वारा विवेकानंद पर्वतीय कृषि अनुसंधान संस्थान, हवलबाग के अनुसंधान फार्म पर उस क्षेत्र में पहाड़ी से बहने वाले झरनों को पुन:निर्मित किया गया। झरने से जल निर्वहन दर वर्ष 2016 के दौरान वर्ष 2000 की तुलना में

120% अधिक दर्ज की गई। जल निर्वहन दर और वर्षा में सहसंबंध (R^2= 0.62) भी स्थापित किया गया। वर्ष 2000 के दौरान लीन अवधि में दर्ज की गई झरने की निर्वहन दर वर्ष 2016 के दौरान उसी अवधि में बहुत अधिक बढ़ गयी। वर्ष 2000 में मासिक निर्वहन दर 794 घन मीटर थी जो वर्ष 2012- 2016 के दौरान 1894.5 घन मीटर तक बढ़ गई। हालांकि इसके विपरीत वर्षा 1201.3 मिलीमीटर से 871.7 मिमी तक घट गई।

जोरहाट केंद्र (कृषि पारिस्थितिकी उप क्षेत्र 15.4) पर गन्ने की फसल के लिये वर्षा जल को सरंक्षित करने हेतु मेड़ पर प्लास्टिक फिल्म की पलवार एवं कुंड में गन्ना अवशेष/खरपतवार बायोमास की पलवार सबसे प्रभावी पायी गई। इस नमी संरक्षण तकनीक ने अन्य तकनीकों की तुलना में मुख्य गन्ने की फसल से 85.3 टन/हे, पहली रेटून फसल से 88.7 टन/हे और दूसरी रैटून फसल से 74.7 टन/हे की काफी अधिक उपज उत्पादित की साथ ही इससे अधिक जल उत्पादकता (1412 किग्रा/ हे-सेमी) भी प्राप्त हुई। इस तकनीक से अन्य विधियों की तुलना में अधिक शुद्ध लाभ (रु. 2,09, 227/हे) और लाभ लागत अनुपात (2.5 9) भी प्राप्त हुआ।

जोरहाट केंद्र (कृषि पारिस्थितिकी उप क्षेत्र 15.4) पर मेलेंग वाटरशेड की एक आदर्श इकाई के रूप में पहचान की गई जो कि आजीविका की सुरक्षा में समग्र विकास के लिये कृषि के साथ-साथ अन्य संबद्ध विभागों के अभिसरण को दिखा रहा था। इस वाटरशेड के कुल जल प्रवाह में सतही जल का 85.81% और शेष 14.19% वर्षा का योगदान था। कुल बाहरी जल प्रवाह के लिये प्रमुख भाग (97.38%) सतही जल से था इसके बाद वाष्पोत्सर्जन (1.9%) और शुद्ध जल की माँग (0.71%) से था। इस पूरे वाटरशेड के साथ-साथ तीन अन्य भूमि उपयोग प्रणालियों के तहत उर्वरता रेटिंग के लिये पौषक तत्व सूचकांक की गणना की गई। इस वाटरशेड में कुल छ: प्रकार की नमी भूमियां फैली हुई थी जिनका संभावित इन सीटू नमी सरंक्षण के लिये विस्तृत जल गुणवत्ता विश्लेषण के साथ सफलतापूर्वक रख रखाव किया गया। भूजल क्षमता क्षेत्र (पूर्व और बाद के मानसून के मौसमों के आधार पर) कुल वाटरशेड का 26.64 घन मीटर था जो सबसे अधिक 1.16-1.32 मीटर की गहराई की श्रेणी में दर्ज किया गया।

दापोली केंद्र (कृषि पारिस्थितिकी उप क्षेत्र 19.2) पर महाराष्ट्र राज्य के 2 जिलों (रायगढ़ और पालघर) में 5 तालुकों के 8 गाँवों में वाटरशेड विकास और वर्षा जल संग्रहण के लिये आदिवासी लोगों की सहभागिता के दृष्टिकोण का पता लगाया गया। यहाँ दोनों जिलों के गाँवों में कुल 136 जलकुंडों का निर्माण किया गया जिनके माध्यम से 544 घन मीटर वर्षा जल को दूर दरदराज एवं पहाड़ी क्षेत्रों की भूमि में संग्रहीत किया गया। कुल आठ प्लास्टिक अस्तरित बाँधों (भंडारा) का निर्माण किया गया जिनका नाम 'कोंकण विजय भंडारा' रखा गया जिनकी ऊँचाई 0.8 से 1.0 मीटर थी और साइड ढ़लान नीचे की ओर से 1: 1 था। सभी भंडारों में संग्रहीत जल की कुल मात्रा 4,26,000 घन मीटर थी। इस संग्रहीत जल के उपयोग से किसानों ने 12 एकड़ भूमि पर तरबूज फसल की एवं 60 एकड़ भूमि पर सब्जियों जैसे मिर्च, टमाटर, बैंगन, कंद फसलों और ककड़ी आदि की खेती की। इसके अतिरिक्त 5 एकड़ भूमि में फव्वारा और ड्रिप सिंचाई प्रणाली की सहायता से 19 से अधिक किसानों को तरबूज, मूँगफली और सब्जियों की उच्च पैदावार प्राप्त करने और मौद्रिक लाभ प्राप्त करने के लिए प्रोत्साहित किया गया।

विषय 4. मृदा-पानी-पौधे वातावरण के संबंध पर आधारभूत अध्ययन

हिसार केंद्र (कृषि पारिस्थितिकी उप क्षेत्र 2.3) पर केवल रबी मौसम में जीरो जुताई एवं पारंपरिक जुताई की तुलना में दोनों मौसम यानि खरीफ एवं रबी में जीरो जुताई से मृदा जैविक कार्बन में वृद्धि हुई। दोनों फसल मौसम की फसल पद्धतियों में विभिन्न जुताई विधियों के तहत जैविक कार्बन का हल्का अंश मृदा में जैविक कार्बन में परिवर्तन के प्रति संवेदनशील रहता है। जीरो जुताई के तहत कम पेनिट्रेसन प्रतिरोध ने बताया कि पारंपरिक जुताई की तुलना में जीरो जुताई मृदा को ढ़ीली बनाये रखती है। मूँग-गेहूँ फसल पद्धति ने ज्वार-गेहूँ फसल पद्धति की तुलना से मृदा में अधिक कार्बन संग्रहण दर को बनाये रखा जिसके परिणामस्वरूप मृदा में अधिक जैविक कार्बन व कुल मृदा रंध्रता तथा कम पेनिट्रेसन प्रतिरोध प्राप्त हुआ।

मॉरेना केंद्र (कृषि पारिस्थितिकी उप क्षेत्र 4.4) पर हेपी सीडर द्वारा बुआई के माध्यम से फसल अवशेषों को मृदा की सतह पर रखने से अन्य बुआई की विधियों की तुलना में बाजरा फसल से बहुत अधिक दाना उपज (4.55 टन/हे) एवं जल उत्पादकता (1.30 किग्रा/घन मीटर) प्राप्त हुई। इस तकनीक से 3.05 लाभ लागत अनुपात के साथ रु. 41,337/हे का शुद्ध लाभ प्राप्त हुआ। निराई की विभिन्न विधियों के मामले में ट्रेक्टर चालित मेड़ व कुंड मशीन+ शाकनाशी के प्रयोग से अधिक बाजरा उपज (4.58 टन/हे) प्राप्त हुई तथा अधिक लाभ (रु. 41267/हे) एवं लाभ लागत अनुपात (2.29) भी प्राप्त हुआ। इससे अधिक जल उत्पादकता (1.31 किग्रा/घन मीटर) भी प्राप्त हुई।

राहुरी केंद्र (कृषि पारिस्थितिकी उप क्षेत्र 6.2) पर जायद मिर्च-तरबूज फसल अनुक्रम (पलवार के साथ) से अधिकतम शुद्ध आय (रु. 32,00,855/हे) प्राप्त हुई जब दोनों फसलों में उर्वरकों की सुझाई गई मात्रा 125% के प्रयोग के साथ 70% फसल वाष्पोत्सर्जन (Etc) के स्तर पर सिंचाई की गयी। इस फर्टिगेसन के उपचार से अन्य उपचारों की बजाय अधिक शुद्ध लाभ (रु. 6638.68 प्रति इकाई जल उपयोग) प्राप्त हुआ और 6.08 टन/हे की मिर्च तुल्य उपज के साथ अधिक जल उपयोग दक्षता (1425.56 किग्रा/हे-सेमी) भी प्राप्त हुई।

फैजाबाद केंद्र (कृषि पारिस्थितिकी उप क्षेत्र 9.2) पर धान की फसल पर तीन वर्षों के प्रयोग ने इंगित किया कि रोपित धान में अन्य रोपण विधियों (ड्रम सीडर के साथ रोपण, जीरो टिलेज मशीन के साथ रोपण, शुष्क स्थिति में रोपण एवं पडल्ड स्थिति के तहत अंकुरित बीजों का छिड़काव) की तुलना में बहुत अधिक दाना उपज (4.24 टन/हे) एवं जल उपयोग दक्षता (7.51 किग्रा/हे-मिमी) प्राप्त हुई। धान के खेत में एक दिन के बाद जल सूखने पर 7 सेमी की सिंचाई करने से अन्य सिंचाई स्तरों (खेत में जल सूखने के 4, 7 एवं 10 दिनों के बाद सिंचाई) के बजाय अधिक दाना उपज (4.55 टन/हे) एवं जल उपयोग दक्षता (6.25 किग्रा/हे-मिमी) प्राप्त हुई।

पंतनगर केंद्र (कृषि पारिस्थितिकी उप क्षेत्र 14.5) पर गेहूँ के साथ पुदीना की रिले फसल पद्धति से केवल पुदीना की फसल (196.6 किग्रा/हे) की तुलना में काफी अधिक तेल तुल्य उपज (242.5 किग्रा/हे) प्राप्त हुई। इससे 2.08 का लाभ लागत अनुपात भी प्राप्त हुआ जो केवल पुदीना की फसल से 1.36 ही था। गेहूँ की फसल के बाद प्रत्यारोपित पुदीना की फसल से 187.2 किग्रा/हे उपज प्राप्त हुई और 1.36 का लाभ लागत अनुपात प्राप्त हुआ। जबकि, अधिकतम जल उपयोग दक्षता (5.35 किग्रा/हे-मिमी) एकल पुदीना की फसल से प्राप्त हुई उसके बाद रिले फसल पद्धति (4.49 किग्रा/हे-मिमी) से प्राप्त हुई। गरम जायद मौसम के दौरान सिंचाई का 1.2 IW:CPE अनुपात स्तर (लगभग 10-11 सिंचाइयाँ) सिंचाई जल के प्रयोग के लिये इष्टतम था जिससे अधिकतम पुदीना तेल तुल्य उपज (233.4 किग्रा/हे) उत्पादित हुई और शुद्ध लाभ रु.1,34,360/हे के साथ 1.93 का लाभ लागत अनुपात प्राप्त हुआ।

पंतनगर केंद्र (कृषि पारिस्थितिकी उप क्षेत्र 14.5) पर खराब जल निकासित भारी मृदा में गेहूँ की फसल में क्राउन जड़ की शुरुआत के बाद (बुआई के 25 दिन बाद) 2% यूरिया का पत्तियों पर छिड़काव करना वानस्पतिक वृद्धि अवस्था के दौरान गेहूँ के जड़ क्षेत्र में अतिरिक्त नमी के हानिकारक प्रभाव को कम करने में बहुत ही प्रभावी विकल्प साबित हुआ। इसके कारण किसानों की पारंपरिक विधि (उपज-3.46 टन,हे एवं जल उपयोग दक्षता-144.1 किग्रा/हे-सेमी) की तुलना से 10.1% अधिक जल उपयोग दक्षता (161.2 किग्रा/हे-सेमी) के साथ 11.9% तक अधिक दाना उपज (3.87 टन/हे) प्राप्त हुई।

बिलासपुर केंद्र (कृषि पारिस्थितिकी उप क्षेत्र 11.0) पर तीन वर्षों के प्रयोग ने बताया कि प्याज की फसल में 60% CPE के सिंचाई स्तर ने 80, 100 एवं 120% CPE के सिंचाई स्तरों की तुलना में काफी अधिक बल्ब उपज (24.01 टन/हे) उत्पादित की। इस सिंचाई स्तर के साथ अधिकतम जल खपत दक्षता (585.84 किग्रा/हे-सेमी) भी प्राप्त हुई और अधिक शुद्ध लाभ (रु.1,93,565/हे) प्राप्त हुआ। सिंचाई स्तरों की संख्या के बीच प्याज में कुल नौ सिंचाइयाँ प्रदान करने पर अधिकतम शुद्ध लाभ रु.1,82,816/हे के रूप में प्राप्त हुआ। सूक्ष्म तत्वों जैसे जिंक का 5 किग्रा/हे की दर + सल्फर का 20 किग्रा/हे की दर से प्रयोग के कारण काफी अधिक बल्ब उपज (21.57 टन/हे) एवं जल खपत दक्षता (686.96 किग्रा/हे-सेमी) प्राप्त हुई और रु. 169424/हे का शुद्ध लाभ प्राप्त हुआ।

चिपलीमा केंद्र (कृषि पारिस्थितिकी उप क्षेत्र 12.1) पर तोरिया की फसल में तीन वर्षों के प्रयोग ने सुझाव दिया कि 100% उर्वरकों के साथ 45 किग्रा/हे सल्फर के प्रयोग एवं 21 दिन के अंतराल (0.6 IW/CPE) पर सिंचाई से अधिक दाना उपज (0.60 टन/हे) एवं जल उत्पादकता (0.36 किग्रा/घनमीटर) प्राप्त हुई जो कि अन्य सिंचाई स्तरों 0.8 व 1.0 IW/CPE तथा सल्फर के स्तरों 30 एवं 60 किग्रा/हे से बहुत अधिक थी। ऊपर दिये गये इस उपचार से अधिक शुद्ध लाभ (रु. 24,568/हे) एवं लाभ लागत अनुपात (1.89) भी प्राप्त हुआ।

चिपलीमा केंद्र (कृषि पारिस्थितिकी उप क्षेत्र 12.1) पर ही धान गहनता पद्धति में संसोधित जल स्तरों के तहत समन्वित खरपतवार प्रबंधन विधियों का मूल्यांकन किया गया। अंकुरण से पहले (प्रेटिलाक्लोर) एवं अंकुरण के बाद (क्लोरीम्यूरोन + मेटसल्फ्यूरोन) शाकनाशियों का प्रयोग तथा उसी दिन 50 मिमी सिंचाई के प्रयोग से 51.25% तक खरपतवार नियंत्रण दक्षता पाई गई और धान की 6.14 टन/हे के रूप में दाना उपज प्राप्त हुई। इस तकनीक से पश्चिम मध्य समतल भूमि क्षेत्र में रु. 51,499/हे का शुद्ध लाभ भी प्राप्त हुआ

पूसा समस्तीपुर केंद्र (कृषि पारिस्थितिकी उप क्षेत्र 13.1) पर चार वर्षों (2013-14 to 2016-17) के प्रयोग के समेकित आँकड़ों से प्राप्त हुआ कि एरोबिक धान में जब फील्ड केपेसिटी (FC) से मृदा में 10% नमी में कमी पर चार सिंचाइयाँ करने एवं फसल की प्रत्येक वृद्धि अवस्थाओं जैसे कल्ले बनना, फूल आने से पहले एवं फूल आने पर आयरन सल्फेट का 2% की दर से तीन छिड़काव करने पर 4.04 टन/हे की अधिक दाना उपज प्राप्त हुई। इसी उपचार के साथ 67.83 किग्रा/हे-मिमी की जल उपयोग दक्षता प्राप्त हुई और अधिकतम शुद्ध लाभ रु 31,858/हे के साथ अधिक लाभ लागत अनुपात प्राप्त हुआ। जबकि मृदा में 10% नमी में कमी पर चार सिंचाइयाँ करने एवं पारंपरिक तरीके से आयरन सल्फेट के प्रयोग से 3.41 टन/हे की दाना उपज, 57.26 किग्रा/हे-मिमी की जल उपयोग दक्षता तथा 0.91 के लाभ लागत अनुपात के साथ रु 25,693/हे का शुद्ध लाभ प्राप्त हुआ।

जम्मू केंद्र (कृषि पारिस्थितिकी उप क्षेत्र 14.2) पर दो वर्ष के अनुसंधान में पाया गया कि धान गहनता पद्धति के तहत एरोबिक सिंचाई एवं खेत में 3 दिन के बाद जल सूखने पर 7 सेमी की सिंचाई करने से क्रमश: 2.46 एवं 2.58 टन/हे उपज प्राप्त हुई जबकि किसानों की पारंपरिक सिंचाई विधि से 2.88 टन/हे उपज मिली। ऊपर वर्णित दोनों सिंचाई विधियों (एरोबिक सिंचाई-1015 मिमी व 3 दिन के बाद सिंचाई -1370 मिमी) से किसानों की विधि (1630 मिमी जल) की तुलना में 37.7% एवं 15.9% की जल बचत हुई।

पालमपुर केंद्र (कृषि पारिस्थितिकी उप क्षेत्र 14.3) पर तीन वर्षों के प्रयोग के परिणामों ने बताया कि बैंगन की फसल में जैविक पलवार का प्रयोग एवं 4 सेमी गहराई की सिंचाई करने पर पोलिथीन पलवार एवं बिना पलवार की तुलना से 9.79% एवं 17.05% तक उपज में वृद्धि हुई। इस तकनीक से जल उपयोग दक्षता में 9.74% एवं 27.57% तक वृद्धि हुई, तथा शुद्ध लाभ 28.92% एवं 17.02 % तक बढ़ा। पोलिथीन पलवार के प्रयोग से बिना पलवार की तुलना में 6.61% तक अधिक उपज एवं 16.26% तक अधिक जल उपयोग दक्षता प्राप्त हुई। अत: बैंगन की फसल से अधिकतम लाभ प्राप्त करने के लिये गोबर की खाद 10 टन/हे, जैविक पलवार एवं 4 सेमी सिंचाई जल के साथ इसको अच्छे से उगाया जा सकता है।

ग्यासपुर केंद्र (कृषि पारिस्थितिकी उप क्षेत्र 15.1) पर रेतीली दोमट मृदा में बोयी गई सूरजमुखी की फसल में पौषक तत्व–नमी की प्रतिक्रिया का अध्ययन किया गया। इससे यह पता चला कि बोरोनेटेड उर्वरकों एवं जीवाणु इनोकुलेसन के माध्यम से मृदा परीक्षण फसल प्रतिक्रिया आधारित उर्वरक के प्रयोग के साथ मृदा में उपलब्ध नमी में 50% कमी पर सिंचाई करने से अधिक दाना उपज (5.48 टन/हे) एवं जल उपयोग दक्षता (10.12 किग्रा/हे-मिमी) प्राप्त हुई।

शिलोंग केंद्र (कृषि पारिस्थितिकी उप क्षेत्र 17.1) पर जीरो जुताई के कारण पारंपरिक जुताई (धान- 4.43 टन/हे) की तुलना से खरीफ धान की दाना उपज (5.93 टन/हे) में 33.8% तक वृद्धि हुई। इसी जुताई के कारण अगले मौसम की रबी फसलों जैसे मटर, तोरिया, एवं बॅकव्हीट की उपज में क्रमश: 14.6% (5.35 टन/हे), 50.5% (1.40 टन/हे) एवं 21.3% (1.68 टन/हे) तक वृद्धि हुई। इस जुताई से पारंपरिक जुताई की तुलना में धान, मटर, तोरिया एवं बॅकव्हीट में 50%, 14.8%, 21.6% एवं 37.4% तक सिंचाई जल की बचत हुई।

शिलोंग केंद्र (कृषि पारिस्थितिकी उप क्षेत्र 17.1) पर 5 टन/हे की दर से गोबर की खाद एवं 5 टन/हे की दर से पलवार का प्रयोग करके ढ़लान की स्थिति पर हल्दी की खेती की गयी जिससे अन्य उपचारों की तुलना में बहुत अधिक राइजोम उपज (10.15 टन/हे) एवं जल उपयोग दक्षता (10.9 किग्रा/हे-मिमी) प्राप्त हुई। यहाँ यह देखा गया कि किसानों की पारंपरिक खेती पद्धति (3.67 टन/हे, 3.9 किग्रा/हे-मिमी) की तुलना में इस तकनीक से राइजोम उपज में 176.7% एवं जल बचत में 179.5% तक वृद्धि हुई।

चलाकुड़ी केंद्र (कृषि पारिस्थितिकी उप क्षेत्र 19.2) द्वारा एक जैविक फिल्टर इकाई विकसित की गई जो कि जैविक खाद (गोबर खाद एवं केंचुआ खाद) के प्रयोग में प्रभावी है। इस इकाई से प्राप्त छनित को ड्रिप सिंचाई प्रणाली के माध्यम से पंप किया गया और इस सिस्टम के माध्यम से किसी भी प्रकार के चोक के बिना सफलतापूर्वक प्रवाहित किया गया। भिंडी की फसल की अधिक पैदावार प्राप्त करने के लिए ड्रिप प्रणाली के माध्यम से 50% पौषक तत्वों के साथ जैविक खाद छनित को प्रयोग करने का सुझाव दिया गया। इस महत्त्वपूर्ण तकनीक का पेटेंट के लिये आवेदन किया गया है।

चलाकुड़ी केंद्र (कृषि पारिस्थितिकी उप क्षेत्र 19.2) पर बैंगन की फसल में मृदा सुधारक के रूप में 4 टन/हे की दर से बायोचार के प्रयोग से उपज में 28%, जल उपयोग दक्षता में 29.8%, नाइट्रोजन उपयोग दक्षता में 28.1% तक वृद्धि हुई साथ ही 106.3% तक अधिक लाभ प्राप्त हुआ। चूना के प्रयोग की तुलना में बायोचार के प्रयोग से उपज को बिना प्रभावित किये जल उपयोग में 67% तक कमी हुई। अगले मौसम में बिना कोई पौषक तत्वों को प्रयोग किये बैंगन की रेटून फसल एवं चंवला से अधिक उपज प्राप्त हुई जो बायोचार का मृदा में पौषक तत्वों की धारण क्षमता को लंबे समय तक बनाए रखने के प्रभाव को बताता है।

दापोली केंद्र (कृषि पारिस्थितिकी उप क्षेत्र 19.2) पर भिंडी की फसल में पौधों की दूरी (120 सेमी x 45 सेमी x 15 सेमी) और ड्रिप फर्टिगेसन (80% ETc और 100% उर्वरकों की सुझाई गई मात्रा) से 17.41 टन/हे की ताजा फली उपज प्राप्त हुई तथा 81.01 किग्रा/हे-मिमी की जल उपयोग दक्षता प्राप्त हुई जो सिंचाई जल और उर्वरकों के इष्टतम उपयोग को दर्शाता है। नियंत्रण उपचार में फली उपज एवं जल उपयोग दक्षता क्रमशः 8.75 टन/हे एवं 10.7 किग्रा/ हे-मिमी प्राप्त हुई। ड्रिप सिंचाई प्रणाली से कुंड सिंचाई विधि की तुलना में 64.2% तक सिंचाई जल की बचत भी हुई।

दापोली केंद्र (कृषि पारिस्थितिकी उप क्षेत्र 19.2) पर काजू की फसल में 25 लीटर/सप्ताह/पौधा सिंचाई स्तर एवं वृद्धि की पीनट अवस्था से लेकर 60 दिन तक सिंचाई जल प्रयोग के संयोजन उपचार से अन्य सिंचाई उपचारों की तुलना से अधिकतम जल उपयोग दक्षता (3.20 किग्रा/हे-मिमी) के साथ काजू की काफी अधिक उपज (1.44 टन/हे) प्राप्त हुई। इससे बिना कोई सिंचाई की तुलना से उपज में 88.2% तक वृद्धि हुई।

नवसारी केंद्र (कृषि पारिस्थितिकी उप क्षेत्र 19.1) पर ही गन्ने की फसल में ड्रिप लेटरल (193 टन/हे एवं 250 किग्रा/हे-मिमी) के उपसतह स्थापन (7.5.सेमी) तथा दो आइड कलियों (199 टन/हे एवं 257.87 किग्रा/हे-मिमी) के रोपण से अन्य उपचारों की तुलना में अधिक उपज एवं जल उपयोग दक्षता प्राप्त हुई। इसी तकनीक के साथ अधिकतम जल उपयोग दक्षता (257.87 किग्रा/हे-मिमी) भी प्राप्त हुई। ड्रिप सिंचाई पद्धति (770 मिमी) से सतही सिंचाई (1210 मिमी) की तुलना में 37% तक सिंचाई जल की बचत हुई।

विषय 5. सतही एवं भूजल के संयोजी उपयोग के लिये प्रबंधन उपायों को विकसित करना

उदयपुर केंद्र (कृषि पारिस्थितिकी उप क्षेत्र 4.2) द्वारा जयसमंद कमांड में संयोजी जल उपयोग के साथ भूमि आवंटन के लिये तीन गुणों जैसे अधिकतम शुद्ध लाभ, अधिकतम उत्पादन एवं अधिकतम श्रम रोजगार आदि को मूल्यांकित किया गया। खरीफ मौसम के दौरान रु. 374 मिलियन का निवेश करने से अधिकतम शुद्ध लाभ रु.156.24 मिलियन प्राप्त हुआ। रबी मौसम के दौरान नहर से जल छोड़ने के 9 दिनों के लिये रु. 439.4 मिलियन का निवेश करने से अधिकतम शुद्ध लाभ रु. 271.3 मिलियन प्राप्त हुआ जबकि नहर से जल छोड़ने के 18, 21, 24 व 30 दिनों हेतु प्रत्येक के लिये रु. 459.8 मिलियन निवेश के साथ रु. 279.5 मिलियन का लाभ प्राप्त हुआ। इसी प्रकार, खरीफ में रु. 374 मिलियन का निवेश करने से 22976.8 टन का अधिकतम उत्पादन प्राप्त हुआ। रबी मौसम के दौरान नहर से जल छोड़ने के 9 दिनों के लिये रु. 458.43 मिलियन का निवेश करने से 45115.0 टन का अधिकतम उत्पादन प्राप्त हुआ। जबकि, नहर से जल छोड़ने के 18, 21, 24 व 30 दिनों हेतु प्रत्येक के लिये रु. 459.8 मिलियन निवेश के साथ 45319.2 टन का उत्पादन प्राप्त हुआ। इन दोनों गुणों के लिये बाँयी एवं दाँयी ओर की मुख्य नहर के लिये खरीफ तथा रबी मौसम में अधिकतम फसल क्षेत्र मक्का एवं गेहूँ की फसलों को आवंटित किया गया।

कोटा केंद्र (कृषि पारिस्थितिकी उप क्षेत्र 5.2) पर गेहूँ की फसल में बुआई पूर्व एवं प्रथम सिंचाई का प्रयोग केवल नहरी जल के साथ तथा जिप्सम (250 किग्रा/हे) व गोबर की खाद (5 टन/हे) के प्रयोग के साथ बाद की सिंचाइयाँ वैकल्पिक रूप से नहर व नलकूप के जल से करने पर अधिकतम दाना उपज (4.73 टन/हे) प्राप्त हुई। इसी उपचार से मृदा गुणवत्ता में भी सुधार प्राप्त हुआ।

भवानीसागर (कृषि पारिस्थितिकी उप क्षेत्र 8.3) एवं कोयंबटूर (कृषि पारिस्थितिकी उप क्षेत्र 9) केन्द्रों पर लोवर भवानी परियोजना की कुगुलर जल वितरणिका में नहर जल आपूर्ति एवं भूजल दोहन विपरीत दिशा में थे। नहर के मुख्य छोर पर संयोजी उपयोग बहुत कम था लेकिन यह नहर के अंतिम छोर की ओर संयोजी उपयोग बढ़ता गया। नहर के मुख्य छोर पर किसान मुख्यतया नहर के जल से सिंचाई कर रहे थे जबकि नहर के अंतिम छोर पर नहर के जल की कम आपूर्ति के कारण वहाँ किसान नलकूप से भी सिंचाई करते थे। गन्ने की फसल के लिये नहर के मुख्य, मध्य एवं अंतिम छोर पर जल की आपूर्ति 26.7, 21.9 एवं 12.1 हेक्टेयर मीटर थी जबकि भूजल आपूर्ति 9.7, 10.9 एवं 15.3 हेक्टेयर मीटर थी। वार्षिक भूजल आवश्यकता 627.8 हे-मीटर थी। कुल भूजल पुन:भरण 1369.0 हे-मीटर, शुद्ध पुन:भरण 1026.78 हे-मीटर एवं वर्तमान भूजल विकास 61.5% पाया गया। दूसरी तरफ, सिंचाई के लिये नहरी जल की उपलब्धता 2239.2 हे-मीटर थी, फसल जल आवश्यकता 2867.0 हे-मीटर एवं भूजल आवश्यकता 627.8 हे-मीटर थी और साथ ही सुरक्षित श्रेणी में 642.1 हे-मीटर भूजल उपलब्ध था। इसलिये, वार्षिक आधार पर 14.32 हे-मीटर भूजल अनुपयोगी था। यह मौजूदा फसल पद्धति के लिये वितरणिका में फसल जल माँग के लिये पर्याप्त भूजल की उपलब्धता को दर्शाता है। नहर के मुख्य छोर पर रहने वाले गाँव के किसानों को अधिक भूजल उपयोग के लिये सुझाव दिया जबकि अंतिम छोर पर रहने वालों के लिये नहरी जल के उपयोग का सुझाव दिया गया।

फैजाबाद केंद्र पर गेहूँ की फसल में नहरी जल से दो सिंचाइयाँ एवं नलकूप के जल से एक सिंचाई का उन्नत सिंचाई पद्धति के माध्यम से प्रत्येक सिंचाई में 6 सेमी सिंचाई जल का प्रयोग संयोजी उपयोग के तहत किया गया। यह सिंचाई फसल की संवेदनशील वृद्धि अवस्थाओं (क्राउन जड़ की शुरुआत, तना वृद्धि एवं दानों में दूध बनने) पर क्यारी (5 x 10 वर्ग मीटर) पद्धति के माध्यम से की गयी। इसके परिणामस्वरूप किसानों की पारंपरिक बाढ़ सिंचाई विधि (उपज-3.24 टन/हे, जल खपत दक्षता-161.86 किग्रा/हे-मिमी) की तुलना में गेहूँ की फसल से बहुत अधिक दाना उपज (4.32 टन/हे) एवं जल खपत दक्षता (242.70 किग्रा/हे-सेमी) प्राप्त हुई।

पूसा समस्तीपुर केंद्र (कृषि पारिस्थितिकी उप क्षेत्र 13.1) पर पत्ता गोभी की फसल में 50% ताजा जल एवं 50% ग्रे जल की सिंचाई से 52.6 टन/हे की उपज प्राप्त हुई। ताजा जल एवं ग्रे जल की वैकल्पिक सिंचाइयों से 49.6 टन/हे की उपज प्राप्त हुई। 50% ताजा जल एवं 50% ग्रे जल की सिंचाई के तहत पत्ता गोभी में सूक्ष्म पौषक तत्वों जैसे जिंक, आयरन एवं मेंगनीज की सांद्रता अधिकतम पायी गई।

ग्यासपुर केंद्र (कृषि पारिस्थितिकी उप क्षेत्र 15.1) पर ब्रोकोली फसल में उथले नलकूप के आर्सेनिक से दूषित जल एवं जलाशय के ताजा जल से सिंचाई ने दिखाया कि ब्रोकोली हेड में आर्सेनिक का हटाव प्राप्त हुआ। आर्सेनिक को हटाने में केवल 100% जलाशय जल (4.67 मिलीग्राम/किलोग्राम) एवं 50% आर्सेनिक से दूषित उथले नलकूप के जल: 50% जलाशय जल (4.77 मिलीग्राम/किलोग्राम) का प्रभाव लगभग बराबर था। इससे यह साबित हुआ कि सतही जल की उपलब्धता एवं आर्सेनिक प्रदूषण को ध्यान में रखते हुये सिंचाई के लिये दोनों ही विकल्पों को किसानों द्वारा अपनाने की सलाह दी गई।

Executive Summary

Theme 1: Assessment of availability and quality of surface water and groundwater

At Sriganganagar (AESR 2.1), relative water supply (RWS) was 0.58 from Khetawali distributary (KWD) of IGNP command during *rabi* 2016, when maximum area was covered by wheat followed by mustard, barley, fodder, gram and vegetables. During *kharif* 2016, RWS was 0.60 when maximum area was covered by American cotton (*Gossypium hirsutum*) crop followed by guar (*Cyamopsis tetragonoloba*) and paddy. As the water supply was deficit in both the seasons, it was suggested to replace part of the area under wheat with mustard or barley and part of area under American cotton with guar and moong in order to match water supply with water requirement of crops in all the irrigation systems.

At Kota (AESR 5.2), assessment of Manasgaon distributary showed that average relative water supply (RWS) during *rabi* 2015-16 was 0.54 (November 2015-February 2016), with maximum RWS (0.66) during February. During *kharif* 2016, the RWS was only 0.06 during October 2016. There were 90 and 6 days of canal running during *rabi* and *kharif*, respectively. Average water availability at field level was 197.83 and 6521.65 ha-cm during *kharif* and *rabi*, respectively. There was surplus water by 329.55 ha-cm during *kharif* season and water deficit by 7754.18 ha-cm during *rabi* season. Command area sown during *kharif* was 996.54 ha and *rabi* was 1056.32 ha.

At Parbhani (AESR 6.2), Jayakwadi Irrigation Project was selected to monitor water table fluctuation and quality of groundwater under ORP. Annual water table fluctuation during 1985 to 2017 ranged from 2.2 to 15.1 m in the command area and 3.8 to 15.1 m in non-command area. With recharge from canal water, groundwater level in the command area was highest during March 2017. Groundwater from command and non command areas was categorized as C_3S_1 and C_2S_1 i.e. high and medium saline water, respectively. Both the waters had no sodium hazard. Groundwater from command area cannot be used on soils with restricted drainage.

At Coimbatore (AESR 8.1), average water discharge for irrigated dry season crops in odd turn sluice command of Kugalur distributary of Lower Bhavani Project command was 66.83 cusec, with RWS of 80.7% from January to October 2016. Out of the total command area of 2011.55 ha for the odd turn 47.73% was consolidated cropped area. Out of 1949.27 ha command area for the even turn, 50.21% was brought under cropping due to recharged canal water to the well.

At Jammu (AESR 14.2), performance indicators evaluated for Basmati-cum-coarse rice during *kharif*, wheat and other crops during *rabi* season showed that RWS and relative irrigation supply (RIS) were less by 65% and 70%, respectively at tail reach of Tawi-Lift canal command area. Performance indicators indicated that there is significant difference in production, water supply and water use in the head, middle and tail reaches. One of the indicators, RWS showed that in head, middle and tail reaches it needs to be improved by 9%, 18% and 65%, respectively to meet crop demand.

Theme 2: Design, development and refinement of surface and pressurized irrigation systems

At Hisar (AESR 2.3), a trial at the University Research Farm, CCSHAU, Hisar showed that water productivity of wheat (3.58 kg/m^3) was the highest under furrow irrigated ridge and bed system (FIRBS) followed by mini-sprinklers (2.99 kg/m^3) and conventional (2.36 kg/m^3).

At Hisar (AESR 2.3), among farm interventions (ORP) for increasing water productivity (WP) in wheat crop, furrow irrigated ridge and bed system (FIRBS)resulted in 6.4% higher grain yield (4.51 t/ha) over conventional sowing and surface irrigation besides saving 3.1 cm (12.6%) of irrigation water. An increase in WP by 36.6 kg/ha-cm was observed under FIRBS over conventional system.

At Sriganganagar (AESR 2.1), transplanting of *Bt* cotton crop under drip irrigation on 30th May produced yield of 3.06 t/ha and gave net seasonal income of Rs.86589/ha with B:C ratio of 1.95. The water expense efficiency (WEE) was 3.65 kg/ha-mm. It was statistically similar to control treatment i.e. direct sowing with drip irrigation on 15th May (Yield=3.43 t/ha, WEE=3.69 kg/ha-mm, net income=Rs.100591/ha and B:C=2.24). Thus, when timely sowing is not possible due to canal closure, seedlings may be raised in polythene bags and transplanted in field up to 30th May with drip irrigation without facing loss in yield.

At Junagadh (AESR 5.1), study of irrigation through oozing pipe (22 mm outer diameter, 16 mm inner diameter) showed that when pressure head varied with various lengths of oozing pipe, pressure head drastically dropped in initial 0-20 m length and thereafter variation in the pressure head was very less in case of 30, 45 and 60 m length of oozing pipes. Emitting characteristics of oozing pipe showed that emitting discharge rate (litres per hour per metre length) decreased with distance from inlet. With wide variation in pressure head, the system showed poor performance with respect to uniformity of emitting rate.

At Parbhani (AESR 6.2), turmeric crop sown with paired row planting on 1.5 m wide raised bed and scheduled to alternate day in-line drip irrigation at 80% of PE resulted in significantly higher fresh rhizome yield of 32.91 t/ha, WUE of 33.18 kg/ha-mm, net profit of Rs.3,54,090/ha and B:C ratio of 3.34 over other irrigation levels. Fertigation at 120% RDF (RDF200:100:100 NPK kg/ha) produced significantly higher fresh rhizome yield (34.04 t/ha) and resulted in higher WUE (32.12 kg/ha-mm).

At Parbhani (AESR 6.2), three years of trial on sprinkler irrigation [3 irrigations (SI) each at grand growth stage (GGS)+flowering stage (FS)+pod formation stage (PFS)] in soybean-chickpea cropping system showed that chickpea produced significantly higher grain yield (2.17 t/ha) and gave higher net return (Rs.62121/ha) with B:C ratio (3.58). Water use efficiency (13.95 kg/ha-mm) of chickpea was highest with one irrigation at PFS while lowest (7.30 kg/ha-mm) was noted with three surface irrigations at GGS+FS+PFS.

At Faizabad (AESR 9.2), drip irrigation at 60% PE with 100% recommended dose of nitrogen (RDN) recorded significantly higher yield of rajmash beans (13.05 t/ha) compared to surface (0.8 IW/CPE) and other surface drip irrigation treatments, except drip at 60%PE with 75% RDN (12.71 t/ha) and 80% PE with 100% N (12.56 t/ha). Water use efficiency for drip at 60% PE with 100% N was 106.4 kg/ha-mm, followed by 99.39 kg/ha-mm with drip at 60%PE with 75% N. Drip irrigation at 60% PE used 132 mm of water, thereby saved 68.2% water compared to surface irrigation (415 mm).

At Bilaspur (AESR 11.0), wheat crop produced significantly higher grain yield of 2.94 t/ha with net profit of Rs. 22649/ha and B:C ratio of 0.79 with sprinkler irrigation after 12 mm CPE than those obtained with sprinkler irrigations after 30, 24 and 18 mm CPE. Water expense efficiency with irrigation after 12 mm CPE was 74.69 kg/ha-cm. Bioregulator (Tricontinol) application also resulted in significantly higher grain yield of 2.84 t/ha and WEE of 93.70 kg/ha-cm compared to application of KCl @ 0.2% and $CaCl_2$ @ 0.1%.

At Chiplima (AESR 12.1), three years of experiment in fine textured soil of western Odisha showed that banana should be drip irrigated at 100% PE with incorporation of paddy straw mulch to produce economically optimum fruit yield (38.7 t/ha). Higher net return (Rs.1,59,138/ha) and B:C ratio (3.33) was obtained with drip irrigation at 100% PE compared to 60% PE and 80% PE with plastic mulch and no mulch conditions.

At Pusa (AESR 13.1), three years of experimentation indicated that drip irrigation at 100% PE with mulch to papaya fruit crop recorded significantly higher yield of 168.62 t/ha, WUE (8.16 t/ha-cm), net return (Rs.23,51,491/ha) and B:C ratio of 13.2 compared to other treatments.

At Gayeshpur (AESR 15.1), surface irrigation (50 mm) and drip irrigation at 1.0 ET_c rendered that cob yield (6.91 t/ha) of sweet corn was significantly higher than yields with drip at 0.8 ET_c and 0.6 ET_c. The cobs showed significant increase in reducing sugar (6.42%), total sugar (20.7%) and TSS (7.4%) with drip at 1.0 ET_c than other treatments. Use of 75% inorganic N + 25% organic N as vermicompost resulted in significantly higher cob yield (6.96 t/ha) and WUE (29.90 kg/ha-mm), with maximum TSS (7.31%) in cobs. Drip irrigation at 1.0 ET_c resulted in water saving of 43.2% (WUE 28.15 kg/ha-mm) compared to 5 irrigations at 10-days interval under surface method (20.19 kg/ha-mm).

At Jorhat (AESR 15.4), subsurface drainage study was conducted with perforated PVC pipes underlain at a depth 45 cm for Assam lemon plantation. With a gradient of 1:100, the drainage system successfully lowered water table below the effective root zone of Assam lemon plants (i.e. 40 cm) during rainy season. These pipes were also used for providing subsurface irrigation at 80% evaporative replenishment (ER) by supplying water by gravity. The benefit-cost ratio of the technology was 2.62. The technology has been submitted for patent.

At Navsari (AESR 19.1), significantly higher fruit weight (215 g) of mango was obtained when drip irrigation (at 0.6 PE on alternate day) was applied 50 cm below ground level (T_4) compared to surface drip (177 g). Although, results with the former treatment were statistically similar with drip irrigation 30, 40 and 60 cm below ground level. Water use efficiency of 43.6 kg/ha-mm was highest with sub surface drip irrigation (applied at 50 cm below ground level) and lowest (30.2 kg/ha-mm) with surface drip.

Theme 3: Development and evaluation of groundwater recharge technologies, and management of rainwater

At Ludhiana (AESR 4.1), influence of agriculture water use (irrigation and deep percolation) on groundwater level due to cultivation of *kharif* rice was studied with CERES-Rice model. Simulation of water balance components for a period of 16 years (1998 to 2014) showed that drainage decreased with fineness of soil texture. Groundwater fluctuation varied from -0.07 to 1.70 m and -0.28 to 1.62 m for experimental site and Ludhiana district, respectively over the 16 years. The return flow from rice was nearly 66% of the total water applied (rainfall+irrigation) for both experimental site and Ludhiana district.

At Ludhiana (AESR 4.1), horizontal composite filter was developed with four layers *viz.*, brick flakes (B), gravel (G), coarse sand (pea gravel) (CS) and granular activated charcoal (C). It was tested for silt removal and surface runoff quality including EC, pH, TDS, RSC and nitrate in the filtered water. The thickness of materials in the layers showed that silt removal efficiency (RE) increased with the increasing number of filter materials, from 7.71% with only 15 cm thick brick flakes layer (B_{15}) to 72.70% with B_{30}:G:CS:C combination. After testing, the nitrate RE was found to be 24.93% and 24.45% for B30:G:CS:C and B15:G:CS:C combinations, respectively.

At Udaipur (AESR 4.2), low cost groundwater (GW) recharge structures were constructed under TSP for effective augmentation of GW table in semi-arid regions of Rajasthan, especially in the hard rock areas. These structures were developed at Doongri Para, Jhanpa and Punjpur villages of three districts (Udaipur, Banswara and Dungarpur). The respective GW storage capacity of these structures was 260 to 3489 m^3, 450 to 8966 m^3 and 1145 m^3. The structures were also utilized to store rainwater and provide life-saving irrigation to *kharif* crops (0.70 ha) suffering from longer dry spells, and *rabi* crops likewheat and gram (7 ha) in the villages. These recharge structures also helped in improving socio-economic status of tribal farmers of the region.

At Junagadh (AESR 5.1), on stream check dam was evaluated which had storage capacity of 4539 m^3. It recharged 11092 m^3 groundwater in Junagadh region at the cost of Rs.0.47/m^3 of groundwater recharge. Recharge basin had storage capacity of 3281 m^3. Groundwater recharged from catchment area of 98600 m^2 was 12906 m^3 at cost of 0.17 Rs./m^3 groundwater recharge. Estimated cost of harvesting roof water runoff varied from Rs. 42 to 88/m^2 of roof. Roof water runoff in Junagadh region was 0.73 m^3/m^2 area of roof. The harvested water was diverted to recharge tubewell and sump.

At Belvatagi (AESR 6.4), pooled data of three years (2014-15 to 2016-17) indicated that seed yield (1.71 t/ha) of sunflower significantly increased with irrigation at 0.8 IW/CPE compared to yield (1.44 t/ha) under rainfed ecosystem. Among different in situ moisture conservation practices, significantly highest sunflower yield (1.71 t/ha), stalk yield (4.72 t/ha) and WUE (5.17 kg/ha-mm) were recorded for broad bed furrow method with sunhemp green manure.

At Coimbatore (AESR 8.1), a study was conducted on artificial recharge for augmentation of groundwater resources in the Uppar Odai watershed located in south of Amaravathi river basin (overexploited category). The natural recharge was estimated as 8-19% of rainfall. Total groundwater recharge was 806.5ha-m, out of which artificial recharge through existing rainwater harvesting structures was 36.4 ha-m. Total runoff was 1343.9 ha-m and crop water demand in the study area was 327.8 ha-m. Potential recharge zones and suitable recharge structures were identified using remote sensing and GIS. It showed that 15.7% of the study area is under 'very good' and 'good' recharge zones, 61.7% was under moderate recharge zone and 22.62% was 'poor' and 'very poor' recharge zone.

At Madurai (AESR 8.1), rainwater and runoff water harvested in a farm pond (dimension 53 x 17 x 1.5 m) and it was recycled during stress periods and critical growth stages of rice crop grown on 5 acre. As a result rice yielded 3.9 t/ha under 61% deficit rainfall and generated additional income of Rs.12740/ha. Groundnut grown in rice fallow by utilizing the water with mini portable sprinkler irrigation system which produced pod yield of 1.3 t/ha with additional income of Rs.3000/ha. Introduction of fine grain high yielding rice varieties *viz.*, ADT-43 and Co-51 in the area, cultivated using SRI gave yields of 4.4 and 4.8 t/ha, respectively, which were ≈17.3% higher than the farmers' practice (3.7 t/ha). The integrated farming system introduced fingerlings of Rohu, Catla, Mirgal, common carp @1000 per tank. This fetched additional income of Rs.41,500/ha from 2 farm ponds. About 20 birds reared per pond also fetched economic benefit (Rs.16000 during second and third years of study). Bird voids were used as feed material for fingerlings @ 20 birds/pond, thereby reducing feed cost by 20-30%. Overall additional income of Rs.72840 was generated by the farmer through effective harvesting and recycling of water.

At Jabalpur (AESR 10.1), strategic planning was done for recharge utilization under changing climate scenario of 15 years period (2000-2015). Remote sensing data and SWAT model were used to estimate groundwater recharge at high spatial and temporal resolution. Simulated groundwater recharge showed good agreement with observed recharge with only 5% deviation obtained with water fluctuation method. SWAT model also showed that about 17% of rainfall is contributing to groundwater either by direct infiltration or by recharge through tank, reservoir, check dam, etc. in seven blocks of Jabalpur district.

At Almora (AESR 14.2), one of the hill springs at VPKAS Hawalbagh farm was revived. The annual discharge from the spring was 120% higher during 2016 compared to that recorded in 2000. Discharge and rainfall were correlated (R^2=0.62). Discharge of the spring greatly increased during lean period compared to discharge recorded in 2000. Monthly discharge increased from 794.0 m^3 before 2000 to 1894.5 m^3 during 2012-2016, although rainfall decreased from 1201.3 mm to 871.7 mm across the years.

At Jorhat (AESR 15.4), ridge mulched with plastic film and furrow mulched with sugarcane trash/weed biomass was most effective in conservation of rainwater for sugarcane crop. This moisture conservation technique led to significantly higher yields for main sugarcane crop (85.3 t/ha), first ratoon (88.7 t/ha) and second ratoon crops (74.7 t/ha) with higher WUE (1412 kg/ha-cm), net income (Rs.2,09,227 per ha) and B:C ratio (2.59) compared to other techniques and the control (recommended practice).

At Jorhat (AESR 15.4), Meleng watershed was identified as an ideal one showing the convergence of agricultural as well as allied departments for overall development in livelihood security of the watershed. Of the total water inflow, 85.81% was contributed from surface water and rest 14.19% from precipitation. For total water outflow, major portion (97.38%) was from surface water followed by ET (1.9%) and net water demand (0.71%). Nutrient index was computed for fertility rating under three land use systems as well as for the entire watershed. Six wetlands spread across the watershed have been revamped and maintained successfully with detail water quality analysis for possible *in situ* exploration. Groundwater potential zone (based on pre- and post-monsoon seasons) had total capacity of 26.64 lakh m^3 of the watershed, highest being recorded in the category of 1.16–1.32 m depth.

At Dapoli (AESR 19.2), tribal people's participatory approach for watershed development and rainwater harvesting was carried out in 8 villages of 5 talukas in 2 districts (Raigad and Palghar) under TSP. Total 136 *jalkund* were constructed in the villages, through which 544 m^3 rainwater was harvested in the remote and hilly lands. Eight plastic lined check dams (Bandhara) named 'Konkan Vijay Bandhara' were constructed with height ranging from 0.8 to 1.0 m and side slope 1:1 at the downstream side only. Total volume of water stored in all the bandhara was 426000 m^3. Farmers cultivated watermelon on 12 acre and vegetables like chilli, tomato, brinjal, tuber crops and cucumber on 60 acre using the bandhara water. Intervention of sprinkler and drip irrigations created for additional 5 acre land facilitated >19 farmers to grow watermelon, groundnut and vegetables with higher yields and monetary benefits.

Theme 4: Basic studies on soil-plant–water-environment relationship

At Hisar (AESR 2.3), zero tillage (ZT) practice in both *kharif* and *rabi* seasons increased soil organic carbon (SOC) over ZT during *rabi* only and conventional tillage (CT). The light fraction of OC was sensitive to changes in SOC under different tillage practices in both the cropping systems. Lower penetration resistance under ZT revealed that ZT maintained the soil more loosely as compared to CT. The mungbean-wheat cropping system maintained higher carbon sequestration rate that resulted in higher SOC, total soil porosity and lower penetration resistance compared to sorghum-wheat system.

At Morena (AESR 4.4), pearlmillet grain yield (4.55 t/ha), net return (Rs.41,337/ha), B:C ratio (3.05) and water productivity (1.30 kg/m^3) were significantly higher under 100% RRSHS (Residue retention through sowing of crop by happy seeder) sowing method compared to other sowing methods. In case of intercultural operations, tractor operated ridge furrow maker + weedicide application resulted in significantly higher yield (4.58 t/ha), net income (Rs.41,267/ha), B:C ratio (2.99) and water productivity (1.31 kg/m^3).

At Rahuri (AESR 6.2), summer chilli-watermelon crop sequence (with mulch) recorded highest net income (Rs.32,00,855/ha) when both crops were irrigated at 70% ET_c with fertigation at 125% RDF. This treatment also recorded highest net profit (6638.68 mm per unit of water used) and WUE (1425.56 kg/ha-cm) with chilli equivalent yield of 60.8 t/ha among all the treatment combinations.

At Faizabad (AESR 9.2), three years' experiment on rice indicated that transplanted rice recorded significantly higher yield of 4.24 t/ha and WUE of 7.51 kg/ha-mm over other planting methods (planting with drum seeder, planting with zero tillage machine, planting under dry condition and broadcasting of sprouted seeds under puddled condition). Irrigation schedule of 7 cm irrigation at 1 DADPW resulted in significantly higher grain yield (4.55 t/ha) over other schedules (7 cm irrigation applied at 4, 7 and 10 DADPW). While, irrigation at 1 DADPW had WUE 6.25 kg/ha-mm.

At Pantnagar (AESR 14.5), relay cropping of menthol mint with wheat recorded maximum and significantly higher oil equivalent yield (242.5 kg/ha) and B:C ratio (2.08) than sole mint crop (196.6 kg/ha, 1.87) and wheat followed by transplanted mint (187.2 kg/ha, 1.36). However, WUE was maximum with sole mint (5.35) followed by relay cropping (4.49). The IW:CPE ratio of 1.2 was optimum for application of irrigation (about 10-11 irrigations) during hot summer season because it produced highest mint oil equivalent yield (233.4 kg/ha) with net return (Rs.1,34,360/ha) and B:C ratio (1.93).

At Pantnagar (AESR 14.5), in poorly drained heavy soil, foliar spray of urea (2%) post CRI stage (25 DAS) of wheat was the most viable option to mitigate the adverse effect of excess moisture in the root zone during its vegetative phase. It produced 10.4% higher grain yield (3.94 t/ha) with 9.7% higher WUE (415.0 kg/ha-cm) than the farmers' practice (3.57 t/ha, 378.2 kg/ha-cm).

At Bilaspur (AESR 11.0), three years of experimentation showed that irrigation level of 60% CPE produced significantly higher onion bulb yield (24.06 t/ha) with maximum WEE (585.84 kg/ha-cm) and net return (Rs.1,93,565/ha) over 80, 100 and 120% CPE levels. Among number of irrigation levels, higher net profit of Rs.1,82,816/ha was found with 9 irrigations. Micronutrient application of Zn @ 5 kg/ha + S @ 20 kg/ha gave significantly higher bulb yield of 21.57 t/ha, with higher WEE of 686.96 kg/ha-cm and net return of Rs.1,69,424/ha.

At Chiplima (AESR 12.1), three years of experiment with toria suggested that application of sulphur @ 45 kg/ha along with RDF (50:25:25) and irrigation scheduled at 21 days interval (IW/CPE = 0.6) resulted in significantly higher seed yield 0.60 t/ha), water productivity (0.30 kg/m^3), net return (Rs.24,568/ha) and B:C ratio (1.89) over irrigation at 0.8 and 1.0 IW/CPE and 30 kg/ha and 60 kg/ha sulphur application.

At Chiplima (AESR 12.1), evaluation of integrated weed management practices under modified water regimes in SRI showed that application of pre-emergence (Pretilachlor) and post-emergence (Chlorimuron ethyl+Metsulphuron methyl) herbicides with 50 mm irrigation on the day before weeding led to highest weed control efficiency of 51.25%, rice grain yield of 6.14 t/ha and net profit of Rs.51,499/ha in West Central Table Land zone.

At Pusa (AESR 13.1), pooled results of 4 years (2013-14 to 2016-17) indicated that four irrigations at 10% moisture depletion of field capacity (FC) and three foliar sprays of 2% $FeSO_4$ at tillering, pre-flowering and flowering stages resulted in significantly higher yield of 4.04 t/ha along with WUE of 67.83 kg/ha-mm, maximum net return of Rs.31,858 and maximum B:C ratio of 1.0 compared to yield of 3.41 t/ha, WUE of 57.26 kg/ha-mm, net return of Rs.25,693/ha and B:C of 0.91 with 10% moisture depletion of FC and traditional application of $FeSO_4$ (Control).

At Jammu (AESR 14.2), in two years' study observed that yields obtained under SRI with aerobic irrigation (S_1) and SRI with 3 DADPW with 7 cm irrigation (S_2) were 2.46 and 2.58 t/ha, respectively, compared to 2.88 t/ha with conventional farmers' practice (transplanting with continuous submergence of 7 cm water). But water saving recorded under S_1 (1015 mm) and S_2 (1370 mm) was 37.7% and 15.9% as compared to farmers' practice (1630 mm).

At Palampur (AESR 14.3), three years' results indicated that application of organic mulch and irrigation of 4 cm water resulted in significantly higher brinjal yields by 9.79% and 17.05%, WUE by 9.74% and 27.57%, net returns 28.92% and 17.02 % with plastic mulch and no mulch. Plastic mulch resulted in significantly higher brinjal yield by 6.61%, WUE by 16.26% and B:C ratio by 47.86% compared to no mulch. Thus, brinjal may be grown with application of FYM @10 t/ha, organic mulch, 4 cm irrigation to get maximum economic returns.

At Gayeshpur (AESR 15.1), nutrient-moisture interactions in sunflower crop grown in sandy loam soil revealed that 50% depletion of ASM with soil test crop response (STCR) based NPK fertilizer application substantiated through boronated fertilizers and bacterial inoculation resulted in significantly higher seed yield (5.48 t/ha) and WUE (10.12 kg/ha-mm).

At Shillong (AESR 17.1), zero tillage resulted in significantly higher grain yield of *kharif* rice by 33.8% (5.93 t/ha) and succeeding *rabi* crops viz., pea by 14.6% (5.35 t/ha), toria by 50.5% (1.40 t/ha) and buckwheat by 21.3% (1.68 t/ha), with water saving of 50, 14.8, 21.6 and 34.7% compared to conventional tillage practice (rice- 4.43 t/ha, pea- 4.67 t/ha, toria- 0.93 t/ha, buckwheat- 1.39 t/ha).

At Shillong (AESR 17.1), turmeric grown under terrace condition with FYM @ 5 t/ha + mulching @ 5 t/harecorded significantly higher rhizome yield (10.15 t/ha) and WUE (10.9 kg/ha-mm) compared to other treatments. It was observed that there was an increase of 176.7% rhizome yield, 179.5% water saving over farmers' practice (3.67 t/ha, 3.9 kg/ha-mm).

At Chalakudy (AESR 19.2), an organic filtration and fertigation unit was developed. It proved to be effective in fertigation to bhindi crop with filtrates of organic manures like cowdung and vermicompost. Filtrates obtained from this unit were pumped through drip irrigation system and was passed successfully through the system without clogging. Organic manure filtrate along with 50% RDF applied to bhindi crop gave higher yield as well as improved nutrient and microbial status of the soil. The technology has been filed for patent.

At Chalakudy (AESR 19.2), application of biochar @ 4 t/ha as soil amendment increased brinjal yield by 28%, WUE by 29.8%, NUE by 28.1% and net return by 106.3%. It reduced water use by 67% without affecting the yield compared to lime application. In subsequent seasons, brinjal ratoon crop yield and residual crop yield of cowpea obtained without any nutrient application revealed the long term effect of biochar in holding nutrients in soil.

At Dapoli (AESR 19.2), crop spacing of 120 cm - 45 cm x 15 cm and drip fertigation (80% ET_c and 100% RDF) recorded highest fresh pod yield of okra (17.41 t/ha) and WUE (81.01 kg/ha-mm), indicating optimum use of water and fertilizer. Yield and WUE for control treatment was 8.75 t/ha and 10.7 kg/ha-mm, respectively. The water saving was 64.2% compared to control (furrow irrigation).

At Dapoli (AESR 19.2), treatment combination of irrigation level of 25 litre/week/tree and water application from peanut stage up to 60 days recorded significantly higher cashewnut yield (1.44 t/ha) with maximum WUE (3.20 kg/ha-mm) as compared to other treatments. The magnitude of yield increase was 88.2% compared to yield obtained with no irrigation.

At Navsari (AESR 19.1), significantly higher sugarcane yield and WUEs were recorded with subsurface placement (7.5. cm) of drip lateral (193.0 t/ha and 250.6 kg/ha-mm) and two eye budded set (199.0 t/ha and 257.9 kg/ha-mm) compared to other treatments. Interaction effects of 20 splits (199.0 t/ha) and 30 splits (195.0 t/ha) of fertigation, each in combination with two eye budded set showed statistically similar yields with interaction of 20 splits of fertigation with three weeks old plant (188.0 t/ha). Drip irrigation (770 mm) saved 37% water compared to surface method (1210 mm).

Theme 5: To evolve management strategies for conjunctive use of surface and groundwater

At Udaipur (AESR 4.2), three parameters viz., net benefit maximization, production maximization and labour employment maximization were evaluated for land allocation with conjunctive use in Jaisamand command. During *kharif* season, maximum net benefit of Rs.156.24 million was obtained with investment of Rs.374 million. During *rabi* season, net benefit was Rs.271.3 million with investment of Rs.439.4 million for 9 canal running days and Rs.279.5 million with investment of 459.8 million for each of 18, 21, 24 and 30 canal running days. Production maximization of 22976.81 tonnes was obtained with investment of Rs.374 million during *kharif* season. During *rabi*, maximum production was 45115.0 tonnes with investment of Rs.458.43 million for 9 canal running days and 45319.2 tonnes with investment of Rs.459.83 million for each of 18, 21, 24 and 30 canal running days. For both the parameters, maximum area was allotted to maize and wheat during *kharif* and *rabi* seasons, respectively for left and right main canal.

At Kota (AESR 5.2), OPR study showed that maximum grain yield of wheat (4.81 t/ha) was observed with pre-sowing and first irrigations applied with canal water (CW) and subsequent irrigations applied alternately with CW and tubewell water (TW) along with application of gypsum @ 250 kg/ha and FYM @ 5 t/ha. Improvement in soil quality was observed in this treatment, with minimum EC 1.16 dS/m and pH 8.20 after crop harvest.

At Bhavanisagar (AESR 8.3) and Coimbatore (AESR 9), pattern of canal water (CW) supply and groundwater (GW) withdrawal was in reverse direction in Kugalur distributary of Lower Bhavani Project (LBP). Conjunctive use was very less at the head reach but increased towards the tail reach of the canal. Farmers at head reach mostly irrigated with CW, whereas bore well water was mostly used in tail reach due to insufficient supply of CW. For sugarcane crop, supply of CW was 26.7, 21.9 and 12.1 ha-m and GW 9.7, 10.9 and 15.3 ha-m for head, middle and tail reaches, respectively. Annual GW requirement was 627.8 ha-m. Gross GW recharge was 1369.0 ha-m, net recharge was 1026.78 ha-m and current stage of GW development was 61.5%. On the other hand, CW available for irrigation was 2239.2 ha-m, crop water demand was 2867.0 ha-m, GW requirement was 627.8 ha-m, GW available in safe category was 642.1 ha-m. Thus 14.32 ha-m GW was unutilized on annual basis. This depicted sufficient availability of GW to meet crop water demand in the distributary for the prevailing cropping system. Villages in the head reach were suggested to use more GW, so that more CW may be available in the tail reach.

At Faizabad (AESR 9.2), ORP study showed that conjunctive use of two irrigations with CW and one with TW through improved irrigation practice of 6 cm water applied at critical growth stages (CRI, late jointing and milking) by check basin (5x10 m^2) method produced significantly higher grain yield (4.32 t/ha) of wheat i.e. 33.3% higher and recorded higher WEE (242.70 kg/ha-cm) i.e. 49.9% higher compared to those with farmers' practice (3.24 t/ha and 161.86 kg/ha-cm) of applying two irrigations from canal with 10 cm water using field to field method (Flooding).

At Pusa (AESR 13.1), cabbage crop produced highest yield of 52.6 t/ha with 50% fresh water + 50% gray irrigation water application followed by alternate irrigations with fresh water and gray water (49.6 t/ha). Micronutrients like Zn, Fe and Mn in cabbage were found in maximum concentration with 50% fresh water + 50% gray water irrigation.

At Gayeshpur (AESR 15.1), ORP study showed that irrigation with arsenic prone shallow tubewell water (STW) and fresh pond water (PW) in broccoli vegetable showed that recovery of arsenic from broccoli head subjected to 100% PW (4.67 mg/kg) and 50 STW:50 PW (4.77 mg/kg) was statistically similar. This implied that both the options may be advocated to the farmers keeping in view of availability of surface water for irrigation and arsenic attenuation simultaneously.

Introduction

All Indian Coordinated Research Project on Water Management (WM) and All India Coordinated Research Project on Groundwater Utilisation (GWU) were merged and 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), Indira Gandhi Krishi Viswa Vidyalaya (Raipur, Bilaspur), Jawaharlal Nehru Krishi Viswa Vidyalaya (Powarkheda and Jabalpur) and Punjab Agricultural University (Ludhiana and Bathinda).

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

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

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

Table 1. Centres and their controlling universities

S. No.	Location of Centre	Controlling University/ICAR Institute
1	Almora	VPKAS, Almora
2	Bathinda, Ludhiana	PAU, Ludhiana
3	Belavatagi	UAS, Dharwad
4	Bhavanisagar, Madurai, Coimbatore	TNAU, Coimbatore
5	Bilaspur, Raipur	IGKVV, Raipur
6	Chalakudy	KAU, Thrissur
7	Chiplima	OUAT, Bhubaneswar
8	Dapoli	DBSKKV, Dapoli
9	Faizabad	NDUAT, Faizabad
10	Hisar	CCSHAU, Hisar
11	Jammu	SKUAST, Jammu
12	Jorhat	AAU, Jorhat
13	Junagadh	JAU, Junagadh
14	Gayeshpur	BCKVV, Mohanpur
15	Kota	AU, Kota
16	Morena	RVSKVV, Gwalior
17	Navsari	NAU, Navsari
18	Palampur	CSKHPKVV, Palampur
19	Pantnagar	GBPUAT, Pantnagar
20	Parbhani	VNMKV, Parbhani
21	Powarkheda, Jabalpur	JNKVV, Jabalpur
22	Pusa	Dr.RPCAU, Pusa
23	Rahuri	MPKV, Rahuri
24	Shillong	ICAR Research Complex for NEH region
25	Sriganganagar	SKRAU, Bikaner
26	Udaipur	MPUAT, Udaipur

Irrigation Commands under AICRP on Irrigation Water Management

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

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

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

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

ECOSYSTEM	AER Description	AESR	Description of AESR	Irrigation region	Centre	Controlling organization
		7.2	North Telangana plateau, hot moist semi-arid ESR with deep loamy and clayey mixed red and black soils, medium to very high AWC and LGP 120-150 days	-	-	-
		7.3	Eastern ghat (south), hot moist semi-arid/dry subhumid ESR with medium to deep loamy to clayey mixed red and black soils, medium AWC and LGP 150-180 days	-	-	-
	8 Eastern Ghats and Tamil Nadu uplands and Deccan (Karnataka) plateau, hot semi-arid eco-region	8.1	Tamil Nadu uplands and leeward flanks of south Sahyadris, hot dry semi-arid eco-subregion with moderately deep to deep, loamy to clayey, mixed red and black soils medium AWC and LGP 90-120 days	Periyar Vaigai Periyar Vaigai	Coimbatore Madurai	TNAU, Coimbatore TNAU, Coimbatore
		8.2	Central Karnataka Plateau, hot moist semi-arid ESR with medium to deep red loamy soils, low AWC and LGP 120-150 days	-	-	-
		8.3	Tamil Nadu uplands and plains, hot moist and ESR with deep red loamy soils, low AWC and LGP 120-150 days	Lower Bhavani	Bhavanisagar	TNAU, Coimbatore
SUBHUMID ECOSYSTEM	9 Northern plain, hot subhumid (dry) eco-region	9.1	Punjab and Rohilkhand plains, hot dry/moist subhumid transitional ESR with deep, loamy to clayey alluvium-derived (inclusion of saline and sodic phases) soils medium AWC and LGP 120-150 days	-	-	-
		9.2	Rohilkhand, Avadh and south Bihar plains, hot dry subhumid ESR with deep loamy alluvium-derived soils, medium to high AWC and LGP 150-180 days	Sharda Sahayak	Faizabad	NDUA&T, Faizabad
	10 Central Highlands (Malwa and Bundelkhand), hot subhumid (dry) eco-region	10.1	Malwa plateau, Vidnyan scarpland and Narmada valley, hot dry subhumid ESR with medium and deep clayey black soils (shallow loamy black soils as inclusion), high AWC and LGP 150-180 days	- Tawa	Jabalpur Powarkheda	JNKVV, Jabalpur JNKVV, Jabalpur
		10.2	Satpura and Eastern Maharashtra plateau, hot dry subhumid ESR with shallow and medium loamy to clayey black soils (deep clayey black soils as inclusion), medium to high AWC and LGP 150-180 days	-	-	-
		10.3	Vidhyan Scarpland and Baghelkhand plateau, hot dry subhumid ESR with deep loamy to clayey mixed red andblack soils, medium to high AWC and LGP 150-180 days	-	-	-
		10.4	Satpura range and Wainganga valley, hot moist subhumid ESR with shallow to deep loamy to clayey mixed red and black soils, low to medium AWC and LGP 180-210 days	-	-	-

ECOSYSTEM	AER Description	AESR	Description of AESR	Irrigation region	Centre	Controlling organization
	11 Moderately to gently sloping Chhattisgarh/ Mahanadi basin, hot moist/ dry subhumid transitional ESR with deep loamy to clayey red and yellow soils, medium AWC and LGP 150-180 days	-	-	Hasdeo Bango -	Bilaspur Raipur	IGKVV, Raipur IGKVV, Raipur
	12 Eastern plateau (Chhotanagpur) and Eastern Ghats, hot subhumid eco-region	12.1	Garjat Hills, Dandakaranya and Eastern Ghats, hot moist subhumid ESR with deep loamy red and lateritic soils, low to medium AWC and LGP 180-210 days	Hirakud	Chiplima	OUAT, Bhubaneswar
		12.2	Eastern Ghats, hot moist subhumid ESR with medium to deep loamy red and lateritic soils, medium AWC and LGP 180-210 days	-	-	-
	13 Eastern plain, hot subhumid (moist) eco-region	13.1	North Bihar and Avadh plains, hot dry to moist subhumid ESR with deep, loamy alluvium derived soils, low to medium AWC and LGP 180-210 days	Gandak	Pusa	RAU, Samastipur
		13.2	Foothills of central Himalayas, warm to hot moist subhumid ESR with deep loamy to clayey Tarai soils, high AWC and LGP 180-210 days	-	-	-
	14 Western Himalayas, warm subhumid (to humid with inclusion of perhumid) eco-region	14.1	South Kashmir and Punjab Himalayas, cold and warm dry semi-arid/dry subhumid ESR with shallow to medium deep loamy brown forest and Podzolic soils, low to medium AWC and LGP 90-120 days	-	-	-
		14.2	South Kashmir and Kumaun Himalayas, warm moist to dry subhumid transitional ESR with medium to deep loamy to clayey brown forest and podzolic soils, medium AWC and LGP 150-210 days	Yamuna Ravi and Tawi	Almora Jammu	VPKAS, Almora SKUAST, Jammu
		14.3	Punjab Himalayas warm humid to perhumid transitional ESR with shallow to medium deep loamy brown forest and podzolic soils, low to medium AWC and LGP 270-300 + days	-	Palampur	HPKVV, Palampur
		14.4	Kumaun Himalayas, warm humid to perhumid transitional ESR with shallow to medium deep loamy red and yellow soils, low AWC and LGP 270-300 + days	-	-	-
		14.5	Foothills of Kumaun Himalayas (subdued), warm humid/perhumid ESR with medium to deep, loamy Tarai sols, medium AWC and LGP 270-300 + days	-	Pantnagar	GBPUAT, Pantnagar
HUMID-PERHUMID ECOSYSTEM	15 Assam and Bengal plains, hot subhumid to humid (inclusion of perhumid) eco-region	15.1	Bengal basin and North Bihar plain, hot moist subhumid ESR with deep loamy to clayey alluvium derived soils, medium to high AWC and LGP 210-240 days	Damodar Valley Corporation (DVC)	Gayeshpur	BCKVV, Mohanpur

ECOSYSTEM	AER Description	AESR	Description of AESR	Irrigation region	Centre	Controlling organization
		15.2	Middle Brahmaputra plain, hot humid ESR with deep, loamy to clayey alluvium derived soils, medium AWC and LGP 240-270 days	-	-	-
		15.3	Teesta, lower Brahmaputra plain and Barak valley, hot moist humid to perhumid ESR with deep, loamy to clayey alluvium-derived soils, medium AWC and LGP 270-300 days	-	-	-
		15.4	Upper Brahmaputra plain, warm to hot perhumid ESR with moderately deep to deep loamy, alluvium derived soils, medium AWC and LGP > 300 days	Jamuna	Jorhat	AAU, Jorhat
	16 Eastern Himalayas, warm perhumid eco-region	16.1	Foot-hills of Eastern Himalayas (Bhutan foot hills) warm to hot perhumid ESR with shallow to medium, loam-skeletal to loamy Tarai soils, low to medium AWC and LGP 270-300 days	-	-	-
		16.2	Darjeeling and Sikkim Himalayas, warm perhumid ESR with shallow to medium deep loamy brown and Red Hill soils, low to medium AWC and LGP > 300 days	-	-	-
		16.3	Arunanchal Pradesh (subdued Eastern Himalayas), warm to hot perhumid ESR with deep, loamy to clayey red loamy soils, low to medium AWC and PGP > 300 days	-	-	-
	17 North-eastern hills (Purvachal), warm perhumid eco-region	17.1	Meghalaya plateau and Nagaland hill, warm to hot moist humid to perhumid ESR with medium to deep loamy to clayey red and lateritic soils, medium AWC and LGP 270-300 + days	Umiam	Shillong	ICAR Complex for NEH Region, Shillong
		17.2	Purvachal (Eastern range), warm to hot perhumid ESR with medium to deep loamy red and yellow soils, low to medium AWC and LGP > 300 days	-	-	-
COASTAL ECOSYSTEM	18 Eastern Coastal plain, hot subhumid to semi-arid eco-region	18.1	South Tamil Nadu plains (Coastal), hot dry semi-arid ESR with deep, loamy to clayey, alkaline coastal and deltaic alluvium-derived soils, medium AWC and LGP 90-120 days	-	-	-
		18.2	North Tamil Nadu Plains (Coastal), hot moist semi-arid ESR with deep, clayey and cracking coastal and deltaic alluvium-derived soils, high AWC and LGP 120-150 days	-	-	-
		18.3	Andhra plain, hot dry subhumid ESR with deep, clayey coastal and deltaic alluvium derived soils, low to medium AWC and LGP 150-180 days	-	-	-
		18.4	Utkal plain and east Godavari delta, hot dry subhumid ESR with deep, loamy to clayey coastal and deltaic alluvium-derived soils, medium AWC and LGP 180-210 days	-	-	-
		18.5	Gangetic delta, hot moist subhumid to humid ESR with deep, loamy to clayey coastal and deltaic alluvium-derived soils, medium AWC and LGP 240-270 days	-	-	-

ECOSYSTEM	AER Description	AESR	Description of AESR	Irrigation region	Centre	Controlling organization
	19 Western Ghats and coastal plain, hot humid-perhumid eco-region	19.1	North Sahyadris and Konkan coast, hot humid ESR with medium to deep loamy to clayey mixed red and black soils, medium to high AWC and LGP 210-240 days	Ukai-Kakrapar	Navsari	NAU, Navsari
		19.2	Central and south Sahyadris, hot moist subhumid to humid transitional ESR with deep, loamy to clayey red and lateritic soils, low to medium AWC and LGP 210-270 days	Chalakudy -	Chalakudy Dapoli	KAU, Thrissur DBSKKV, Dapoli
		19.3	Konkan, Karnataka and Kerala coastal plain, hot humid to perhumid transitional ESR with deep, clayey to loamy, acidic, coastal alluvium-derived soils, low AWC and LGP 240-270 days	-	-	-
ISLAND ECOSYSTEM	20 Islands of Andaman-Nicobar and Lakshadweep, hot humid to perhumid island eco-region	20.1	Andaman-Nicobar group of islands, hot perhumid ESR with shallow to medium deep, loamy to clayey red and yellow and red loamy soils, low to medium AWC and LGP > 300 days	-	-	-
		20.2	Level Lakshadweep and group of islands hot humid ESR with shallow to medium deep loamy to sandy black, sandy and littoral soils, low to medium AWC and LGP 240-270 days	-	-	-

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

Locality Characteristics of AICRP on Irrigation Water Management Centres

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

Table 3. Locality characteristics of AICRP centres in irrigation commands

Name of centre	Soil texture	Depth of water table (m)	Annual rainfall (mm)	Source of irrigation	Irrigation project (IP)
Almora	Loamy sand to clay/silty clay loam	No ground water. Subsurface water concentrated at specific place and come out in surface in the form of water springs	1150 (Almora) 1003 (Hawalbagh)	Lift irrigation Canal	Yamuna IP
Belavatagi	Sandy loam to clay	Very deep	556	Canal	Malaprabha IP
Bathinda	Loamy sand to sandy loam	1-4 m	400	Canal Tubewell	IGNP Bhakra IP
Bhavanisagar	Red sandy loam to clay loam	3-10 m	702	Canal	Lower Bhavani IP
Bilaspur	Sandy loam to clay	> 2 m	1249	Canal	Hasdeo Bango IP
Chalakudy	Loamy sand to sandy loam, slightly acidic	> 2 m	3146	Canal	Chalakudy River Diversion Scheme
Chiplima	Sandy loam to sandy clay loam	0.2-5 m	1349	Canal	Hirakud IP
Coimbatore	Red loamy soil (Black soil)	5-20 m	774	Dug well Tubewell Canal	Parambilulam Aliyar IP

Name of centre	Soil texture	Depth of water table (m)	Annual rainfall (mm)	Source of irrigation	Irrigation project (IP)
Dapoli	Sandy loam to sandy clay loam	0.2-5 m	1349	Canal	-
Faizabad	Silty loam to silty clay loam	4-7.5 m	1022	Canal Tubewell	Sharda Sahayak IP
Gayeshpur	Sandy loam to clay loam	0.2-2 m	1315	Canal Tubewell	DVC IP
Hisar	Loamy sand to sandy loam	0.4-1 m	430	Canal Tubewell	Bhakra IP
Jabalpur	Clay loam to clay	>3 m	1354	Canal Tubewell	RABS IP
Jammu	Sandy loam to silty loam	>4 m	1175	Canal	Ravi and Tawi IP
Jorhat	Sandy loam to sandy clay loam, slightly to moderately acidic	0.5-4.5 m	2083	Canal Tubewell	Charaipani IP, Jamuna IP and Deep Tubewell Project in few locations
Junagadh	Clay loam (medium black)	2-20 m	800	Tubewell Open well	-
Kota	Clay loam to clay	0.7-2 m	777	Canal	Chambal IP
Madurai	Sandy loam to clay loam	0.5-2 m	858	Canal	Periyar Vaigai IP
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	Chambal IP
Navsari	Clayey	1-5 m	1418	Canal	Ukai-Kakrapar Project (UKC)
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	Haripura IP, Jamrani IP
Parbhani	Medium to deep black clayey	>1- 3 m	861	Canal Well	Jayakwadi/Purna IP (Godavari basin)
Powarkheda	Deep black clay	3-6 m	1087	Canal and Tubewell	Tawa IP
Pusa	Sandy loam	2-6 m	1200	Canal Tubewell	Gandak Koshi and Sonecanal system
Rahuri	Deep black clayey	2-5 m	523	Canal	Mula IP
Raipur	Sandy loam to clay loam	>2 m	1154	Canal Tubewell	-
Shillong	Sandy loam	>2 m	2400	*Jalkund* Ponds	Umiam IP
Sriganganagar	Loam to silty clay loam	> 10 m	276	Canal Tubewell	IGNP IP
Udaipur	Sandy loam	12-18 m	670	Canal Tubewell	-

Theme 1

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

Under Theme 1, prospects of groundwater (GW) have been studied by Jorhat and Jabalpur centres. Groundwater potential zones were identified and mapped using RS&GIS. Temporal fluctuation and spatial changes in water table (WT) depth were modelled. Based on model predictions of WT depletion over a period of time, sites requiring artificial recharge were suggested. Otherwise, based on GW resource, selection of pumps suitable for lifting water and possibility of using such pumps to irrigate unit area were prepared in the form of map. Factor responsible for WT fluctuation was identified and its impact on groundwater draft was studied by Raipur centre. Canal water (CW) supply from various major and minor irrigation projects were assessed by Sriganganagar, Coimbatore, Chalakudy, Kota and Rahuri centres. The centres made efforts to measure demand and supply of CW and match the supply with crop water requirement in terms of relative water supply (RWS). In case of deficit RWS, alternate cropping systems were suggested for the head, middle and tail reaches of the canal commands. The suggestions aimed at uniform distribution of water in all the reaches and growing low water consuming yet profitable crops, especially in the tail reach. A tubewell command (Jorhat) and a tank command (Coimbatore) were also studied. Temporal changes in soil fertility status in the tank command area were estimated with a gap of 16-18 years. Wastewater as a source of surface water irrigation was characterized by Madurai centre. Despite many negative impacts, one positive impact of applying untreated wastewater was that it helped in carbon sequestration in soils.

1.1. Sriganganagar (AESR 2.1)

1.1.1. Assessment of water use efficiency and its improvement through introduction of technological interventions at selected outlet in Gang canal command area

Total command area under the 20 Z outlet of Z distributary in Gang canal command is 304 ha. Total cropped area during *rabi* 2015-16 and *kharif* 2016 was 276 and 176 ha (Table 1.1.1), respectively with irrigation intensity of 148.7%. There were only six water reservoirs in the outlet command, out of which only 2.0 ha (Kinnow orchard) was under drip irrigation. During *rabi* 2015-16 and *kharif* 2016, 7010.22 and 4581.72 ha-cm water (excluding rainfall) was released against requirement of 12080 and 11144 ha-cm, respectively. Water supply was deficit in both the seasons with relative water supply (RWS) of 0.66 and 0.82 during *rabi* and *kharif*, respectively (Table 1.1.1).

Table 1.1.1. Water requirement (ha-cm) and relative water supply (RWS) to crops in Gang canal command

Rabi 2015-16										
Parameter	Wheat	Mustard	Barley	Gram	Fodder	Vegetable	-	-	Total	RWS
Area	82	155	28	5	5	1	-	-	276	0.66
IWR	4428	5967.5	1232	152.5	250	50	-	-	12080	
***Kharif* 2016**										
Parameter	A. Cotton	D. Cotton	Bajra	Cluster bean	Mung bean	Sugar-cane	Fodder	Orchard	Total	RWS
Area	10	14	5	89	22	23	7	6	176	0.82
IWR	760	945	205	3382	605	4600	287	360	11144	

A. Cotton-American cotton, D. Cotton-Desi cotton, IWR-Irrigation water requirement (ha-cm)

1.1.2. Assessment of water availability at distributary level and to devise intervention for matching of water supply and demand for maximization of production

Khetawali distributary (KWD) of IGNP command was selected for the study. The distributary has 16 outlets in KWD system, 6 outlets in Khetawali minor (KWM) system and 2 outlets in Amarpura minor (ARM) system. The design discharge of KWD system, KWM and APM are 74.64, 17.05 and 4.0 cusec, respectively. During 2015-16, flow in KWD, KWM and APM systems was 72 cusec, 14.9 cusec and 2.5 cusec, respectively. The flow was almost constant during *rabi* and *kharif* seasons. During *rabi* 2015-16, canal ran for 78 days from October 2015 to March 2016. Wheat crop covered maximum area in the command area and utilized most of the canal water. Average RWS (0.60) was low during *rabi* season. During *kharif* 2016, canal water was supplied for 61 days and American cotton occupied maximum area. Average RWS (0.67) during *kharif* season also showed deficit irrigation (Table 1.1.2). Thus it was suggested to replace part of the area under wheat by mustard or barley during *rabi* and some parts of American cotton by low water requiring crops like guar and moong during *kharif* in order to match water supply with water requirement in the KWD, KWM and ARM systems.

Table 1.1.2. Area and irrigation water requirement of crops and relative water supply (RWS) under Khetawali distributary system

System[#]	Area (ha)	Irrigation water requirement (ha-cm)	Canal water diverted (ha-cm)	Water available at field (ha-cm)	Effective rainfall (ha-cm)	Total water supply (ha-cm)	RWS
***Rabi* 2014-15**							
KWD	2675	131712.5	103550.85	64180.82	12572.50	76753.32	0.58
KWM	760	38849.0	28211.91	18151.54	3572.00	21723.54	0.56
APM	109	5180.0	4771.35	2982.09	512.30	3494.39	0.67
***Kharif* 2016**							
KWD	2841	190593	76879.7	47650.1	67615.8	115265.9	0.60
KWM	714	56214	20431.4	13145.6	16993.2	30138.8	0.54
APM	100	5391	3645.8	2278.6	2380.0	4658.6	0.86

[#]KWD-Khetawali distributary (16 outlets), KWM-Khetawali minor (6 outlets), APM-Amarpura minor (2 outlets)

1.2. Ludhiana (AESR 4.1)

1.2.1. Assessment of groundwater contamination from N, P and K fertilizers in central Punjab

Four districts of central Punjab *viz.*, Ludhiana, Patiala, Moga and Fatehgarh Sahib were selected for testing N, P and K and bacterial contamination in groundwater from tubewells located in agricultural fields. Sampling was done after the monsoon season of 2016. Twenty samples from Fatehgarh Sahib and Ludhiana, thirteen samples from Moga, and twelve samples from Patiala showed that concentrations of N, P and K in groundwater were below the permissible limits. The permissible limit for nitrate in drinking water is 45 ppm, whereas for NO_3-N it is 10 ppm (EPA). The permissible limit for total N is 100 ppm and for P it is 5 ppm (IS-10500). Microbiological testing of the samples showed that groundwater at some of the places *viz.*, Latur, Badaushi Kalan, Sidhiwal, Samshernagar, Uchha Niwana, Pinder Kalan, Jalalabad, Sasibrahmana, Hasanpur, Haripur and Sanaur under the four districts was bacteriologically unsafe.

1.3. Kota (AESR 5.2)

1.3.1. Assessment of water availability and deficit at field level for Manasgaon distributary

The study was carried out for Manasgaon distributary to assess availability of water at field level and calculate irrigation water requirement for *rabi* and *kharif* crops. Water supplied in the distributary was maximum (14762.81 ha-cm) during November 2015 and minimum (359.69 ha-cm) during October 2016. Relative water supply was highest (65.9%) during February 2016 with 20 canal running days and lowest (6.13%) during October 2016 with 6 canal running days. Canal water availability at field level during *rabi* and *kharif* seasons of 2015-16 was 26086.61 and 197.83 ha-cm, respectively. Total sown area during *rabi* was 1056.32 ha, where wheat (787.9 ha) and mustard (156.87 ha) occupied maximum area. Total sown area during *kharif* was 1056.32 ha, soybean (676.9 ha) and paddy (256.2 ha) occupying maximum area. Surplus water of 329.55 ha-cm during *kharif* and total water deficit of 7754.18 ha-cm during *rabi* were estimated for the distributary. Season-wise water availability at field level through canal and rainfall and the total water requirement of the crops is shown in Table 1.3.1.

Table 1.3.1. Season-wise water availability for Manasgaon distributary during 2015-16

Crop season	Canal running days	Water released (ha-cm)		Water available at field level (ha-cm)	Rainfall (ha-cm)	RWS (%)	Crop water requirement (ha-cm)	Deficit / Surplus in water supply (ha-cm)
		Designed	Actual					
Rabi (Nov'15-Feb'16)	90	88086.5	32667.4	26086.6	12654.2	54.4	46495.5	-7754.2
Kharif (Oct'16)	6	5872.4	359.7	197.8	57999.6	6.1	57867.9	329.6

1.4. Rahuri (AESR 6.2)

1.4.1. Assessment of performance of irrigation in Musalwadi minor irrigation project

The study was conducted to evaluate water delivery performance of Musalwadi minor irrigation project canal with different performance indicators like equity, adequacy and excess for all outlets for the year 2008-09. The canal was 6.7 km with design discharge of 18 cusec and covering command area of 762 ha (4 villages). It had 12 outlets covering 840.9 ha. Net irrigated area in *kharif*, summer (*zaid*) and *rabi* seasons was 336.38 ha each. Rotation-wise water released during summer, *kharif* and *rabi* was 324680, 509820 and 978430 m^3 against crop water requirement of 3044922.7, 1567064.1 and 3866423.6 m^3, respectively. Overall performance of the minor irrigation project for *kharif*, *rabi* and *zaid* seasons is presented in Table 1.4.1. When estimated on volume basis, equity estimated using different methods indicated good performance of the project at both outlet and farm levels. Adequacy of the irrigation project was 0.10, 0.48 and 0.26 for *kharif*, *rabi* and summer seasons respectively, indicating non release of water as per crop water requirement.

Table 1.4.1. Performance of Musalwadi minor irrigation project

Performance indicator Equity (Volume based)	*Kharif* season		*Rabi* season		Summer season	
	Outlet	Farm	Outlet	Farm	Outlet	Farm
-Christianson coefficient	0.97	1	0.97	1	0.97	1
-Inter-quartile ratio	0.96	1	0.96	1	0.96	1
-Modified Inter-quartile ratio	0.94	1	0.94	1	0.94	1
-Coefficient of variance	0.06	0	0.06	0	0.06	0
-Theils index	-0.03	-5.84	-0.03	-5.93	-0.03	-6.21
Adequacy	0.10		0.48		0.26	
Excess	0.00		0.01		0.00	

1.5. Coimbatore (AESR 8.1)

1.5.1. Assessment of water availability in the Kugalur distributary of LBP command area and to devise interventions for matching water supply with the integral production systems and demand

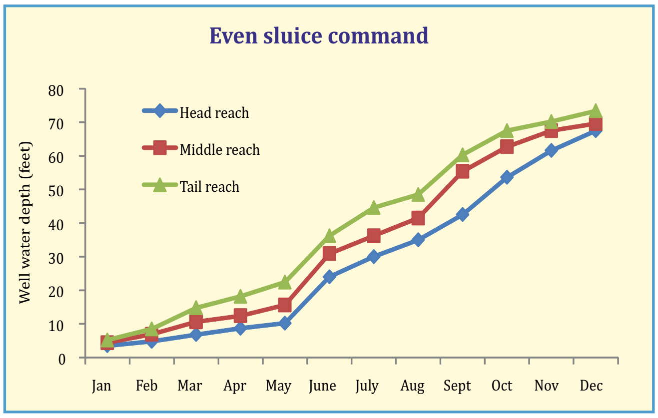
Kugalur distributary of Lower Bhavani Project (LBP) reservoir was selected to reconciliate the supply and demand of water in the outlets and to study the physical and chemical properties of soils in the command area from January-December 2016. Out of total ayacut area under odd turn, 978.84 ha cropped area was chosen. Out of the total ayacut area under even turn 632.86 ha cropped area were chosen. Average water discharge in the selected distributary for irrigated crops during dry season was 66.83 cusec which is 80.71% of relative water supply (RWS) (Table 1.5.1a). In the study area of 978.84 ha in odd turn sluice command, sugarcane, banana, turmeric, tapioca, maize, sorghum, groundnut, vegetables, coconut, cotton and mulberry were cultivated with 47.7% cropped area and 52.3% fallow. In the study area of 632.86 ha in even turn sluice command, sugarcane, banana, rice, turmeric, tapioca, maize, sorghum, groundnut, gingelly, vegetables, coconut, cotton and mulberry were cultivated with 50.2% cropped area and 49.8% fallow (Table 1.5.1a). Soil water and wellwater properties analysed are shown in Table 1.5.1b. Water table depths in the wells in head, middle and tail reaches ranged from 2.4 to 62.8, 2.9 to 68.6 and 3.4 to 74.2 feet, respectively (Fig. 1.5.1).

Table 1.5.1a. Discharge, relative water supply (RWS) and consolidated cropped area from January to December 2016 in sluice command of Kugalur distributary

Reach	Discharge (cusec)	RWS (%)	In odd turn sluice command		In even turn sluice command	
			Cropped area (ha)	Fallow (ha)	Cropped area (ha)	Fallow (ha)
Head	66.83	80.71	147.4	89.8	139.4	122.0
Middle			131.4	120.6	81.3	100.1
Tail			188.4	301.3	97.0	93.0

Table 1.5.1b. Soil water and wellwater properties during January to December 2016 in sluice command of Kugalur distributary

Reach	Soil properties			Available nutrients in soil (kg/ha)			Properties of well water						
	pH	EC (dS/m)	BD (Mg/m^3)	N	P	K	pH	EC (dS/m)	CO_3^{2-} (me/l)	HCO_3^- (me/l)	Ca (ppm)	Mg (ppm)	TSS (ppm)
Head	7.0	0.21	1.21	226	12.5	353	7.6	0.57	1.50	2.78	5.92	4.92	373
Middle	6.9	0.32	1.35	232	12.0	327	7.4	0.56	1.51	2.99	5.96	4.00	357
Tail	7.1	0.26	1.31	187	10.6	288	7.4	0.71	2.08	2.40	6.02	3.85	327



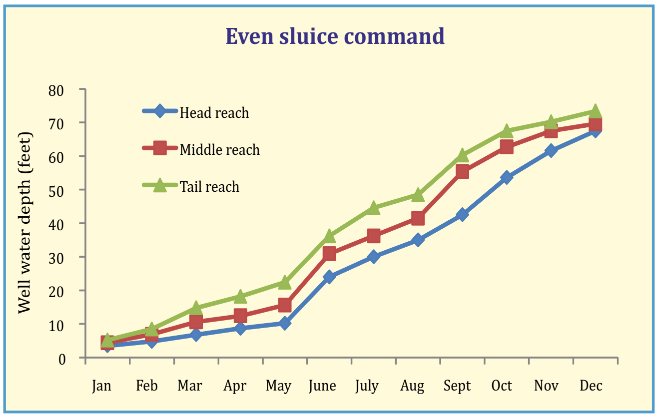


Fig. 1.5.1. Water depth in selected wells in odd and even sluice command

1.5.2. Assessment of soil fertility status and temporal changes of soil properties in Arumbanur tank command through GIS technique

Temporal variation in soil physiochemical properties was studied to assess the impact of agrotechnologies in i) system tank in the village of Andaman and ii) Mathur tank command area. Random soil samples were collected with GPS coordinates, analysed and soil fertility maps were prepared. The GIS software was also used to estimate the area falling under different classes of available nutrients.

Temporal variation of soil fertility in Mathur tank: Soil was alkaline in Mathur east and west tanks due to continuous dry climate coupled with fertilizer usage. This resulted in increase in soil pH compared to year 2000. Electrical conductivity (EC) showed an alarming rise due to continuous use of fertilizers and other agrochemicals in soil. Since 2000, SOC has declined due to very low application of organic manure or green leaf manure or lack of cultivation green manuring crops. About 88% samples in east and 84% samples in west tank showed low available N due to volatilization, low application of organic manure and high uptake by rice crop. On the other hand, liberal use of P (mostly in form of DAP) and K fertilizers enhanced the availability of P and K in the soils. Iron content showed slight reduction, but Mn and Cu were almost same compared to year 2000. Zinc content drastically declined due to continuous cultivation of rice with the application of major nutrients, no application of Zn fertilizer, high level of P and alkalinity in the soil.

Temporal variation of soil fertility in Andaman tank: Almost 90% of the soil samples showed neutral pH; minimum increase in pH was noticed compared to the year 1998. During 2016, EC of soil was within safe limits, with slight salinity in some areas. But there was high rate of increase in the EC since 1998, due to the continuous use of fertilizers and other agrochemicals. Similar to Mathur tank, SOC and available N showed decline over the years and available P and K increased over the years. Micronutrients like Fe, Cu and Mn showed slight decrease compared to year 1998. But similar to Mathur tank, Zn also showed a sharp decline (Table 1.5.2).

Table 1.5.2. Temporal variation in soil fertility status of Mathur tank (2000 vs. 2016) and Andaman tank (1998 vs. 2016)

Property/ Nutrient	Fertility status in Mathur tank						Fertility status in Andaman Tank		
	Year 2016				Year 2000		Year 2016		Year 1998
	East tank		West tank		East tank	West tank			
	Min	Max	Min	Max	Mean	Mean	Min	Max	Mean
pH	8.8	9.5	9.2	9.7	9.1	9.2	7.8	8.9	8.2
EC (dS/m)	0.45	1.29	0.73	1.19	0.42	0.46	0.55	1.24	0.45
OC (%)	0.23	0.59	0.26	0.59	0.41	0.45	0.23	0.57	0.43
Available N (kg/ha)	108	305	114	352	186	192	108	316	176
Available P (kg/ha)	10.4	34.8	10.6	31.5	18.0	18.0	12.8	28.3	11.2
Available K (kg/ha)	107	295	97	303	146	134	256	481	298
Available Fe (ppm)	3.7	18.9	4.1	15.5	8.2	8.4	4.6	12.7	9.6
Available Mn (ppm)	1.58	5.53	1.24	6.21	3.23	3.55	2.62	6.93	4.26
Available Cu (ppm)	0.67	2.59	0.86	2.64	1.41	1.61	0.89	2.54	1.67
Available Zn (ppm)	0.76	2.62	0.62	2.58	1.53	1.67	0.75	1.86	1.52

1.6. Madurai (AESR 8.1)

1.6.1. Characterization of municipal wastewater for irrigation in Madurai

The study was conducted to assess the quantity of wastewater (sewage) generated in Municipal Corporation of Madurai, characterize raw and treated wastewater at different discharge points to assess the suitability and irrigation potential of treated wastewater for raising crops. Sewage water was collected from eleven collection points in north and south zones of Madurai. Both raw and treated sewage effluents were analysed at Avaniapuram and Sakkimangalam sewage treatment plants (STP). Twenty five surface soil and 23 subsurface soil samples were collected from Avaniyapuram and Sakkimangalam sewage farms, respectively (Plate 1.6.1). Colour of the sewage water was light brown/ black to dark brown/ black in raw condition but changed to light yellow/yellow after treatment at both the STPs for all the seasons. This might be due to the filtration of suspended solids and oxygenation. The samples also became odourless or had slight odour. Temperature of the sewage waters increased after treatment at both the STPs, might be due to digestion of organic compounds during oxygenation process. Alarming level of total soluble solids (TSS) in raw sewage (more than 300 mg/l) dropped within permissible limit (around 10 mg/l) in treated sewage. Turbidity also reduced in the treated sewage, with limited values of 0-1 NTU as compared to the raw sewage (6-14 NTU). Changes in other physical properties along with chemical and biological properties in both STPs are shown in Table 1.6.1a and 1.6.1b. In raw sewage water, concentration of heavy metals was higher with addition of large quantities of effluents due to movement of fertilizers, agricultural ashes and industrial effluents (Table 1.6.1c). Despite the negative effects of sewage in soil, its application to soil was identified as a carbon building/sequestrating and soil quality sustaining practice. Sewage irrigated soils recorded higher available N, P and K indicating a low grade cheap fertilizer as a substitute to chemical fertilizer. This can markedly reduce the cost of cultivation. As EC was normal to slightly saline, it was anticipated that cultivation of crops will not be a problem even after continued application of the sewage water. But long-term irrigation with contaminated sewage effluents from urban sources resulted in accumulation of heavy metals (Pb, Ni, Cd and Cr) in the plough layer of agricultural soils.

Plate 1.6.1. Wastewater collection at sewage plant and soil sampling from sewage irrigated farm soil (2016-17)

Table 1.6.1a. Properties of raw and treated sewage water analyzed at Avaniyapuram sewage treatment plant (STP)

Season	Physical properties				Chemical properties														Heavy metals							
	TSS (mg/l)		Turbidity (NTU)		pH		EC (dS/m)		OC (%)		TDS (g/l)		NO_3-N (mg/l)		P (mg/l)		K (mg/l)		DO (mg/l)		BOD (mg/l)		COD (mg/l)		TC (mg/l)	
	RS	TS	RS	TS	RS	TS	RS	TS	RS	TS	RS	TS	RS	TS	RS	TS	RS	TS	RS	TS	RS	TS	RS	TS	RS	TS
SW monsoon (June-Sep)	316	9	14	2	7.2	8.1	1.8	1.9	2.4	1.9	1.2	1.3	50	43	21	9	0.7	0.7	0	2.9	252	9	484	79.1	39	19
NE monsoon (Oct-Dec)	351	8	12	1	7.5	7.7	1.6	1.8	4.4	2.8	1.1	1.2	47	41	13	6	0.9	0.9	0	2.5	315	7	458	54.0	28	12
Winter (Jan-Feb)	343	12	8	1	7.3	7.5	2.2	2.3	5.6	3.9	1.5	1.5	43	35	19	7	1.2	1.0	0	3.6	224	11	441	68.2	16	8
Summer (Mar-May)	382	10	7	0	7.9	8.3	2.3	2.4	7.7	5.3	1.5	1.6	87	81	24	11	1.6	1.4	0	2.7	286	9	517	94.0	9	2

RS- Raw sewage water, TS- Treated sewage water, SW- South west, NE- North east, TSS- Total soluble solids, TDS- Total dissolved solids, TC-Total coliforms

Table 1.6.1b. Properties of raw and treated sewage water analyzed at Sakkimangalam STP

Season	Physical properties				Chemical properties														Biological properties							
	TSS (mg/l)		Turbidity (NTU)		pH		EC (dS/m)		OC (%)		TDS (g/l)		NO_3-N (mg/l)		P (mg/l)		K (mg/l)		DO (mg/l)		BOD (mg/l)		COD (mg/l)		TC (MPN/ 100ml)	
	RS	TS	RS	TS	RS	TS	RS	TS	RS	TS	RS	TS	RS	TS	RS	TS	RS	TS	RS	TS	RS	TS	RS	TS	RS	TS
SW monsoon (June-Sep)	320	10	12	1	7.1	8.1	1.9	2.0	2.0	1.6	1.2	1.3	48	41	17	8	0.7	0.7	0	2.8	260	8	480	80.0	34	12
NE monsoon (Oct-Dec)	360	9	11	1	7.5	7.6	1.6	1.8	4.0	2.3	1.0	1.2	42	38	11	4	0.9	0.8	0	2.5	310	7	458	55.0	27	9
Winter (Jan-Feb)	356	11	8	0	7.2	7.3	2.2	2.3	4.3	3.1	1.4	1.5	42	35	15	6	1.0	1.0	0	3.4	230	10	456	64.0	11	6
Summer (Mar-May)	390	10	6	0	8.0	8.2	2.3	2.4	7.2	4.6	1.4	1.5	96	84	21	9	1.1	1.0	0	2.7	290	9	504	96.0	7	2

RS- Raw sewage water, TS- Treated sewage water, SW- South west, NE- North east, TSS- Total soluble solids, TDS- Total dissolved solids, TC-Total coliforms

Table 1.6.1c. Traces of heavy metals in raw and treated sewage water analyzed at Avaniyapuram and Sakkimangalam STPs

Avaniyapuram STP								Sakkimangalam STP							
Pb (mg/l)		Ni (mg/l)		Cd (mg/l)		Cr (mg/l)		Pb (mg/l)		Ni (mg/l)		Cd (mg/l)		Cr (mg/l)	
RS	TS	RS	TS	RS	TS	RS	TS	RS	TS	RS	TS	RS	TS	RS	TS
15.9	3.29	0.7	0.3	0.7	0.2	0.5	0.2	16.1	3.2	0.7	0.4	0.6	0.2	0.5	0.1
17.0	3.81	0.4	0.2	0.8	0.5	0.6	0.3	17.2	3.5	0.5	0.3	0.8	0.4	0.7	0.2
18.2	4.22	0.3	0.1	1.3	0.7	0.7	0.3	18.3	4.1	0.3	0.2	1.1	0.7	0.8	0.4
19.8	4.64	0.2	0.1	1.4	0.8	0.9	0.5	19.5	4.5	0.3	0.1	1.4	0.8	1.0	0.5

RS- Raw sewage water, TS- Treated sewage water

1.7. Jabalpur (AESR 10.1)

1.7.1. Mathematical modelling of groundwater and neural network modelling for water table fluctuations

Water table fluctuation from 2005 to 2015 was studied using artificial neural network (ANN) for Hoshangabad district of Madhya Pradesh. It is located between river Narmada in the north and Satpura forest in the south. The region has predominantly alluvial sand and gravel and/or alluvial silty sand and gravel. Hydraulic conductivity of the aquifer (Narmada basin) exhibited a large spatial variability (65 to 804 m/day), suggesting considerable heterogeneity in the upper Narmada basin (UNB). The overall flow of groundwater in the basin is from south to north towards Narmada, with significant river-aquifer interaction in large portion of the basin. Seven sites were selected based on long term availability of daily water table data and continuity of the data at individual site. Four statistical indicators *viz.*, bias, RMSE, MAE and NSE were used to examine performance of the ANN models for both training (2005-2012) and testing (2012-2015) periods.

Statistical analyses of model prediction showed that NSE (highest accuracy at 1.0) varied from 0.86 (Site B) to 0.95 (Site A), RMSE from 0.77 (Site B) to 0.95 (Site C) and MSE from 0.59 (Site G) to 0.97 (Site B). Low value of MSE indicated less error. It was found that increasing the neuron decreased MSE value (i.e. increased performance). Similarly, increasing layers from 2 to 3 also improved model prediction. Values of bias during training and testing of the models were negative in most of the sites (except Site C and Site D), which indicated over-prediction of the water table by the ANN model (Fig. 1.7.1a). MLP neural network architecture was used for predicting monthly water table fluctuations in the study area considering relevant meteorological and hydrological input variables. ANN model was found to be efficient for predicting monthly water tables at almost all the sites. Thus ANN technique can be used for forecasting water table fluctuation, especially in regions where sufficiency and quality of field data are serious issues for groundwater management. Total surface water available for the UNB is 2694755 ha-m, where major contributors are Seoni (16%), Shahdol (13.6%), Hoshangabad (12.8%) and Mandla (10.9%). Total available groundwater is 7337750 ha-m, with major contributors Narsinghpur (15.8%), Seoni (9.7%) and Shahdol (8.8%) (Fig. 1.7.1b). Total addition to soil moisture due to rainfall is 2244684 ha-m, comprising 65.5% of surface water and groundwater. Total evaporation loss from the UNB is 820216 ha-m that is 16.9% of the total available water resources. Water balance showed that all the districts have surplus water. Five districts have more than double and two districts (Mandla and Umaria) have three-fold excess water (Fig. 1.7.1b). Rice, soybean, wheat and gram are major crops, soybean being the dominant one using nearly 45% of total crop water requirement in the basin i.e. 3326267 ha-m.

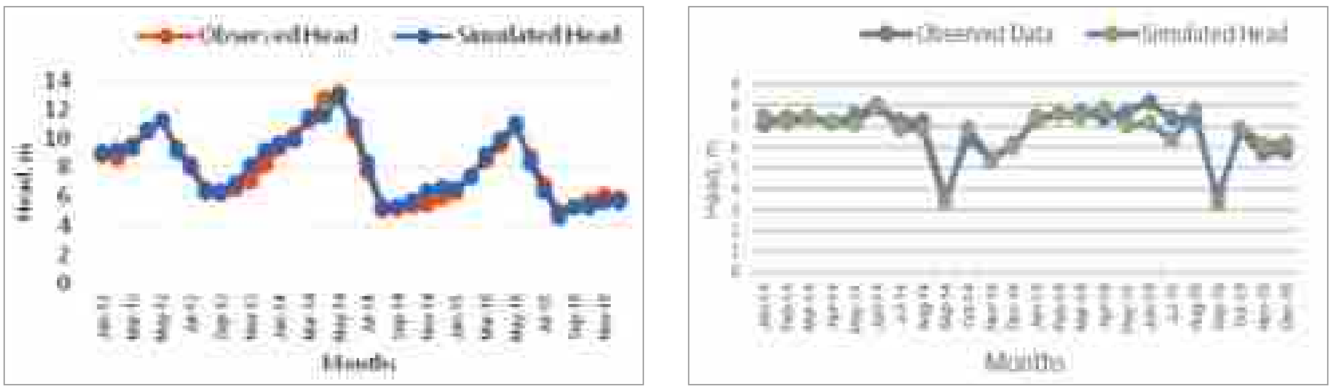


Fig. 1.7.1a. Observed and Simulated water heads using ANN model at Site A (left) and Site D (right) for training (2013-2015) period

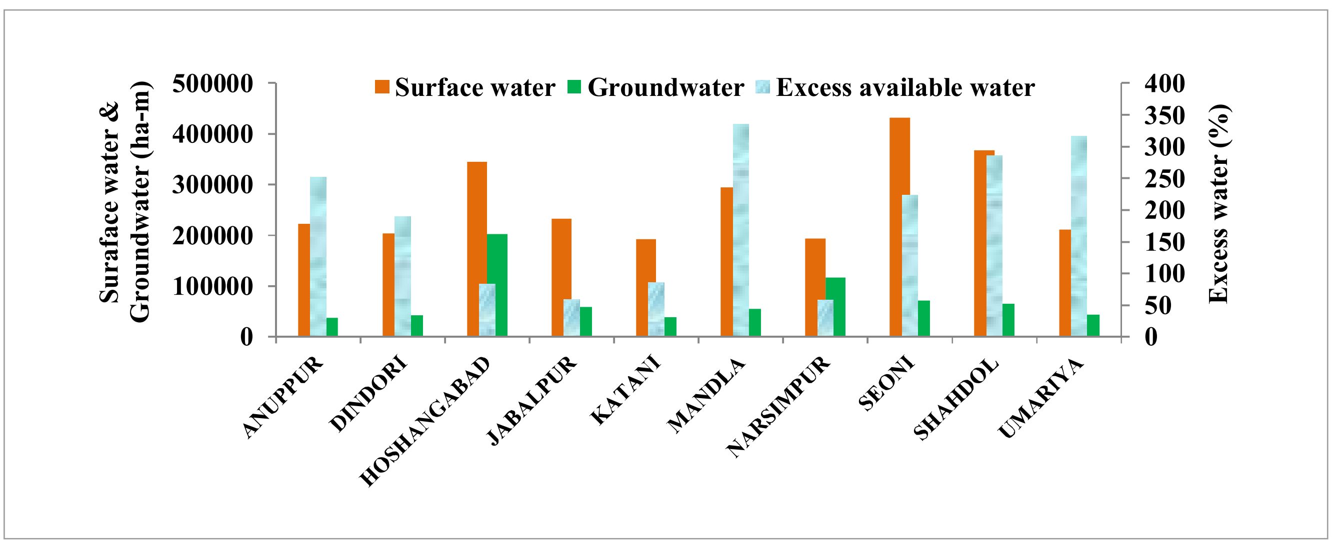


Fig. 1.7.1b. Surface water, groundwater availability and excess water in various districts

1.8. Raipur (AESR 11.0)

1.8.1. Studies on aquifer parameters and effect of climate change on groundwater availability in the Kharun watershed

Analysis of the trend of groundwater draft was done in Kharun sub basin using long term meteorological data from 2001 to 2010. The data reflected linear trend between rainfall and pre-monsoon groundwater level. But analyses of the trends of long term temperature, water level fluctuation and rainfall data of the study area showed no trend between the meteorological and hydrological data. Then population of Raipur district comprising of four blocks (Dharsiwa, Abhanpur, Arang and Tilda) was compared with average groundwater fluctuation to identify the impact of anthropogenic effect on groundwater draft. It was observed that growth in population and utilization of groundwater for civil construction in Naya Raipur (Abhanpur block) resulted in increase in groundwater fluctuations (Fig. 1.8.1) in the Kharun watershed. This explained the exponential use of the groundwater in the region. Data of number of tubewells during 2001 and 2011 may also help us better understanding of the use of groundwater along with increase in the population in the study area.

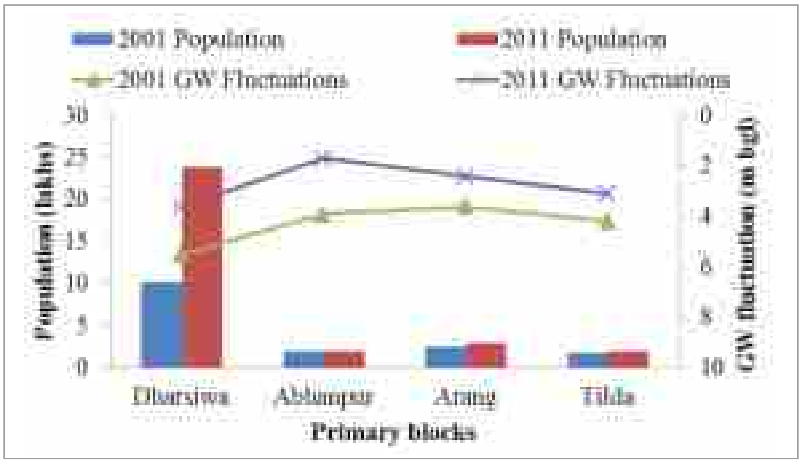


Fig. 1.8.1. Block-wise comparison of population and groundwater (GW) fluctuation of Kharun watershed for years 2001 and 2011

1.9. Jammu (AESR 14.2)

1.9.1. Optimization of land and water resources of Tawi - Lift canal command area of Jammu for rice-wheat sequence

Irrigation infrastructure of the canal command area (18,000 ha) of Tawi-Lift canal (TLIC) was benchmarked and performance indicators (Table 1.9.1) were evaluated for Basmati and coarse rice grown during *kharif* season and wheat (covering 80 to 90% of farmers' area) and other crops grown during *rabi* season. Relative water supply (RWS) and relative irrigation supply (RIS) were less by 65% and 70%, respectively at tail end reach of TLIC. This is because water was not supplied through Ravi feeder canal from Punjab into distributary D-11 to D-9. As a result, water productivity of rice-wheat crop sequence in the area was severely affected. Performance indicators indicated that there was significant difference in production, water supply and water use in the head, middle and tail reaches. They also indicated scope for improvement if command area development works are accelerated in participatory mode for efficient on farm water management.

Table 1.9.1. Performance indicators of Tawi-Lift canal command area of Jammu

Properties	Reach	Water duty (ha/m^3)	Actual water duty (ha/m^3)	Inference
	Head	716	1218	-
	Middle	401	1221	
	Tail	657	1218	
Output per unit command (Rs./ha)	**Reach**	**Output/command (Rs./ha)**	**Maximum output per command (Rs./ha)**	The indicator was 24% less in middle and 58% less in tail compared to the head reach
	Head	56258	95798	
	Middle	42452	90515	
	Tail	23074	74914	

Output per unit cropped area (Rs./ha)	**Reach**	**Output/cropped area (Rs./ha)**	**Maximum output per unit cropped area (Rs./ha)**	The indicator was 13% less in middle and 34% less in tail compared to the head reach
	Head	70323	119748	
	Middle	60653	119748	
	Tail	46148	119748	
Gap between cropped to actual command (%)	**Reach**	**Gap between cropped to actual command (%)**	**Gap per unit command to maximum potential yield per command (%)**	**Gap per unit irrigable command to maximum potential yield per irrigable command (%)**
	Head	20.0	41.2	41.2
	Middle	30.0	53	49
	Tail	46.0	69	61
Output per unit water consumed (Rs./m^3)	**Reach**	**Volume of water consumed in ET m^3)**	**Output per unit water consumed (Rs./m^3)**	Production value per unit of water consumed in head reach is > 13.7% than mid reach and 34.2 % than tail reach.
	Head	35899360	7.3	
	Middle	43283600	6.3	
	Tail	48171080	4.8	
Output per unit irrigation supply	**Reach**	**Diverted irrigation supply (m^3)**	**Output per unit irrigation supply (Rs./m^3)**	Higher value of this indicator in the tail reach indicates lower irrigation supply by 9% & 22% over head reach and middle reach.
	Head	42063840	6.2	
	Middle	51184224	5.3	
	Tail	34145280	6.8	
Water delivery capacity	**Reach**	**Peak consumptive demand (m^3/day)**	**Water delivery capacity**	Indicator values >1 showed no difficulty in meeting short term peak demands
	Head	402657	1.40	
	Middle	554897	1.41	
	Tail	864481	1.51	
Relative water supply	**Reach**	**Crop demand (m^3)**	**Relative water supply**	In head, middle and tail reach, RWS needs to be improved by 9%, 18% and 65%, respectively to meet the crop demand
	Head	44874200	0.91	
	Middle	61840600	0.82	
	Tail	96342160	0.35	
Relative irrigation supply	**Reach**	**Irrigation demand (m^3)**	**Relative irrigation supply**	In head, middle and tail reach, RWS needs to be improved by 18%, 28% and 70%, respectively to meet the crop demand
	Head	51205000	0.82	
	Middle	70565000	0.72	
	Tail	109934000	0.31	

1.10. Jorhat (AESR 15.4)

1.10.1. Integrated approach using remote sensing and GIS techniques for mapping of groundwater prospects in Jorhat district, Assam

RS&GIS was used as a tool for groundwater (GW) prospect mapping for Jorhat district (285200 ha) to demarcate potential GW resource during pre-monsoon season. The study was completed with area-wise GW potential information for the district in form of maps. Out of 336 geo-referenced GW potential zones recorded from 56 villages of the district covering eight blocks (Fig. 1.10.1), pre-monsoon water table depths ranged from 2.22 to 17.58 m bgl (Table 1.10.1). Maximum area of 73950 ha was observed under water table depth of 6.16-6.82 m bgl and minimum area of 7834 ha was under water table depth of 4.20-4.95 m bgl. Based on the depth of GW resource, selection of pump suitable for lifting water and possibility of using such pumps to irrigate unit area were also prepared in the form of maps. Out of the total geographic area of the district, 51023 ha was demarcated with GW table within 5.0 m depth while the rest showed a depth of more than 5.0 m. Accordingly, decision was taken on installation of suitable pump sets. Regarding water table depth during post-monsoon season, maximum area of 115632 ha was observed under 3.44-4.11 m bgl category, while minimum area of 19878 ha was noticed in 4.11-8.78 m bgl category. It was estimated that if 50% of the water resource available from the difference in water table depths recorded during pre- and post-monsoon periods was utilized, then potential water resource available for instant water use for different purposes across the district would be about 9219.26 m^3.

Table 1.10.1. Details of GW potential zones in Jorhat district identified using RS&GIS

1	2	3	4
0.07 - 2.24	879.45	1.16	1020.16
2.24 - 3.15	743.09	2.71	2013.77
3.15 - 4.31	593.74	3.73	2214.65
4.31 - 5.80	486.72	5.06	2462.80
5.80 - 14.57	149.00	10.12	1507.88
Total	2852.00	-	9219.26

1- Category of pre-monsoon GW table depth (m bgl)
2- Area under each category of No.1 (m^2)
3- Average GW table depth (m) for pump sets
4- Potential water resource available for water use during pre-monsoon season (m^3)

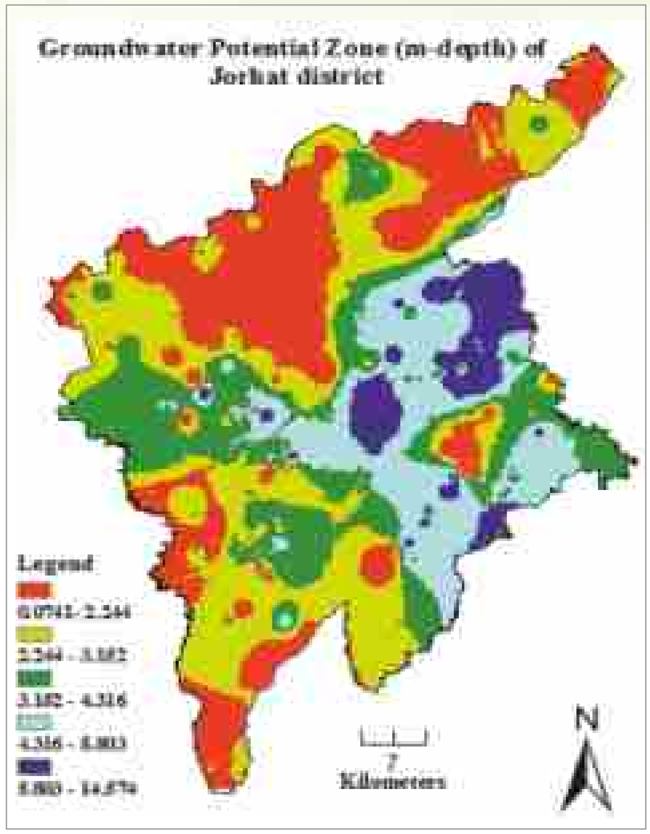


Fig. 1.10.1. GW potential zones identified in Jorhat district

1.10.2. Optimal cropping pattern for Moran Gaon deep tubewell command

An attempt was made to work out the optimal cropping pattern in Moran Gaon deep tubewell command, to achieve the national objective of self-sufficiency in agricultural production. The capacity of the scheme vis-à-vis cropping pattern is presented in Table 1.10.2. Results showed that tubewells have sufficient capacity to sustain a wide range of cropping pattern in the study area (Fig. 1.10.2). However, farmers of the region are yet to use the potential of tubewell.

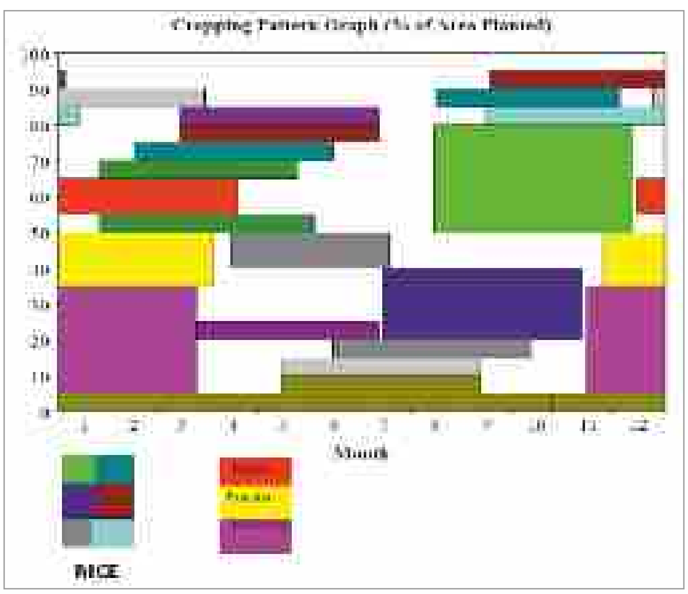


Fig. 1.10.2. Possible cropping pattern in Morangaon Irrigation project command area

Table 1.10.2. Status of irrigation scheme in Moran Gaon deep tubewell command

Month	Irrigation requirement (l/s/ha)	Scheme total (cumec)	Capacity of tubewell (cumec)	Status	Comment
January	0.23	0.00460	0.04167	0.20	Sufficient
February	0.34	0.00681	0.04167	0.29	Sufficient
March	0.38	0.00764	0.04167	0.33	Sufficient
April	0.16	0.00314	0.04167	0.13	Sufficient
May	0.34	0.00681	0.04167	0.29	Sufficient
June	0.43	0.00860	0.04167	0.37	Sufficient
July	0.54	0.01078	0.04167	0.46	Sufficient
August	1.16	0.02314	0.04167	0.99	Sufficient
September	0.12	0.00244	0.04167	0.10	Sufficient
October	0.09	0.00184	0.04167	0.08	Sufficient
November	0.13	0.00265	0.04167	0.11	Sufficient
December	0.10	0.00199	0.04167	0.08	Sufficient

1.11. Chalakudy (AESR 19.2)

1.11.1. Survey and intervention studies in Left Bank Canal of Chalakudy river

The study was conducted to assess water availability, work out water budgeting and device interventions for matching water supply and demand for Koratty branch of K.V. main branch of Left Bank Canal of Chalakudy Irrigation Project. Areas covered under head reach, middle reach and tail reaches were demarcated and water flow in each sector was measured using float method. The area consists of 31 branch canals of Chalakudy river with ayacut area of 5597 ha. During 2016, relative water supply (RWS) in the head, middle and tail reaches was 1.02, 0.94 and 0.43, respectively (Table 1.11.1). Major crops grown in the head reach are vegetables, banana, coconut, arecanut and nutmeg. Canal water supply in the tail reach was very less and sometimes observed no flow. Rubber is the major crop grown in the tail reach because it can resist drought. In many areas of the tail reach, gap between supply and demand of irrigation water caused scarcity, forcing majority of the farmers keep their lands fallow during summer months. Thus it was ***recommended*** to raise pulses, oilseeds and drought tolerant varieties of vegetable in the area for efficient and economic use of water in rice fallows.

Table 1.11.1. Relative water supply along Koratty branch canal

Canal reach	Area covered (ha)	Canal water diverted (ha-cm)	Effective rainfall (ha-cm)	Total water supply (ha-cm)	Water requirement (ha-cm)	Relative water supply (RWS)
Head	40.4	3691	711.1	4402.1	4321.7	1.02
Middle	42.9	3919	754.5	4673.5	4935.5	0.94
Tail	37.7	1140	663.5	1803.5	4205.1	0.43

Theme 2

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

Under Theme 2, the centres have successfully demonstrated that suface irrigation methods can be modified such that less was is applied to crop without compromising yield and economic returns. Similarly, various methods of micro-irrigation using surface drip, sub-surface drip, sprinkler, mini-sprinkler, oozing pipe were used to grow low water requiring crops like pulses, etc. to high water consuming crops like sugarcane, rice, banana, etc. to have more crop per drop. Most of the crops performed well with increase in yield and economic returns compared to the traditional practices.

2.1. Hisar (AESR 2.3)

2.1.1. Demonstration on mini-sprinkler, FIRBS and FIRBS-drip in wheat

Comparative assessment of mini-sprinkler with wetting diameter of 6 m, FIRBS (3 rows of wheat on bed) with drip, FIRBS without drip and conventional method of irrigation was done in wheat. It was observed that least amount of water (35.1 cm) was applied for FIRBS with drip, followed by mini-sprinklers (37.2 cm) and FIRBS without drip (39.8 cm). Water consumption was highest (44.2 cm) for conventional method. Grain yield of 6.63 t/ha, irrigation water productivity of 3.58 kg/m^3 were highest under FIRBS with drip (Table 2.1.1).

Table 2.1.1. Performance of wheat under varying methods of irrigation

Irrigation method	Yield (t/ha)	Irrigation water (cm)	IWP (kg/m^3)	TWP (kg/m^3)	Net return ('000 Rs./ha)	B:C
Mini-sprinkler	6.22	20.8	2.99	1.67	35.0	1.45
FIRBS	6.29	21.6	2.91	1.58	43.2	1.61
FIRBS-Drip	6.63	18.5	3.58	1.89	37.3	1.45
Conventional	5.61	23.8	2.36	1.27	30.4	1.43

Rainfall=3.0 cm, IWP-Irrigation water productivity, TWP-Total water productivity

2.2. Sriganganagar (AESR 2.1)

2.2.1. Irrigation scheduling for *kharif* planted brinjal and *Bt* cotton under plastic mulch

Brinjal: Three years of experimentation (2013 to 2016) with *kharif* brinjal showed that fruit yield of 66.54 t/ha in drip irrigated raised bed with plastic mulch (PM) was statistically higher than yield obtained in raised bed without plastic mulch (WPM), but statistically similar with yield in flat bed with PM (65.73 t/ha) (Table 2.2.1). In case of irrigation scheduling, brinjal yield of 67.36 t/ha with irrigation applied at 1.0 ET_c was significantly higher than yields obtained with 0.4 ET_c and 0.6 ET_c, but statistically similar to yield with 0.8 ET_c treatment (66.65 t/ha). Total water use for drip at 0.8 ET_c with PM was 550 mm against 797 mm for surface irrigation (at IW/CPE 1.0) and 623 mm for 1.0 ET_c WPM. Thus drip at 0.8 ET_c with PM gave 12.2% higher fruit yield over the surface irrigation method, with net income of Rs.7,32,916 and incremental B:C ratio of 2.43. Drip at 0.8 ET_c also saved 34.1% irrigation water over surface irrigation and 15.7% over drip irrigation at 1.0 ET_c WPM. Thus it was ***recommended*** to grow *kharif* brinjal with drip irrigation scheduled at 0.8 ET_c and 30 micron bicolour (grey and black) plastic mulch.

Cotton: Three years of experimentation (2013 to 2016) with cotton var. Bioseed-6588 showed that raised bed with PM gave significantly higher seed cotton yield (3.12 t/ha) compared to rest of the treatments with PM and WPM (Table 2.2.1). Yield of 3.06 t/ha was recorded with treatment 0.8 ET_c, which was significantly higher than yields with 0.4 and 0.6 ET_c, but statistically similar to yield with 1.0 ET_c (3.08 t/ha). Drip irrigation at 0.8 ET_c with PM on raised bed gave 8.3% higher seed cotton yield and saved 12.6% irrigation water compared to drip irrigation at 1.0 ET_c WPM (Control). The treatment gave WEE of 5.11 kg/ha-mm against 3.84 kg/ha-mm with control. It was the most remunerative treatment with net seasonal income worth Rs.86,374 and B:C ratio of 1.65. Thus it was ***recommended*** to irrigate *Bt* cotton with drip at 0.8 ET_c on raised bed with bicolour plastic mulch.

Table 2.2.1. Effect of mulching and irrigation scheduling on performance of *kharif* brinjal and *Bt* cotton

Treatment	Water applied (mm)		Yield (t/ha)		WEE (kg/ha-mm)		Net income (Rs.)		B:C	
	Brinjal	Cotton	Brinjal	Cotton	Brinjal	Cotton	Brinjal	Cotton	Brinjal	Cotton
Irrigation schedule										
0.4 ET_c (PM)	243.82	222.28	58.65	2.48	148.33	5.31	696533	45925	1.99	1.29
0.6 ET_c (PM)	316.73	300.03	62.39	2.82	132.76	5.55	706215	82944	2.15	1.57
0.8 ET_c (PM)	389.65	377.82	66.65	3.06	122.47	5.11	732916	86374	2.43	1.65
1.0 ET_c (PM)	462.57	455.58	67.36	3.08	109.07	4.47	674596	74833	2.09	1.62
Control-Flood at IW/CPE 1.0 (PM)	636.67	-	59.31	-	76.85	-	556090	-	-	-
Control-Drip at 1.0 ET_c (WPM)	462.57	472.26	68.84	2.88	111.76	4.02	737595	86033	3.83	2.06
$CD_{0.05}$	-	-	3.60	0.16	-	-	-	-	-	-

Mulching treatment effects on yield

Crop	Raised bed with PM	Raised bed WPM	Flat bed with PM	$CD_{0.05}$	$CD_{0.05}$ (Control/Mulch)
Kharif brinjal	66.54	59.03	65.73	3.12	4.93
Bt cotton	3.12	2.67	2.79	0.14	0.21

PM-Plastic mulch, WPM-Without plastic mulch

2.2.2. Transplantation of cotton under drip and surface irrigation

Cotton crop var. Bioseed-6588 sown in different dates showed that water use in 15th May direct sown crop was 755.70 mm with WEE of 3.69 kg/ha-mm against water use of 744.62 mm and WEE of 3.65 kg/ha-mm in 30th May transplanted crop (Table 2.2.2). Transplanted cotton crop with drip irrigation on 30th May, 10th June and 20th June gave 15.4, 24.2 and 47.0% higher seed cotton yield over drip irrigated direct sown crop on these dates, respectively. It was observed that WEE decreased with delay in sowing as well as transplanting. Net seasonal incomes for drip irrigated *Bt* cotton crop transplanted on 30th May, 10th June and 20th June were Rs.86,589, Rs.66,289 and Rs.43,437/ha with B:C ratios of 1.95, 1.73 and 1.48, respectively against seasonal income of Rs.1,00,591/ha and B:C ratio of 2.24 for drip irrigated crop with direct sowing on 15th May. It was concluded that when timely sowing of rice is not possible due to canal closure or some other reason, seedlings of *Bt* cotton can be raised in plastic bags and transplanted in field up to 30th May (instead of 15th May) with drip irrigation to avoid yield loss.

Table 2.2.2. Performance of late sown cotton crop due to canal closure

Treatment	Irrigation water applied (mm)	Total water use (mm)	Seed cotton yield (t/ha)	WEE (kg/ha-mm)
15th May Direct Sowing (Drip)	476.03	755.70	3.13	3.69
30th May Direct Sowing (Drip)	464.95	744.62	2.65	3.16
30th May Transplant (Drip)	464.95	744.62	3.06	3.65
30th May Transplant (Flood)	560.00	839.67	2.46	2.64
10th June Direct Sowing (Drip)	425.02	704.15	2.18	2.80
10th June Transplant (Drip)	425.02	704.15	2.71	3.38

10th June Transplant (Flood)	533.33	812.47	2.18	2.40
20th June Direct Sowing (Drip)	415.52	680.38	1.58	2.16
20th June Transplant (Drip)	415.52	680.38	2.32	3.02
20th June Transplant (Flood)	450.00	746.79	1.92	2.40
$CD_{0.05}$	-	-	0.19	-

Effective rainfall = 279.67 mm; Total water use=Irrigation+Rainfall

2.3. Morena (AESR 4.4)

2.3.1. Effect of planting methods, irrigation scheduling and method of irrigation on paddy-mustard cropping system in alluvial soil

Different establishment methods of *kharif* paddy crop showed that conventional method of transplanting by puddling resulted in significantly higher yield of 4.55 t/ha compared to conventional sowing (4.21 t/ha) and direct seeding (4.17 t/ha); although water productivity (WP), net return and B:C ratio were lowest with transplanting. Also, water use was highest in case of transplanting (7730 m^3) compared to conventional sowing and direct seeding. Among the irrigation scheduling methods, maximum grain yield of 4.54 t/ha, WP of 0.67, net return of Rs.41501/ha and B:C ratio of 2.29 were observed with sub-surface irrigation (SSI) at 1.25 IW/CPE with fertigation. These results were statistically similar to those obtained with SSI at 1.0 IW/CPE with fertigation and surface drip irrigation at 1.25 IW/CPE with fertigation (Table 2.3.1, Plate 2.3.1).

Table 2.3.1. Effect of establishment methods and irrigation scheduling on performance of paddy under paddy-mustard sequence in alluvial soil

Treatment	Grain yield (t/ha)	Net return (Rs./ha)	B:C	Total water use (m^3/ha)	Water productivity (kg/m^3)
Method of establishment					
Conventional transplanting	4.55	37296	2.02	7730	0.589
Direct seeding	4.17	41074	2.55	6820	0.612
Conventional sowing	4.21	37713	2.24	6929	0.607
$CD_{0.05}$	0.10	-	-	-	
Irrigation scheduling					
Traditional method of irrigation	4.16	33867	2.01	8650	0.480
SDI at 1.0 IW/CPE with fertigation	3.99	34599	2.15	6633	0.601
SDI at 1.25 IW/CPE with fertigation	4.44	40293	2.27	7025	0.632
SSI at 1.0 IW/CPE with fertigation	4.42	41147	2.35	6480	0.682
SSI at 1.25 IW/CPE with fertigation	4.54	41501	2.29	6730	0.675
$CD_{0.05}$	0.15	-	-	-	-

SSI: Sub-surface drip irrigation; SDI: Surface drip irrigation; Total water use=Irrigation+Rainfall

Plate 2.3.1. Paddy just after transplanting and at maturity under drip irrigation

2.4. Junagadh (AESR 5.1)

2.4.1. Evaluation of hydraulic performance of oozing pipe irrigation

The experiment was conducted in Junagadh region having well-drained calcareous medium black soil with clay texture (Plate 2.4.1). The objective was to study the discharge emitted through unit length of porous oozing pipe at different distances from inlet for various input pressure heads. Field capacity and infiltration rate of the soil were estimated to be 23.77% and 1 cm/h, respectively. Source of water was borewell. Static water level and steady state pumping water level during the experiment were 10 m and 15 m below ground surface, respectively. A submersible pump of 80 mm x 7.5 hp x 6 stages was used for pumping water with discharge of 10 litres per second. An underground PVC pipe was used for conveying water from bore well to the experimental site. A screen filter (200 micron) was used to filter water for irrigation. A pressure gauge was fitted before and after the filter to measure the pressure of the filtered water. A bypass assembly was used to regulate the flow. A pipe of 63 m x 4 kg/cm^2 was used as main/sub-main pipe to convey water from filter unit to 16 mm LDPE lateral (Length=1 m) connected with sub-main by grommet take off. The oozing pipes were installed and kept open on level open semicircular channel made of PVC. The experimental layout with different length of oozing pipes is shown in Fig. 2.4.1a. Results showed that pressure head drastically dropped in the initial 0-20 m length of the oozing pipe, but the head loss was very less beyond 20 m. In case of 30, 45 and 60 m long oozing pipes, pressure head was more or less similar for input pressure heads of 2, 4 and 6 m (Fig. 2.4.1b). Observations on emitting characteristics of the oozing pipe showed that emitting or discharge rate decreased with distance from inlet. Average emitting rates of 3.13, 6.53 and 8.06 litres per hour per metre (lph/m) were observed in 30 m long oozing pipe at input pressure heads of 2, 4 and 6 m, respectively. Average emitting rates of 6.53, 5.67 and 4.12 lph/m were found at input pressure head of 4 m for 30, 45 and 60 m long oozing pipes, respectively (Fig. 2.4.1c).

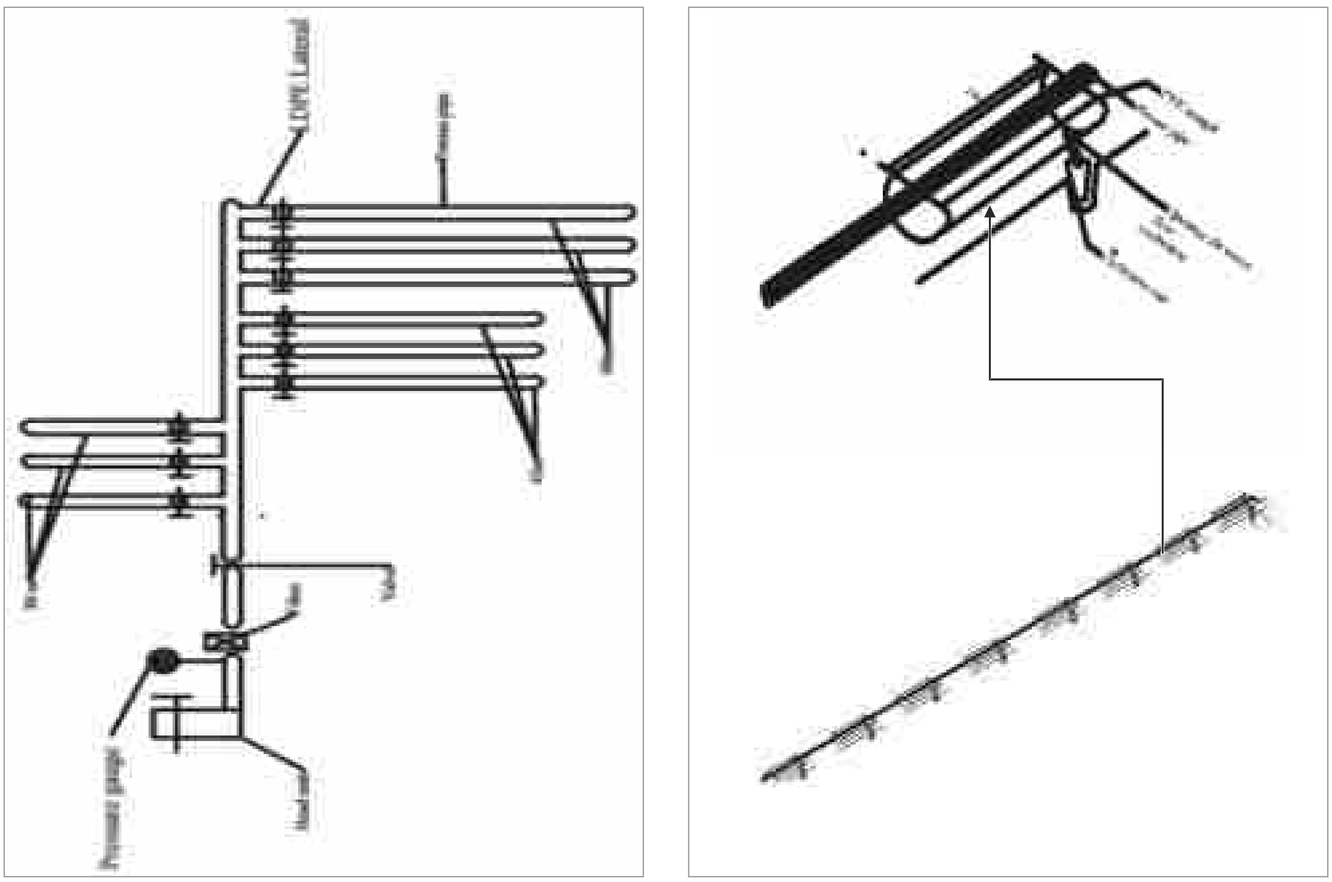


Fig. 2.4.1a. Experimental layout (left and rotated) and schematic diagram of semicircular pipe with oozing pipe and collector cans (right)

PVC trough (75 mm pipe) cut into semi-circular halves

Placement of oozing pipe on PVC trough (trough length-1 m)

Arrangement for emitting rate measurement

Collection of water from PVC trough

PVC troughs placed at 5 m interval along oozing pipe

Checking joints of the arrangements

Close view of water emitting oozing pipe

Pressure head measurement using digital manometer

Pressure head measurement in field

Wetting pattern at 6 m head after 1 hour

Wetting pattern towards the tail of oozing pipe

Measurement of surface wetting pattern

Plate 2.4.1. Installation and measurement of water emission through oozing pipe arrangement

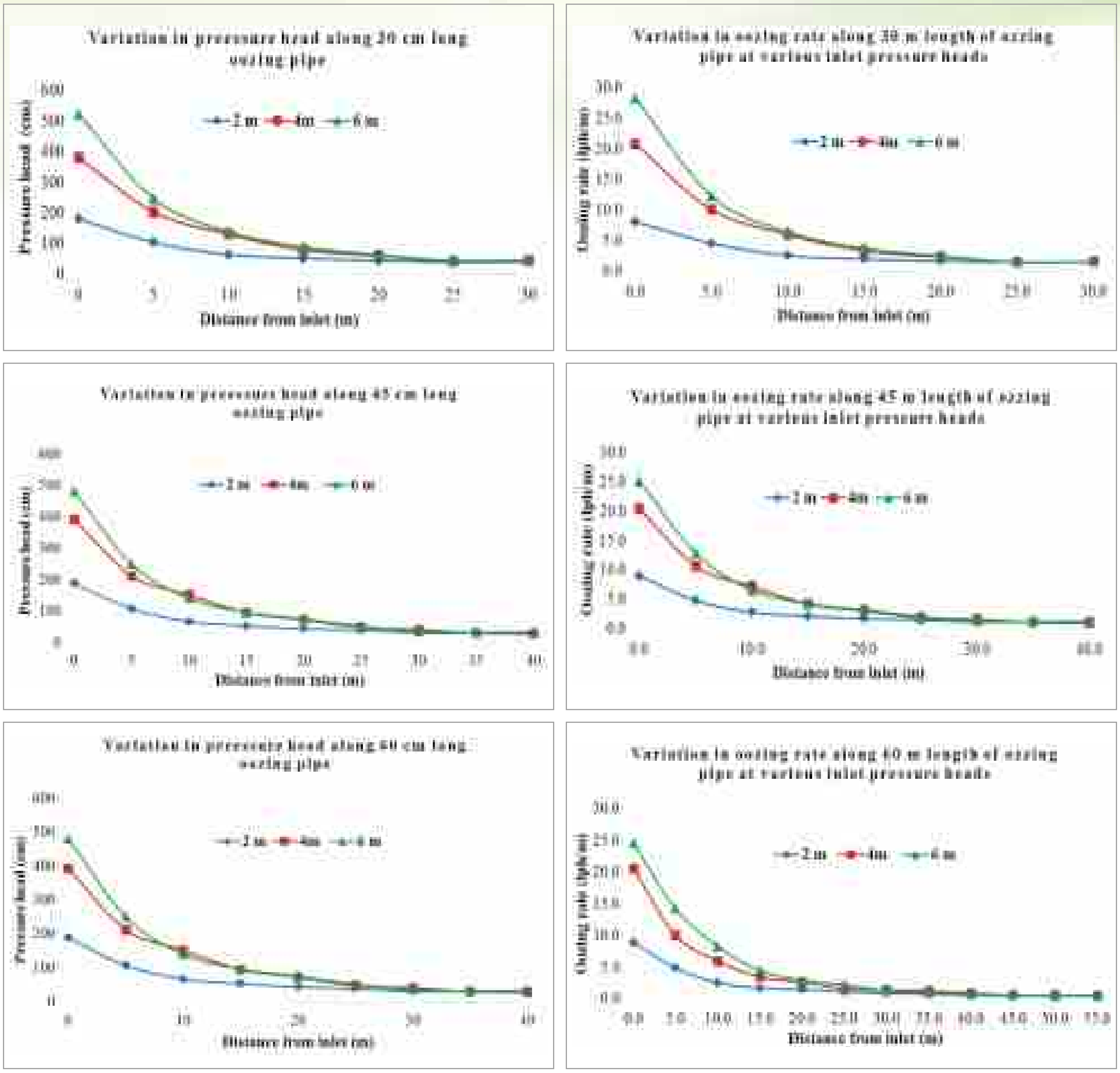


Fig. 2.4.1b. Variation in pressure head and discharge rate along lengths of oozing pipes

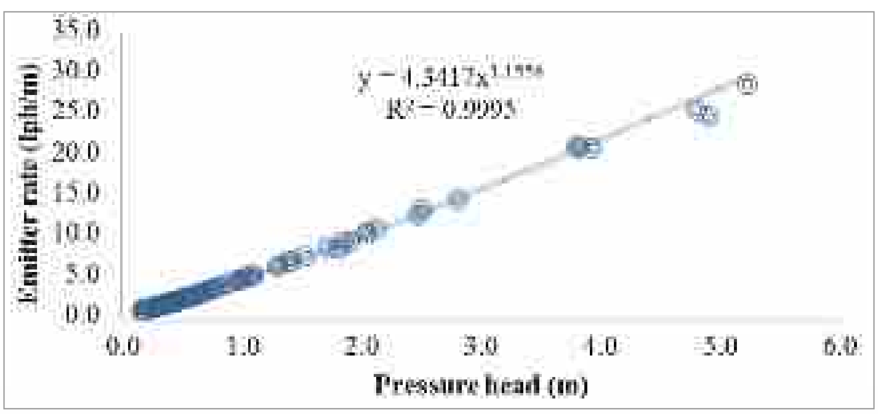


Fig. 2.4.1c. Relationship between pressure head and discharge rate of emitter

2.5. Kota (AESR 5.2)

2.5.1. Performance evaluation of sprinkler irrigation and nutrient management on the productivity of pea-okra in S-E Rajasthan

Pea: Three years (2014-15 to 2015-16) of study with pea crop showed that yield was highest under sprinkler irrigation at IW/CPE 1.0 (1.97 t/ha) and 125% of RDF (1.84 t/ha). Effect of irrigation treatment was not significant on yield due to rainfall events during the experiment period. Fertility levels did not have significant effect on yield, but there was slight increase in yield with increase in the dose. Maximum WUE 8.0 kg/ha-mm was observed with IW/CPE=0.8 (Table 2.5.1).

Okra: Two years of trial (2015 and 2016) with okra crop showed that yield of 13.26 t/ha was significantly higher under sprinkler irrigation at IW/CPE 1.0 followed by 11.5 t/ha obtained with irrigation at IW/CPE ratio of 0.8. There was water saving of 18.3% and 35.5% with irrigation at IW/CPE 1.0 and IW/CPE 0.8, respectively compared to surface irrigation. Maximum WUE of 19.54 kg/ha-mm was obtained with irrigation at IW/CPE 0.8. Between the fertilizer levels, yield was significantly higher (12.43 t/ha) with 125% RDF than 100% RDF (Table 2.5.1). WUEs for interaction effect of IW/CPE 0.8 and 125% RDF were significantly higher for pea (8.09 kg/ha-mm) and okra (20.06 kg/ha-mm) among the interaction effects of the treatments.

Table 2.5.1. Performance of pea in pea-okra cropping system under sprinkler irrigation

Treatment	Yield (t/ha)		Depth of irrigation (mm)		WUE (kg/ha-mm)		Net return (Rs./ha)		B:C	
	Pea	Okra	Pea	Okra	Pea	Okra	Pea	Okra	Pea	Okra
Irrigation schedule										
Surface Irrigation	1.73	10.16	260	840	6.95	14.42	24232	100355	2.28	2.97
IW/CPE=0.8	1.87	11.50	228	620	8.00	19.54	21519	93226	1.85	2.17
IW/CPE=1.0	1.97	13.26	240	710	7.68	17.06	24044	119656	1.95	2.51
$CD_{0.05}$	NS	1.29	-	-	-	-	-	-	-	-
Fertility level										
100% RDF	1.81	11.79	-	-	7.46	16.56	-	-	-	-
125% RDF	1.84	12.43	-	-	7.59	17.46	-	-	-	-
$CD_{0.05}$	NS	1.11	-	-	-	-	-	-	-	-

WUE-Water use efficiency, NS-Non-significant

2.6. Belavatagi (AESR 6.4)

2.6.1. Evaluation of irrigation levels to different sunflower based cropping systems under pressurized (drip) method of irrigation

During *kharif* 2016, sunflower var. Sunbred-293 grown with drip irrigation at 1.0 ET_o recorded significantly higher yield of 2.34 t/ha compared to yield (1.85 t/ha) with farmers' method of applying flood irrigation at critical growth stages. Amount of water applied for drip at 1.0 ET_o was 463.5 mm compared to 594.3 mm applied through flood, i.e. there was 28.2% water saving. Equivalent yields and economic returns from the cropping system of sunflower during *kharif* and intercrop of chickpea (JG-11), wheat (UAS-334) and groundnut (DH-101) during *rabi* are shown in Table 2.6.1. Sunflower and *rabi* crops *viz.*, wheat grown with drip at 0.6 ET_o, chickpea grown with drip at 0.9 ET_o and groundnut grown with drip at 0.8 ET_o are shown in Plate 2.6.1.

Table 2.6.1. Performance of sunflower in *kharif* and wheat, chickpea and groundnut in *rabi* under sunflower based cropping system as influenced by drip irrigation in Malaprabha command area during 2015-16

Treatment interaction#	Sunflower eqv. yield (t/ha)	Wheat eqv. yield (t/ha)	Chickpea eqv. yield (t/ha)	Groundnut eqv. yield (t/ha)	Net return (Rs./ha)	B:C
M_1S_1	2.48	4.73	2.48	2.31	80,994	4.51
M_1S_2	2.01	2.01	1.05	0.98	18,541	1.72
M_1S_3	2.55	5.21	2.73	2.55	69,130	2.52

M_2S_1	2.21	4.22	2.21	2.06	69,752	4.02
M_2S_2	1.85	1.85	0.97	0.91	15,233	1.77
M_2S_3	2.33	4.77	2.50	2.33	59,395	2.31
M_3S_1	2.00	3.81	2.00	1.87	60,834	3.63
M_3S_2	1.62	1.62	0.85	0.79	10,169	1.40
M_3S_3	2.00	3.93	2.14	2.00	44,410	1.98
$CD_{0.05}$	0.34	0.51	0.27	0.25	11,107	0.40

#M: Main strip plot, S: Sub-strip plot; Drip irrigation to sunflower at 1.0 ET_0 (M_1), 0.8 ET_o (M_2), Critical growth stages (M_3); S_1- Chickpea with drip at 0.6 ET_o, S_2- Wheat at 0.9 ET_o, S_3- Groundnut at 0.8 ET_o; eqv.- equivalent


Plate 2.6.1. Sunflower at flowering stage under drip irrigation (Left). Intercropping of rabi crops under drip irrigation after harvest of sunflower (Right)

2.7. Parbhani (AESR 6.2)

2.7.1. Response of drip irrigated turmeric to different levels of irrigation and fertigation

Three years of experiment (2014 to 2017) with turmeric var. Salem showed that higher fresh rhizome yield of 32.91 t/ha, WUE of 33.18 kg/ha-mm, net monetary return (NMR) of Rs.3,54,090/ha and B:C ratio of 3.34 were obtained with irrigation at 0.8 PE during three consecutive years (Table 2.7.1). Among fertigation levels, rhizome yield of 34.04 t/ha, WUE of 32.12 kg/ha-mm, NMR of Rs.3,55,624/ha were highest with 120% RDF through drip; lowest being with soil application of 100% RDF (RDF-200:100:100). Benefit-cost ratio for fertigation levels was highest with 80% RDF through drip (3.19), although at par with 120% RDF through drip (3.16). Thus, 40% fertilizer saving was observed every year compared to 120% RDF. It was ***recommended*** that alternate day in-line drip irrigation may be scheduled at 80% CPE for turmeric crop planted on 1.5 m wide raised bed with paired row planting (45 x 15 cm). Drip fertigation with NPK 160:80:80 may be applied to the crop, with N in five doses @ 17.5% in equal splits at an interval of 30 days from 30 to 150 DAP and sixth dose of N @ 12.5% at 180 DAP. Both P_2O_5 and K_2O may be applied in three splits of 50%, 25% and 25%, at the time of planting, 60 DAP and 120 DAP, respectively.

Table 2.7.1. Pooled performance of turmeric under drip irrigation scheduling and fertigation (2014 to 2017)

Treatment	Irrigation water (mm)	Rhizome yield (t/ha)	WUE (kg/ha-mm)	NMR (Rs./ha)	B:C
Irrigation level					
I_1: Irrigation at 0.6 PE	417.7	26.64	31.68	260285	2.77
I_2: Irrigation at 0.8 PE	553.7	32.91	33.18	354090	3.34
I_3: Irrigation at 1.0 PE	689.5	31.28	27.64	329590	3.20
I_4: Irrigation at 1.2 PE	825.4	29.76	23.40	306342	3.06
$CD_{0.05}$	-	2.12	-	27214	-

Fertigation level					
F_1: RDF through soil application	621.6	24.68	23.29	246636	2.87
F_2: 60% RDF through drip	621.6	28.04	26.44	287769	3.03
F_3: 80% RDF through drip	621.6	31.21	29.38	328299	3.19
F_4: 100% RDF through drip (NPK 200:100:100)	621.6	32.77	30.89	344231	3.18
F_5: 120% RDF through drip	621.6	34.04	32.12	355624	3.16
$CD_{0.05}$	-	2.79	-	37381	-
$CD_{0.05}$ (I x F)	-	NS	-	NS	-

Mean rainfall (2014 to 2017)=458.3 mm; NS-Non-significant; NMR: Net monetary return

2.7.2. Water management in soybean-chickpea cropping system through sprinkler irrigation

Three years of experimentation (2014-2017) showed that sprinkler irrigation (SI) at different growth stages of soybean var. MAUS-71 did not have significant effect on its seed yield. But seed yield of chickpea var. Akash (BDNG-797) was significantly higher with SI at grand growth (GGS), flowering (FS) and pod formation stages (PFS) (Table 2.7.2). Although amount of water applied under SI and flood irrigation (FI) treatments at GGS, FS and PFS was same i.e. 240 mm, the respective increase in chickpea yield with SI was 19.4%, 19.3%, 30.8% and 25.4%, compared to FI. There was also increase in net monetary return and benefit-cost ratio with SI to chickpea crop. Sprinkler irrigation at FS and PFS of chickpea also fetched 45.3% and 47.7% higher WUE, respectively compared to FI. Thus it was ***recommended*** to apply two irrigations of 60 mm depth each at flowering stage and pod formation stage of chickpea through sprinkler method for obtaining higher yield and economic return from soybean-chickpea cropping system.

Table 2.7.2. Pooled performance of soybean-chickpea cropping system under sprinkler irrigation (2014 to 2017)

Treatment	Seed yield (t/ha)		WUE (kg/ha-mm)	NMR (Rs./ha)	B:C
	Soybean	Chickpea	Chickpea	Chickpea	Chickpea
T_1 : SI at GGS	1.28	1.50	12.47	37536	2.70
T_2 : SI at FS	1.32	1.60	13.35	41074	2.84
T_3 : SI at PFS	1.34	1.67	13.95	43682	2.94
T_4 : SI at GGS+FS	1.34	1.78	9.89	48081	3.14
T_5 : SI at GGS+PFS	1.46	1.87	10.38	50842	3.19
T_6 : SI at FS+PFS	1.42	2.05	11.39	57813	3.46
T_7 : SI at GGS+FS+PFS	1.41	2.17	9.05	62121	3.58
T_8 : FI at GGS+FS+PFS	1.35	1.75	7.30	42959	2.67
$CD_{0.05}$	NS	0.22	-	-	-

SI-Sprinkler Irrigation, GGS-grand growth stage, FS-flowering stage, PFS-pod formation stage, FI-Flood irrigation, NMR-net monetary return; NS-Non-significant

2.8. Rahuri (AESR 6.2)

2.8.1. Response of drip fertigation on growth, yield and quality of papaya

Harvest of papaya cv. Taiwan 786 for six months (16 pickings) showed that fruit yield of 183.27 t/ha was significantly higher in case of drip irrigation at 1.2 ET_c. The yield was statistically similar with drip irrigation at 1.0 ET_c (172.6 t/ha). The yield with irrigation at 1.2 ET_c increased by 40.3%, and yield with irrigation at 1.0 ET_c increased by 65.6% over the control treatment i.e. surface irrigation + RDF (250:250:500). But irrigation at 1.0 ET_c resulted in highest WUE of 2.53 t/ha-cm and water saving of 64.5%, followed by WUE of 2.69 t/ha-cm and water saving 68.5% with irrigation at 1.2 ET_c. After harvest of papaya, available N in soil was significantly higher with 1.2 ET_c (191.64 kg/ha) and 125% RDF (182.93 kg/ha) compared to 170.39 kg/ha in the control plot (Table 2.8.1).

Table 2.8.1. Performance of papaya in drip fertigation in papaya and available nutrients in soil

Treatment	Fruit yield (t/ha)	Irrigation water (cm)	WUE (t/ha-cm)	Water saving (%)	B:C	Available N (kg/ha)
Irrigation level						
I_1: 0.6 ET_c	103.55	24.61	2.17	77.81	1.13	164.81
I_2: 0.8 ET_c	135.26	32.81	2.42	72.52	1.39	172.13
I_3: 1.0 ET_c	172.60	41.02	2.69	68.50	1.65	183.28
I_4: 1.2 ET_c	183.27	49.22	2.53	64.47	1.72	191.64
$CD_{0.05}$	19.41	-	-	-	-	8.49
Fertigation level						
F_1: 75% RDF	116.31	36.91	1.94	70.51	1.44	171.43
F_2: 100% RDF	148.65	36.91	2.47	70.51	1.48	179.54
F_3: 125% RDF	181.05	36.91	3.01	70.51	1.51	182.93
$CD_{0.05}$	14.02	-	-	-	-	4.72
Control: Surface irrigation+RDF	87.50	180.00	0.43	-	1.68	403.20

2.9. Coimbatore (AESR 8.1)

2.9.1. Optimization of irrigation and fertigation schedule in turmeric under different lateral spacing and to study the moisture and nutrient movement in soil

Three years of experiment was conducted with turmeric var. BSR 2 grown in sandy loam soil during *kharif* seasons of 2013 to 2015. Goal of the study was to develop i) optimal drip irrigation and fertigation schedules for turmeric for different drip lateral spacings and ii) estimate the impact of the drip system on temporal and spatial distribution of soil water content (SWC) and N and K in soil. According to the results, moisture content showed a conventional increase with increase in depth i.e. from 0 - 15 cm to 15 - 30 cm. Available N and K in soil increased with distance from drip laterals in the treatments which received more irrigation water and higher fertigation levels i.e., I_1F_1, I_2F_1, I_4F_1 and I_5F_1. The reason may be that with increased application of water, N must have been pushed towards the outer periphery of the wetted diameter. In the treatments receiving less irrigation water and higher fertigation level, available N was higher near the laterals. Irrespective of irrigation levels and fertigation levels, available N and K were higher at 15-30 cm compared to 0-15 cm soil depth. This may be due to leaching of nutrients during percolation of water. Performance of turmeric is shown in Table 2.9.1. It was ***recommended*** that drip irrigation at 40% of PE with lateral spacing of 90 cm may be applied to the turmeric variety for lower water use and higher WUE. Secondly, drip irrigation at 80% of PE with lateral spacing of 90 cm and 100% RD of N and K through fertigation (I_1F_2) may be adopted for higher yield and economics.

Table 2.9.1. Performance of turmeric under different drip layouts, irrigation schedules and fertigation schedules

Treatment*	Yield (t/ha)	Net return (Rs.)	B:C	TWU (mm)	WUE (kg/ha-mm)
I_1F_1 (90 cm, 80% PE, 125 RD)	35.37	2,36,617	3.1	1076	34.4
I_1F_2 (90 cm, 80% PE, 100 RD)	40.40	2,76,373	3.7		
I_1F_3 (90 cm, 80% PE, 75 RD)	35.90	2,41,854	3.3		
I_2F_1 (90 cm, 60% PE, 125 RD)	35.85	2,39,772	3.1	918	39.6
I_2F_2 (90 cm, 60% PE, 100 RD)	38.89	2,66,139	3.5		
I_2F_3 (90 cm, 60% PE, 75 RD)	34.75	2,32,376	3.2		
I_3F_1 (90 cm, 40% PE, 125 RD)	33.39	2,20,192	2.9	760	43.8
I_3F_2 (90 cm, 40% PE, 100 RD)	34.82	2,33,852	3.1		
I_3F_3 (90 cm, 40% PE, 75 RD)	31.95	2,10,690	2.9		

I_4F_1 (150 cm, 120% PE, 125 RD)	35.09	2,39,545	3.3	1433	24.4
I_4F_2 (150 cm, 120% PE, 100 RD)	36.82	2,52,259	3.6		
I_4F_3 (150 cm, 120% PE, 75 RD)	33.20	2,25,292	3.3		
I_5F_1 (150 cm, 100% PE, 125 RD)	33.57	2,26,179	3.1	1283	25.6
I_5F_2 (150 cm, 100% PE, 100 RD)	34.28	2,31,053	3.3		
I_5F_3 (150 cm, 100% PE, 75 RD)	30.84	2,05,566	3.0		
I_6F_1 (150 cm, 80% PE, 125 RD)	30.80	2,01,372	2.8	1123	26.8
I_6F_2 (150 cm, 80% PE, 100RD)	31.88	2,09,032	3.0		
I_6F_3 (150 cm, 80% PE, 75 RD)	29.87	1,94,774	2.9		
I_7F_1 (150 cm, 60% PE, 125 RD)	28.13	1,77,600	2.5	970	29.2
I_7F_2 (150 cm, 60% PE, 100 RD)	29.86	1,90,312	2.7		
I_7F_3 (150 cm, 60% PE, 75 RD)	27.37	1,72,311	2.5		
$CD_{0.05}$					
I at F	3.82	-	-	-	-

*Drip irrigations at 40, 60, 80, 100 and 120% of PE; lateral spacings of 90 and 150 cm; fertigation levels of 75, 100 and 125% of recommended dose (RD) of N & K; TWU-Total water use

2.9.2. Evaluation of suitable irrigation and fertigation schedule and to study the moisture and nutrient movement for Sustainable Sugarcane Initiative (SSI) in sub surface drip irrigation for Western zone of Tamil Nadu

Main crop of sugarcane var. Co 86032 was grown in 2014 followed by two ratoon crops during 2015 and 2016. Soil samples were collected at three horizontal distances across drip laterals (0, 37.5 and 75 cm) and at two vertical distances (0-15 and 15-30 cm) from all the treatment plots. The samples were collected at germination, tillering, grand growth and ripening stages to analyse SWC, available N and available K. Analysis was done to study mobility of the nutrients at different irrigation and fertigation levels. For estimating SWC, samples were taken just before irrigation. Results showed that SWC decreased as horizontal distance across the laterals increased. Available N and available K increased with distance from the laterals in all treatments. It was also observed that nutrient contents were higher at 15-30 cm depth compared to 0-15 cm depth, which may be due to leaching during percolation of water. Available N was highest when sub surface drip irrigation (SSDI) was applied at 100% PE along with fertigation of 100% RD of N and K (T_1). Treatments T_1 (SSDI at 100% PE + 100% RD of N&K) and T_7 (SDI at 100% PE + 75% RD of N&K) showed significantly higher yields of 147.77 and 142.88 t/ha, respectively compared to other treatments, but statistically similar to each other. Treatments T_1 and T_7 also had similar WUEs, net return and B:C ratios (Table 2.9.2). Thus it was ***recommended*** that SSDI at 100% PE and fertigation with 100% RD of N and K may be applied for higher yield of Co 86032 and its economics under SSI for western zone of Tamil Nadu having sandy loam soil.

2.9.2. Pooled performance of sugarcane under surface and sub surface drip fertigation

Treatment	Cane yield (t/ha)	TWU (mm)	WUE (kg/ha-mm)	Net return (Rs./ha)	B:C
T_1 (SSDI 100% PE, 100% RD of N & K)	147.77	1566	97.9	209405	2.6
T_2 (SSDI 100% PE, 75% RD of N & K)	135.89	1566	90.1	183324	2.4
T_3 (SSDI 80% PE, 100% RDF)	134.08	1313	105.3	176075	2.4
T_4 (SSDI 80% PE,75% RDF)	125.07	1313	99.0	159936	2.2
T_5 (SSDI 60% PE,100% RDF)	115.25	1044	113.4	134319	2.0
T_6 (SSDI 60% PE,75% RDF)	112.85	1044	109.0	126507	2.0
T_7 (SDI 100%PE,100% RDF)	142.88	1570	94.2	197639	2.5
T_8 (SDI 100% PE,75% RDF)	118.00	1570	77.9	143396	2.1
$CD_{0.05}$	7.32	-	-	-	-

SSDI-Sub surface drip irrigation; SDI-Surface drip irrigation; Fertigation levels of 75 and 100% of recommended dose (RD) of N & K; TWU-Total water used (Irrigation + Rainfall)

2.10. Faizabad (AESR 9.2)

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

Drip irrigation at 60% PE with 100% recommended dose of N (I_5) resulted in significantly higher yield of beans (13.05 t/ha) and WUE (106.40 kg/ha-mm) over other treatments of drip and surface irrigations, except for treatments I_3, I_4 and I_6 (Table 2.10.1). It was inferred that N dose (100% and 75% of RDN) did not have significant effect on yield under drip irrigation. Rather it had significant effect on yield under surface irrigation. Surface irrigation treatment 0.8 IW/CPE with 75% RDN recorded lowest yield 7.87 t/ha and WUE 18.96 kg/ha-mm. Drip irrigation increased yield and WUE in water sensitive rajmash crop, thereby saving 57.83 to 78.92% irrigation water in comparison to surface irrigation.

Table 2.10.1. Performance of rajmash crop under drip and surface irrigation treatments during 2015-16

Treatment	Rajmash beans (t/ha)	WUE (kg/ha-mm)	Water applied (cm)	Water saved (%)
I_1- Surface irrigation (5 cm at 0.8 IW/CPE ratio) with 100% N	9.05	21.81	415.0	-
I_2- Surface irrigation (5 cm at 0.8 IW/CPE ratio) with 75% N	7.87	18.96	415.0	-
I_3- Drip irrigation @ 80% PE with 100% N	12.56	75.74	175.0	57.83
I_4- Drip irrigation @ 80% PE with 75% N	12.02	71.54	175.0	57.83
I_5- Drip irrigation @ 60% PE with 100% N	13.05	106.40	132.0	68.19
I_6- Drip irrigation @ 60% PE with 75% N	12.71	99.39	132.0	68.19
I_7- Drip irrigation @ 40% PE with 100% N	10.02	125.89	87.5	78.92
I_8- Drip irrigation @ 40% PE with 75% N	9.54	112.49	87.5	78.92
$CD_{0.05}$	1.12	-	-	-

2.11. Pantnagar (AESR 14.5)

2.11.1. Drip fertigation study in maize for green cob during spring season

Two years of field experiment (2015 and 2016) was conducted with spring maize var. Pant Sankul Makka-3 in sandy loam soil. The goal was to compare performance of the crop under flood and drip fertigations using randomised block design. Drip irrigations were applied at 60, 80 and 100% CPE. Nutrient levels were 75% and 100% RDF. P and K were applied in two ways- both applied in equal splits throughout the crop season or 70% P and 70% K applied up to tasseling stage and 30% of them applied thereafter. For control, flood irrigation was applied at IW:CPE 1.0 without mulch and at IW:CPE 0.80 with mulch. Pooled analysis of results revealed that application of 100% NPK produced significantly higher green cob yield over 75% NPK (Table 2.11.1). Splitting of P and K failed to cause significant variation in cob yield. Irrigation water saving was 40.5% (drip at 60% CPE), 21.3% (drip at 80% CPE), 1.8% (drip at 100% CPE) and 15.3% (flood at IW:CPE 0.8 with husk/mulch) compared to flood irrigation without mulch. Drip irrigation at 60 and 80% CPE recorded higher IWUE than flood irrigations with mulch and without mulch, highest (477 kg/ha-cm) being with drip at 60% CPE, and lowest (320 kg/ha-cm) with flooding without mulch (Table 2.11.1, Plate 2.11.1). It was concluded that spring maize needs to be drip irrigated at 100% CPE at two days interval. Application of 100% recommended dose of NPK i.e. 120:60:40 should be adopted. Application of P and K should be splitted, such that 70% is given up to tasseling stage and 30% thereafter.

Table 2.11.1. Performance of spring maize under drip irrigation

Treatment	Green cob weight (t/ha)		Mean irrigation depth (cm)	Water saving (%)	IWUE* (kg/ha-cm)
	with husk	without husk			
Moisture regime (drip treatment)					
CPE 60%	14.56	11.06	23.2	40.5	477
CPE 80%	15.14	12.26	30.7	21.3	399
CPE 100%	15.85	12.92	38.3	1.8	337
$CD_{0.05}$	0.50	0.58	-	-	-

NPK level					
75% NPK	14.98	11.79	30.7	-	384
100% NPK	15.39	12.36	30.7	-	403
CD$_{0.05}$	0.40	0.47	-	-	-
P & K splits					
Equal splits	15.00	11.81	30.7	-	385
70:30	15.36	12.35	30.7	-	402
CD$_{0.05}$	NS	NS	-	-	-
Surface flood (control)					
With mulch (IW:CPE 0.8)	15.22	12.95	33.0	15.3	392
No mulch (IW:CPE 1.0)	14.80	12.49	39.0	-	320

*Based on cob yield without husk; Husk was used as mulch; NS: Non-significant

Maize with surface flood irrigation

Maize with straw mulch @ 6 t/ha applied just after sowing

Maize with drip irrigation, 100% CPE, 100% NPK

Plate 2.11.1. Spring maize crop grown under conventional and water saving methods

2.12. Bilaspur (AESR 11.0)

2.12.1. Effect of different levels of irrigation and mulch on growth and yield of capsicum under drip environment

Capsicum var. Indra was grown with black, red, blue and transparent polythene mulches and paddy straw mulch under drip environment (Plate 2.12.1). Three years experimentation (2014 to 2017) showed that fruit yield of 4.78 t/ha with irrigation level 100% PE was significantly higher than yield with 80% PE. But WEE of 180.63 kg/ha-cm was higher with 80% PE. Mulching with 50 micron LLDPE black film resulted in significantly higher fruit yield of 5.91 t/ha and WEE of 259.55 kg/ha-cm followed by those with blue film (Table 2.12.1). Thus drip irrigation at 100% PE along with 50 micron LLDPE blue film mulch proved to be promising for Indra variety of capsicum grown in sandy loam soil of Bilaspur.

Table 2.12.1 Performance of capsicum under drip irrigation levels and mulching

Treatment	Fruit yield (t/ha)	Water expense efficiency (kg/ha-cm)
Irrigation level		
100% PE	4.78	180.63
80% PE	4.56	212.98
CD$_{0.05}$	0.11	-
Mulching		
No mulch	3.32	126.20
Mulch with 50 micron LLDPE black film	5.91	259.55
Mulch with 50 micron LLDPE red film	5.02	220.84
Mulch with 50 micron LLDPE Blue film	5.64	247.79
Mulch with 50 micron LLDPE transparent film	4.35	191.84
Mulch with organic material (paddy straw)	3.80	155.27
CD$_{0.05}$	0.63	-

Plate 2.12.1. Capsicum grown with drip and mulch

2.12.2. Effect of change of micro-environment on wheat crop by sprinkler irrigation

Wheat var. HD 2932 showed that grain yield of 2.94 t/ha was significantly higher under eight sprinkler irrigations applied after 12 mm CPE compared to other irrigation levels. The treatment also gave highest net profit of Rs.22649/ha and B:C ratio of 0.79. Foliar spray of bioregulator Tricontinol resulted in significantly higher yield of 2.84 t/ha compared to other biregulators. Use of Tricontinol also gave highest WEE of 93.70 kg/ha-cm, total income of Rs.49292/ha, net profit of Rs.21520/ha and B:C ratio of 0.77 (Table 2.12.2).

Table 2.12.2. Performance of wheat under sprinkler irrigation and bioregulators

Treatment	Yield (t/ha)	WEE (kg/ha-cm)	Total income (Rs./ha)	Net profit (Rs./ha)	B:C
Levels of irrigation*					
Sprinkler after 30 mm CPE	2.34	96.26	40672	13530	0.50
Sprinkler after 24 mm CPE	2.57	94.07	44778	17336	0.63
Sprinkler after 18 mm CPE	2.68	88.49	46973	19231	0.69
Sprinkler after 12 mm CPE	2.94	74.69	51291	22649	0.79
$CD_{0.05}$	0.35	-	-	-	-
Foliar spray of bioregulator					
KCl 0.2%	2.55	84.23	44599	16717	0.60
$CaCl_2$ 0.1%	2.50	82.58	43911	16339	0.59
Cytokinine/Tricontinol	2.84	93.70	49292	21520	0.77
$CD_{0.05}$	0.16	-	-	-	-

*Initially two common irrigations were applied by border strip method up to 50 days after sowing

2.13. Chiplima (AESR 12.1)

2.13.1. Effect of irrigation and mulching on yield and water use efficiency in banana

Performance evaluation of drip irrigation system with two and four emitters per plant showed that the irrigation system operated with very good uniformity and satisfactory emitter performance. Hence, the variations in yield of banana was little affected by drip irrigation system, but largely affected by the imposed treatments. Three years of experimentation showed that fruit yield at irrigation regimes 0.8 PE (34.21 t/ha) and 1.0 PE (36.69

t/ha) were statistically similar, but were significantly higher than yield (29.92 t/ha) under irrigation regime 0.6 PE (Table 2.13.1). Irrigation at 1.0 PE and paddy straw mulch showed highest net return of Rs.1,60,813 and Rs.1,59,138 and B:C ratio of 3.04 and 3.33, respectively among the treatments. Fruit yields with paddy straw and plastic mulch were statistically similar and significantly higher than the yield of control plot (30.81 t/ha). Interaction effect of irrigation and mulching was non-significant for all the three years. It was ***recommended*** that banana may be irrigated by drip irrigation system at 1.0 PE under paddy straw mulching for producing higher fruit yield and better economic return in fine textured soil of western Odisha.

Table 2.13.1. Pooled effect of irrigation and mulching on yield of banana (2013 to 2016)

Treatment	Irrigation water (mm)	Yield (t/ha)	IWP (kg/ha-mm)	Water saved (ha/mm-year)	Net return (Rs./ha)	B:C
Irrigation regime						
I_1: 0.6 PE	597.67	29.92	50.06	399.00	120979	2.74
I_2: 0.8 PE	797.33	34.21	42.91	199.33	146288	2.98
I_3: 1.0 PE	996.67	36.69	36.82	-	160813	3.04
$CD_{0.05}$	-	3.24	-	-	-	-
Mulching						
M_1: No mulch	797.33	30.81	38.78	-	126581	2.69
M_1: Paddy straw mulch	797.33	35.61	44.79	-	159138	3.33
M_2: Plastic mulch	797.33	34.41	43.29	-	142453	2.79
$CD_{0.05}$	-	2.54	-	-	-	-

IWP-Irrigation water productivity; Cost of pumping using diesel pump:Rs.16.32/ha-mm; Market price (banana):Rs.6,000/t

2.14. Pusa (AESR 13.1)

2.14.1. Performance of microirrigation system and mulch under organic farming conditions on papaya

Three years of trial (2011-12, 2012-13 and 2015-16) with papaya var. Red Lady showed that fruit yield of 168.62 t/ha, WUE of 8.16 t/ha-cm, net return of Rs.23,51,491/ha and B:C ratio of 13.2 were significantly higher with the interaction effect of drip irrigation at 100% PE and mulching (Plate 2.14.1) compared to interaction effects of other treatments (Table 2.14.1).

Table 2.14.1. Performance of papaya under different irrigation regimes and mulching

Treatment	Yield (t/ha)	WUE (kg/ha-mm)	Net return Rs./ha)	B:C
Interaction effect				
M_1I_1 (Drip with mulch x 100% PE)	168.62	8.16	2351491	13.22
M_1I_2 (Drip with mulch x 80% PE)	148.07	7.17	2043740	11.52
M_1I_3 (Drip with mulch x 60% PE)	119.49	5.78	1615556	9.14
M_1I_4 (Drip with mulch x 40% PE)	89.08	4.31	1159955	6.58
M_2I_1 (Drip without mulch x 100% PE)	155.44	7.52	2161452	12.70
M_2I_2 (Drip without mulch x 80% PE)	132.34	6.40	1815396	10.70
M_2I_3 (Drip without mulch x 60% PE)	107.20	5.19	1438939	8.70
M_2I_4 (Drip without mulch x 40% PE)	73.53	3.56	934532	5.55
M_3I_1 (Surface irrigation x 100% PE)	119.59	5.79	1621692	9.42
M_3I_2 (Surface irrigation x 80% PE)	110.62	5.35	1488070	8.69
M_3I_3 (Surface irrigation x 60% PE)	88.12	4.25	1151700	6.77
M_4I_4 (Surface irrigation x 40% PE)	61.00	2.95	745845	4.41
$CD_{0.05}$ (M x I)	6.79	0.33	101818	0.59

Drip irrigation with mulch in papaya

Drip irrigation in potato

Plate 2.14.1. Drip irrigation in papaya and potato

2.14.2. Comparative study of drip and surface irrigation methods on potato

The experiment was conducted for three years (2013-14 to 2015-16) to determine water requirement and water use efficiency of potato var. Kufri Ashoka (Plate 2.14.1) under in-line drip irrigation at different operating pressures. Pooled results revealed that tuber yield of 32.40 t/ha, net return of Rs.117396/ha and B:C ratio of 1.52 were significantly higher with in-line drip irrigation at different operating pressure of 1.6 kg/cm^2 compared to those with operating pressures of 1.2, 1.0, 0.8, 0.6 kg/cm^2 and the control (surface irrigation at IW/CPE ratio of 1.0), but statistically similar to those obtained with operating pressure of 1.4 kg/cm^2. Significantly higher WUE of 337.73 kg/ha-mm was obtained with operating pressure of 1.4 kg/cm^2 compared to other treatments, except 1.6 and 1.2 kg/cm^2 (Table 2.14.2). Tuber yields obtained with surface irrigation at IW/CPE 1.0 (25.27 t/ha) and drip irrigation at operating pressure of 1.0 kg/cm^2 (26.83 t/ha) were statistically similar. Among the treatments, surface irrigation showed significantly lowest yield, WUE, net return and B:C ratio.

Table 2.14.2. Performance of potato under drip and surface irrigation method

Irrigation treatment	Yield (t/ha)	WUE (kg/ha-mm)	Net return (Rs./ha)	B:C
I_1: Surface irrigation at IW/CPE 1.0 (Control)	25.27	142.92	67968	0.81
I_2: In-line drip at operating pressure 0.6 kg/cm^2	17.74	167.68	27814	0.33
I_3: In-line drip at operating pressure 0.8 kg/cm^2	21.15	208.16	48809	0.62
I_4: In-line drip at operating pressure 1.0 kg/cm^2	26.83	270.36	83300	1.07
I_5: In-line drip at operating pressure 1.2 kg/cm^2	28.70	296.00	94682	1.22
I_6: In-line drip at operating pressure 1.4 kg/cm^2	31.70	337.73	112821	1.46
I_7: In-line drip at operating pressure 1.6 kg/cm^2	32.44	334.75	117396	1.52
$CD_{0.05}$	2.12	43.12	12697	0.16

2.15. Almora (AESR 14.2)

2.15.1. Effect of irrigation scheduling on garlic

In this study, performance of garlic under drip irrigation, check basin method and farmers' practice were compared (Table 2.15.1). Mean yield of garlic (14.28 t/ha) and gross return (Rs.277700/ha) under drip irrigation at 1.0 CPE-R was higher compared to check basin irrigation (5.06 t/ha) and farmers' practice (6.03 t/ha). Lowest yield (3.83 t/ha) and WUE (15.4 kg/ha-mm) were obtained under check basin irrigation scheduled at 0.8 IW:CPE. Water use efficiency was highest with drip irrigation at 0.8 (CPE-R), followed by 1.0 (CPE-R).

Table 2.15.1. Performance of garlic under surface and drip irrigations at different levels

Treatment	Bulb yield (t/ha)	WUE (kg/ha-mm)	Gross return ('000 Rs./ha)	Gross return per mm applied water ('000 Rs./ha)
Drip				
0.4 (CPE-R)	6.92	36.3	134.5	1.07
0.6 (CPE-R)	10.27	41.1	199.8	1.06
0.8 (CPE-R)	12.54	46.0	243.9	0.97
1.0 (CPE-R)	14.28	43.4	277.7	0.89
CB at IW:CPE 0.8	3.83	15.4	74.6	0.37
CB at IW:CPE 1.0	6.29	22.2	122.4	0.49
Farmers' practice	6.03	27.4	117.2	0.65
Drip mean	11.00	41.7	214.0	1.07
Check basin mean	5.06	36.3	98.5	1.06
$CD_{0.05}$	3.54	13.6	68.9	0.34

Effective rainfall =93.2; CB-check basin

2.16. Jammu (AESR 14.2)

2.16.1. Evaluation of drip irrigation layout and irrigation effect on Tomato-Broccoli-Cauliflower

Local variety of tomato was grown with different drip layouts of drip during summer season of 2014 and 2016. Pooled results showed that irrigation at 0.75 PE recorded significantly higher yield (24.5 t/ha) of local variety of tomato over 0.25 PE but statistically similar to yield, fruit diameter and number of fruits per plant obtained with irrigation at 0.50 PE (Table 2.16.1). Total water applied under drip irrigation system with irrigation levels of 0.25, 0.50 and 0.75 PE was 224, 460 and 702 m^3, respectively as compared to 4000 m^3 for the control. Water saving under 0.25, 0.50 and 0.75 PE was 94.4, 88.5 and 82.4 l/ha, respectively over the control.

Table 2.16.1. Performance of tomato under drip irrigation levels and drip layouts

Treatment	Fruit Diameter (cm)	Fruit weight (g)	Yield (t/ha)
Spacing*			
S_1: 60x60-60x50 cm	16.25	58.18	23.72
S_2: 90x50-45x60 cm	17.60	60.98	25.27
S_3: 120x40-60x40 cm	13.80	53.17	19.95
$CD_{0.05}$	2.05	3.10	2.40
Irrigation levels			
I_1: PE=0.25	12.50	55.78	20.85
I_2: PE=0.50	15.90	57.91	23.60
I_3: PE=0.75	16.60	58.65	24.54
$CD_{0.05}$	1.00	1.25	1.30
Absolute control (IW:CPE=1.0)	11.20	50.30	15.70

*Spacing: Lateral x Dripper-(Row-Row) x (Plant-Plant)

2.17. Palampur (AESR 14.3)

2.17.1. Effect of drip irrigation and fertigation levels on yield and quality of potato in an acid Alfisol

The study was conducted to evaluate the effect of irrigation depth and NPK fertigation through gravity fed drip irrigation system on potato crop. Results showed that varying depth of irrigation from 0.4 PE to 0.8 PE did not affect tuber yield of potato. Irrigation WUE was significantly higher (137.60 kg/ha-mm) under 0.4 PE compared to other irrigation levels. On the other hand, increase in fertigation level from 50% to 75% of RDF resulted in significant increase of potato tuber yield by 22.0%, IWUE by 22.0%, net return by 47.5 and B:C ratio by 17.6% (Table 2.17.1). Further increase in fertigation level from 75% to 100% PE showed reduction in all the parameters. Yield, IWUE, net return and B:C ratio also increased by 17.1%, 81.7%, 28.5% and 7.6%, respectively under different combinations of drip irrigation and fertigation levels (named as 'Others') compared to recommended practice i.e. application of RDF (120:80:60) and surface irrigation (Table 2.17.1). Thus it was suggested to raise potato under drip irrigation with irrigation depth of 0.8 PE and fertigation with 75% of RDF.

Table 2.17.1. Performance of potato under drip fertigation in acid Alfisol

Treatment	Tuber yield (t/ha)	IWU (mm)	IWUE (kg/ha-mm)	Net return (Rs./ha)	B:C
Irrigation level (depth of irrigation)					
0.4 PE	18.93	138	137.60	95262	1.72
0.6 PE	20.93	206	101.42	119262	1.90
0.8 PE	21.13	275	76.82	121729	1.92
$CD_{0.05}$	NS	-	12.95	-	-
Fertigation level					
50% RDF	18.01	206	93.06	89299	1.70
75% RDF	21.97	206	113.51	131729	2.00
100% RDF	21.02	206	109.26	115225	1.84
$CD_{0.05}$	2.35	-	12.95	-	-
Recommended practice (RP) vs. Others					
RP	17.37	300	57.89	87235	1.72
Others	20.33	206	105.28	112084	1.85
$CD_{0.05}$	NS	-	16.70	-	-

2.18. Gayeshpur (AESR 15.1)

2.18.1. Effect of drip irrigation and nitrogen sources on yield, water use efficiency and quality of sweet corn

Three years of experimentation with sweet corn var. Sugar 75 (Hybrid) showed that both gravity drip irrigation at 1.0 ET_c and surface irrigation @ 50 mm depth (farmers' practice) resulted in highest cob yield of 6.91 t/ha which was superior to drip irrigation at 0.8 ET_c (6.22 t/ha) and 0.6 ET_c (5.41 t/ha). But unlike farmers' practice, only drip irrigation at 1.0 ET_c showed higher values of quality parameters like reducing sugar (6.42%), total sugar (20.70%) and total soluble solids (7.40%) in corn compared to other drip irrigation schedules and surface irrigation (Table 2.18.1b). Interaction of surface irrigation along with 75% inorganic N as fertilizer and 25% organic N as vermicompost (I_4N_2) recorded significantly higher cob yield of 8.43 t/ha (Table 2.18.1a). But maximum WUE of 36.01 kg/ha-mm was obtained with interaction of drip irrigation at 0.6 ET_c and 100% N as inorganic fertilizer (I_3N_1).

Table 2.18.1a. Effects of interaction of irrigation schedule and nitrogen management on performance of sweet corn

Treatment interaction	Cob yield (t/ha)	Total water use (mm)*	WUE (kg/ha-mm)
I_1N_1	6.72	245.66	27.35
I_1N_2	7.38	245.55	30.05

I_1N_3	6.88	245.51	28.02
I_1N_4	6.67	245.52	27.17
I_2N_1	6.13	203.12	30.19
I_2N_2	6.53	203.18	32.14
I_2N_3	5.88	203.19	28.92
I_2N_4	6.35	203.14	31.27
I_3N_1	6.05	168.05	36.01
I_3N_2	5.51	168.36	32.73
I_3N_3	5.16	168.40	30.67
I_3N_4	4.91	168.20	29.19
I_4N_1	6.01	344.72	17.44
I_4N_2	8.43	341.25	24.69
I_4N_3	7.58	341.38	22.21
I_4N_4	5.61	341.38	16.42
$CD_{0.05}$ (IxN)	0.48	-	-

*includes 20 mm pre-sowing irrigation for seed germination and crop establishment; Refer to I and N treatments in Table 2.18.1b.

Table 2.18.1b. Effect of irrigation schedules and nitrogen management on quality of sweet corn

Treatment	Reducing sugar (%)	Total sugar (%)	TSS (%)
Irrigation schedule			
I_1 (Drip 1.0 ET_c)	6.42	20.70	7.40
I_2 (Drip 0.8 ET_c)	6.25	20.10	6.70
I_3 (Drip 0.6 ET_c)	5.71	19.60	7.10
I_4 (Surface irrigation)	5.92	18.90	6.50
$CD_{0.05}$	0.73	0.82	0.92
Nitrogen management			
N_1 (100% inorganic N)	4.77	17.70	5.96
N_2 (75% inorganic + 25% vermicompost)	6.29	20.30	7.31
N_3 (75% inorganic + 25% FYM)	5.96	20.80	6.79
N_4 (75% N inorganic + 25% mustard cake)	7.14	21.10	7.17
$CD_{0.05}$	1.15	1.41	1.36

2.19. Jorhat (AESR 15.4)

2.19.1. Integration of subsurface drainage and irrigation in Assam lemon

An integrated system for subsurface drainage (SSD) and partial root zone irrigation was designed and tested in experimental farm during 2014-15, 2015-16 and 2016-17. Hydraulic conductivities of upper layers of soil (above 80 cm depth) were 0.2, 0.18, 0.23 m/day and those beyond 80 cm ranged from 0.001-0.02 m/day. For water table draw down of 100, 200 and 300 mm/day, drain spacings (no surface drainage) were 13, 8 and 6 m, respectively. As Assam lemon plants are susceptible to waterlogging and have effective root zone depth within 45 cm, water table draw down of 300 mm/day and 6 m drain spacing were selected for the study. Assam lemon plants were planted at 3 m spacing. Drains were located in the middle of alternate rows of plants i.e. spacing between drains was 6 m. As subsurface drain was designed with blind inlet (no loss of land) and soil was organic, design drainage coefficient was 38-51 mm/day. Half of PVC pipes of diameter 76 mm were punctured with 0.5 cm holes at 2 cm spacing. Also, bamboos of same diameter were split and their internodes were removed. One half of a split bamboo was punctured. Envelope material consisting of rough sand (0.5-1.0 mm) and rice husk were laid to a depth of 10 cm on the trenches dug up to 60 cm (Fig. 2.19.1). Each of the perforated pipes (both PVC and bamboo) were then wrapped with 40 mesh size plastic net and laid at a slope of 1:100. Backfilling was done with the envelope material up to 10 cm depth overlaid by dug soil. Moderation of depth to groundwater table for the treatment with perforated PVC pipe was more prominent (T-1 and T-2). These subsurface drains could drain the subsurface water table below the effective root zone of the lemon plants.

Pooled results of three years showed that drainage with plastic pipe with mineral envelope resulted in maximum average drainage coefficient (4.04) along with significantly higher average fruit yield of 143660 fruits/ha compared to the other treatments. The treatment showed maximum WUE of 411.11 kg/ha-mm, although same amount of irrigation water (42.1 mm) was applied for all the treatments. It also fetched highest net seasonal income of Rs.1,67,381/ha and B:C ratio of 2.32 among the treatments (Table 2.19.1). Being a new technology, it will be filed for a patent.

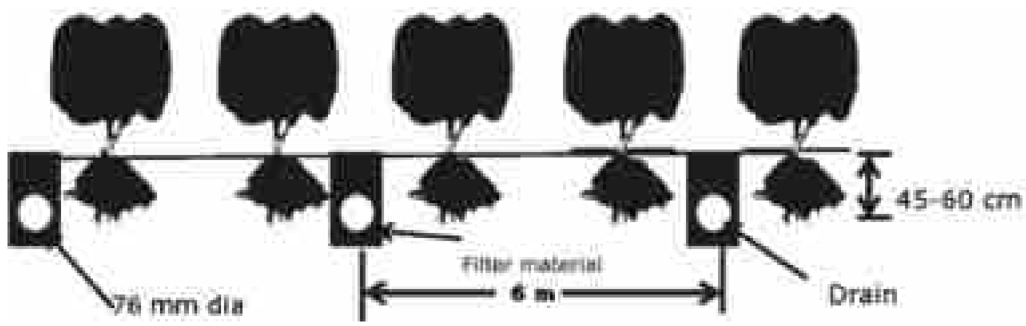


Fig. 2.19.1. Drainage layout for Assam lemon

Table 2.19.1. Performance of Assam lemon with sub surface drainage (2014 to 2017)

Treatment	Drainage coefficient	Water used (mm)	Yield[#] ('000/ha)	WUE (kg/ha-mm)	Total seasonal cost (Rs./ha)	Net seasonal income (Rs./ha)	B:C
T_1- Plastic pipe with mineral envelope	4.04	42.1	143.66	411.11	72052	167381	2.32
T_2-Plastic pipe with organic envelope	1.89	42.1	124.75	334.74	72052	135864	1.89
T_3- Drain pipe made from split bamboo with mineral envelope	1.46	42.1	109.41	282.03	63552	118798	1.87
T_4- Drain pipe made from split bamboo with organic envelope	0.61	42.1	98.75	246.03	63552	101031	1.59
T_5- Deep open drain	1.26	42.1	113.83	269.87	96052	93664	0.98
T_6- Control (no drain)	-	42.1	85.00	201.52	87052	54615	0.63
$CD_{0.05}$	-	-	16.70	-	-	-	-
$CD_{0.05}$ (Interaction between Treatment and Environmental effect)	-	-	28.93	-	-	-	-

[#]Yield- Number of fruits per hectare

2.20. Navsari (AESR 19.1)

2.20.1. Effect of water application in different layers of soil on growth and yield of drip irrigated young mango plantation

A long term experiment with mango var. Kesar in its fifth year showed that drip irrigation (DI) applied at 50 cm below ground level of mango trees resulted in significantly higher weight (215 g) and volume (210 ml) of fruit compared to those obtained with surface drip i.e. control (Table 2.20.1). But the former treatment showed non-significant difference in weight and volume of fruit for DI at 30, 40 and 60 cm below ground. Fruit yield of mango (55.8 kg/tree) was highest with irrigation at 50 cm below ground. Water applied for every treatment was 512 mm. Water use efficiency of 40.2 kg/ha-mm was highest with DI at 50 cm below ground, followed by DI 60 cm below ground (40.2 kg/ha-mm). Thus DI 50 cm below ground proved to be promising for mango. Plate 2.20.1 shows a view of the experiment.

Table 2.20.1. Performance of mango influenced by depth of drip irrigation

Treatment	Volume of fruit (ml)	Weight of fruit (g)	Fruit yield (kg/tree)	WUE (kg/ha-mm)
Surface drip	172	177	38.6	30.2
30 cm below ground level through drip	194	202	49.3	30.2
40 cm below ground level through drip	195	201	51.4	38.5
50 cm below ground level through drip	210	215	55.8	40.2
60 cm below ground level through drip	202	209	52.7	43.6
$CD_{0.05}$	22	20	NS	-

NS-Non-significant

Plate 2.20.1. Drip irrigation at different soil depths in mango plantation

Theme 3

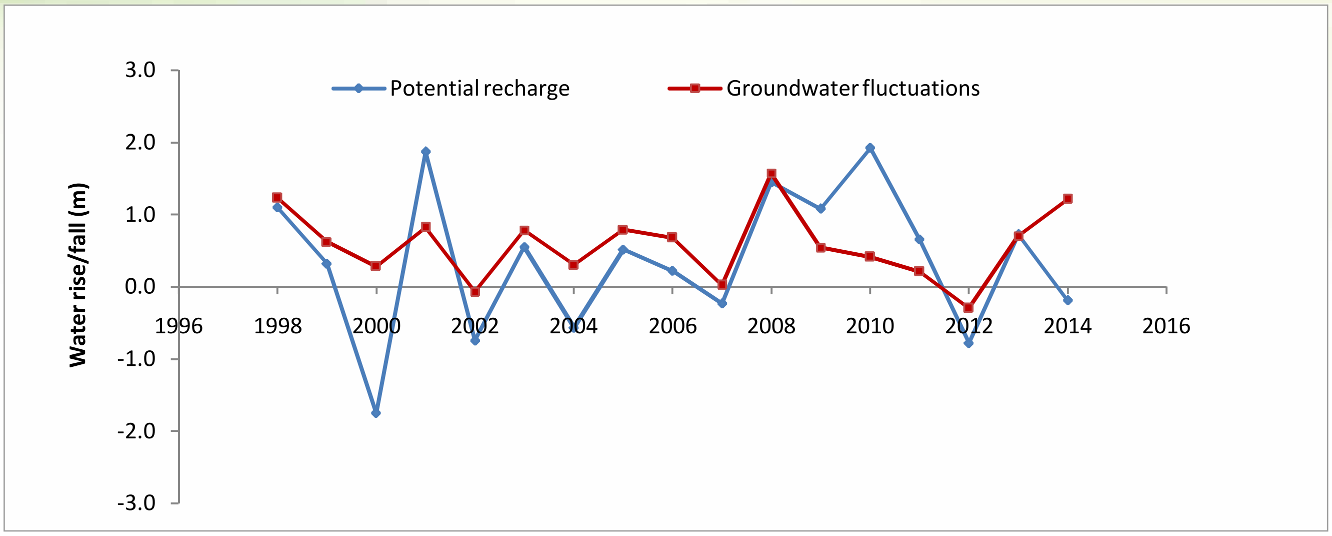
Management of rainwater for judicious use and to develop and evaluate groundwater recharge technologies for augmenting availability under different hydro-ecological conditions

All the centres working on Theme 3 succesfully carried out studies on groundwater recharge and *in situ* moisture conservation through rainwater harvesting. Effects of seasonal crop water balance components on GW fluctuation and effective recharge were studied by Ludhiana centre to correlate GW level with net agriculture water use. Several structures such as on-stream check dam, recharge basin and roof water harvesting structures were constructed by Junagadh centre. These structures successfully recharged groundwater of the study area. A composite filter having different combinations of gravel, pea gravel and activated granular charcoal was developed by Ludhiana centre to remove silt and improve quality of surface runoff used for irrigation. Under Belavatagi, Jorhat and Madurai centres, different field layouts, green manuring and mulching were evaluated for effective rainwater harvesting and *in situ* moisture conservation for standing crops. In this way, yield, water productivity and net return of sunflower, sugarcane and rice were improved under rainfed condition. Water productivity was further increased with Integrated Farming System studied by Madurai centre. Under Almora centre, roof and surface runoff was artificially recharged in trenches of hills. Plantation on hills helped to avoid evaporation and increase water in aquifers. In Jabalpur centre, efforts were made to recharge GW in unconfined aquifer. Contour map for water table fluctuation was also prepared by Jabalpur centre. Case studies on Meleng watershed and Uppar Odai waterhed were done by Jorhat and Coimbatore centres, respectively. Augmentation of GW resources through recharge and identification of GW potential zones was done by Coimbatore centre.

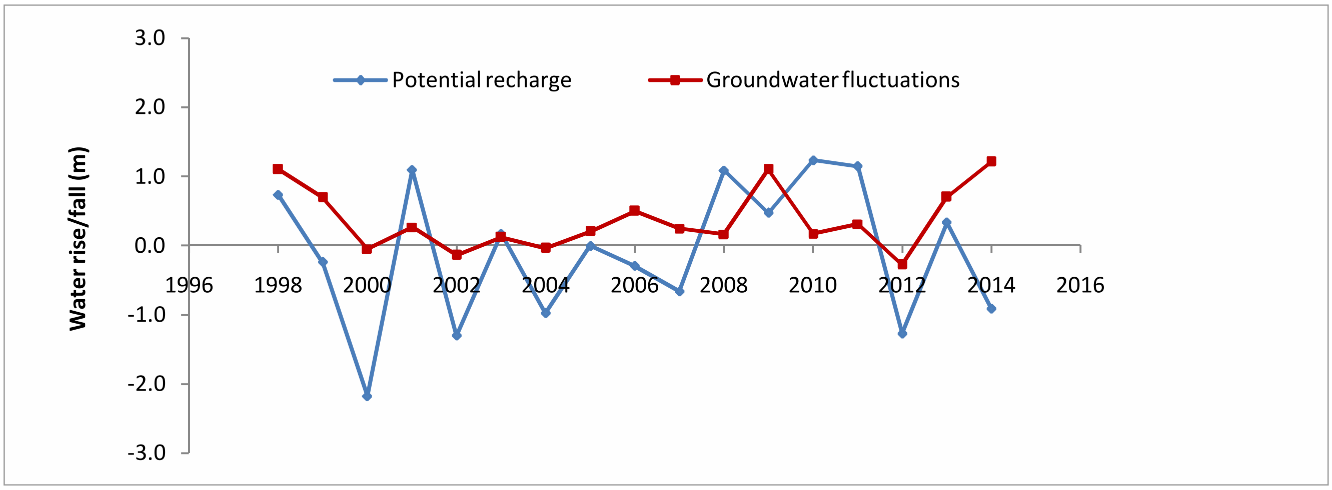
3.1. Ludhiana (AESR 4.1)

3.1.1. Evaluation of Cropping System Model for estimation of groundwater use

The study was carried out with an objective to correlate GW level as influenced by net agriculture water use (irrigation and deep percolation) in *kharif* season rice in Punjab. Field data showed that yields of rice transplanted on 21st June were 23 and 32% more than yields of rice transplanted on 5th June and 5th July, respectively. Tensiometer based irrigation treatment showed best results in terms of yield and biomass.CERES-Rice model simulation of response of grain yield and biomass accumulation to dates of sowing and irrigation regimes showed trends similar to measured responses, with differences in magnitude. Simulations of yield (from 1998 to 2014) using four dominant soil series of Ludhiana district showed that the simulated yield, averaged across different soil series, was higher in fine textured soils. However, simulations of water balance components showed that drainage decreased with fineness of soil texture. It was 24% in silt loam as compared to loamy sand. Effects of seasonal crop water balance components on GW fluctuation and effective recharge (drainage-irrigation) are represented in Fig. 3.1.1a. The water table showed a rise by 0.44 m post monsoon for Ludhiana district with exception in the years 2000, 2002, 2004, and 2012, when water table dropped marginally post monsoon. A maximum rise of 1.70 and 1.62 m was observed during 2013 for the experimental site and Ludhiana district, respectively. It was observed that June to October was the period when GW level showed relatively poor response to irrigation water requirement, since soil water during the rainy season was also absorbed. This indicated that the change in GW level from June to October was negatively correlated to the seasonal water requirement. Years with highest irrigation water use and deficit rainfall showed decline in GW table and vice versa. The model also showed agreement between estimated recharge and changes in seasonal GW level in both experimental site and Ludhiana district (Fig. 3.1.1b). The simulated effective recharge was able to explain GW level fluctuations in terms of trends/magnitude in most of the years, except for years receiving exceptionally low/high rainfall, which may be due to limitations in directly linking changes in GW level and crop water use.

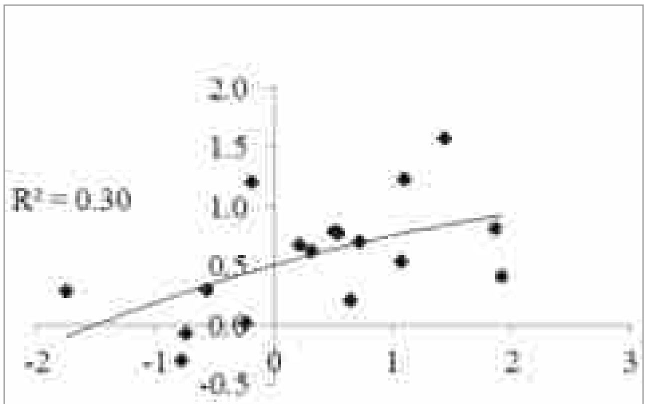


(i)



(ii)

Fig. 3.1.1a. Relationship between effcetive recharge and groundwater fluctuation for (i) experimental site and (ii) Ludhiana district



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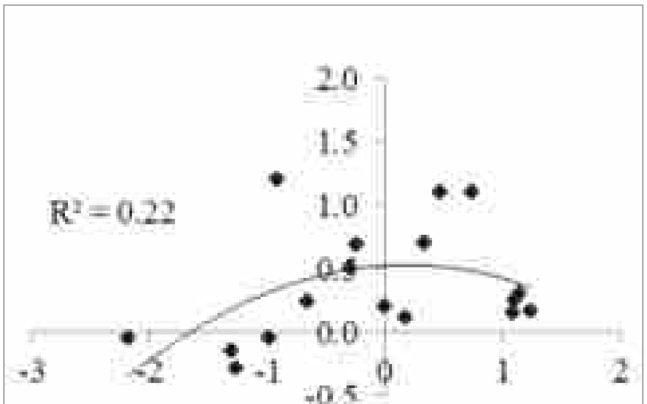


(ii)

Fig. 3.1.1b. Observed and simulated groundwater fluctuation in (i) experimental site and (ii) Ludhiana district

3.1.2. Evaluation of composite filter for groundwater recharge

A horizontal composite filter developed was installed at field (Plate 3.1.2a and 3.1.2b) and study was conducted for silt removal and improvement in quality of surface runoff. Hydraulic conductivities of constituents of the filter i.e. gravel (10-15 mm), pea gravel (2-4 mm) and activated granular charcoal (2-5 mm) were 2.5, 1.7 and 1.75 cm/s, respectively. Hydraulic conductivity of another constituent brick flakes could not be determined as porosity was very high for this material. Performance of the filter showed that highest silt removal efficiency (RE) of 72.7% was obtained with material combination of Brick flakes:Gravel:Coarse sand:Activated granular charcoal with the maximum filtration rate of 1.5 l/s (Table 3.1.2). There was no substantial effect of different filter media on pH of water before and after passing through the filter. Activated charcoal was specially used to remove nitrate from runoff water. Concentration of nitrate in water was maintained at 75 ppm, which is higher than the permissible limit (45 ppm). Nitrate removal efficiency was 24.93, 24.45, 1.47 and 0.93% for B_{30}:G:CS:C, B_{15}:G:CS:C, B_{30}:G:CS and B_{15}:G:CS, respectively. Concentration of nitrate after passing through the filter was 56.7, 56.3, 73.9 and 74.3 ppm for B_{30}:G:CS:C, B_{15}:G:CS:C, B_{30}:G:CS and B_{15}:G:CS, respectively. There was no effect on EC before and after passing through brick flakes, gravel, coarse sand or the combinations of these materials. The filtered water had EC 2.38, 2.38, 2.41 and 2.40 mS/cm for B_{30}:G:CS:C, B_{15}:G:CS:C, B_{30}:G:CS and B_{15}:G:CS, respectively (Initial EC=2.50 mS/cm). Practical implication of these observations is that in areas where soluble chemicals (e.g. nutrients like nitrate) are the critical pollutants in water, filter media containing activated charcoal may prevent movement of these chemicals to underground soil layers and groundwater. Otherwise, filtering through brick flakes, gravel, pea gravel will be efficient for silt removal.

Plate 3.1.2a. Composite filter installed in field laboratory

Plate 3.1.2b. Composite filter in operation

Table 3.1.2. Performance of horizontal composite filter

Material combination	pH		Silt removal efficiency (%)
	Before filtering	After filtering	
B_{30}:G:CS:C	7.76	7.73	72.7
B_{15}:G:CS:C	7.44	7.40	67.7
B_{30}:G:CS	7.67	7.61	56.1

B_{15}:G:CS	7.74	7.62	47.5
B_{30}:G:C	7.82	7.70	34.7
B_{15}:G:C	7.84	7.73	35.3
B_{30}:CS:C	7.56	7.41	45.0
B_{15}:CS:C	7.81	7.73	44.6
B_{30}:G	7.84	7.74	26.7
B_{15}:G	7.76	7.73	24.4
B_{30}:CS	7.82	7.80	34.2
B_{15}:CS	7.90	7.61	30.2
B_{30}:C	7.91	7.84	40.2
B_{15}:C	7.92	7.65	37.4
G:CS:C	7.84	7.60	40.2
G:CS	7.80	7.76	34.8
CS:C	7.85	7.85	41.3
G:C	7.90	7.70	38.7
B_{30}	7.91	7.73	12.7
B_{15}	7.65	7.41	7.7
G	7.81	7.60	25.9
CS	7.80	7.74	33.8
C	7.85	7.69	35.6

B_{30}-Brick flakes of 30 cm thickness; B_{15}-Brick flakes of 15 cm thickness; G-Gravel of 15 cm thickness; CS-Coarse sand (pea gravel) of 15 cm thickness; C-Granular activated charcoal of 15 cm thickness

3.2. Junagadh (AESR 5.1)

3.2.1. Evaluation of groundwater recharges techniques for Junagadh region

On-stream water harvesting structure

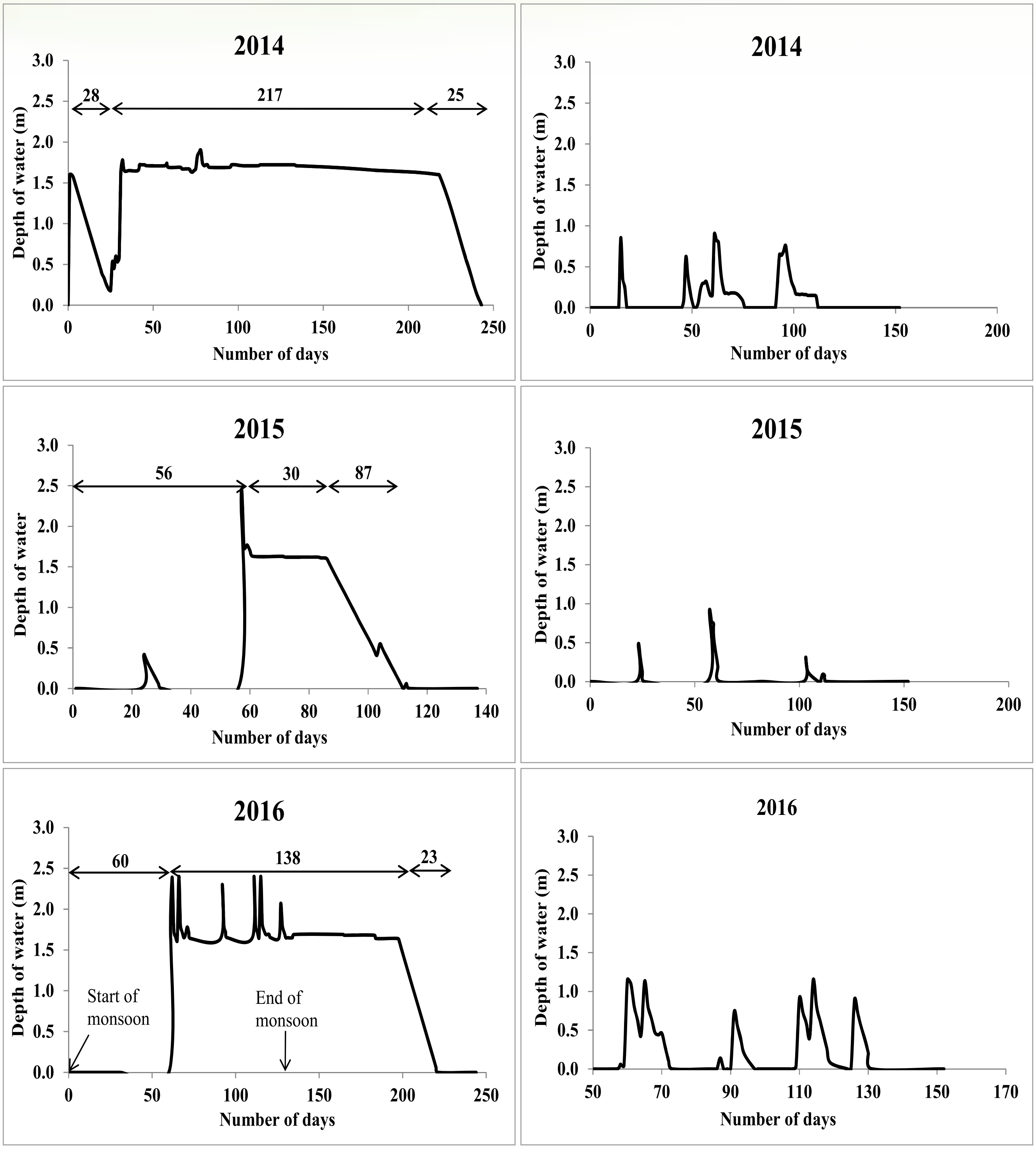
Check dam at Instructional Farm, College of Agricultural Engineering and Technology, JAU, Junagadh was considered for on-stream water harvesting and evaluation of GW recharge. Three years of experiment (2014 to 2016) showed that occurrence of annual average runoff from catchment of the check dam was 115610 m^3, runoff excess was 2056 m^3 and recharge-cum-storage capacity of the check dam was 13554 m^3. Total recharge through the check dam was 11960 m^3 after a net escaped runoff of 11392 m^3 (average evaporation loss: 2253.7 m^3). There was recharge of 0.17 m^3/m^2 of the catchment (Table 3.2.1a). Recharge cost was estimated as Rs.0.4/m^3 of recharge volume considering 20 years effective service of the structure. Hydrographs of check dam were prepared from start of monsoon (1st June) to end of monsoon (10th October) depicting runoff trapping periods (28, 56, 60), stream flowing periods (217, 30, 138) and drying periods (25, 87, 23) from year 2014 to 2016 are shown in Fig. 3.2.1. On-stream check dam recharge structure was ***recommended*** as an effective groundwater recharge technique for adoption by farmers, NGOs and line department of the government of Gujarat.

Table 3.2.1a. Evaluation of groundwater recharge through on farm check dam

Year	Net recharge (m^3)	Cost (Rs.)	Life of structure (year)	Catchment area (m^2)	Recharge cost (Rs./m^3)	Recharge of catchment (m^3/m^2)
2014	14420	95000	20	72341	0.33	0.20
2015	6897				0.69	0.10
2016	11960				0.40	0.17
Mean	11092	-	-	-	0.47	0.15

Evaluation of recharge basin technique

A recharge basin structure was constructed at Instructional Farm, Collage of Agricultural Engineering and Technology, JAU, Junagadh. Three years of experimentation showed that during monsoon season, total runoff volume of 25671 m^3 was generated from catchment area of recharge basin, out of which 13194 m^3 was recharged in the recharge basin and 12476 m^3 escaped from the basin. The evaporation loss from the basin was estimated to be 288 m^3 and net recharge was 12906 m^3 (Table 3.2.1b). Hydrographs of the recharge basin (2014 to 2016) are shown in Fig. 3.2.1. Considering 15 years of effective life of the recharge basin for Junagadh region, cost of recharging was Rs.0.17/m^3. Thus the recharge basin having storage capacity of 3281 m^3 for catchment area of 98600 m^2 was ***recommednded*** for Jungadh region.



(A) (B)

Fig. 3.2.1. Hydrographs of A) check dam (left column) and B) recharge basin (right column) for years 2014, 2015 and 2016. Number of days in x-axis starts from Ist June to end of monsson in October

Table 3.2.1b. Evaluation of groundwater recharge through recharge basin structure

Year	Total runoff from catchment of basin year 2015 (m^3)	Runoff collected in basin (m^3)	Runoff escaped from basin (m^3)	Evaporation loss (m^3)	Recharge volume (m^3)	Total cost of basin (Rs.)	Recharge cost (Rs./m^3)
2014	33381	15510	17870	657	14853	25500	0.12
2015	14591	6210	8381	54	6156	25500	0.28
2016	29041	17863	11178	153	17710	25500	0.10
Mean	25671	13194	12476	288	12906	25500	0.17

Evaluation of groundwater recharge through harvested roof water

A roof water harvesting system was installed at the southern part of the Department of Soil and Water Engineering, College of Agricultural Engineering and Technology, JAU. Nearby tubewells were used for recharging. The tubewells were also used as observation wells for evaluating the harvesting system (Table 3.2.1c). The estimated cost of harvesting roof water runoff of storm of continuous five days with maximum rainfall in sump varied from Rs.42 to 88/m^2 of roof for 10 years return period. Estimated runoff of continuous five days with maximum rainfall varied from 0.19 to 0.39 m^3/m^2 of roof for 10 years return period. Annual average, lowest, highest and 10 years return period of roof water runoff were estimated to be 0.62, 0.1, 1.94 and 0.96 m^3/m^2 of roof, respectively. The observations of roof water runoff recharged and collected in the sump showed that, out of 0.79 m^3/m^2 of roof area, 0.23 m^3 contributed to GW recharge and 0.56 m^3 was collected into sump. The system cost was Rs.158/m^2 of roof area. The annual runoff coefficient for roof area was 0.70. It was ***recommended*** that out of the possibility of roof water runoff of 0.74 m^3/m^2 of roof in Junagadh region, 0.22 m^3 may be diverted to recharge well and 0.52 m^3 may be collected into the sump. Total cost of the system without recharge was Rs.199/m^2 of roof area.Total cost of the system with recharge well and sump was Rs.150/m^2 of roof area. The capacity of storage tank in combination with recharge tubewell under maximum rainfall in one day indicated that a buffer storage tank of 0.02 m^3/m^2 of roof is required.

Table 3.2.1c. Observation of auto distribution of roof water runoff from 2014 to 2016

Year	Annual rainfall (mm)	Roof water runoff (m^3)	Roof water runoff contributed to tubewell recharging (m^3)	Roof water runoff collected into sump (m^3)	Total cost of system without recharge (Rs.)	Total cost of system with recharge (Rs.)	Annual runoff coefficient
2014	1234.0	665	196	469	176139	132039	0.70
2015	731.5	415	122	293	119031	91473	0.74
2016	1125.0	604	178	426	161517	121425	0.70
Mean	928.3	561	165	396	152229	114979	0.71
Analysis per square metre of roof area							
Mean	-	0.73	0.22	0.52	198.59	149.86	-

3.3. Belavatagi (AESR 6.4)

3.3.1. Efficient rainwater harvesting with land layouts and green manuring under irrigated conditions in sunflower-chickpea cropping sequence

In situ moisture conservation potential in different land layouts under varying irrigation and green manuring treatments was studied for sunflower var. Sunbred-293 during late *kharif* season of 2014-15 to 2016-17. Pooled results showed that broad bed furrows with green manure of sunhemp resulted in highest average grain yields of 1.80, 1.62 and 1.72 t/ha, WUEs of 4.82, 5.50 and 5.21 kg/ha-mm, net incomes of Rs.22897, 21260 and 35949 and B:C ratios of 2.18, 2.05, 2.98 during the years 2014-15, 2015-16 and 2016-17, respectively (Table 3.3.1). Two irrigation levels IW/CPE 0.6 and IW/CPE 0.8 showed non-significant difference in yield (1.71 and 1.68 t/ha), but were significantly higher than yield obtained (1.44 t/ha) under rainfed condition.

Table 3.3.1. Effect of irrigated ecosystems, land modules and green manuring on sunflower (2014-15 to 2016-17)

Treatment	Seed yield* (t/ha)	WUE* (kg/ha-mm)	Net return* (Rs.)	B:C*
L_1 - Compartment bunding without sunhemp	1.45	4.43	21167	2.16
L_2 - Compartment bunding with sunhemp	1.52	4.66	22447	2.20
L_3 - Broad bed furrows without sunhemp	1.67	4.98	25887	2.38
L_4 - Broad bed furrows with sunhemp	1.71	5.17	23512	2.38
L_5 - Furrows without sunhemp	1.63	4.83	24551	2.36
L_6 - Furrows with sunhemp	1.67	4.95	25843	2.36
	$CD_{0.05}$			
Irrigation (I)	0.083	NS	1659.5	NS
Land modules (L)	0.045	0.165	1151.5	0.044
I x L	NS	NS	NS	NS

*The values are mean of the 3 irrigation treatments; NS-Non-significant; I_1: Rainfed, I_2: IW/CPE 0.8, I_3: IW/CPE 0.6

3.4. Coimbatore (AESR 8.1)

3.4.1. Augmentation of groundwater resources by artificial recharge and identification of potential recharge zones in selected watershed of Amaravathi river basin

The study was carried out in Uppar Odai watershed for augmenting GW resources by artificial recharge and to identify potential recharge zones. The watershed falls under the catchment area of Amaravathi river basin and encompasses an area of about 79.5 km^2. The study area depends mainly on north-east monsoon rainfall with mean annual rainfall of 670 mm. Total GW recharge was estimated by adding the recharge from rainfall, recharge from return flow of irrigation water and recharge due to seepage from rainwater harvesting structures. The recharge from rainfall calculated using standard empirical methods was 759.76 ha-m. The existing rainwater harvesting structures *viz.*, farm pond, percolation pond and check dam in the study area were identified using Google Earth followed by ground truth data collection. Recharge due to seepage from rainwater harvesting structures was 36.39 ha-m and recharge from return flow of irrigation water was 10.35 ha-m. Thus, total GW recharge in the study area was 806.50 ha-m.

The annual average volume of runoff of the study area was 1343.89 ha-m and crop water demand of the study area was 327.84 ha-m. Hence, it was planned that crop water demand may be met by creating additional water harvesting structures by utilizing the available excess runoff. It was calculated that additional recharge structures with storage volume of 168.2 ha-m needs to be constructed. Identification of potential recharge zone was analyzed by superimposing seven thematic layers like Lineament, Drainage density, Soil, Land Use/Cover, Slope, Geology and Rainfall maps using ArcGIS 9.3. The GIS model was applied using weighted overlay technique to derive GW rechargeable zones, where the higher sum values represented greater potential for GW. For a particular area being evaluated, each parameter class was scaled on an evaluated scale according to its importance. The weightage values were assigned in terms of their importance w.r.t. GW recharge. In the present study, highest weightage was assigned to Geology and Lineament followed by the Soil and Drainage density and least weightage was allotted to Land use/Cover, Slope and Rainfall map.

An integrated map, associated with particular set of information of all thematic layers was prepared. Evaluation of GW recharge in the output map was based on the added values of scores. Total scores obtained by integration were classified into five categories *viz.*, very good, good, moderate, poor and very poor GW rechargeable zones in order to facilitate delineation. The recharge zonation map is shown in Fig. 3.4.1a. The average annually exploitable GW reserve in the very good and good zones was estimated to be 15.7%, whereas it was 61.7% for the moderate zone and 22.6% for the poor and very poor zones. Criteria were followed for site selection and making decision on construction of suitable water harvesting structures as per the guidelines of Central Ground Water Board. Thus, construction of five check dams, three percolation ponds and four farm ponds were recommended for harvesting surface water as shown in Fig. 3.4.1b.

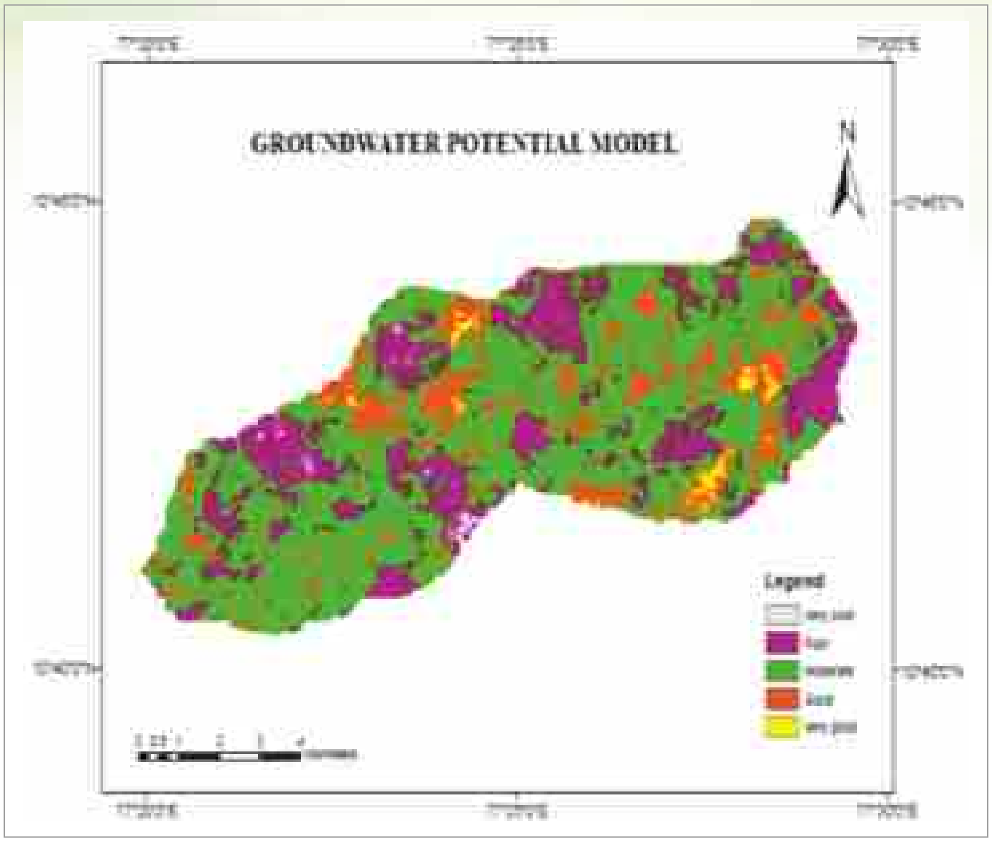


Fig. 3.4.1a. Recharge zonation map of Uppar Odai watershed

Fig. 3.4.1b. Location of water harvesting structures in Uppar Odai watershed

3.5. Madurai (AESR 8.1)

3.5.1. Enhancing the water productivity of rainfed crops through rainwater harvesting and recycling

The study was initiated in 2013 to harvest rainwater, reuse it for crop production, enhance water productivity through integrated farming approach and study economic feasibility of introducing micro irrigation for rainfed crops with harvested water. A farmer was selected in the rainfed area of village Karayepatti, block Melur, district Madurai. Due to absence of groundwater in the nearby fields, the farmer had to draw water from more than half a kilometre for the cultivation of rice crop. A farm pond of dimension 53.0 m x 17.0 m x 1.5 m and capacity 1350.0 m^3 was constructed. The soil was highly alkaline (EC=9.26) in nature with low infiltration capacity. Water harvesting was done from SW monsoon for a catchment area of 14 acre. Several interventions and benefits observed during four years of study are listed in Table 3.5.1.

Table 3.5.1. Benefits realized from interventions made on rainwater harvesting and recycling using improved practices

Conventional practices		Improved practices suggested and their benefits			
Practice	Benefit obtained	Intervention made	Benefit obtained	Increase in production	Additional economic benefit realized
Use of private paddy varieties (NLR/JGL)	3.6 to 4.2 t/ha	Use of improved, high yielding season-specific variety like Co 51	4.8 t/ha	23%	Rs.12600/ha
-	-	Introduction of green manuring crop sunhemp prior to SW monsoon	Fresh biomass of 13.8 t/ha was added to enrich the soil	About 110 kg of nitrogen was added	The soil health was maintained
Conventional planting without any crop geometry	-	Planting rice seedlings under SRI to conserve harvested water and promote tillering	Additional yield of 0.91 t/ha was realized under SRI	19.6%	Additional income of Rs.12740
Harvested water used only for crop production	-	1000 fingerlings/ pond (as IFS* component) were introduced to increase multiple use of water	540 kg fish was harvested	100%	Rs.41500/ha
Growing country birds for home consumption	Egg and chicken for home consump-tion	Rearing country birds as a component of IFS was suggested and reared @ 20 birds/pond for economic benefit as well as to recycle the bird voids as feed material for fingerlings @ 20 birds/pond for 2 ponds	1. Feed cost for fingerlings was reduced by 20 to 30% 2. Remuner-ation from the culling birds at the end of season apart from home needs	About 40 kg of live birds for sale	Additional income of Rs.6000 after meeting out of feed and chicken cost
–	Overall additional income generated by the farmer through the interventions by effective harvesting and recycling of water				Rs.72840/ha

*IFS- Integrated farming system

Tangible benefits obtained from the study are:

- Raising of groundnut crop with micro sprinkler irrigation resulting in an additional income of Rs.3000/ha during first and second years of implementation
- Rearing of fish fingerlings (1000 nos.) gave additional income of Rs.41500 from two farm ponds during second year of implementation
- By selling native birds, farmer could realize an income of Rs.6000 during the second year and Rs.10000 during the third year
- Additional area was brought under cultivation through harvested rainwater
- Benefits of rainwater harvesting in farm pond motivated the farmer to excavate three more farm ponds

3.6. Jabalpur (AESR 10.1)

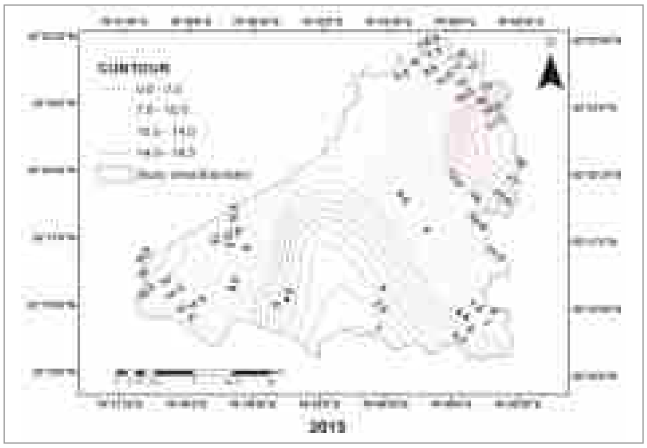
3.6.1. Groundwater recharge strategies for Patan block of Jabalpur

The study was conducted for Patan block because it is covering the highest area under rainfed farming among seven blocks of Jabalpur district. Considering hydrogeology situation of the area, a tremendous scope for artificial recharge work was seen in the block. Net groundwater availability in the block is 12681 ha-m and groundwater (GW) draft for all uses is 6250 ha-m, making stage of GW development to be 49% for the block. After making allocation for future domestic and industrial supply for next 25 years, available GW for irrigation in future is 6191 ha-m as a balance. The block has rock formations such as Alluvium, Vindhyan sandstone with total geographical area of 1,00,400 ha, with no hilly region. It has 29,902 ha of command area and 70,498 ha of non command area. Due to alluvium, there is tremendous scope for GW recharge to unconfined aquifer. Wheat, paddy and soybean being the major crops, average water table fluctuations in the block from 2000 to 2015 are shown in Table 3.6.1.

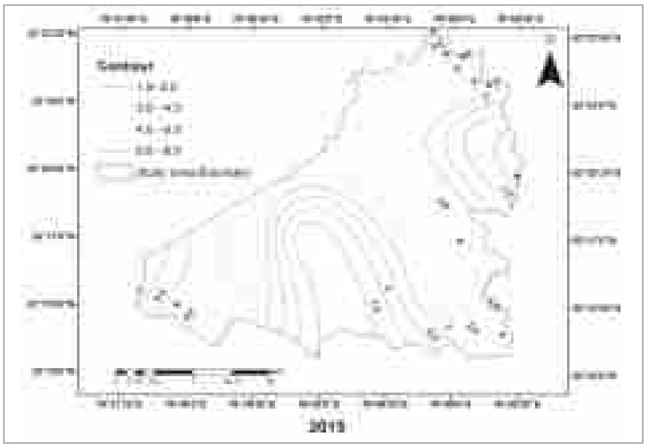
Water table fluctuation in observation wells: From seven observation wells and three piezometric wells in the block, average water level fluctuation recorded was 4.29 m. Contour maps of water table during pre-monsoon and post-monsoon seasons and water table fluctuations in the block are shown in Fig. 3.6.1.

Table 3.6.1. Average water table (WT) fluctuation in Patan block

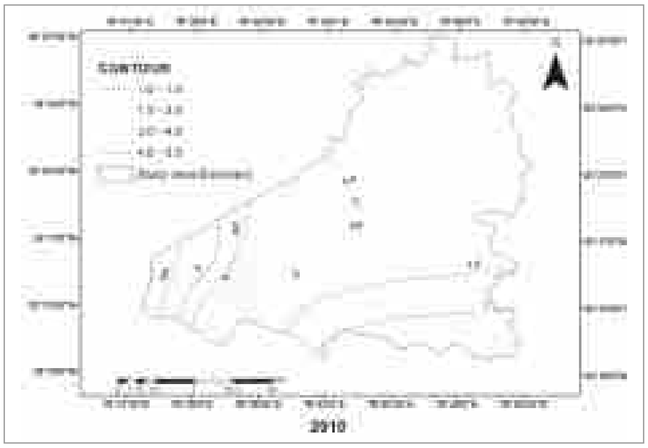
S. No.	Year	Paddy (ha)	Soybean (ha)	Pre-monsoon WT (m)	Post-monsoon WT (m)	WT fluctuation (m)
1	2000	7135	5589	7.31	5.53	3.28
2	2005	11108	509	7.14	3.88	3.72
3	2010	9768	1107	8.17	5.20	3.40
4	2015	19386	3400	9.43	4.80	4.09



Contour map of pre-monsoon water table (2015)



Contour map of post-monsoon water table (2015)



Contour map of water table fluctuation (2010)

Fig. 3.6.1. Contour maps of water table and its fluctuations in Patan block

3.6.2. Quantification of groundwater recharge in Jabalpur district using SWAT

This study aimed at computation of GW recharge on block basis for Jabalpur district. SWAT model for basin was set up with ArcSWAT version 2009.93.7b using available Digital Elevation Model (DEM), stream, soil, land use, rainfall, temperature and weather generated data for Jabalpur district. After delineation of watershed using DEM, the following base maps *viz.*, hydrologic response unit, slope map and drainage map for the basin were developed. Ground features were identified on the basis of reflectance recorded by sensor and converted into digital values which were classified with the help of supervised and unsupervised classifications. In Jabalpur district, land use/land cover classes i.e. water body, agriculture, open/fallow, built-up land, wasteland and forest land were identified using unsupervised classification. It was observed that the area under water body and wasteland remained same during the study period, but the area under agriculture and built-up land increased with decrease in the cost of open land. To carry out the investigation on GW recharge, water level data was collected from a network of 53 observation and 17 piezometer wells spread over the study area. Pre- and and post-monsoon GW levels were observed in 23 locations covering the study area lying in the Upper Narmada Basin. These levels were reduced to mean sea level and the difference of pre-monsoon and post-monsoon levels were contoured using ArcGIS. Then water level fluctuation (WTF) contours were prepared for years 2000, 2005, 2010 and 2015. Change in GW storage, that is the recharged water during a year was computed as: GW recharge = Area between successive contours x Water table fluctuation x Specific yield. Based on the temporal variation from 2000 to 2015, it was observed that GW recharge estimated by WTF method was 11% of annual rainfall. During this period, minimum recharge was 112 mm and maximum recharge was 321 mm. Average observed recharge in the site from 2000 to 2015 was 193.8 mm and simulated recharge was 201.9 mm. SWAT model simulated for recharge during four time periods corresponding to the LU/LC of 2000, 2005, 2011 and 2015. Long-term trend indicated that recharge value was getting increased.

Conclusions drawn with the observed results are:

1. The analysis of the LULC classification and change detection revealed that there was a slight increment in agriculture from 45.02% to 48.50% in Jabalpur district. Also the built-up area increased from 0.83% to 1.42% during 2000 to 2015 i.e. 70.8% increase. This led to excessive usage of GW.
2. Recharge to the aquifer showed a higher temporal variability with annual values (78.7-245 mm/year), which corresponded to approximately 8-24% of the annual mean precipitation.
3. Hydrological response was analyzed using observed time series hydrological data corresponding to the LULC change period. The result indicated that GW recharge increased from 2000 to 2015.
4. Increase in rainfall by 5% and 10% led to increase in recharge by 5 mm and 10 mm, respectively. Similarly, reduction in rainfall by 5 and 10% resulted in reduction in recharge by 0 mm and 10 mm, respectively. Temperature increase by 1, 2 and 3 °C had no significant effect on the recharge values.
5. Rate of GW recharge showed spatial-temporal variability due to different climatic conditions, land use, and hydrogeological heterogeneity.
6. Simulated GW recharge showed good agreement with the observed values obtained with water fluctuation method. It revealed that total average deviation from observed recharge and simulated recharge varied by 5% approximately.
7. It was observed from modelling that 17% of the rainfall joined GW either by direct infiltration or by recharge through various structures such as tanks, reservoirs, check dams, etc.

The policy makers can forecast how the changes in maximum and minimum temperatures and rainfall are likely to affect GW recharge for the next decade. Consequently, they can take timely decisions for the best possible options to mitigate impacts of climate change.

3.7. Raipur (AESR 11.0)

3.7.1. Groundwater recharge planning for Raipur district using RS&GIS

Out of 146 blocks in Chhattisgarh, 22 blocks were categorized as semi-critical because stage of GW development in these areas was more than 70% but less than or equal to 90%. For example, Pussore block of Raigarh district and Dharsiwa block of Raipur district having GW development stage of 76.15% and 73.06%, respectively fall under the semi-critical category. Effective GW recharge structures were lacking in the region. Moreover, relentless increase in population and resulting spurt in the demand for water requirement demanded careful planning and management of the limited water. Th meet the objective, various thematic maps including drainage map, slope map, district and block boundary maps, soil texture and lineament maps were generated for the districts (Fig. 3.7.1a, Table 3.7.1b). Groundwater recharge plan was developed by superimposing the thematic maps including classified satellite image, lineament map, drainage map, slop map and GW fluctuation map. Sites for constructing recharge structures and their number (Fig. 3.7.1b) were suggested for Raigarh district (Table 3.7.1a)

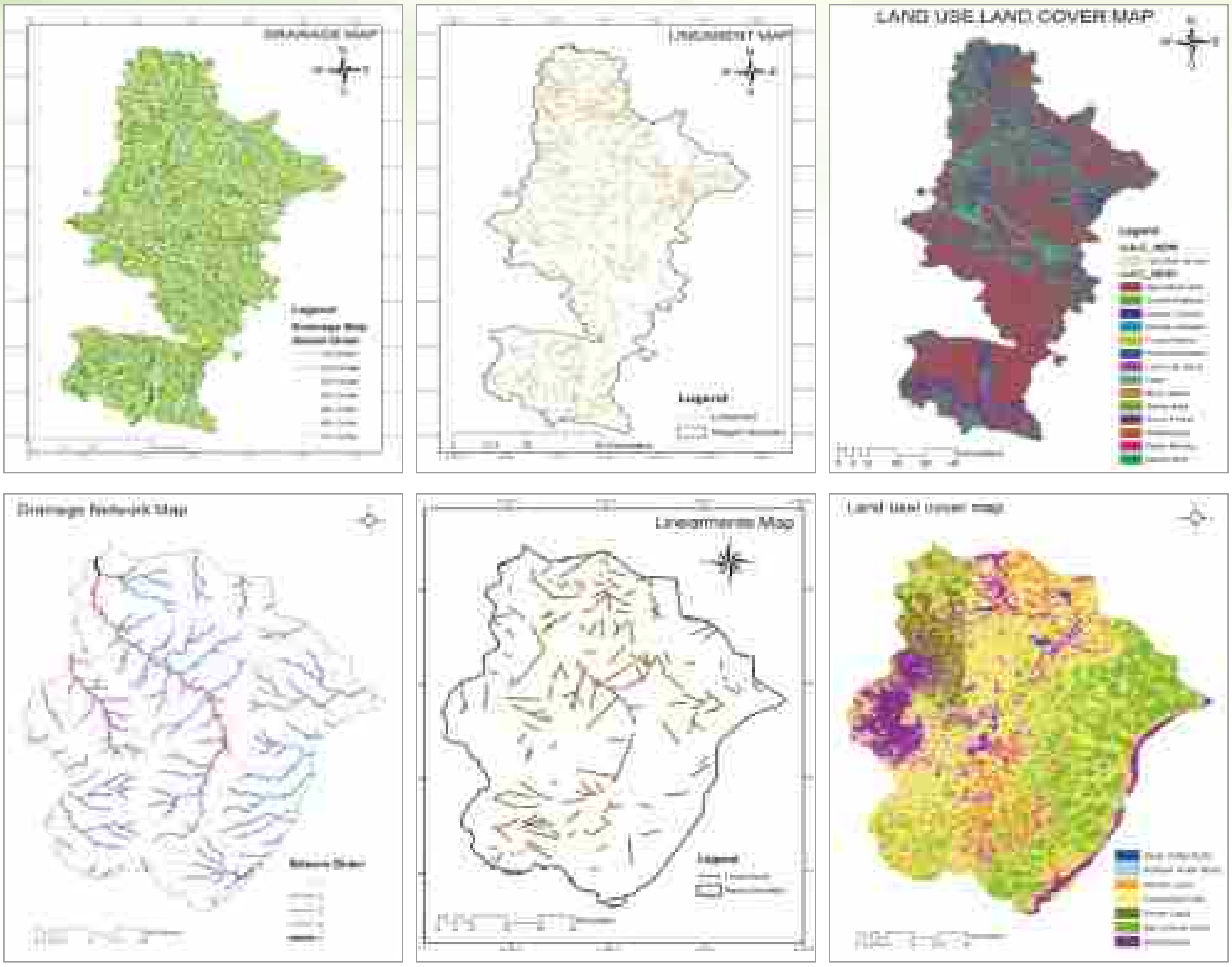


Fig. 3.7.1a. Thematic maps of Raigarh (1st row) and Raipur (2nd row) districts for artificial groundwater recharge map

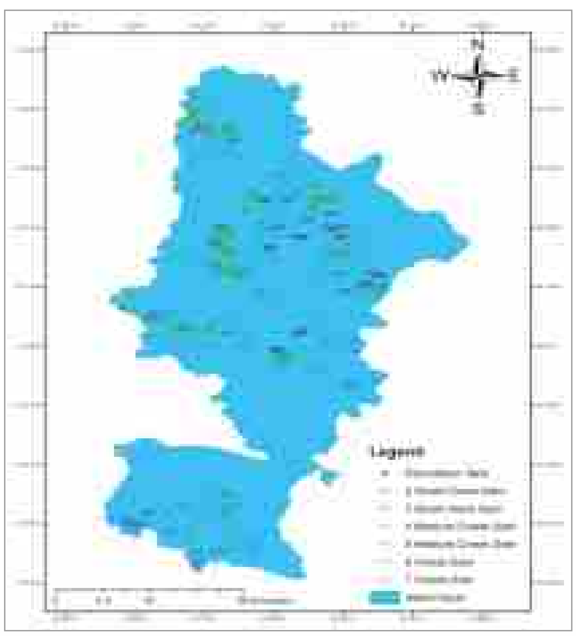


Fig. 3.7.1b. Sites identified for developing GW recharge structures in Raigarh district

Table 3.7.1a. Suitable recharge structure for different slopes in Raigarh district

S. No.	Topographic slope	Check dam (Intersection point of drainage and lineament)	Percolation tank (sink point of lineament with overland flow)	Stream order	Land use/land cover map
1	Moderate to gentle slope (2 to 5%)	Small size and medium size	Small size and medium size	1st and 2nd	Agriculture land
2	Gental slope (< 2%)	Large size	Large size	3rd and 4th	Agriculture land

Table 3.7.1b. Summary of stream and lineament in Raipur district

Particular	Order	Count	Max length (m)	Total length (km)
Stream	1	1449	6576	966.1
Stream	2	657	57556	507.4
Stream	3	354	4665	202.3
Stream	4	246	4737	126.8
Stream	5	6	1035	3.2
Lineament	-	173	10315	531.2

3.8. Almora (AESR 14.2)

3.8.1. Artificial recharging techniques for hill springs

Roof water and surface water were harvested in trenches along with plantation on trenches to avoid evaporation and increase concentration of water in aquifer recharging zone. During five-year periods of 2006-2010, 2007-2011, 2008-2012, 2009-2013, 2010-2014, 2011-2015 and 2012-2016, annual discharges of hill spring was higher by 73.2, 100.7, 114.2, 135.9, 148.8, 145.8 and 138.6%, respectively compared to annual discharge recorded before inception of the treatments in the year 2000. During the five-year periods, there was deficit of mean annual rainfall ranging from -4.2 and -27.5%, but annual discharge was 120% higher during 2016 compared to the discharge before year 2000. Increase in correlation between discharge and rainfall showed that the treatment enhanced water percolation into soil (Fig. 3.8.1). Discharge of hill spring greatly increased during lean period compared to discharge recorded in 2000.

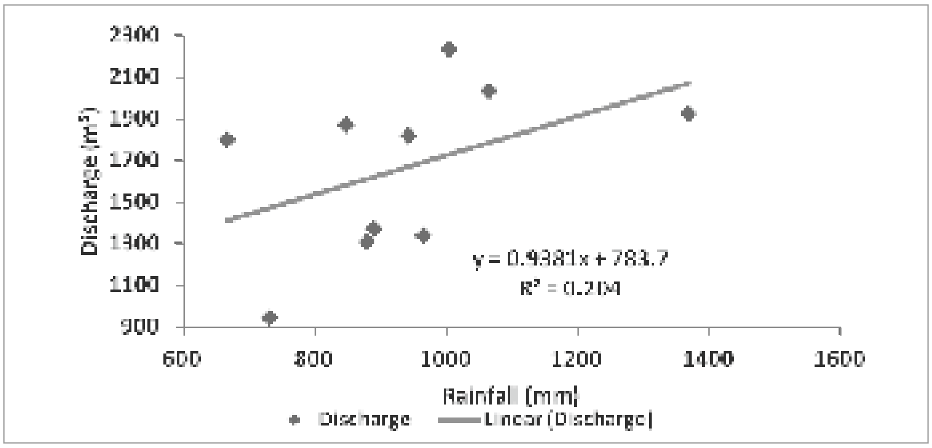


Fig. 3.8.1. Relationship between spring discharge and rainfall after the treatment inception

3.9. Jorhat (AESR 15.4)

3.9.1. Effect of rainwater harvesting with ridge and furrow on yield of sugarcane with different methods of planting

Main crop followed by two ratoon crops of sugarcane var. Dhansiri showed that pooled cane yield (82.9 t/ha), WUE (1412 kg/ha-cm), net income (Rs.209226.67) and B:C ratio (2.59) of the three crops grown with ridge mulch by plastic film and furrow with sugarcane trash/weed were significantly higher than other water harvesting techniques. This treatment had lowest water use i.e. 587.7 mm (Table 3.9.1). No significant difference was observed between the methods of planting for water use and water uses efficiency.

Table 3.9.1. Pooled performance of sugarcane main and ratoon crops under water harvesting techniques (2013 to 2016)

Treatment	Total water use (mm)	Cane yield (t/ha)	WUE (kg/ha-cm)	Net return (Rs.)	B:C
Method of planting (M)					
Planting with pre-germinated setts	658.3	69.4	1054	171326.67	2.39
Planting with ungerminated setts	658.5	68.0	1033	167726.67	2.39
$CD_{0.05}$	-	NS	-	-	-
Water harvesting technique (H)					
Ridge and furrow*	761.4	56.9	747	138226.67	2.27
Ridge and furrow with sugarcane trash/weed biomass	512.5	60.7	1184	151526.67	2.49
Ridge mulch by plastic film and furrow	622.6	74.3	1193	179126.67	2.21
Ridge mulch by plastic film and furrow with sugarcane trash/weed biomass	587.7	82.9	1412	209226.67	2.59
$CD_{0.05}$	-	5.7	-	-	-
Control vs. Treatment					
Control (Recommended practice)	728.7	51.8	711	119726.67	1.94
Treatment	-	68.7	-	169526.67	2.39
$CD_{0.05}$	-	6.1	-	-	-
Interaction (M x H)	-	NS	-	-	-

*Ridge will act as runoff area and furrow will act as infiltration basin; NS-Non-significant

3.9.2. Meleng watershed – a case study in Jorhat district, Assam

Meleng watershed in Jorhat district is an ideal watershed showing the convergence of agricultural as well as allied departments for all round development in livelihood of the watershed. Initially, villagers and other stakeholders, unaware about improved agricultural technologies, followed all sorts of traditional practices in crop and animal improvement programs. Soon after initiation of watershed development approaches by the AICRP on Irrigation Water Management, Jorhat centre, an overwhelming response irrespective of caste, creed and sex was observed in implementing the program for enhancing overall productivity of the entire watershed. The significant aspect after adoption of watershed development program was to increase confidence in the farmers to approach with their day to day agri-related problems/issues to the concerned departments. As a result, a good linkage between government officials and farmers was established.

Positive water balance computed from the difference of average water inflow and outflow indicated sufficient recharge of GW highlighting enough scope to draft GW from the watershed after maintaining the average water depth of existing identified wetlands. Of the total water inflow, 85.81% was contributed from surface water and the rest 14.19% from precipitation only. For total water outflow, major portion was from surface water (97.38%) followed by ET (1.9%) and net demand (0.71%). Area-wise soil fertility mapping for pH, OC, available nutrients, WHC, etc. of the watershed was done and need based site specific intervention was framed-out. In this context 31-point strategic action plan was submitted for implementation. Nutrient Index for fertility rating of OC, available N, available P, available K and available S under three land use systems and for entire watershed was computed. Higher values for OC (>2.33) and available S (2.31-2.66), medium values for available P (1.67-2.33) and available K (1.69-1.79), and lower values for available N (<1.67) were observed across rice fallow, tea plantation, area under rice-vegetable cropping system and the entire watershed. Six wetlands spread across the watershed were revamped and maintained successfully with detailed water quality analysis for possible *in situ* exploration. Groundwater potential zones based on difference in GW table depths during pre- and post-monsoon seasons were worked out with total capacity of 26.64 lakh cubic meter of the watershed, where highest recorded water table depth was 1.16–1.32 m.

Theme 4

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

Centres working for Theme 4 studied the effects of various components of soil fertility, soil water status, land preparation practices before crop sowing, land configuration, crop habitat, method and timing of irrigation, water management, nutrient management (including micronumtrients), organic manuring, weed management, intercultural operations, weather condition, soil moisture conservation practices, cropping sequences, intercropping systems, relay cropping on plant growth and development and economic returns. Lysimetric study was also conducted by Jabalpur centre to estimate evapotranspiration and crop water requirement of *kharif* and *rabi* season crops. An organic manure filtration unit was developed by Chalakudy centre. Cowdung and vermicompost filtrates applied to bhindi crop through drip fertigation unit resulted in higher crop yield and improved soil and microbial status.

4.1. Hisar (AESR 2.3)

4.1.1. Effect of varying moisture regimes in zero-till wheat succeeding mungbean and sorghum

Water use components *viz.*, soil moisture depletion, GW contribution and water use (irrigation and total) for wheat crop were higher with succeeding sorghum crop than those with mungbean crop (Table 4.1.1a). Wheat succeeding mungbean produced significantly higher grain yield (4.70 t/ha), irrigation WP (3.07 kg/m^3), net return (Rs.21700/ha) and B:C ratio (1.32) than sorghum (4.31 t/ha, 2.71 kg/m^3, Rs.13200/ha and 1.19). Application of irrigation at IW/CPE=0.90 produced significantly higher grain yield of wheat (5.14 t/ha), net return (Rs.27100/ha) and B:C ratio (1.39) which decreased with decrease in the level of moisture regime. Interaction effects between preceding crop and tillage practice, preceding crop and moisture regime, and tillage practice and moisture regime were significant for yield components. Tillage practice did not have significant effect on yield, but zero tillage during *rabi* resulted in highest net return Rs.22400/ha and B:C ratio 1.36 and lowest due to conventional practice (Rs.16600/ha and 1.24).

Carbon sequestration, carbon fraction and physical quality index: Eight years of experimentation showed that zero tillage for both the cropping systems increased soil organic carbon (SOC) (16.86 and 17.62 Mg/ha) and rate of carbon sequestration (0.47 and 0.52 Mg/ha/year) over those with other tillage practices in the surface soil (0-15 cm) during both the seasons (Table 4.1.1b). Penetration resistances were lowest for two moisture regimes in the zero tilled plots under both the cropping sequences. This revealed that zero tillage maintained the soil more loosely compared to conventional tillage. Mungbean-wheat cropping resulted in higher SOC and total soil porosity and lower penetration compared to sorghum-wheat cropping system.

Table 4.1.1a. Water use and performance of wheat crop under tillage practices and moisture regimes preceding mungbean and sorghum

Treatment	SMD (cm)	GWC (cm)	Irrigation (cm)	Total CU (cm)	Yield (t/ha)	IWP (kg/m^3)	Net return ('000 Rs./ha)	B:C
Preceding crop								
Mungbean	11.2	8.9	15.3	38.4	4.70	3.07	21.7	1.32
Sorghum	11.8	9.7	15.9	40.4	4.31	2.71	13.2	1.19
$CD_{0.05}$	-	-	-	-	0.19	-	-	-
Tillage practice								
Conventional	12.3	8.7	16.3	40.3	4.49	2.76	16.6	1.24
Zero-*rabi* only	11.2	9.5	15.3	39.0	4.52	2.96	22.4	1.36
Zero-both seasons	11.0	9.7	15.2	38.9	4.51	2.96	21.6	1.34
$CD_{0.05}$	-	-	-	-	NS	-	-	-

Moisture regime								
IW/CPE=0.60	12.2	9.8	10.8	35.8	3.79	3.51	3.3	1.05
IW/CPE=0.75	11.2	9.1	15.4	38.7	4.59	2.98	17.6	1.26
IW/CPE=0.90	11.1	9.0	20.6	43.7	5.14	2.49	27.1	1.39
$CD_{0.05}$	-	-	-	-	0.13	-	-	-

SMD-Soil moisture depletion, GWC-Groundwater contribution, CU-Consumptive use, Total rainfall=30.5 mm, Water table fluctuation=165 to 190 cm, IWP-Irrigation water productivity

Table 4.1.1b. Effect of tillage and crop sequence on SOC, carbon sequestration and physical quality indices of surface soil at different moisture regimes (0-15 cm)

Treatment	SOC (Mg/ha)	C sequestration rate (Mg/ha/year)	SOC (g/kg)		Total porosity (%)		Penetration resistance (MPa)	
			$M_{0.75}$	$M_{0.90}$	$M_{0.75}$	$M_{0.90}$	$M_{0.75}$	$M_{0.90}$
Sorghum-Wheat								
CT-CT (R-K)	14.75	-	6.66	6.70	44.2	44.5	4.78	4.63
CT-ZT (R-K)	15.44	0.16	7.00	7.12	44.5	45.3	4.59	4.41
ZT-ZT (R-K)	16.86	0.47	7.70	7.78	44.9	46.0	4.12	3.96
Mungbean-Wheat								
CT-CT (R-K)	14.99	-	6.88	6.94	44.5	45.3	4.62	4.56
CT-ZT (R-K)	16.04	0.18	7.30	7.38	44.9	45.5	4.24	4.12
ZT-ZT (R-K)	17.62	0.52	8.10	8.17	45.3	46.4	3.94	3.87
$CD_{0.05}$	-	-	0.66	0.63	NS	NS	NS	NS

CT-Conventional tillage, ZT-Zero tillage, R-*Rabi*, K-*Kharif*, SOC-Soil organic carbon, $M_{0.75}$ and $M_{0.90}$–Moisture regimes

4.2. Sriganganagar (AESR 2.1)

4.2.1. Response of *kharif* planted brinjal under plastic mulch and bitter gourd to fertigation through drip

Brinjal: Fruit yield (68.01 t/ha) of brinjal var. Barsatma and WEE (110.32 kg/ha-mm) were significantly higher with 100% RDF in 12 splits among all treatments, but statistically similar with yield (66.60 t/ha) obtained with 80% RDF in 12 equal splits (Table 4.2.1). It saved 20% fertilizers thereby maintaining yield and WEE. Thus application of 80% RDF i.e. N:P:K::96:64:48 in 12 equal splits each at an interval of 10 days with drip irrigation at 1.0 ET_c was ***recommended*** as optimum fertigation schedule for *kharif* brinjal. Application of 30 micron bicolour mulch (gray and black) on the soil was also suggested to the local farmers for better performance of the crop. Please note: Drip irrigation was applied at 1.0 ET_c for all treatments after pre-sowing irrigation by flood method.

Bitter gourd: Significantly higher yield (40.80 t/ha) of bitter gourd var. Amanshri was obtained with 80% RDF in 12 splits at an interval of 11 days compared to other treatments (Table 4.2.1). Yield was lowest with 60% RDF in 9 splits at 15 days interval, which was statistically similar to yields obtained with the control (100% RDF with flood irrigation at IW/CPE 1.0). Treatment 80% RDF showed 11.5% higher yield than the control. With 80% RDF in 12 splits, total water used, WEE and fertilizer use efficiency (FUE) were 486.7 mm, 83.83 kg/ha-mm and 283.3 kg/kg NPK against 1033.5 mm, 35.42 kg/ha-mm and 203.4 kg/kg NPK for 100% RDF with flood irrigation, respectively. There was also 20% fertilizer saving. Treatment 80% RDF in 12 splits had highest IBCR (3.2) with net seasonal income worth Rs.7,03,773 among the treatments. Thus it was ***recommeneded*** to apply N:P:K::80:32:32 in 12 splits each at an interval of 11 days with drip irrigation at 1.0 ET_c for optimum performance and economic return from bitter gourd crop.

Table 4.2.1. Performance of *kharif* brinjal and bitter gourd under fertigation

Fertigation#	Yield (t/ha)		WEE (kg/ha-mm)		FUE (kg/kg NPK)		IBCR	
	Brinjal	Bitter gourd	Brinjal	Bitter gourd	Brinjal	Bitter gourd	Brinjal	Bitter gourd
Control	68.01	36.61	110.32	35.42	-	203.4	-	-
80% RDF	63.37	35.55	102.67	73.04	-	246.9	-	2.2
80% RDF	66.60	40.80	107.78	83.83	-	283.3	-	3.2
60% RDF	57.06	35.01	92.78	71.92	-	324.1	-	2.2
60% RDF	57.65	37.33	93.41	76.70	-	345.6	-	2.7
$CD_{0.05}$	3.81	2.44	-	-	-	-	-	-

#**Brinjal-** Control was 100% RDF applied in 12 splits at 10 days interval, 9 splits at 13 days interval, 12 splits at 10 days interval; **Bitter gourd-** Control was RPP with flood irrigation, 9 splits at 15 days interval, 12 splits at 11 days interval. RDF for brinjal 120:80:60, RDF for bitter gourd 100:40:40. IBCR- Incremental Benefit Cost Ratio

4.3. Morena (AESR 4.4)

4.3.1. Effect of irrigation scheduling and residue management through sowing methods on pearl millet–wheat cropping system on growth, yield and water productivity in alluvial soils

Wheat var. RVW 4106 sown with 'Turbo Happy Seeder' (Plate 4.3.1) with 100% residue retention of *kharif* crop resulted in significantly higher grain yield of 4.60 t/ha and WP of 1.39 kg/m^3 compared to yield and WP obtained with conventional tillage (CT) and zero tillage (ZT) (Table 4.3.1a). Among irrigation levels, significantly higher grain yield of 4.64 t/ha was obtained with five irrigations at five critical growth stages of wheat over three and four irrigtaions. Total water use was minimum with 100% RRSHS (Table 4.3.1a), with 10.69% water saving than with CT. Physicochemical properties such as EC, pH and OC of soil remained unchanged after harvest of wheat. Availability of N, P, K and S in soil were significantly influenced by residue retention, with maximum availability under 100% RRSHS. For the succeeding crop i.e. *kharif* pearl millet (hybrid), 100% RRSHS and weed management with tractor operated ridge furrow maker + weedicide addition showed significantly higher yields of 4.58 and 1.31 kg/m^3, WPs of 1.30 and 1.31 kg/m^3, net returns of Rs.41337/ha and Rs.41267/ha, benefit-cost ratios of 3.05 and 2.99, with minimum water use of 3498 and 3504 m^3/ha, respectively among all treatments (Table 4.3.1b).

Table 4.3.1a. Effect of residue management through sowing method and irrigation level on performance of wheat under pearl millet-wheat cropping sequence

Treatment	Grain yield (t/ha)	Net return (Rs./ha)	B:C	WP (kg/m^3)	Available nutrient (kg/ha)			
					N	P	K	S
Sowing method*								
CT	4.12	49337	2.72	1.11	164	10.4	180	17.5
ZT	4.37	56887	3.20	1.25	167	10.5	182	18.0
25% RRSHS	4.49	57744	3.11	1.30	173	10.9	190	19.2
50% RRSHS	4.54	57652	3.00	1.34	179	11.2	195	20.9
100% RRSHS	4.60	55713	2.75	1.39	182	11.5	199	22.1
$CD_{0.05}$	0.12	-	-	-	3.6	0.25	2.9	0.61
Irrigation level#								
3 Irrigation (CRI, LJ, M)	4.12	49918	2.75	1.40	174	11.0	190	19.8
4 Irrigation (CRI, T, LJ, M)	4.52	55851	2.89	1.31	172	10.8	189	19.5
5 Irrigation (CRI, T, LJ, M, D)	4.64	57778	2.89	1.15	172	10.8	189	19.3
CD (P=0.05)	0.06	-	-	-	NS	NS	NS	NS

*CT-Conventional tillage, ZT-Zero tillage, RRSHS-Residue retention sowing through happy seeder; #CRI-Crown root initiation, T-Tillering, LJ-Late jointing, M-Milking, D-Dough stages; WP-Water productivity; Nutrients before crop sowing: N-161, P-10.2, K-181, S-19.3 kg/ha

Table 4.3.1b. Effect of sowing method and intercultural operation on performance of pearl millet

Treatment	Grain yield (t/ha)	Net return ('000 Rs./ha)	B:C	Total water use (m^3/ha)	WP (kg/m^3)
Sowing method					
CT	4.26	34032	2.44	3892	1.09
ZT	4.12	32505	2.40	3700	1.11
25% RRSHS	4.36	36400	2.61	3645	1.20
50% RRSHS	4.49	38438	2.72	3600	1.25
100% RRSHS	4.55	41337	3.05	3498	1.30
$CD_{0.05}$	0.13	-	-	-	-
Intercultural operation#					
I_1	4.34	34839	2.46	3876	1.12
I_2	4.14	35967	2.79	3685	1.12
I_3	4.58	41267	2.99	3504	1.31
$CD_{0.05}$	0.11	-	-	-	-

#I_1-Intercultural operation (IO) through hand weeding, I_2- IO through tractor operated ridge furrow maker,
I_3- Use of weedicide + IO through tractor operated ridge furrow maker

Sowing of wheat by Turbo Happy Seeder

Intercultural operation through tractor operated ridge furrow maker

Plate 4.3.1. Implements under operation

4.4. Kota (AESR 5.2)

4.4.1. Water use by crops in soybean + pigeon pea inter cropping system grown in south-eastern Rajasthan

Pooled data of three years (2014 to 2016) revealed that soybean equivalent yield of 1.70 t/ha, WUE of 26.78 kg/ha-cm, net return of Rs.38,503 and B:C ratio of 1.83 were significantly higher under soybean+pigeon pea (4:2) intercropping compared to other treatments, but statistically similar to those with soybean+pigeon pea (3:2) intercropping system. Soybean equivalent yield, WUE and economics were not significantly influenced by irrigation schedule (Table 4.4.1).

Table 4.4.1. Effect on irrigation schedule and intercropping system on soybean + pigeon pea system

Treatment	Soybean equivalent yield (t/ha)	WUE (kg/ha-cm)	Net return (Rs./ha)	B:C
Irrigation schedule				
Irrigation at 60% depletion of ASM	1.51	23.42	32265	1.57
Rainfed	1.43	22.79	29130	1.43
$CD_{0.05}$	NS	NS	NS	NS
Intercropping system				
Soybean + Pigeon pea (4:2)	1.70	26.78	38503	1.83
Soybean + Pigeon pea (2:3)	1.40	22.05	28403	1.39
Soybean + Pigeon pea (3:2)	1.63	25.57	36253	1.78
Sole soybean	1.38	21.73	26618	1.23
Sole pigeon pea	1.24	19.40	23912	1.25
$CD_{0.05}$	0.19	3.01	6495	0.32

Soybean variety: JS-95-60, Pigeon pea variety: Pusa-991, NS: Non-significant

4.5. Belavatagi (AESR 6.4)

4.5.1. Zinc and iron requirement for wheat under varied moisture regimes in Vertisol

Pooled results from three years of experiment (2013-14 to 2015-16) indicated that application of RDF + 7.5 t/ha FYM + 20 kg/ha $ZnSO_4$ + 20 kg/ha $FeSO_4$ resulted in significantly higher grain yield (2.32 t/ha, WUE (6.30 kg/ha-mm), net return (Rs.22613/ha) and B:C ratio (1.86) of wheat var. UAS-304 over nine fertilizer combinations (Table 4.5.1). Yield (1.59 t/ha), WUE (4.33 kg/ha-mm), net return (Rs.16474/ha) and B:C ratio (1.68) were lowest with treatment RDF+FYM. After harvest of wheat crop, it was found that there was significant build-up of available Zn (0.66 ppm) and Fe (5.93 ppm) in soil due to application of RDF+FYM+20 kg/ha $ZnSO_4$+20 kg/ha $FeSO_4$ compared to that with RDF+FYM (Zn=0.51 ppm, Fe=3.83 ppm).

Table 4.5.1. Pooled performance of wheat on effect of irrigation and nutrient levels during 2013-14 to 2015-16

Treatment	Grain yield* (t/ha)	WUE (kg/ha-mm)	Net return (Rs./ha)	B:C	Zn (ppm)	Fe (ppm)
F_1= RDF+FYM	1.59	4.33	16474	1.68	0.51	3.83
F_2= F_1+15 kg/ha S (through gypsum)	1.71	4.60	17691	1.68	0.51	3.42
F_3= F_1+10 kg/ha $ZnSO_4$	1.82	4.88	20416	1.79	0.61	3.48
F_4= F_1+20 kg/ha $ZnSO_4$	1.89	5.05	21634	1.82	0.64	3.58
F_5= F_1+10 kg/ha $FeSO_4$	1.82	4.87	20225	1.78	0.51	4.77
F_6= F_1+20 kg/ha $FeSO_4$	1.89	5.03	21877	1.84	0.53	5.68
F_7= F_1+10 kg/ha $ZnSO_4$+10 kg/ha $FeSO_4$	1.97	5.30	23614	1.89	0.61	5.17
F_8= F_1+10 kg/ha $ZnSO_4$+20 kg/ha $FeSO_4$	2.05	5.50	25463	1.96	0.63	5.75
F_9= F_1+20 kg/ha $ZnSO_4$+10 kg/ha $FeSO_4$	2.14	5.82	27339	2.01	0.65	4.90
F_{10}= F_1+20 kg/ha $ZnSO_4$+20 kg/ha $FeSO_4$	2.32	6.30	31401	2.16	0.66	5.93
	$CD_{0.05}$					
I x F	NS	NS	NS	NS	NS	NS

*All the parameters are average of IW/CPE 0.8 & IW/CPE 0.6. So all the observed data in the table is interaction effect of irrigation and nutrient

4.6. Rahuri (AESR 6.2)

4.6.1. Response of irrigation regime and fertigation levels for summer chilli–watermelon crop sequence with mulch

Experiment conducted in clay loam soil with hybrid chilli var. Sitara (hybrid) and watermelon var. Sugar queen showed that interaction of treatments 90% ET_c and 125% of RDF (I_3F_3) had chilli equivalent yield of 67.04 t/ha (Table 4.6.1). Water used by the cropping sequence was 53.08 cm with WUE of 1263.0 kg/ha-cm and B:C ratio of 2.35. Treatment I_3F_3 fetched net extra income of Rs.25,66,853/ha and net profit of Rs.4835.82/mm of water used. Two control treatments a) control recommended package of practices (RPP) and b) absolute control with no fertilizer (NF) application used 132.6 cm water each. The control and absolute control had chilli equivalent yield of 29.70 and 24.86 t/ha, WUE of 223.98 and 187.48 kg/ha-cm, and B:C ratio of 0.99 and 0.91, respectively. Soil study revealed that after harvest of chilli there was negative balance of N and K for all the irrigation regimes. Fertigation level of 75% RDF showed negative balance of N and K while 100% RDF and 125% RDF showed negative balance of K only. After harvest of watermelon, no negative balance under the irrigation regimes was observed, but under fertigation levels negative balance of K was observed with 125% RDF. Please note: Black silver polythene mulch of 40 micron was common for all the treatments.

Table 4.6.1. Effect of irrigation and fertigation levels on chilli-watermelon cropping sequence

Treatment	Water applied (ha-cm)		Fruit yield (t/ha)		WUE (kg/ha-cm)		Water saving (%)		Total FUE (kg/kg)	
	C	W	C	W	C	W	C	W	C	W
Irrigation level										
I_1: 70% ET_c	32.2	10.5	38.4	38.9	1193.1	3717.0	67.1	69.7	0.10	0.12
I_2: 80% ET_c	36.5	11.4	42.3	40.1	1159.3	3510.1	62.8	66.9	0.12	0.12
I_3: 90% ET_c	41.0	12.2	44.8	44.8	1093.3	3688.1	58.3	64.8	0.13	0.15
I_4: 100% ET_c	45.3	13.3	45.3	45.8	999.1	3434.7	53.8	61.4	0.14	0.16
CD@5%	-	-	3.9	3.8	-	-	-	-	0.02	0.02
Fertigation level										
F_1: 75% of RDF	38.7	11.8	38.3	35.8	988.9	3025.3	60.5	65.7	0.14	0.14
F_2: 100% of RDF	38.7	11.8	43.0	42.4	1109.4	3585.0	60.5	65.7	0.12	0.14
F_3: 125% of RDF	38.7	11.8	45.8	48.6	1181.5	4109.9	60.5	65.7	0.11	0.14
CD@5%	-	-	3.2	2.7	-	-	-	-	NS	NS
Interaction	-	-	NS	NS	-	-	-	-	0.12	0.14
Control (RP)	98.1	34.5	22.9	17.1	232.9	496.4	-	-	0.01	0.01
Absolute control (NF)	98.1	34.5	19.1	14.6	194.2	421.9	-	-	0.02	-

C-Chilli; W-Watermelon; Total FUE-Total fertilizer use efficiency includes N, P and K; RPP: Recommended package of practices; NF: No fertilizer

4.7. Coimbatore (AESR 8.1)

4.7.1. Influence of irrigation regimes and crop geometry on the rice varieties under aerobic rice system

Two years of experiment was conducted with split split plot design, where three irrigation regimes were in main plot, three plant geometries were in sub-plot and six rice varieties were in sub sub plot. Among the rice varieties, bold grain aerobic rice variety APO1 had highest grain yield of 3.40 t/ha, that was statistically similar to yield of CB MAS SalTol (3.19 t/ha). Among the irrigation regimes, irrigation once in 4 days recorded higher grain yield of 3.21 t/ha. It also saved irrigation water by 26% and 38% with irrigation once in 5 and 6 days, respectively. Among the plant geometries, 20 x 10 cm spacing resulted in significantly higher yield of 3.32 t/ha. Treatment combinations showed that APO1 grown with spacing of 20 x 10 cm and irrigated once in four days had highest yield of 4.30 t/ha and B:C ratio of 2.76 than the other combinations. Otherwise, highest WUE of 5.25 kg/ha-mm and water productivity of Rs.113.6/ha-mm were obtained with APO1, spacing 20 x 10 cm and irrigated once in five days. It was ***recommended*** to grow aerobic rice variety APO1 in clay loam soil (Typic Udic Haplustalf) with raised bed width of 90 cm, furrow width of 30 cm, crop spacing of 20 x 10 cm and irrigation once in four days.

4.7.2. Water productivity in rainfed areas with different land configurations in Lower Bhavani basin

The experiment was conducted for two years (2014 and 2015) to study water productivity and moisture conservation with different land configurations in farmers' field (Plate 4.7.2). Crop rotation followed in the farmers' field was groundnut+castor-fodder sorghum/ horsegram. Effect of six land configurations on soil moisture content (SMC) showed that broad bed and furrow recorded highest SMC during vegetative (20.52%), flowering (23.22%) and harvesting (5.64%) stages of rainfed groundnut. Soil moisture content in broad bed and furrow was statistically similar to that in compartmental bunding for rainfed groundnut (Table 4.7.2). Pooled analysis of results showed that compartmental bunding recorded increased pod yield (1.71 t/ha) and haulm yield of rainfed groundnut (1.35 t/ha), with higher net return of Rs.62182/ha and B:C ratio of 3.39. The results were statistically similar to those obtained with broad bed and furrow. Farmers' practice or control showed lowest SMC as well as pod yield, haulm yield, net return and B:C ratio for rainfed groundnut amongst the land configurations (Table 4.7.2).

Table 4.7.2. Pooled results of the effect of land configurations on yield and economics of rainfed groundnut

Treatment	Soil moisture content (%)			Pod yield (t/ha)	Haulm yield (t/ha)	Net return (Rs./ha)	B:C
	VS[#]	FS[#]	HS[#]				
T_1 - Summer ploughing	5.97	4.60	3.20	1.52	1.20	54483	3.28
T_2 - Broad bed and furrow	20.52	23.22	5.64	1.67	1.32	61520	3.37
T_3 - Ridge and furrow	8.75	15.08	4.05	1.66	1.32	59716	3.30
T_4 - Compartmental bunding	19.58	21.12	4.98	1.71	1.35	62182	3.39
T_5 - Contour bunding	4.91	8.44	2.64	1.54	1.21	55315	3.33
T_6 - Random tie ridging	16.93	17.48	4.30	1.67	1.32	60053	3.33
T_7 - Control (Farmers' practice)	3.35	5.01	2.07	1.54	1.14	37646	2.55
$CD_{0.05}$	4.34	5.31	0.93	0.10	0.07	-	-

[#]VS, FS, HS- Vegetative stage, Flowering stage, Harvesting stage

Broad bed & furrow

Compartmental bunding

Ridge and furrow

Plate 4.7.2. Land configurations for raising rainfed groundnut

4.8. Faizabad (AESR 9.2)

4.8.1. Effect of methods of planting and irrigation scheduling on micro fauna, root growth and yield of rice

Among different planting methods, transplanted rice system showed significantly higher mean grain yield of 4.24 t/ha and WUE of 7.51 kg/ha-mm for three years (2014 to 2016). Among irrigation schedules, highest yield of 4.55 t/ha was observed with 7 cm irrigation at 1 DADPW (Table 4.8.1). Among treatment intercations, transplanting with 7 cm irrigation at 1 DADPW accured maximum yield of 5.37 t/ha, net return of Rs.51350.50/ha and B:C ratio of 1.94. However, net return (Rs.54401.00/ha) and B:C ratio (2.37) were highest with combination of planting with drum seeder and 7 cm irrigation at 1 DADPW. Therefore, irrigation schedule of 7 cm water at 1 DADPW was ***recommended*** for both drum seeded and transplanted rice.

Table 4.8.1. Performance of rice var NDR 359 under different planting methods and irrigation schedules and their combinations (2014 to 2016)

Treatment	Grain yield (t/ha)	WUE (kg/ha-mm)	
Planting method (Main plot)			
i) Planting with zero tillage machine	3.38	5.76	
ii) Planting with drum seeder	3.87	6.68	
iii) Seeding under dry condition	3.18	5.53	
iv) Broadcasting of sprouted seeds under puddled condition	3.59	6.37	
v) Transplanting after puddling	4.24	7.51	
$CD_{0.05}$	0.30	-	
Irrigation schedule (Sub-plot)			
i) 7 cm irrigation at 1 DADPW	4.55	6.33	
ii) 7 cm irrigation at 4 DADPW	4.27	6.59	
iii) 7 cm irrigation at 7 DADPW	3.36	6.62	
iv) 7 cm irrigation at 10 DADPW	2.42	6.58	
$CD_{0.05}$	0.31	-	
Treatment combination	**Grain yield (t/ha)**	**Economics**	
		NR (Rs./ha)	**B:C**
M_1I_1	4.10	39464.50	1.97
M_1I_2	3.89	37905.00	2.05
M_1I_3	3.09	28334.00	1.72
M_1I_4	2.16	16747.50	1.16
M_2I_1	5.34	54401.00	2.37
M_2I_2	4.56	44663.50	2.08
M_2I_3	3.34	28372.00	1.43
M_2I_4	2.87	23100.50	1.25
M_3I_1	4.08	37587.50	1.75
M_3I_2	3.76	34476.50	1.72
M_3I_3	3.12	26682.00	1.44
M_3I_4	2.37	17394.00	1.02
M_4I_1	4.23	39378.50	1.79
M_4I_2	4.28	41516.50	2.03
M_4I_3	3.41	30445.00	1.60
M_4I_4	2.31	15937.00	0.91
M_5I_1	5.37	51350.50	1.94
M_5I_2	5.02	47804.50	1.92
M_5I_3	3.64	41948.00	1.79
M_5I_4	2.97	31514.00	1.43

Market price of rice (Rs./q) = 1450

4.8.2. Effect of different moisture regimes and nitrogen management on potato crop

Every furrow irrigation method resulted in significantly higher yield (27.59 t/ha) of potato var. Kufri Chandramukhi compared to 25.60 t/ha obtained with alternate furrow irrigation method, although WUE was higher with the latter (256.00 kg/ha-mm). Moisture regime 1.0 IW/CPE showed significantly higher yield of potato i.e. 27.77 t/ha than with 1.2 IW/CPE, but statistically similar (26.49 t/ha) with 0.8 IW/CPE. Nitrogen management treatment 75% RDN + 25% N through FYM showed significantly higher potato yield of 28.23 t/ha with WUE of 141.16 kg/ha-mm over other nitrogen management treatments. However, potato yields obtained under 100% RDN through urea (25.92 t/ha) and 50% RDN + 50% N through FYM (25.61 t/ha) were statistically similar (Table 4.8.2).

Table 4.8.2. Potato crop under different irrigation methods, moisture regimes and nitrogen management (2015-16)

Treatment	Yield (t/ha)	WUE (kg/ha-mm)
Irrigation method		
Every furrow irrigation	27.59	137.95
Alternate furrow irrigation	25.60	256.00
$CD_{0.05}$	1.33	-
Moisture regime		
0.8 IW/CPE	26.49	176.60
1.0 IW/CPE	27.77	138.85
1.2 IW/CPE	25.52	102.09
$CD_{0.05}$	1.63	-
Nitrogen management		
100% RDN through urea	25.92	129.59
75% RDN + 25% N through FYM	28.23	141.16
50% RDN + 50% N through FYM	25.61	128.07
$CD_{0.05}$	1.00	-

4.9. Pantnagar (AESR 14.5)

4.9.1. Performance of yellow mustard (*Brassica rapa* L. var. yellow sarson) under crop establishment methods, mulch and irrigation levels

Two of years experiment with yellow mustard var. Pant Peeli Sarson-1 showed that seed yield of 1.33 t/ha was significantly higher with IW:CPE 1.2 than with IW:CPE 0.3 and 0.6, but statistically similar to yield (1.19 t/ha) with IW:CPE 0.9 (Table 4.9.1). Irrigation at IW:CPE 1.2 also resulted in highest stover yield with maximum net return of Rs.20,031/ha and B:C ratio of 0.80 among the treatments. Application of rice straw mulch @ 6 t/ha significantly increased seed yield by 20.5%, net return by 47.9% and B:C ratio by 37.5% than no mulch treatment. Also, interaction of IW:CPE 1.2 and mulching led to higher yield (1.48 t/ha) of yellow mustard than no mulch condition. Raised bed sowing produced significantly higher seed yield of 1.17 t/ha, stover yield of 1.80 t/ha and gave net return of Rs.14,841/ha compared to flat sowing. Findings of the present study indicated that in a sandy loam soil, yellow mustard may be irrigated at IW:CPE 0.90 using irrigation depth of 5 cm in flat beds and 3.5 cm in raised beds (about 3 irrigations). Raised bed sowing and incorporation of rice straw mulch @ 6 t/ha at crop establishment may be advocated for higher seed yield and water productivity.

Table 4.9.1. Productivity and economics of yellow mustard as affected by irrigation level, sowing methods and mulch (2014 to 2016)

Treatment	Seed yield (t/ha)	Stover yield (t/ha)	Cost of production (Rs./ha)	Net return (Rs./ha)	B:C
Irrigation level					
IW:CPE 0.3	0.91	1.14	22850	7489	0.33
IW:CPE 0.6	1.07	1.54	23650	12105	0.51

IW:CPE 0.9	1.19	1.99		24050		15999		0.66
IW:CPE 1.2	1.33	2.29		24850		20031		0.80
$CD_{0.05}$	0.17	0.35		-		5323		0.21
Sowing method								
Flat	1.08	1.68		23050		12971		0.54
Raised bed	1.17	1.80		24650		14841		0.60
$CD_{0.05}$	0.04	0.08		-		1377		NS
Mulch								
No mulch	1.02	1.66		23400		11217		0.48
Rice straw 6 t/ha	1.23	1.82		24300		16595		0.66
$CD_{0.05}$	0.04	0.08		-		1377		0.06
Interaction (IxM) $CD_{0.05}$ = 0.083	**Yield (t/ha)**							
	I_1M_0	**I_1M_1**	**I_2M_0**	**I_2M_1**	**I_3M_0**	**I_3M_1**	**I_4M_0**	**I_4M_1**
	0.82	0.99	0.94	1.19	1.13	1.25	1.19	1.48

4.9.2. Optimization of irrigation schedule in menthol mint (*Mentha arvensis* L.) under different cropping systems

Compiled results of two years showed that in a sandy loam soil, sole mint crop var. CIM-Sarayu recorded significantly higher fresh herbage yield to the tune of 27.6% and 83.9% over intercropped and late transplanted mint crops, respectively (Table 4.9.2). Oil content from mint crop was maximum (0.96%) in late transplanted mint crop and minimum (0.89%) with timely planted sole mint crop. But because of having higher fresh herbage yield, timely planted sole mint crop resulted in the maximum oil yield (Table 4.9.2). Wheat+mint intercropping system had maximum oil equivalent yield (0.24 t/ha) and was most remunerative with highest net return of Rs.143522/ha and B:C ratio of 2.08 among the cropping systems. Among the irrigation levels, irrigation schedule of IW:CPE 1.2 recorded significantly higher fresh herbage yield, oil yield, mint oil equivalent yield, net return and B:C ratio than remaining irrigation schedules, though the oil content was found to be the highest (0.95%) with IW:CPE 0.6. Net return and B:C ratio were at par with 1.0 IW:CPE. Water productivity was 13.0% and 69.8% higher and IWUE was 19.2% and 51.9% higher with sole mint crop compared to wheat+mint and wheat-mint, respectively.

Table 4.9.2. Performance of wheat (only 2015-16) and mint (pooled) under cropping systems and irrigation schedules

Treatment	Wheat yield (t/ha)	Mint herbage yield (t/ha)	Oil content (%)	Oil yield (t/ha)	Mint oil equivalent yield (kg/ha)	Net return (Rs./ha)	B:C	WP for oil (kg/ha-cm)
Cropping system								
Sole mint (timely)	-	22.17	0.89	0.20	196.6	112470	1.87	3.82
Wheat+mint (2:1)	5.12	17.37	0.94	0.16	242.5	143522	2.08	3.38
Wheat-Transplanted mint (late)	4.41	12.05	0.96	0.12	187.2	94215	1.36	2.25
$CD_{0.05}$	0.30	0.67	0.011	0.01	6.53	5801	0.08	-
Irrigation schedule								
IW:CPE 0.6	-	13.23	0.95	0.13	176.9	93677	1.53	2.96
IW:CPE 0.8	-	16.38	0.94	0.15	203.3	112746	1.74	3.05
IW:CPE 1.0	-	18.79	0.91	0.17	221.5	126158	1.87	3.13
IW:CPE 1.2	-	20.39	0.91	0.18	233.4	134360	1.93	3.00
$CD_{0.05}$	-	0.77	0.011	0.01	7.59	6697	-	-

4.9.3. Herbicide moisture interaction study in transplanted rice

Three years of experimentation (2014 to 2016) showed that grain yield of transplanted rice (var. Pant Dhan 4) was highest with two weeks of initial ponding maintained during initial phase of establishment of seedlings i.e. 15 DAT. Three treatments *viz.*, two week ponding, one week ponding and weed free condition recorded statistically similar grain and straw yields (Table 4.9.3). Also, grain yield did not differ significantly between one week ponding and 1 DADSW. Rather, rice yield decreased significantly beyond 1 DADSW i.e. 3, 5 and 7 DADSW. It was observed that both grain and straw yields gradually decreased as the moisture level was increased during initial phase i.e. 15 DAT. Thus it was inferred that irrigation can be differed by only 1 day after disappearance of ponded water (DADSW) without significant loss in yield of rice. Application of post-emergence (18-20 DAT or 2-leaf stage) herbicide Bispyribac-Na @ 200 ml/ha suppressed weeds at all the moisture regimes resulting in higher rice yield than yield obtained after application of pre-emergence (0-3 DAT) herbicide Pretilachlor @ 0.75 kg/ha. But the difference in yield on application of Bispyribac-Na and Pretilachlor was narrower under severe stressed condition i.e. irrigation beyond 1 DADSW. Interaction effect of moisture regime and herbicide did not have any significant effect on yield of rice but had significant effect on dry weight of weeds (Table 4.9.3). Plot with 'weed free' treatment recorded 62.2% higher grain yield than 'weedy check' plot. It was concluded that under limited water availability in sandy loam soil of Pantnagar, effective weed management can be done with bispyribac-Na for transplanted rice. Soil moisture content of 32-34% was considered as threshhold for better efficacy of Pretilachlor.

Table 4.9.3. Effect of irrigation regime and herbicide application and their interaction on yield of transplanted rice and weed population

Treatment	Rice yield (t/ha)		Weed dry matter (g/m^2)	
	Grain	Straw	20 DAT	60 DAT
Moisture regime				
2 week ponding	6.24	7.80	2.67	8.06
1 week ponding	6.04	7.49	3.14	9.00
1 DADSW	5.73	7.34	3.66	9.53
3 DADSW	5.22	6.90	4.21	12.04
5 DADSW	4.99	6.53	4.81	14.07
7 DADSW	4.87	6.52	4.95	14.95
$CD_{0.05}$	0.32	0.50	0.21	1.44
Herbicide application				
Pretilachlor	5.37	6.90	3.43	13.32
Bispyribac-Na	5.66	7.30	4.38	9.22
$CD_{0.05}$	0.12	0.15	0.18	0.58
Weedy	3.74	5.37	5.95	3.75
Weed free	6.07	7.99	3.33	16.45

Weed dry matter under interaction effect (g/m^2)

Herbicide	Moisture regime					
	2 WP	1 WP	1 DADSW	3 DADSW	5 DADSW	7 DADSW
Pretilachlor	9.59	10.20	11.15	15.31	16.15	17.53
Bispyribac-Na	6.52	7.79	7.91	8.77	11.99	12.36
$CD_{0.05}$ = 1.41						
Weed free	3.75					
Weedy check	16.45					

WP-week(s) ponding; DADSW-days after disappearance of surface water

4.9.4. Mitigating excess moisture stress in wheat through irrigation, chemicals and sowing time management

Results of two years of study showed that in poorly drained heavy soils, foliar spray of urea @ 2% at CRI stage produced 11.9% higher grain yield of wheat var. DBW-17, 10.1% higher irrigation water use efficiency (IWUE) and Rs.6212/ha higher net return than conventional practice of applying irrigation at CRI, tillering, heading, grain filling stages (Table 4.9.4). Basal application of gypsum @ 250 kg/ha produced 5.5% higher grain yield and 9.0% higher B:C ratio than conventional practice. Sowing dates (10[th] and 25[th] November) did not cause any significant variation in grain yield of wheat. Delay in CRI irrigation by one week did not produce any adverse impact on wheat productivity and net return.

Table 4.9.4. Performance of wheat under moisture management practices

Treatment	Wheat yield (t/ha)	WP (kg/ha-cm)	IWUE (kg/ha-cm)	Net return (Rs./ha)	B:C
Sowing date					
November 10	3.58	145.8	378.2	28477	0.99
November 25	3.77	153.6	399.5	31548	1.10
$CD_{0.05}$	NS	-	-	NS	NS
Irrigation management					
Conventional: Irrigation at CRI, tillering, heading, grain filling (T_1)	3.54	145.7	379.5	28260	1.00
T_1 but delayed CRI irrigation at 28 DAS	3.58	146.2	378.1	28208	0.97
Farmers' practice	3.57	145.4	378.2	28081	0.97
T_1+2% urea spray after CRI irrigation	3.94	160.4	415.0	34472	1.22
T_1+Gypsum @ 250 kg/ha	3.73	152.2	399.8	31041	1.09
$CD_{0.05}$	0.16	-	-	-	-

During 2014-15 and 2015-16, irrigation depth was 6 and 24 cm, rainfall was 18.7 and 0.34 cm; WP-Water productivity; IWUE-Irrigation water use efficiency; Farmers' practice-Urea at 23 DAS + CRI irrigation at 28 DAS + Micronutrient spray at 35 DAS

4.10. Jabalpur (AESR 10.1)

4.10.1. Lysimeter/Field water balance studies for determination of water requirement of major crops

Water requirement of *kharif* crops paddy and soybean was higher in semi-arid regions i.e. Gird and Bundelkhand (Table 4.10.1). But water requirement of other *rabi* crops wheat and gram was lower in these regions due to lower temperatures during winter season.

Table 4.10.1. Water requirement of crops in different regions of Madhya Pradesh

Region	Paddy		Soybean		Wheat		Gram	
	ET_o (mm)	CWR[#] (mm)	ET_o (mm)	CWR (mm)	ET_o (mm)	CWR (mm)	ET_o (mm)	CWR (mm)
Chhattisgarh	637	637	522	339	714	524	714	482
Northern hills	720	720	583	379	812	595	812	548
Kymore plateau and Satpura hills	756	756	625	406	759	557	759	512
Central Narmada valley	730	730	593	385	800	587	800	540
Vindhya P	759	759	619	402	802	588	802	542
Gird region	787	787	650	422	772	566	772	521
Bundelkhand	800	800	663	431	789	579	789	533

Satpura	723	723	591	384	798	585	798	538
Malwa	722	722	585	381	797	584	797	537
Nimar	744	744	602	391	849	622	849	573
Jhabua hills	728	728	596	387	801	587	801	541

#CWR-Crop water requirement

4.11. Powarkheda (AESR 10.1)

4.11.1. Effect of fertilization (for maize), planting geometry (for pigeon pea) and different land configuration on maize and pigeon pea

Among fertility levels for maize var. JM 216, maximum seed yield of 3.71 t/ha was recorded with 125% RDF (N:P:K::150:75:50). It was significantly higher than yield obtained under the RDF i.e. 120:60:40. Water use efficiency of 34.61 kg/ha-cm, water productivity of 0.35 kg/m^3, net monetary return of Rs.19046/ha and B:C ratio of 1.52 were higher under 125% RDF over other fertility levels. In another experiment with pigeon pea var. ICPL 8803, planting geometry of 60x30 cm gave significantly higher seed yield of 2.59 t/ha, WUE of 16.78 kg/ha-cm, water productivity of 0.168 kg/m^3, net monetary return of Rs.80234/ha and B:C ratio of 2.59 (Table 4.11.1). For both the crops, method of sowing showed non-significant effect on yield.

Table 4.11.1. Performance of maize and pigeon pea crops

Treatment	Mean yield of 2015 and 2016 (t/ha)	Yield of 2016 (t/ha)	WUE (kg/ha-cm)		Water productivity (kg/m^3)	
	Maize	Pigeon pea	Maize	Pigeon pea	Maize	Pigeon pea
Method of sowing						
Broad Bed Furrow	2.93	2.62	27.38	16.97	0.274	0.17
Ridge and Furrow	3.08	2.28	28.78	14.75	0.288	0.15
Flat bed	3.27	2.41	30.58	15.63	0.306	0.16
$CD_{0.05}$	NS	NS	-	-	-	-
Fertility levels						
90:45:30 kg/ha	2.56	-	23.86	-	0.239	-
120:60:40 kg/ha	3.03	-	28.25	-	0.283	-
150:75:50 kg/ha	3.71	-	34.61	-	0.346	-
$CD_{0.05}$	0.23	-	-	-	-	-
Planting geometry						
60 x 15 cm	-	2.43	-	15.73	-	0.157
60 x 30 cm	-	2.59	-	16.78	-	0.168
45 x 15 cm	-	2.26	-	14.67	-	0.147
45 x 30 cm	-	2.47	-	15.98	-	0.160
$CD_{0.05}$	-	0.29	-	-	-	-
Water depth (cm)	107.05	154.3	-			

4.12. Bilaspur (AESR 11.0)

4.12.1. Effect of level of irrigation and micronutrient (zinc and sulphur) on growth and yield of onion

Three years of experiment (2014 to 2016) with onion var. N53 (Nasik red) showed that irrigation level of 60% CPE resulted in significantly higher yield of 24.01 t/ha with WEE of 585.84 kg/ha-cm along and net profit of Rs.1,93,565/ha among other irrigation treatments. Application of micronutrients Zn @ 5 kg/ha + S @ 20 kg/ha resulted in significantly higher yield of 21.57 t/ha, WEE of 686.96 kg/ha-cm and gave net profit of Rs.1,69,424/ha, although yield was statistically similar to yield obtained on application of S @ 20 kg/ha (Table 4.12.1).

Table 4.12.1. Performance of onion under varying irrigation levels and micronutrients

Treatment	Bulb yield (t/ha)	Water expense efficiency (kg/ha-cm)	Net profit (Rs./ha)
Irrigation level			
120% CPE	15.34	664.42	105367
100% CPE	19.49	693.91	148291
80% CPE	21.39	645.57	167867
60% CPE	24.06	585.84	193565
$CD_{0.05}$	1.58	-	-
Micronutrient			
Control	18.79	599.42	143916
Zn @ 5 kg/ha as basal	19.48	621.43	148621
Sulphur @ 20 kg/ha as basal	20.37	649.56	158787
Zn @ 5 kg/ha + S @ 20 kg/ha	21.57	686.96	169426
$CD_{0.05}$	1.38	-	-

4.13. Chiplima (AESR 12.1)

4.13.1. Growth and yield response of toria to irrigation scheduling and sulphur application

Toria var. Sushree grown with different levels of sulphur showed that 45 kg/ha S applied as basal resulted in significantly higher yield (6.04 t/ha) of toria (Table 4.13.1). The treatment led to 11.6% increase in yield compared to control (30 kg/ha S), with higher water productivity (WP) of 0.30 kg/m^3, net return (NR) of Rs.24,568/ha, B:C ratio of 1.89 among the other sulphur treatments. Irrigation scheduled at 0.6 IW/CPE had highest WP of 0.36 kg/m^3. Irrigation scheduling did not have any significant effect on yield. It was ***recommended*** to apply 45 kg/ha S along with RDF 50-25-25 and irrigation scheduled at IW/CPE = 0.6 (21 days interval) to obtain higher yield and water productivity of toria.

Table 4.13.1. Performance of toria under irrigation scheduling and sulphur levels

Treatment	Yield (t/ha)	WP (kg/m^3)	NR (Rs./ha)	B:C
Irrigation schedule (Main plot)				
0.6 IW/CPE	0.55	0.36	21,864	1.82
0.8 IW/CPE	0.58	0.29	23,770	1.88
1.0 IW/CPE	0.59	0.24	24,099	1.88
$CD_{0.05}$	NS	-	-	-
Sulphur level (Sub-plot)				
30 kg/ha S	0.54	0.27	21,090	1.78
45 kg/ha S	0.60	0.30	24,568	1.89
60 kg/ha S	0.56	0.28	21,846	1.77
$CD_{0.05}$	0.03	-	-	-

4.13.2. Evaluation of different integrated weed management practices under modified water regimes in SRI

Application of 50 mm water on the day before weeding operation (I_1) led to significantly higher rice (var. MTU 1010) grain yield of 5.81 t/ha, net return of Rs.49,017/ha, B:C ratio of 2.73 than those obtained with other water application treatments. Although irrigation water used (881 mm/ha) was maximum and water productivity (0.64 kg/m^3) was lowest for this treatment, difference in WP was non-significant among the irrigation treatments. Among the weeding methods, application of pre-emergence herbicide+post-emergence herbicide (W_4) showed significantly higher yield of 6.14 t/ha, WP of 0.78

kg/m^3, net return of Rs.51,499/ha and B:C ratio of 2.79 than other treatments. Yield increase in I_1 and W_4 over the control was 18.2% and 43.40, respectively. Most importantly, weed control efficiency (WCE) was higher for I_1 and W_4 (Table 4.13.2). It is ***recommended*** to apply pre-emergence (Pretilachlor) and post-emergence (Chlorimuron ethyl+Metsulphuron methyl) herbicides with 50 mm of irrigation water on the day before weeding for SRI method of rice cultivation in sandy loam soil.

Table 4.13.2. Effect of irrigation and methods of weed control performance of rice and weeds

Treatment	Yield (t/ha)	Net return (Rs./ha)	B:C	IWU (mm/ha)	WP (kg/m^3)	Water saved (mm/ha)	WCE (%)
Water application method							
I_1: 50 mm*	5.81	49,017	2.73	881.0	0.64	-	38.73
I_2: 25 mm*	5.10	38,540	2.25	783.5	0.65	97.5	16.44
I_3: Saturation (≈15 mm)*	4.91	35,492	2.13	693.5	0.66	187.5	-
$CD_{0.05}$	0.61	-	-	-	-	-	-
Weeding method							
W_1	4.28	34,237	1.96	810.5	0.53	15.0	-
W_2	5.20	39,613	2.05	825.5	0.63	-	-
W_3	5.47	41,513	2.26	825.5	0.66	-	16.26
W_4	6.14	51,499	2.79	786.5	0.78	39.0	51.25
$CD_{0.05}$	0.41	-	-	-	-	-	-

*Water applied on the day before weeding operation; WCE-weed control efficiency; IWU-Irrigation water use

W_1 : Weeding by Mandwa weeder at an interval of 7 days starting from 10 DAT;

W_2 : Application of pre-emergence herbicide (Pretilachlor @ 750 g a.i./ha) at 3 DAT + use of Mandwa weeder at 20 DAT at an interval of 7 days up to 50 DAT

W_3 : Weeding by Mandwa weeder at 10 DAT + application of a post-emergence herbicide (Chlorimuron ethyl + Metsulphuron methyl @ 4 g a.i./ha) at 20 DAT

W_4 : Application of pre-emergence herbicide (Pretilachlor @ 750 g a.i./ha) at 3 DAT + post-emergence herbicide (Chlorimuron ethyl + Metsulphuron methyl @ 4 g a.i./ha) at 20 DAT

4.14. Pusa (AESR 13.1)

4.14.1. Effect of moisture regimes and levels of iron on growth and yield of rice under aerobic condition

Pooled results of four years of experiment (2013-14 to 2016-17) showed that grain yield of aerobic rice was significantly influenced by moisture regimes and levels of iron (Table 4.14.1). Significantly higher yield of 3.84 t/ha, WUE of 68.71 kg/ha-cm, gross return of Rs.64,476/ha were recorded with moisture regime receiving 4 irrigations at 10% moisture depletion of field capacity (FC) compared to 2 irrigations at 20% depletion of FC. However, net return of Rs.31,858/ha and B:C ratio of 1.0 were highest under interaction effect of moisture regime receiving 4 irrigations at 10% moisture depletion of FC and 3 foliar applications of 1% $FeSO_4$ at tillering, pre-flowering and flowering stages. But results obtained with both the treatment combinations were statistically similar.

Table 4.14.1. Pooled performance of aerobic rice under varying moisture regimes and levels of iron (2013-14 to 2016-17)

Treatment	Yield (t/ha)	WUE (kg/ha-mm)	Net return (Rs./ha)	B:C
Interaction effect				
M_1I_1	3.41	57.26	25693	0.91
M_1I_2	3.83	64.20	23761	0.65
M_1I_3	4.04	67.83	31858	1.00

M_1I_4	4.10	68.71	29456	0.84
M_2I_1	2.89	53.97	19227	0.73
M_2I_2	3.28	61.24	16917	0.49
M_2I_3	3.52	65.77	25423	0.84
M_2I_4	3.55	66.35	22690	0.68
M_3I_1	2.49	49.23	13770	0.55
M_3I_2	2.85	56.48	11081	0.33
M_3I_3	3.12	61.73	19934	0.68
M_4I_4	3.14	62.10	17012	0.52
$CD_{0.05}$ (M x I)	NS	NS	NS	NS

M_1- Irrigation at 10% moisture depletion of field capacity (FC), M_2- Irrigation at 20% moisture depletion of FC, M_3- Irrigation at 30% moisture depletion of FC; I_1- Control; I_2- Basal application of 25 kg/ha $FeSO_4$ + 5 t/ha FYM; I_3- 3 foliar applications of 1% $FeSO_4$ at tillering, pre-flowering and flowering stages; I_4- 3 foliar applications of 2% $FeSO_4$ at tillering, pre-flowering and flowering stages; Depth of irrigation=3cm

4.15. Almora (AESR 14.2)

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

Recommended fertilizer dose of NPK + 10 t/ha FYM recorded significantly higher grain yield (4.67 t/ha) of wheat var. VL 804, with WUE of 12.8 kg/ha-mm, water productivity (WP) of 1.9 kg/m^3 and net return of Rs.1,62,400/ha compared to other fertilizer levels (Table 4.15.1). The control (no application of FYM or fertilizer) showed significantly lower yield (1.78 t/ha), WEE (4.9 kg/ha-mm), WP (0.7 kg/m^3) with a loss of Rs.9300/ha from the cost. Treatment NPK+FYM showed 161% and 155.8% increase in yield and WUE over the control. There was significant residual effect of fertilization on performance of subsequent crop i.e. soybean. As a result, seed yield (3.44 t/ha) of soybean (var. VLS 2), WUE of 8.9 kg/ha-mm and net return of Rs.75000/ha were significantly higher with treatment NPK+FYM compared to the other treatments.

Table 4.15.1. Performance of wheat and soybean under nutrient dynamics and effect of residual fertility on soybean

Treatment	Grain (t/ha)		WUE (kg/ha-mm)		Net return ('000 Rs./ha)		Net return (Rs./mm applied water)	
	Wheat	Soybean	Wheat	Soybean	Wheat	Soybean	Wheat	Soybean
Control	1.8	1.3	5.0	2.9	-9.3	5.5	-37.1	8.4
FYM	3.5	2.7	9.9	6.0	18.4	52.4	73.5	78.6
NPK	3.6	1.6	10.3	4.1	30.6	19.2	122.2	31.1
NPK+FYM	4.7	3.4	12.8	8.9	40.6	75.0	162.4	123.5
N+FYM	3.8	3.0	11.1	6.4	28.9	59.1	115.6	87.2
N alone	2.4	1.2	6.9	2.7	5.2	2.4	20.9	3.6
NPK-NPK	3.4	1.8	9.5	4.5	33.2	20.3	132.8	32.6
$CD_{0.05}$	0.5	0.5	1.4	1.1	4.7	15.1	18.9	23.2

Total irrigation applied for wheat=250 mm; NR-net return

4.16. Jammu (AESR 14.2)

4.16.1. Evaluation of basmati rice varieties under aerobic system and wheat established under conventional and zero-till planting for irrigated plains of Jammu

Irrigation regimes under aerobic system significantly affected yield of basmati rice varieties. Although conventional method of irrigation (Farmers' practice-Irrigation at 7 days interval under transplanting conditions by check basin method) showed highest grain yield (2.99 t/ha), two treatments *viz.*, irrigation at 0.2 bar saturation with 40 mm depth of irrigation (I_2) and sprinkler irrigated at 150% PE at 2 days interval (I_5) showed yields of 2.66 and 2.50 t/ha, which were statistically similar and only 10.7 and 16.3% lower than the conventional method (Table 4.16.1). These two irrigation regimes also helped in water saving by 40% and 67.5% over the conventional method. The respective

WUEs of 2.39 and 2.91 kg/ha-mm, B:C ratios of 1.12 and 1.09 with the two treatments were against WUE 1.99 kg/ha-mm and B:C ratio 1.14 with the conventional method. Among the varieties, Basmati 370 fetched B:C ratio of 2.02, which was higher than other two varieties. Therefore, farmers in canal commands of Jammu having light textured soil may adopt Basmati 370 under aerobic cultivation technique by applying irrigation at 0.2 bar saturation (Tensiometer based) with depth of irrigation 40 mm or can alternatively irrigate through sprinkler method at 150% PE with 2 days frequency. The two years' trial also showed that wheat can be successfully grown as a succeeding crop under zero tillage resulting in B:C ratio of 1.88 (Table 4.16.1).

Table 4.16.1. Performance of rice (*Kharif* 2014-2016) and succeeding crop wheat (*Rabi* 2014-2016) under different irrigation regimes and establishment methods

Treatment	Grain yield (t/ha)		Total water applied (mm)		WUE (kg/ha-mm)		Net return (Rs./ha)		B:C	
	Rice	Wheat	Rice	Wheat	Rice	Wheat	Rice	Wheat	Rice	Wheat
Irrigation regime										
I_1	2.99	2.90	1494	474	1.99	6.12	38266	37915	1.14	1.75
I_2	2.66	2.87	1112	474	2.39	6.04	33866	37254	1.12	1.72
I_3	2.24	2.75	1033	474	2.16	5.79	23594	34660	0.78	1.60
I_4	2.12	2.63	815	474	2.59	5.54	21130	32344	0.71	1.50
I_5	2.50	2.79	858	474	2.91	5.88	30274	35598	1.02	1.64
$CD_{0.05}$	0.35	NS	-	-	-	-	-	-	-	-
Variety (Rice) / Establishment method (Wheat)										
Basmati-370 / Zero tillage	2.43	2.60	1061	444	2.28	5.86	58346	35048	2.02	1.88
Pusa-1121 / Farmers' practice	2.71	2.97	1061	474	2.55	6.26	17985	35962	0.59	1.45
Pusa-1509	2.37	-	1061	-	2.23	-	10444	-	0.33	-
$CD_{0.05}$	0.16	NS	-	-	-	-	-	-	-	-

I_1: Farmers' practice (Irrigation at 7 days interval under transplanting conditions) or Check, I_2: Irrigation/Saturation at 0.2 bar (Tensiometer reading at 15 cm depth), I_3: Irrigation/Saturation at 0.3 bar (Tensiometer reading at 15 cm depth), I_4: Irrigation at 2 days interval through sprinkler at 125% PE (Cumulative value of PE for 2 days), I_5: Irrigation at 2 days interval through sprinkler at 150% PE (Cumulative value of PE for 2 days); Depth of irrigation=40 cm; Effective rainfall (ER) during rice was 560 mm (for check) and 555 mm (for other treatments); ER during wheat=354 mm; Average selling price of Basmati-370 is Rs.3600/q and Pusa-1509 is 1800/q; Average selling price of wheat is 1600/q and wheat straw is 300/q.

4.16.2. Performance evaluation of system of rice intensification (SRI) over scientific management practices for basmati rice at Jammu

Water requirement of scented rice (Basmati 370) was evaluated with three establishment methods. Yield obtained under SRI with aerobic irrigation (AI) and SRI with 3 DADPW with 7 cm irrigation were 2.46 and 2.58 t/ha, respectively, compared to 2.88 t/ha with conventional method (Farmers' practice- Transplanting with continuous submergence of 7 cm water). A significant reduction in total water use was observed under SRI with AI (1545.6 mm) and SRI with AWD (1900.6 mm) against that with conventional method (2093.0 mm). Water use efficiency 1.59 kg/ha-mm was highest using SRI with AI (Table 4.16.2). Thus it was ***recommended*** that farmers facing problems due to skewed distribution of water in the tail end of Ranbir canal command may grow Basmati 370 under SRI (AI) and SRI (3 DADPW), as it saved irrigation water by 38% and 16%, respectively, compared to farmers' practice. From 15th April to 15th June, farmers may enrich the soil by green manuring with dhaincha or moong.

Table 4.16.2. Performance of rice under SRI and fertility regimes during *kharif* 2015 and 2016 in Ranbir canal command

Treatment	Yield (t/ha)	Total water use (mm)	Water use efficiency (kg/ha-mm)
Establishment method			
S_1: SRI (Aerobic irrigation, AI)	2.46	1015.0	1.59
S_2: SRI (3 DADPW*)	2.58	1370.0	1.36
S_3: Farmers' practice	2.88	1630.0	1.37

Fertility regime			
F_1: 100% N through FYM	2.59	1622.6	1.37
F_2: 100% N through dhaincha	2.66	1622.6	1.40
F_3: 100% N through moong	2.67	1622.6	1.41
F_4: 100% N through urea	2.66	1622.6	1.40

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

The experiment was conducted to improve water productivity of rice in 60% area under Ranbir canal command having light textured (sandy loam) soil with low water holding capacity and high percolation rate. On farm trial with test crop of Basmati 370 showed that among three puddling methods, rotavator puddling gave highest yield of 2.6 t/ha, WUE of 1.40 kg/ha-mm and B:C ratio of 1.5 although water applied and water used were same (185 mm) for all the three methods (Table 4.16.3). Puddling with rotavator proved a promising one with 10.6 and 12.6% higher yield, 10.2 and 12.9% higher WUE and 19.0 and 24.0% higher benefit-cost ratio compared to farmers' practice and tractor mounted puddler, respectively in light textured soil (Table 4.16.3). Among the irrigation regimes, 3 DADPW resulted in 18.6% water saving compared to continuous submergence.

Table 4.16.3. Pooled performance of rice under different puddling methods and irrigation regimes

Treatment	Grain yield (t/ha)			Irrigation water applied (mm)			Total water used (mm)	WEE (kg.ha-mm)	B:C
	2015	2016	Mean	2015	2016	Mean			
Puddling method									
P_1 (with cultivator –Farmers' practice)	1.95	2.66	2.31	1650	1295	1472	1850.5	1.24	1.21
P_2 (with Rotavator)	2.39	2.81	2.60	1650	1295	1472	1850.5	1.40	1.50
P_3 (with Puddler)	2.10	2.61	2.35	1650	1295	1472	1850.5	1.27	1.26
$CD_{0.05}$	NS	0.14	-	-	-	-	-	-	-
Irrigation regime									
I_1 (Continuous submergence-Farmers' practice)	2.51	2.71	2.61	1720	1540	1630	2008	1.29	1.50
I_2 (3 DADPW)	2.12	2.68	2.40	1580	1050	1315	1693	1.41	1.30
$CD_{0.05}$	NS	NS	-	-	-	-	-	-	-
Interaction effect	NS	NS	-	-	-	-	-	-	-

4.17. Palampur (AESR 14.3)

4.17.1. Management of soil moisture in summer crop of brinjal in high rainfall areas of Himachal Pradesh

Three years (2014 to 2016) of experiment with brinjal crop showed that use of organic mulch resulted in significantly higher brinjal yield (20.08%), WUE (29.75%) and net return (22.26%) than crop grown without mulch (Table 4.17.1). Further, organic mulch was also superior to plastic mulch in all respects. Application of FYM @ 10 t/ha resulted in significantly higher yield of brinjal (6.58%), net return (7.80%) and WUE (6.32%) than crop with FYM @ 5 t/ha. Crop irrigated with 4 cm of water depth resulted in significantly higher brinjal yield (8.27%), net return (14.35%) and B:C ratio (14.93%) than crop irrigated with 2 cm of water depth. There was significant interaction between mulch source and irrigation level. Use of organic mulch and no mulch, both with irrigation depth of 4 cm resulted in significantly higher brinjal yield (8.85 and 16.33%), net return (16.56 and 28.47%) and B:C ratio (16.11 and 28.15%), respectively than with irrigation depth of 2 cm. On the other hand, under irrigation depth of 4 cm, application of organic mulch resulted in significantly higher brinjal yield (9.79 and 17.05%), WUE (9.74 and 27.57%) and net return (28.92 and 17.02%) than under application of plastic and no mulch. Therefore, it was concluded that production, economics and WUE of brinjal can be improved by planting the crop after incorporation of FYM @ 10 t/ha, mulching with organic material and irrigating with 4 cm of water.

Table 4.17.1. Performance of summer brinjal under mulching, FYM and irrigation depth

Treatment	Brinjal yield (t/ha)	Total water use (ha-mm)	WUE (kg/ha-mm)	Net return (Rs./ha)	B:C
Mulch source (M)					
Organic mulch	9.63	1534 (10)	6.28	89107	1.61
Plastic mulch	9.19	1534 (10)	6.01	74470	1.17
No mulch	8.02	1657 (15)	4.84	72886	1.54
$CD_{0.05}$	0.33	-	0.21	4910	0.09
FYM level (F)					
5 t/ha	8.66	1575 (12)	5.54	75864	1.42
10 t/ha	9.23	1575 (12)	5.89	81778	1.46
$CD_{0.05}$	0.27	-	0.17	4009	NS
Irrigation level (I)					
2 cm	8.59	1474 (12)	5.85	73545	1.34
4 cm	9.30	1676 (11)	5.57	84097	1.54
$CD_{0.05}$	0.27	-	0.17	4009	0.07
Control vs. Others					
Control	7.33	955 (0)	7.68	67613	1.59
Others	8.95	1575 (12)	5.71	78821	1.44
$CD_{0.05}$	0.48	-	0.31	7228	0.13
Interaction (MxI)					
M_1I_1	9. 18	-	6.37	82295	1.49
M_1I_2	10.09	-	6.20	95920	1.73
M_2I_1	9.19	-	6.38	74536	1.18
M_2I_2	9.19	-	5.65	74403	1.17
M_3I_1	7.41	-	4.81	63803	1.35
M_3I_2	8.62	-	4.86	81970	1.73
$CD_{0.05}$	0.46	-	0.30	6944	0.13

*Values in parenthesis indicate number of irrigations; NS denotes non-significant

4.18. Gayeshpur (AESR 15.1)

4.18.1. Integrated management of irrigation water and fertilizers for wheat crop

Three-year pooled results showed that interaction effect of irrigation and fertilizer levels significantly influenced grain yield and water use efficiency of wheat var. PBW 343. Yield of 3.55 t/ha was significantly higher with 45% maximum allowable depletion (MAD) of available soil moisture (ASM) and $N:P_2O_5:K_2O$ @ 120:60:60. Maximum WEE 9.84 kg/ha-mm was obtained with 45% MAD of ASM and $N:P_2O_5:K_2O$ 160:80:80 (Table 4.18.1). About 13.24% irrigation water was saved with treatment 45% MAD of ASM over 30% MAD of ASM without non-significant decrease in yield. Fertilizer doses did not show any marked effect on moisture consumption from soil, but relatively higher trend of consumption was registered with successive increment in fertilizer rates.

CERES-Wheat model showed relatively good agreement between predicted and observed grain yield as influenced by three irrigations regimes and four fertilizer levels in sandy loam soil. Average (for three years) coefficient of determination (R^2) between the observed and predicted values was 0.95 and NRMSE of 8.25 (Table 4.18.1). Simulation was more accurate for 30% MAD of ASM with fertilization @ 120:60:60 in 2013-14, having least deviation from the observed values. It was concluded that CERES-Wheat model may be a useful decision support system to assist farmers in selecting optimum irrigation and fertilizer schedules to improve yield and remuneration with wheat crop.

Table 4.18.1. Interaction effects of irrigation regimes and fertilizer levels on performance of wheat (pooled 2013 to 2016)

Treatment	Water applied (P+I+R), mm	Grain yield, t/ha	WUE, kg/ha-mm	D, %
I_1F_0	417.99	1.59	3.81	21.8
I_1F_1	418.21	2.90	6.92	9.8
I_1F_2	418.68	3.57	8.52	5.6
I_1F_3	419.08	3.60	8.60	6.3
I_2F_0	362.81	1.49	4.10	18.5
I_2F_1	362.94	2.84	7.84	12.2
I_2F_2	363.13	3.55	9.77	7.8
1_2F_3	363.47	3.58	9.84	8.8
I_3F_0	305.74	1.37	4.48	13.7
I_3F_1	306.24	2.47	8.07	16.2
I_3F_2	306.38	2.74	8.95	10.1
I_3F_3	306.72	2.79	9.11	7.0

Irrigation levels: $I_{1,}$ $I_{2,}$ I_3 – 30%, 45% and 60% MAD of ASM; Fertilizer levels: F_1 - N:P_2O_5:K_2O @ 0:0:0, F_2 - 80:40:40, F_3 - 120:60:60, F_4 - 160:80:80; P-Profile contribution, I-Irrigation, R-Effective rainfall; D-Deviation between observed and predicted yields, MAD-maximum allowable depletion, ASM-available soil moisture

4.18.2. Effects of irrigation schedules and integrated nitrogen management on yield and water use efficiency of lettuce

Lettuce (var. Hybrid F_1) had significantly higher fresh head yield of 11.31 t/ha obtained with interaction of irrigation schedule IW/CPE 1.0 (I_4) and 50% inorganic N + 50% organic N fertilizers through vermicompost (VC) (N_2) among all the treatments. It was statistically similar to yield (11.14 t/ha) obtained with treatments IW/CPE 0.8 (I_3) and 50% inorganic N + 50% organic N (Table 4.18.2). Water use efficiency of 91.11 kg/ha-mm was highest with interaction of IW/CPE 0.6 and 50% inorganic N + 50% organic N fertilizers. It was minimum (48.50 kg/ha-mm) with surface irrigation coupled with 100% inorganic N fertilizer. A relationship was established between fresh head yield of lettuce and amount of irrigation water applied. It showed that maximum yield of 10.7 t/ha was obtained with 110 mm irrigation water. In farmers' conventional practice, higher amount of water applied at 15 days interval each at 30 mm depth resulted in the decline in economic yield. On the other hand, irrigating the crop based on IW/CPE 1.0 throughout crop season enhanced yield. This may be because shallow rooted lettuce plant is a heavy feeder of water and nutrients. Thus IW/CPE 1.0 may be considered as an optimum irrigation schedule for Hybrid F_1 of lettuce grown in sandy loam soil.

Table 4.18.2. Performance of lettuce under interaction of irrigation scheduling and integrated nitrogen management

Treatment	Water use* (mm)	Fresh head yield (t/ha)	WUE (kg/ha-mm)	SMD at 15 cm (mm)
I_1N_1	187.22	9.64	51.49	65.46
I_1N_2	186.86	10.01	53.57	68.39
I_1N_3	186.66	9.18	49.18	62.84
I_2N_1	104.09	9.06	87.04	35.76
I_2N_2	103.94	9.47	91.11	35.92
I_2N_3	103.88	8.61	82.88	33.32
I_3N_1	130.43	10.41	79.81	42.46
I_3N_2	130.17	11.14	85.58	43.39
I_3N_3	130.04	9.80	75.36	41.25
I_4N_1	157.72	10.46	66.32	58.51
I_4N_2	157.66	11.31	71.74	60.42
I_4N_3	157.46	9.97	63.32	57.30
$CD_{0.05}$	-	0.54	-	-

**includes 20 mm irrigation for seedling emergence and crop establishment*; I_1: Surface irrigation, I_2, I_3, I_4: IW/CPE 0.6, 0.8, 1.0; N_1:100% N as inorganic, N_2:50% N as inorganic+50% N as VC, N_3:100% N as VC; VC-vermicompost; SMD-soil moisture depletion

4.18.3. Integrated nutrient and water management for sunflower in an Inceptisol

Sunflower var. PAC-361 (Advanta) grown in sandy clay loam soil with irrigation scheduled at 50% ASMD and INM treatment of STCR (Soil Test Crop Response) based NPK + boronated fertilizer @ 10 kg/ha rendered highest yield (5.48 t/ha) and WUE (10.12 kg/ha-mm). Modified moisture regime significantly reduced available NPK from 30 to 90 cm depth of soil profile. Maximum uptake of available NPK was observed with STCR based NPK+boronated fertilizer. Interaction effect of 50% MAD of ASW and STCR based NPK+boronated fertilizer enhanced NPK uptake up to 30 cm soil depth (Table 4.18.3). Internal efficiencies of NPK were significantly higher under 30% ASMD than other moisture regimes. Therefore, combination of 50% ASMD and STCR based NPK+boronated fertilizer was rewarding in terms of yield, WUE and nutrient recoveries for sunflower crop.

Table 4.18.3. Interaction effects of simulated moisture situation and INM on performance of sunflower crop, available NPK in soil after harvesting, and internal efficiencies of nutrients (2013 to 2016)

Treatment interaction	Seed yield (t/ha)	WUE (kg/ha-mm)	Available N (kg/ha)			Available P (kg/ha)			Available K (kg/ha)			IEN (kg/kg)	IEP (kg/kg)	IEK (kg/kg)
			30 cm	60 cm	90 cm	30 cm	60 cm	90 cm	30 cm	60 cm	90 cm			
I_1F_1	3.82	7.05	83.63	44.95	43.96	12.95	8.21	6.60	143.15	69.52	46.60	70.27	111.29	130.00
I_1F_2	4.83	8.93	127.01	90.94	71.08	15.29	11.72	8.26	171.60	108.68	65.49	71.15	95.52	139.67
I_1F_3	4.99	9.00	133.28	100.87	55.91	16.71	14.66	9.45	196.31	116.01	79.13	55.14	70.78	107.59
I_1F_4	3.95	7.31	103.49	77.88	37.58	13.70	9.11	7.83	151.95	90.09	57.49	68.15	87.69	114.36
I_1F_5	5.35	9.88	116.55	83.63	51.93	16.22	11.40	7.22	153.60	102.29	60.06	72.62	105.55	72.54
I_2F_1	3.40	6.49	84.15	24.57	23.83	10.40	8.04	6.18	123.16	67.43	44.11	61.72	86.35	84.18
I_2F_2	3.35	6.40	131.71	97.22	54.88	15.59	12.10	9.05	184.84	94.20	69.19	37.82	48.00	106.94
I_2F_3	5.48	10.12	153.14	110.28	57.44	17.08	14.11	10.03	221.94	106.55	75.86	39.91	47.05	70.01
I_2F_4	4.32	8.26	86.24	56.45	30.84	9.35	10.23	5.25	134.82	72.16	44.40	68.01	92.19	92.72
I_2F_5	4.71	9.52	98.78	67.42	44.95	13.65	10.05	7.77	157.89	81.58	39.75	70.94	83.53	141.95
I_3F_1	2.65	5.34	79.45	86.76	42.34	7.98	8.62	5.72	129.29	57.31	36.12	35.41	60.21	69.77
I_3F_2	3.47	7.00	136.42	77.88	49.13	12.43	10.18	8.13	132.15	86.42	35.90	39.75	57.35	72.71
I_3F_3	3.85	7.75	146.87	89.38	55.93	14.01	10.03	8.15	156.60	79.13	47.04	37.08	49.28	75.67
I_3F_4	3.57	7.00	93.03	41.81	40.77	5.62	7.47	9.93	105.31	58.12	72.42	56.12	77.98	96.08
I_3F_5	3.77	7.59	109.76	80.49	28.22	9.53	7.52	7.54	132.40	60.50	38.02	39.45	59.70	54.40
$CD_{0.05}$	1.19	2.26	9.93	16.13	NS	1.06	1.19	2.64	16.47	NS	15.25	NS	NS	NS

I_1, I_2, I_3: 30%, 50% and 70% MAD of ASW; F_1-RDF (80:60:40), F_2- STCR based NPK administration, F_3- F_2+Boronated fertilizer @ 10 kg/ha, F_4- [1/2(N+P_2O_5)+Full K_2O] of F_2+FYM @ 10 kg/ha+Azotobacter+P solubilizing bacteria, F_5- F_4+Boronated fertilizer @ 10 kg/ha; IEN, IEP and IEK- Internal efficiency of N, P and K; kg/kg- kg seeds per kg uptake of N, P and K; 30, 60 and 90- Root depths of sunflower; MAD- Maximum allowable depletion; ASW- Available soil moisture, STCR-Soil Test Crop Response

4.19. Shillong (AESR 17.1)

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

Different tillage practices had significant influence on yield and yield attributes of *rabi* (toria, pea and buckwheat) and *kharif* (rice) crops. Yield of toria 1.4 t/ha, pea 5.35 t/ha and buckwheat 1.68 t/ha were significantly higher under zero tillage (ZT) with residue retention compared to conventional tillage (CT) with residue removal. The results were statistically similar to yields obtained with ZT for *rabi* season crops only and reduced tillage with residue incorporation (Table 4.19.1). Similarly, WUE of toria 20.1 kg/ha-mm, pea (76.9 kg/ha-mm) and buckwheat (24.2 kg/ha-mm) were highest under ZT for both seasons than WUE obtained with CT.

Table 4.19.1. Effect of residue management and conservation tillage on rice-based cropping system

Year (Season)	Treatment	Yield (t/ha)	WUE (kg/ha-mm)	B:C	Water saving* (%)	Yield enhancement* (%)	Income enhancement* (%)
2015-16 (*Rabi*)	**Toria**						
	Best treatment	1.40	20.10	1.19	50.0	50.5	164.0
	Control	0.93	13.40	0.45	-	-	-
	SEM	0.08	1.18	-	-	-	-
	LSD (p<0.05)	0.29	4.10	-	-	-	-
	Pea						
	Best treatment	5.35	76.90	1.90	14.8	14.6	24.2
	Control	4.67	67.00	1.53	-	-	-
	SEM	0.06	0.92	-	-	-	-
	LSD (p<0.05)	0.22	3.20	-	-	-	-
	Buckwheat						
	Best treatment	1.68	24.20	1.43	21.6	21.4	41.6
	Control	1.39	19.90	1.01	-	-	-
	SEM	0.04	0.55	-	-	-	-
	LSD (p<0.05)	0.13	1.92	-	-	-	-
2016 (*Kharif*)	**Rice var. Shahsarang 1**						
	Best treatment	5.93	10.1	1.27	34.7	33.8	81.4
	Control	4.43	7.5	0.70	-	-	-
	SEM	0.29	0.49	-	-	-	-
	LSD (p<0.05)	1.01	1.71	-	-	-	-

*Over control; Best treatment: ZT-ZT for both seasons (Residue retention) Control: CT-CT (Residue removal)

Organic carbon (OC) content in surface soil (0-15 cm) under various tillage and residue management practices showed that OC was highest (1.62%) with ZT was for *kharif* and *rabi* season crops (ZT-ZT), followed by CT (*kharif*) - ZT (*rabi*) and reduced tillage in both seasons with residue incorporation. CT-CT recorded significantly lower OC (40.7%) than ZT-ZT (Fig. 4.19.1).

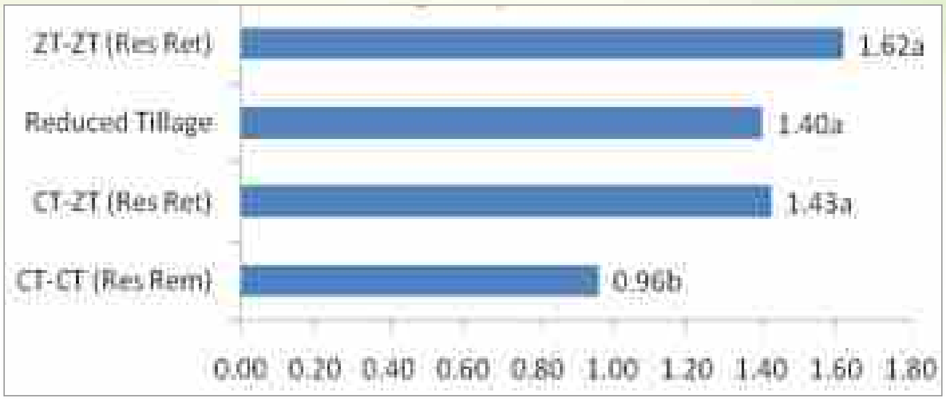


Fig. 4.19.1. Effect of tillage on rice crop and residue management (in *rabi* crops) on organic carbon content of soil (0-15 cm depth). LSD (p<0.05) = 0.39.

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

Tillage practices resulted in differential results under *in situ* residue management for maize (cv. DA 61A) and toria (TS-36) as test crops. During *rabi* 2015-16, toria crop showed highest yield of 1.39 t/ha and WUE of 6.2 kg/ha-mm with CT along with maize stalk cover (MSC)+poultry manure+*Ambrosia* sp. @ 5 t/ha compared to yield of 0.70 t/ha and WUE of 3.1 kg/ha-mm with the control (CT with no residue management). During *kharif* 2016, ZT along with MSC+poultry manure+*Ambrosia* resulted in highest yield of maize 6.75 t/ha and WUE of 10.9 kg/ha-mm compared to yield and WUE with the control (Table 4.19.2). Combination of ZT with MSC+poultry manure+*Ambrosia* @ 5 t/ha also recorded significantly higher OC content (1.88%) in the surface soil (Fig. 4.19.2).

Table 4.19.2. Summary of results for experiment with toria (*Rabi* 2015-16) and maize (*Kharif* 2016)

Year (Season)	Treatment	Yield (t/ha)	WUE (kg/ha-mm)	B:C	Water saving* (%)	Yield enhancement* (%)	Income enhancement* (%)
2015-16 (*Rabi*)	**Toria**						
	Best interaction	1.39	6.2	1.18	100.0	99.8	1375.0
	Control	0.70	3.1	0.08	-	-	-
	SEM	0.11	0.47	-	-	-	-
	LSD (p<0.05)	0.31	1.37	-	-	-	-
2016 (*Kharif*)	**Maize**						
	Best interaction	6.75	10.9	2.62	43.4	43.1	71.2
	Control	4.72	7.6	1.53	-	-	-
	SEM	0.24	0.39	-	-	-	-
	LSD (p<0.05)	0.70	1.13	-	-	-	-

*Over control

For Toria: Best treatment combination/interaction- Conventional tillage and MSC+Poultry manure+*Ambrosia* sp. @ 5 t/ha; Control - Conventional tillage with no residue management (same for both crops); **For Maize:** Best treatment combination/interaction- Zero tillage and MSC+Poultry manure+*Ambrosia* sp. @ 5 t/ha

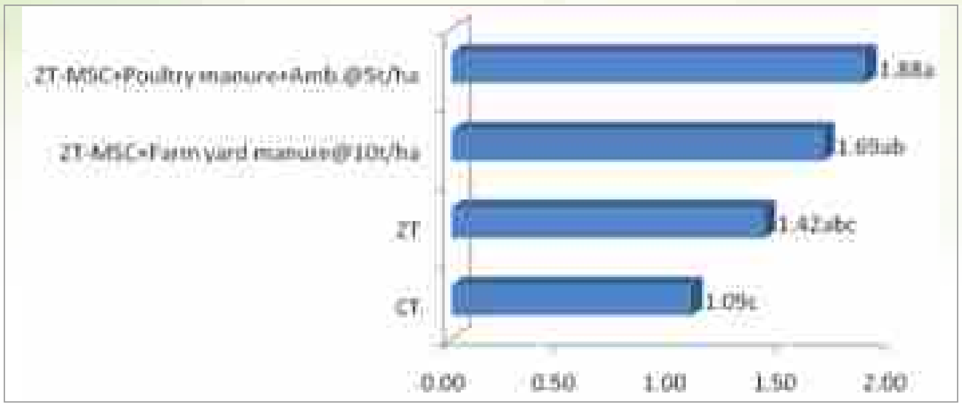


Fig. 4.19.2. Effect of tillage on maize crop and *in situ* residue management (in *rabi* crops) on organic carbon content of soil (0-15 cm depth). LSD (p<0.05) = 0.47

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

Rhizome yield (10.15 t/ha) and WUE (10.9 kg/ha-mm) of turmeric var. Lakadong were significantly higher using Farm Yard Manure @ 5 t/ha + straw mulch @ 5 t/ha among the other treatments. Yield (3.67 t/ha) and WUE (3.9 kg/ha-mm) were lowest yield under control i.e. farmers' practice (Table 4.19.3). The treatment led to yield increase by 176.8%, water saving by 179.5% and income enhancement by 921% compared to farmers' practice.

Table 4.19.3. Effect of manures and straw mulch on yield of turmeric during 2016-17

Treatment	Rhizome yield (t/ha)	WUE (kg/ha-mm)
Control	3.67e	3.9e
Poultry manure + mulching	6.93bc	7.5bc
Pig manure + mulching	8.96ab	9.7ab
*FYM + mulching	10.15a	10.9a
Paddy straw mulching	6.11cd	6.6cd
Bio waste mulching	4.67de	5.0de
LSD (p<0.05)	2.10	2.27

*Best treatment

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

Among different interactions between ZT and CT practices and eight intercropping/residue management practices, seed yield (0.93 t/ha) and WUE (4.1 kg/ha-mm) of toria var. M-27 during *rabi* 2015-16 were significantly high in the treatment where residue of sole maize crop was retained under CT (Table 4.19.4a). This interaction effect led to highest B:C ratio (0.54), with 15.6% yield enhancement, 63.6% income enhancement compared to the control (Table 4.19.4b). During *kharif* 2016, maize equivalent yield (MEY) of 7.50 t/ha and WUE of 11.8 kg/ha-mm showed that ZT with residue retention of maize+groundnut was the best among all interactions. However, this combination showed statistically similar yield (6.86 t/ha) with CT with residue retention of maize+groundnut (Table 4.19.4a). The interaction effect also led to highest B:C ratio, yield increase, water saving and income enhancement (Table 4.19.4b). Thus it was suggested that groundnut intercropped with maize with residue retention in either form of tillage may be the best option for farmers.

Table 4.19.4a. Interaction effects of tillage and residue/intercrop treatments on yield and WUE of toria and maize equivalent yield (MEY)

Intercropping/Residue management	Tillage practice	Toria		Maize	
		Seed yield (t/ha)	WUE (kg/ha-mm)	MEY (t/ha)	WUE (kg/ha-mm)
Maize sole (Residue removed)	Conventional tillage (CT)	0.80abc	3.5abc	5.95bcd	9.4bcd
Maize sole (Residue removed)	Zero tillage (ZT)	0.48ef	2.1ef	4.88d	7.7d
Maize sole (Residue retention)	CT	0.93a	4.1a	6.31bc	9.9bc
Maize sole (Residue retention)	ZT	0.55cdef	2.4cdef	6.03bcd	9.5bcd
Maize + Groundnut paired row (Residue removed)	CT	0.80abc	3.5abc	6.41abc	10.1abc
Maize + Groundnut paired row (Residue removed)	ZT	0.65abcdef	2.9abcdef	6.14bcd	9.7bcd
Maize + Groundnut paired row (Residue retention)	CT	0.85ab	3.8ab	6.86ab	10.8ab
Maize + Groundnut paired row (Residue retention)	ZT	0.43ef	1.9ef	7.50a	11.8a
LSD (p<0.05)	-	0.25	1.1	1.07	1.7

Table 4.19.4b. Summary of results on experiment with toria and maize intercrop

Year (Season)	Crop (s)	Yield (t/ha)	WUE (kg/ha-mm)	B:C	Water saving* (%)	Yield enhancement* (%)	Income enhancement* (%)
2015-16 (*Rabi*)	**Toria**						
	Best treatment	0.93	4.09	0.54	15.5	15.6	63.6
	Control	0.80	3.54	0.33	-	-	-
2016 (*Kharif*)	**Maize**						
	Best treatment	6.86	11.3	1.68	32.9	15.3	48.7
	Control	5.95	8.5	1.13	-	-	-

*Over control

For Toria: Best treatment- Interaction effect of Conventional tillage and Maize crop with residue retention; **For Maize:** Best treatment- Interaction effect of Zero tillage and Maize+Groundnut paired row with residue retention; Controls- Conventional tillage and sole Maize crop with residue removal.

4.20.Chalakudy (AESR 19.2)

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

The experiment was planned to combat high acidity in soil that develops in the plant root zone due to continuous fertigation. High acidity leads to nutrient imbalances in soil. To ameliorate this, biochar was applied in field due to its high carbon content, alkaline pH, and high water and nutrient holding capacities. These properties of biochar were utilized with an objective to conserve water, minimize the problems associated with fertigation and improve crop productivity. In this experiment, long term effect of biochar was studied by growing main crop of brinjal var. Haritha during summer season, ratoon crop of brinjal as rainfed crop (without applying any nutrients) during rainy season. After harvest of brinjal, cowpea crop was grown with life saving irrigations after rainy season. Three treatments of microirrigation (daily, once in two days and once in three days) and three treatments of soil amendments (biochar @ 2 t/ha, biochar @ 4 t/ha and lime) were applied (Plate 4.20.1). Amendments were applied to main/first crop of brinjal only.

Results showed that irrigation frequency did not affect have significant effect on brinjal yield. Rather, irrigation once in three days was sufficient to meet the water need of brinjal crop without affecting growth parameters and yield. Among the soil amendments, biochar application @ 4 t/ha led to significant increase in yield, WUE, NUE, net return and B:C ratio compared to biochar @ 2 t/ha and lime application (Table 4.20.1). This may be due to significant increase in the growth parameters such as plant spread, number of branches, and yield parameters such as fruit number and fruit weight. Yield of cowpea was also highest in the plot where biochar @ 4 t/ha was applied. Application of biochar helped to reduce water use by 67% without affecting the yield of brinjal. Application of biochar @ 4 t/ha resulted in 28% increase in brinjal yield compared to yield with lime application (Table 4.20.1). Brinjal ratoon crop and cowpea crop performed well (without application of nutrients) due to long-term effect of biochar in holding the nutrients in soil (Plate 4.20.1).

Table 4.20.1. Effect of microirrigation and soil ammendments on performance of main and ratoon crops of brinjal and succeeding cowpea crop

Treatment	Brinjal - main crop					Brinjal - ratoon crop	Cowpea
	Yield (t/ha)	WUE (kg/ha-m)	NUE (kg/kg)	NR (Rs.)	B:C	Yield (t/ha)	Yield (t/ha)
Irrigation frequency							
Drip irrigation - Daily	3.81	6146.3	27.22	15118	1.08	12.87	1.68
Drip irrigation - Once in 2 days	3.79	12240.1	27.10	16042	1.10	10.59	1.80
Drip irrigation - Once in 3 days	3.64	18181.4	25.97	14129	1.07	1.71	
CD (0.05%)	NS	841.74	1.79	-	-	NS	
Soil amendment							
Biochar @ 2t/ha	3.78	12456.8	26.96	16823	1.11	1.70	
Biochar @ 4t/ha	4.19	13618.8	29.94	19171	1.13	1.91	
Lime based on soil test	3.27	10492.2	23.38	9294	1.00	1.57	
CD (0.05%)	0.24	841.748	1.79	-	-	NS	


Biochar made from crop residue


Biochar application in field


Ratoon crop of brinjal


Cowpea crop after brinjal ratoon

Plate 4.20.1. Cultivation of brinjal and cowpea crops with biochar

4.20.2. Pot culture study for analyzing quality of organic filtrates and evaluating their effects on soil properties and plant growth

Three years of experiment was conducted in pots to study the effect of organic filtrates through fertigation on bhindi var. Arka Anamika. An organic filter unit was developed. Separate filtrates of cowdung (Plate 4.20.2) and vermicompost were prepared in separate tanks by thoroughly mixing cowdung and vermicompost each with water in the proportion of 1 kg organic manure:30 litres of water. This was kept overnight to settle large debris at the bottom of the tank. The supernatant was successfully passed (without clogging) through filtration unit of the organic drip fertigation system (Plate 4.20.2). Pooled results of three years indicated that application of vermicompost filtrate along with 50% of ad-hoc recommended dose for fertigation (RDF) recorded significantly higher yield of 425.3 g/plant, WUE 265.8 of kg/ha-cm and gave gross return of Rs.3,14,697 over rest of the treatments (Table 4.20.2). But net return and benefit-cost ratio were low with vermicompost filtrate due to the higher cost of vermicompost than cowdung manure. After the experiment, bacterial, fungal and Actinomycetes populations in soil were higher with vermicompost filtrate compared to cowdung filtrate. Nutrient status of soil revealed that available K increased drastically in T_5 and all the vermicompost treatments (Table 4.20.2). It was concluded that the organic filter unit developed was effective in organic manure fertigation using cowdung and vermicompost filtrates. Between the two manures, vermicompost was found superior to cowdung in terms of production/yield of bhindi, while cowdung was more profitable in terms of net return and B:C ratio because of its lower cost. It was ***recommended*** that organic manure filtrate along with 50% RDF should be applied to get higher yield of bhindi and improve soil and microbial status.

Cowdung filtrate in tank

Organic fertigation unit

Bhindi crop under organic manure fertigation

Plate 4.20.2. Preparation of organic manure filtrate and its application to soil through drip system

Table 4.20.2. Effect of organic filtrates through fertigation on bhindi crop, microbial status of soil and nutrient status of soil before and after treatment

Treatment	Yield (g/plant)	WUE (kg/ha-cm)	Net return (Rs.)	B:C	Total bacteria (10^5) (CFU/ml or g)		Total fungi (10^3) (CFU/ml or g)		Total Actinomycetes (10^2) (CFU/ml or g)		OC (%)		Available P (kg/ha)		Available K (kg/ha)	
					Initial	Final	Initial	Final	Initial	Final	Initial	Final	Initial	Final	Initial	Final
T_1: Application of cowdung as per organic POP	251.1	156.9	112616	2.54	30	38.5	15.5	20	29	12	1.4	2.6	129.4	125.5	243.5	215.3
T_2: Application of vermicompost as per organic POP	258.9	161.8	123199	2.80	17.5	27.5	13	36	10.5	16	1.4	2.3	74.3	72.4	190.1	225.5
T_3: Cowdung filtrate (quantity based on organic POP) through organic fertigation	321.7	201.1	146053	2.59	50.5	10.5	18	49.5	21.5	18	1.4	2.5	72.0	102.2	232.4	283.2
T_4: T_3 + 50% of ad-hoc recommendation for fertigation	311.3	194.6	148324	2.81	16	39.5	6	99.5	10.5	11	1.3	2.1	85.4	77.6	174.4	222.9
T_5: 50% of T_3 + 50% of ad-hoc recommendation for fertigation	291.1	182.0	2228	1.01	77	33.5	14	121	28.5	38	1.4	2.5	87.9	143.5	199.9	500.1
T_6: Vermicompost filtrate (quantity based on organic POP) through organic fertigation	334.8	209.2	39396	1.19	10	43	9	113.5	21.5	23	1.0	2.2	77.6	72.0	231.5	321.8
T_7: T_6 + 50% of ad-hoc recommendation for fertigation	425.3	265.8	82667	1.35	24	52.5	8.5	54.5	8	26	1.1	2.1	126.8	67.5	225.3	340.2
T_8: 50% of T_6 + 50% of ad-hoc recommendation for fertigation	308.1	192.6	75989	1.50	27	31	3.5	22.5	10	19	1.1	2.2	106.7	90.6	232.6	385.4
$CD_{0.05}$	45.2	28.2	33433	0.32	-	-	-	-	-	-	0.2	0.3	NS	44.9	NS	146.2

4.21. Dapoli (AESR 19.2)

4.21.1. Effect of water application, crop spacing and fertilizer application methods to okra in lateritic soils of Konkan region

Irrigation water applied at 100% ET_c, 80% ET_c and 60% ET_c were 268.6, 214.9 and 161.2 mm respectively. Under the control treatment, 600 mm was applied with furrow irrigation @ 50 mm depth at 7 days interval. Silver-black mulch sheet of 25 micron was installed in plots along with drip irrigation set. Interaction of drip irrigation at 80% ET_c with crop spacing of 120-45 x 45 cm (I_6) and drip fertigation at 100% RDF (F_3) showed highest fresh pod yield (17.41 t/ha) and WUE (103.75 kg/ha-mm), with lowest WUE in the control (14.58 kg/ha-mm) of okra var. Varsha Upahar. Thus through treatment combination I_6F_3, okra yield increased by 99% with water saving of 64.4% over control treatment (Table 4.21.1). This proved to be the most effective combination for the okra variety in lateritic soils of Konkan region.

Table 4.21.1. Performance of okra under different irrigation levels, crop spacings and fertilization methods

Treatment combination	Fresh pod yield (t/ha)	Irrigation water use efficiency (kg/ha-mm)
Irrigation level and crop spacing x Fertilization method		
I_1F_1	7.24	34.51
I_1F_2	8.08	38.51
I_1F_3	9.35	44.57
I_2F_1	10.33	49.24
I_2F_2	9.49	45.23
I_2F_3	13.10	62.44
I_3F_1	14.41	68.68
I_3F_2	14.21	67.73
I_3F_3	16.54	78.84
I_4F_1	8.68	51.73
I_4F_2	8.78	52.32
I_4F_3	10.38	61.86
I_5F_1	10.53	62.75
I_5F_2	10.32	61.50
I_5F_3	13.77	82.07
I_6F_1	13.51	80.51
I_6F_2	13.55	80.75
I_6F_3	17.41	103.75
I_7F_1	5.35	42.46
I_7F_2	6.05	48.02
I_7F_3	6.87	54.52
I_8F_1	7.27	57.70
I_8F_2	6.59	52.30
I_8F_3	8.60	68.25
I_9F_1	9.99	79.29
I_9F_2	9.50	75.40
I_9F_3	11.65	92.46
Control	8.75	14.58
$CD_{0.05}$ (Interaction)	NS	-

I_1: 100% ET_c through drip irrigation with crop spacing 120 cm - 45 cm x 45 cm, I_2: 100% ET_c through drip irrigation with crop spacing 120-45x30 cm, I_3: 100% ET_c through drip irrigation with crop spacing 120-45x15 cm, I_4: 80% ET_c through drip irrigation with crop spacing 120-45x45cm, I_5: 80% ET_c through drip irrigation with crop spacing 120-45x30 cm, I_6: 80% ET_c through drip irrigation with crop spacing 120-45x15cm, I_7: 60% ET_c through drip irrigation with crop spacing 120-45x45cm, I_8: 60% ET_c through drip irrigation with crop spacing 120-45x30cm, I_9: 60% ET_c through drip irrigation with crop spacing 120-45x15cm; F_1: Traditional ring method fertilizer at 100%RDF; F_2: Annapurna briquette at 100%RDF; F_3: Fertigation at 100%RDF; Control: Furrow irrigation @ 50 mm depth every 7 days

4.21.2. Enhancing cashew yield through irrigations at critical stages during fruit development

Interaction effect of amount of irrigation and its application at critical growth stages of cashew showed that cashewnut yield of 1.51 t/ha was highest with WUE of 1.26 kg/ha-mm when irrigation was applied @ 50 l/week/plant (amounting to 12 ha-mm) up to 80 days after peanut stage of fruit development (Table 4.21.2).

Table 4.21.2. Performance of cashew different water application

Treatment*	Water applied (ha-mm)	Cashew nut yield (t/ha)	Water use efficiency (kg/ha-mm)
I_0T_1	-	0.68	-
I_0T_2	-	0.69	-
I_0T_3	-	0.92	-
I_0T_4	-	0.77	-
I_1T_1	1.50	1.01	6.76
I_1T_2	3.00	1.21	4.03
I_1T_3	4.50	1.44	3.20
I_1T_4	6.00	1.30	2.17
I_2T_1	3.00	1.01	3.38
I_2T_2	6.00	1.35	2.24
I_2T_3	9.00	1.49	1.65
I_2T_4	12.00	1.51	1.26

*I_0 – No irrigation, I_1 -25 l/week/tree, I_2 – 50 l/week/tree; Water application from peanut stage up to 20 days (T_1), 40 days (T_2), 60 days (T_3) and 80 days (T_4). Total no. of trees=54

4.22. Navsari (AESR 19.2)

4.22.1. Effect of precise application of planting material, irrigation and fertilizer on productivity of sugarcane

The experiment was conducted with sugarcane var. CoN 7072 in heavy rainfall zone (AES-III) in south Gujarat. Placement of lateral (I) and planting material (P) had significant effects on cane yield. Sub surface placement of lateral and planting material of 2-eye budded set resulted in 193 and 199 t/ha cane, significantly higher than other treatments of lateral placement, planting material and control (100% RDF + Irrigation at 1.0 IW/CPE, 60 mm depth + 3-eye budded set) (Table 4.22.1a). Fertigation frequency (F) had no significant effect on cane yield, but FxP was found to be significant on cane yield. Interaction of fertigation with 30 equal splits at weekly interval (F_2) and 2-eye budded set (P_1) yielded 202 t/ha cane, followed by 195 t/ha with F_2P_1 (Table 4.22.1b). Analysis of control vs. other treatments showed that all treatments with drip irrigation recorded significantly higher cane yield than surface method of irrigation. Average amount of water applied with drip and surface methods was 770 mm and 1210 mm, respectively. Highest WUEs 250.6 and 257.87 kg/ha-mm were observed with sub surface placement of drip lateral and 2-eye budded set, respectively (Table 4.22.1b).

Table 4.22.1a. Interaction effect of fertigation frequency and planting materials (FxP) on sugarcane yield (t/ha)

Frequency/Planting material	F_1: 20 splits	F_2: 30 splits
P_1	195.0	202.0
P_2	169.0	170.0
P_3	188.0	183.0
Interaction	SEm±	$CD_{0.05}$
F x P	5.6	17.0

Table 4.22.1b. Performance of sugarcane under influence of lateral placement, planting material and fertigation frequency

Treatment	Cane yield (t/ha)	Water applied (mm)	WUE (kg/ha-mm)
Main plot: Placement of lateral (I)			
I_1: Surface placement	176.0	770	228.5
I_2: Subsurface placement	193.0	770	250.6
$CD_{0.05}$	14.2	-	-
Fertigation frequency (F)			
F_1: 20 splits	184.0	770	238.9
F_2: 30 splits	185.0	770	240.2
$CD_{0.05}$	NS	-	-
Sub plot: Planting material (P)			
P_1: 2 eye budded set	199.0	770	257.9
P_2: 1 week sprouted nod	169.0	770	219.6
P_3: 3 weeks old plant	186.0	770	241.2
$CD_{0.05}$	11.9	-	-
Significant interaction	F x P	-	-
Drip mean	184.0	-	-
Control (Surface irrigation) mean	126.0	1210	104.0
Control vs. Others			
$CD_{0.05}$	15.6	-	-

Theme 5

To evolve management strategies for conjunctive use of surface and groundwater resources for sustainable crop production

Centres working under Theme 5 have conducted trials using water from different sources like surface/canal water (CW), groundwater (GW), rainwater (RW) and wastewater (WW) to irrigate crops. The studies were done mainly in canal command areas where supply of CW is less during *rabi* season or quality of GW is poor for crop health. Coimbatore and Udaipur centres covered all three reaches of canal command. It was suggested by Coimbatore centre that use of GW should be maximum at head reach with gradual decrease towards the tail end, so that farmers of the tail end can use more CW. Faizabad centre showed that 2 CW:1TW facilitated higher yield and water productivity (WP) of wheat in the middle reach of Chandpur distributary. Bathinda centre observed that alternate use of CW and saline and/or sodic TW led to higher yield and WUE for cauliflower and wheat crops compared to CW only at the tail reach. They found wheat varieties PBW 550 and PBW 343 suitable for TW irrigation. Morena centre observed that conjunctive use of water with improved irrigation method resulted in higher yield and WP of crops grown in command area, compared to conjunctive use of water with farmers' method of irrigation. Rice-wheat system performed well with value added dairy surface water and TW combined with INM. Pusa centre observed that use of 50% WW and 50% fresh GW improved growth and yield of cabbage. Nutrient enrichment in post-harvest soil and higher concentration of micronutrients in plant occurred due to irrigation with WW. The studies showed that water from different sources can be harmoniously combined in order to minimize the undesirable physical, environmental and economical effects of each type of water. This can also optimize water demand-supply balance to meet crop water requirement.

5.1. Bathinda (AESR 2.1)

All the experiments on conjunctive use of water by Bathinda centre were conducted in the tail end of canal system falling in south-western zone of Punjab.

5.1.1. Evaluation of drip irrigation system in vegetable crops using brackish water

Feasibility of drip irrigation with different qualities of water was tested for cropping system of vegetables [Cucumber var. Punjab Naveen (February to May)-Bottlegourd var. Punjab Komal (June to October)-Cauliflower var. Girja (Seminus) (November to February)].

Cauliflower (var. Girja): Pooled data of three years (2012 to 2015) showed that curd yield of cauliflower was significantly higher by 7.8% with saline sodic TW (RSC 6.2 meq/l, EC 2200 µmhos/cm) mixed with canal water (CW) in ratio 1:1 (RSC 2.9 meq/l, EC 1130 µmhos/cm) than that with TW alone, but at par with CW alone (Table 5.1.1). It was ***recommended*** that cauliflower crop may be irrigated using CW and TW in ratio 1:1 in loamy sand soil under semi-arid conditions of south-west Punjab to obtain optimum curd yield.

Cucumber (var. Punjab Naveen) and bottle gourd (var. Punjab Komal): Among all the treatments, irrigation with only CW fetched significantly higher yield, WUE, net return and B:C ratio (Table 5.1.1) for both the crops. Yield was 31.4% and 18.1% higher with CW than that with saline sodic TW alone. It was ***recommended*** to grow cucumber and bottle gourd under drip irrigation with CW alone in loamy sand soil under semi-arid conditions of south west Punjab.

Table 5.1.1. Effect of different qualities of water on performance of vegetables

Treatment	Total water use (cm)	Yield (t/ha)	WUE (q/ha-cm)	Water saved (m^3/ha)	Net return (Rs)	B:C	Superiority over existing practice (%)
Cauliflower							
CW	20.8	21.44	10.3	1120	22739	1.39	35
1 CW:1 TW*	21.1	20.35	9.6	1136	18619	1.32	35
1 CW:2 TW*	20.6	19.75	9.6	1109	16351	1.28	35

1 CW:3 TW*	20.6	19.37	9.4	1109	14914	1.26	35
TW	21.0	18.88	9.0	1131	13062	1.22	35
$CD_{0.05}$	-	1.36	-	-	-	-	-
Cucumber							
CW	51.1	15.33	3.0	6246	27303	1.55	55
1 CW:1 TW*	51.6	13.50	2.6	6307	18153	1.37	55
1 CW:2 TW*	50.8	12.00	2.4	6209	10653	1.22	55
1 CW:3 TW*	51.6	11.54	2.2	6307	8353	1.17	55
TW	51.4	10.52	2.0	6282	3253	1.07	55
$CD_{0.05}$	-	0.76	-	-	-	-	-
Bottle gourd							
CW	43.8	40.40	9.2	5353	148335	3.39	55
1 CW:1 TW	43.3	37.75	8.7	5292	134528	3.16	55
1 CW:2 TW	43.8	36.44	8.3	5353	127703	3.05	55
1 CW:3 TW	43.7	34.07	7.8	5341	115355	2.86	55
TW	43.0	34.22	8.0	5256	116137	2.87	55
$CD_{0.05}$	-	2.49	-	-	-	-	-

*Proportions of canal water (CW) and tubewell water (TW)

5.1.2. Effect of quality of water on growth, yield and quality of okra under varying mulching conditions

The six-year long experiment (2010-2015) showed that alternate application of saline sodic TW with CW significantly enhanced the green okra yield by 51.1% compared to only TW application (Table 5.1.2). Alternate use of CW and TW under straw mulch and plastic mulch increased the green okra yield by 14.1% and 19.5%, respectively over no mulch. Yield was increased by 14.8 and 21.2% on application of rice straw and plastic mulch over no mulch regardless of the quality of water. However, plastic mulch proved to be superior to straw mulch by 5.5% w.r.t crop yield. Effect of quality of irrigation water on soil properties under varying mulching conditions showed that mulch application decreased pH and ESP of the surface layer (0-15 cm) of soil under TW and CW/TW treatments (table not shown). Organic C status of the soil improved with the application of straw mulch. Thus, cyclic use of TW and CW with rice straw mulch @ 6 t/ha (Plate 5.1.2) is recommended to obtain higher green okra yield and to maintain soil health. The outcome of this research will help in judicious use of poor quality GW in conjunction with good quality CW for okra without affecting the economic returns for the growers along with minimal effect on soil quality.

Table 5.1.2. Performance of okra crop under varying quality of irrigation water and mulching (Pooled mean of 6 years)

Treatment#	Green okra yield (t/ha)	WEE (kg/ha-cm)	Net return (Rs./ha)	B:C
CW M_0	7.58	92.3	43340	0.73
TW M_0	4.40	53.2	269	-
CW/TW M_0	6.46	78.1	28229	0.48
CW M_s	8.60	106.3	53246	0.84
TW M_s	5.20	63.4	7101	0.11
CW/TW M_s	7.37	90.2	36537	0.58
CW M_p	9.22	114.9	45640	0.58
TW M_p	5.40	66.5	-6204	-0.08
CW/TW M_p	7.72	95.4	25330	0.32
$CD_{0.05}$	0.82	-	-	-

#M_0 – No mulch, M_s – Rice straw mulch @ 6 t/ha, M_p - Plastic mulch 50 micron

Plate 5.1.2. Okra crop with rice straw mulch

5.1.3. Screening of wheat cultivars under varying saline sodic irrigation water conditions

Several wheat varieties were tested under saline sodic water from tubewell and fresh water from canal. At PAU Regional Station (RS), total CW applied to the varieties PBW-343, DBW-17, KRL-19, PBW-590 and PBW-550 was 43.0, 43.4, 44.4, 43.2 and 44.7 respectively. At the RS, total TW applied to the varieties was 43.7, 44.6, 44.1, 44.7 and 43.9, respectively. At village Gehri Buttar (GB) and village Bandi (B), total water applied to the varieties was uniform i.e. 37.5 cm. Quality of water did not have significant effect on grain yield of wheat cultivars in the three sites. Grain yield was significantly different among wheat cultivars. Among qualities of water, average WEE was higher (93.44 kg/ha-cm) with CW than that (90.34 kg/ha-cm) with TW (Table 5.1.3). Amongst varieties, PBW-550 fetched higher yield, WUE, net return (average of three sites = Rs.29981) in TW treatment. PBW-343 showed best performance (average net return of three sites (Rs.32841) under CW treatment. It was concluded that PBW-550 and KRL-19, DBW-17 performed better under saline-sodic TW irrigation water than CW at RS Farm. Varieties PBW 550 and PBW 343 gave significantly higher grain yield than other varieties under both CW and TW. However, PBW-343, DBW-17 and PBW-550 performed better than all the varieties under TW (sodic water) alone. Varieties PBW-343 and PBW-550 performed better than all the varieties under saline water in Bandi. Water use efficiency was higher under CW than TW for all varieties and all sites. DBW-17 showed minimum reduction in yield on use of sodic water compared to good quality CW. DBW-17 and PBW-550 showed minimum reduction in yield under saline water compared to CW. Use of poor quality irrigation water resulted in increased soil pH and EC in all the sites.

Table 5.1.3. Performance of wheat under varying saline sodic irrigation water at three sites of Bathinda (Pooled 2010-2015)

Cultivar	Grain yield (t/ha)			WEE/WUE (kg/ha-m)			B:C			Superiority/Inferiority over CW than TW (%)		
	RS*	GB*	B*	RS	GB	B	RS	GB	B	RS	GB	B
Canal water												
PBW-343	4.05	4.28	4.33	99.4	121.7	128.0	1.88	1.99	2.01	-	-	-
DBW-17	3.81	3.99	3.98	93.3	111.5	116.5	1.77	1.75	1.85	-	-	-
KRL-19	3.53	3.61	3.64	85.9	105.9	108.3	1.64	1.58	1.69	-	-	-
PBW-590	3.75	3.63	3.56	96.2	102.6	105.8	1.75	1.50	1.66	-	-	-
PBW-550	3.91	4.33	4.25	92.4	136.3	124.8	1.82	2.01	1.98	-	-	-

Tubewell water												
PBW-343	3.93	3.93	4.12	93.1	116.6	121.4	1.83	1.75	1.91	-2.86	-8.09	-4.92
DBW-17	3.84	3.96	3.85	88.1	108.9	113.6	1.78	1.84	1.79	+0.76	-0.65	-3.27
KRL-19	3.64	3.38	3.43	85.6	94.2	101.3	1.69	1.50	1.60	+3.29	-6.56	-5.66
PBW-590	3.70	3.39	3.40	85.7	92.4	100.7	1.72	1.57	1.58	-1.36	-6.80	-4.55
PBW-550	4.07	4.19	4.09	99.3	136.6	120.4	1.89	1.95	1.90	+4.23	-3.32	-3.74
$CD_{0.05}$												
A	NS	NS	0.13	-	-	-	-	-	-	-	-	-
B	0.21	0.30	0.31	-	-	-	-	-	-	-	-	-

*RS-Regional Station; Villages Gehri Buttar (GB) and Bandi (B); A-Quality of water; B-Variety

5.1.4. Evaluation of water purifier for irrigation purposes in field crops

After passing the saline-sodic water through water purifier cum descaler, no variation is water quality was observed. Pooled mean of five-year long study (2011-12 to 2015-16) revealed that during *kharif* season, seed cotton yields obtained through application of poor quality TW, PTW and PTW/TW (alternately) were statistically at par (Table 5.1.4). But yield with CW alone was significantly higher than those with all three TW treatments. During *rabi* season, irrigation water treatments did not have significant effect on grain yields of wheat var. HD 2967 and raya var. PBR-91. Similar response was observed in case of changes in pH, EC, SAR and organic carbon content. Unlike CW, irrigation with TW, PTW and TW/PTW resulted in increase in pH, EC and SAR and decrease in organic carbon of the surface soil. Thus it is recommended not to fit water purifier cum descaler on delivery pipe because quality of poor quality TW did not improve after passing through it. This may save farmers from exploitation due to wrong propaganda and notion disseminated by companies regarding change in groundwater quality by using such a system.

Table 5.1.4. Effect of treated and untreated tubewell water on performance of cotton, wheat and raya

Treatment	Yield (t/ha)			Water expense efficiency (kg/ha-cm)			Net return (Rs./ha)			B:C		
	Cotton	Wheat	Raya	Cotton	Wheat	Raya	Cotton	Wheat	Raya	Cotton	Wheat	Raya
CW	2.10	4.53	2.09	28.9	96.4	54.1	24991	30796	35055	1.38	1.88	2.04
TW	1.60	4.40	2.01	22.2	94.1	52.8	3530	28908	30414	1.05	1.83	1.96
Purified TW	1.64	4.39	2.06	22.5	90.8	54.0	3892	26920	30399	1.06	1.73	1.91
Purified TW / TW	1.67	4.38	2.05	23.8	91.7	52.8	4839	26847	29910	1.07	1.73	1.89
$CD_{0.05}$	0.22	NS	NS	-	-	-	-	-	-	-	-	-

CW-Canal water, TW-Tubewell water

5.2. Udaipur (AESR 4.2)

5.2.1. Development of optimal allocation plan for conjunctive use of water in Jaisamand command

The objective was to bring more area under cultivation or to increase production per unit area of available land and water resources. Estimation of CW, rainwater (RW) and GW of the canal area showed that respective discharges of the Jaisamand right main canal (RMC) and left main canal (LMC) were 1.53 and 7.56 cumec, with only 25 average canal running days. Average runoff in the command area from 2000 to 2014 was 261.28 mm, which was 34.6% of average rainfall in these years. Water table fluctuation estimated from 19 wells in 19 locations from 1995 to 2014 was 3.28 cm/year. Availability of rainwater through surface runoff, surface/canal water and groundwater (through recharge) was 1203.2, 1963.44, 844.8 ha-m, respectively. Total availability of water from these sources was used for optimal allocation to crops during *kharif* and *rabi* seasons. When canal running days are less and canal water was insufficient for *rabi* crops, rainwater/runoff and GW were used to provide supplemental irrigation to the crops during long dry spell.

System performance showed that conveyance efficiency (CE) of RMC in three 200 m long locations each at head, middle and tail was 90.20, 80.39 and 67.32%, respectively. Conveyance efficiency of Jhadol and Pahadi minors ranged from 66.7 to 89.3%. Overall CE and water application efficiency of Jaisamand command area were 78.5 and 77.9%, respectively. Field application efficiency was carried out for 616.31 ha. On farm application efficiency for major crops in the command area i.e. wheat, gram and mustard was 61.0%. Respective field WUE and crop WUE for the same crops were 50.0, 19.9 and 18.3 kg/ha-cm and 81.8, 32.6 and 29.8 kg/ha-cm.

Further, three objectives *viz.*, net benefit maximization (NBM), food production maximization (FPM) and labour employment maximization (LEM) were evaluated to develop an optimal irrigation plan for Jaisamand command area during *kharif* and *rabi* seasons (Table 5.2.1). During *rabi*, CW and GW were considered for the irrigation planning on the basis of number of canal running days in a month of a growing season (9, 18, 21, 24 and 30 canal running days). During *kharif* season, maximum area was allocated to maize for objectives NBM and FPM, and moong for objective LEM under RAC and LMC. Among wheat, gram, mustard and barley grown during *rabi* season, wheat occupied maximum area for NBM, FPM and LEM under RAC and LMC.

Table 5.2.1. Optimal allocation of surface and groundwater for net benefit, production and labour employment maximization during *kharif* and *rabi* seasons

Source of irrigation	Investment (Rs. in million)	Achievement		
		Net benefit maximization (Rs. in million)	Farm production maximization (tonnes)	Labour employment maximization (man days)
***Kharif* season**				
Surface runoff and groundwater	374.00	156.24	-	-
	374.00	-	22976.8	-
	246.87	-	-	1356478
***Rabi* season**				
Canal water				
Canal running days (CRD) - 9	439.43 (NBM)	271.32	-	-
	458.43 (FPM)	-	45115.0	-
	437.00 (LEM)	-	-	1424254
CRD - 18	459.83	279.46	45319.2	1512880
CRD - 21	459.83	279.46	45319.2	1512880
CRD - 24	459.83	279.46	45319.2	1512880
CRD - 30	459.83	279.46	45319.2	1512880

5.3. Coimbatore (AESR 8.1)

5.3.1. Evaluation of water productivity in Integrated Farming System in different situations for western zone in Tamil Nadu

Assessment of multiple use of water was done to work out water requirements, number of man days and economics from cropping components and livestock components (Plate 5.3.1) in Integrated Farming System (IFS). The habitats adopted under the IFS were wetland, gardenland and rainfed, each habitat covering one hectare. Performance of crop, fishery and livestock components in wetland and gardenland habitats is shown in Tables 5.3.1a and 5.3.1b.

Plate 5.3.1. Crop, pigeon, vermicompost, chicken and ducks under Integrated Farming System

Table 5.3.1a. Water productivity and economics of crop and livestock components in wetland IFS

Crop (Variety)	Area	Irrigation water used (mm)	Water consumed (L/day/ animal)	Total water consumed (L)	Economic yield	WP (kg/L of water)	Income (Rs.)	Physical WP (kg/m^3)	Economic WP (Rs./m^3)
Rice (ADT R 45)	0.80 ha	375 (506)#	-	4048000	6.35 t/ha	0.00125	80160	1.25	19.80
Rice (IW Ponni)	0.80 ha	525 (575)	-	4600000	6.50 t/ha	0.00113	88400	1.13	19.22
CO (CN) 4 grass	0.15 ha	1050 (1341)	-	2011500	276 t	0.02058	62100	20.58	30.86
Dairy (Jersey)	2 nos.	-	135.80*	83098	4673 L	0.05623	94000	56.23 L	1131
Fish pond	0.03 ha	-	-	1250000	940 kg	0.00075	158882	0.75	127
Poultry	30 nos.	-	0.30	2744	80	0.02915	16000	29.15	5831
Pigeon	20 nos.	-	0.05	304	14	0.04605	2800	46.05	9211
Duck	30 nos.	-	0.64	6094	340	0.05579	28900	55.79	4742

#Figures in parentheses-Total water used (mm); *Water consumption for cow includes drinking, washing and shed cleaning

Table 5.3.1b. Water productivity and economics of crop and livestock components in grassland IFS

Crop (Variety)	Area	Irrigation water used (mm)	Water consumed (L/day/ animal)	Total water consumed (L)	Economic yield	WP (kg/L of water)	Income (Rs.)	Physical WP (kg/m^3)	Economic WP (Rs./m^3)
Sugarcane (CO 86032)	0.20 ha	650 (802)[#]	-	1604000	-	-	-	-	-
Banana (Kathali)	0.20 ha	1250 (1409)	-	2818000	16.50 t/ha	0.00117	82500	1.17	29.27
Turmeric (BSR 2)	0.20 ha	650 (757)	-	1514000	-	-	-	-	-
Maize (CO 6)	0.20 ha	350 (357)	-	714000	5.83 t/ha	0.00163	16338	1.63	22.88
CO (CN) 4 grass	0.18 ha	1200 (1369)	-	2464200	240 t/ha	0.18278	64800	17.53	26.30
Dairy (Jersey)	2 nos.	-	135.80	83098	4673 L	0.01753	158882	56.55 L	1912
Poultry	50 nos.	-	0.30	4574	100	0.02186	24000	21.86	5247
Vermicompost	2 units	-	-	12240	3550	0.29003	35500	290.03	2900

[#]Figures in parentheses-Total water used (mm)

5.3.2. Conjunctive use of groundwater and canal water in the command area of Lower Bhavani Project (Bhavanisagar and Coimbatore)

The study was conducted to assess problem of rising groundwater level and seek solutions by adopting conjunctive use of surface water and groundwater in the command area (3960.8 ha) of Kugalur distributary of Lower Bhavani Project (LBP). About 14% of the command area under head reach faces waterlogging during canal water release for wet crops, because water table is less than 1 m compared to 3-4 m in the middle reach area. Besides rainfall, canal water and groundwater are major sources of irrigation in the area. Conjunctive use is low at the head reach and increased towards the tail reach for high water consuming crops like banana and sugarcane (Table 5.3.2). Irrigated wet crop paddy and irrigated dry crop groundnut depended on canal water only.

Crop water demand and supply scenario in the study area: Annual crop water demand/requirement during 2015 was 2867.0 ha-m, of which canal water supplied was 2239.2 ha-m. Maximum supply of 527.1 ha-m was in September followed by 326.1 ha-m in October 2015. No canal water was supplied in May, June and July. Annual groundwater requirement was 627.82 ha-m, maximum requirement being from May to July (Fig. 5.3.2). Thus a balance of 14.32 ha-m was unutilized groundwater (on annual basis). It depicted sufficient availability of groundwater to meet crop water demand in the distributary for prevailing cropping system.

Table 5.3.2. Scenario of conjunctive use for heavy water consuming crops in 2015

Canal reach	Area irrigated (ha)		Canal water supply (ha-m)		Groundwater withdrawal (ha-m)		Conjunctive use (ha-m)	
	Sugarcane	Banana	Sugarcane	Banana	Sugarcane	Banana	Sugarcane	Banana
Odd turn sluice command								
Head	20	18	26.74	38.89	9.74	8.99	6.82	5.30
Middle	18	14	21.93	25.99	10.90	11.25	8.72	8.50
Tail	15	11	12.09	13.99	15.27	15.27	9.92	10.87
Even turn sluice command								
Head	18	17	-	-	32.83	45.22	-	-
Middle	19	19	-	-	34.66	50.54	-	-
Tail	12	12	-	-	21.89	31.92	-	-

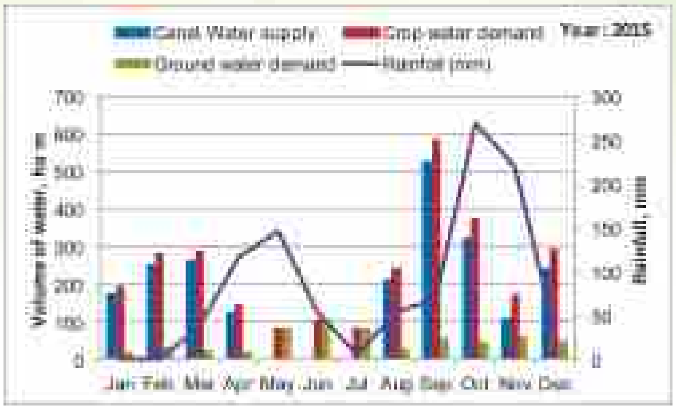


Fig. 5.3.2. Monthly canal water supply, crop water demand and groundwater requirement for Kugalur distributary during 2015

Groundwater budgeting in study area: On annual basis, net recharge was 1668.89 ha-m i.e. 85% of gross recharge. Net groundwater draft was 1026.76 ha-m i.e. 75% of gross draft. Thus groundwater balance was 642.14 ha-m and current stage of groundwater development was 61.5%.

Village-wise plan for development of groundwater resource: Farmers in the head reach are using both canal water and groundwater during the period of canal water supply. Instead of this, villages at the head reach of the distributary may use groundwater for irrigation so that more canal water may reach tail end of the distributary. Farmers along the length of the canal may also increase groundwater usage.

Groundwater fluctuation: Total 18 wells, three each in head, middle and tail reaches of both odd turn and even turn sluice commands were identified. Depth of open wells ranged from 13 to 30 m bgl and depth of bore well ranged from 60 to 245 m bgl. Depth to water level in the distributary varied from 8-12 m bgl and 20-25 m bgl during 2015 and 2016, respectively in the head, middle and tail reaches. Depths to water level during pre-monsoon period were 8.5 m bgl (September 2015) and 15-20 m bgl (September 16). Depths to water level during post-monsoon period were 1.0 to 7.5 m bgl (January 2015) and 1.0 to 3 m bgl (January 2016) in the distributary. Study on long term (1971-2013) fluctuation in water table using data from observation well indicated that rise and fall in water level in the distributary ranged from 0.03 - 0.09 and 0.01 - 0.5 m/year, respectively.

Conclusion and recommendation: Waterlogging and salinity problems in Kugalur distributary are minimum and easily manageable. Groundwater status is under safe category. Water level reaches the ground level during canal water supply. Canal and groundwater can be managed conjunctively for minor irrigation command areas by following alternate wet and dry crops or implementing microirrigation in high water consuming cash crops like sugarcane and banana. Less water may be delivered to the head end of canal, thus redirecting flow towards the tail end. Canal rotations may be periodically skipped so that farmers at the head reach use groundwater during canal water supply. Problem of waterlogging may be avoided by i) pumping groundwater from wells into the canal system and ii) developing community wells. The first one will augment canal water to lower the water table. This will prevent waterlogging and increase canal water supply. Pipe irrigation for canal water supply may be adopted by farmers in the tail end.

5.4. Bilaspur (AESR 11.0)

5.4.1. Effect of value added water and integrated nutrient management on growth and yield of rice-wheat crop sequence under conjunctive use condition

The experiment was conducted to study the impact of value added dairy and tubewell water along with integrated nutrient management on paddy and residual effect on wheat. Physical and chemical properties of both the waters were analysed. Properties bulk density, pH, N, K were non-significant in dairy and tubewell water. Only P and K varied significantly among the nutrient management treatments. Dairy surface water produced significantly higher grain yield of 4.80 t/ha for *kharif* rice var. MTU-1010 and net return Rs.28288 than other sources of water. Among the INM treatments, 75% RDF+BGA resulted in significantly higher grain and straw yields of 5.10 t/ha and straw 5.80 t/ha (Table 5.4.1), respectively with net return of Rs.25559. In the following crop, *rabi* wheat var. HD-2932 grain yield of 3.44 t/ha and net return of Rs.30955 were significantly higher with dairy surface water than other treatments. Among INM treatments, 75% RDF+Green manure resulted in significantly higher grain yield 3.36 t/ha, straw yield 3.98 t/ha and net return Rs.29422 than other treatments except, 75% RDF+BGA (Table 5.4.1).

Table 5.4.1. Performance of rice and wheat under different treatments and residual effect of the treatments on soil properties

Treatment	Grain yield (t/ha)		Straw yield (t/ha)		pH	N (kg/ha)	P_2O_5 (kg/ha)	K_2O (kg/ha)	BD (g/cm^3)
	Rice	Wheat	Rice	Wheat					
Source of water									
Dairy surface water	4.80	3.44	5.43	4.15	6.57	232.09	11.56	256.29	1.33
Tubewell water	4.36	2.97	5.05	3.60	6.60	228.89	10.98	250.65	1.33
Dairy surface water+Tubewell water	4.53	3.16	5.26	3.88	6.61	231.02	11.21	255.27	1.32
$CD_{0.05}$	0.25	0.30	NS	0.38	NS	NS	NS	NS	NS
Integrated nutrient management									
100% RDF	4.82	3.10	5.67	3.89	6.64	233.26	11.92	256.67	1.33
75% RDF	3.88	3.14	4.41	3.84	6.54	224.75	10.52	247.27	1.33
75% RDF + Green manure	4.79	3.36	5.45	3.98	6.62	234.14	11.58	257.04	1.31
75% RDF + Brown manure	4.20	3.09	4.92	3.72	6.50	226.84	10.74	248.76	1.32
75% RDF+BGA	5.10	3.25	5.80	3.94	6.62	234.37	11.48	260.78	1.32
$CD_{0.05}$	0.44	NS	0.66	NS	NS	NS	0.91	8.56	NS

5.5. Pusa (AESR 13.1)

5.5.1. Safe utilization of gray water for sustainable crop production

Characteristics of gray water and fresh groundwater: In gray water samples, pH, EC, Na^+, K^+, Ca^{2+}+Mg^{2+}, TDS, carbonates, bicarbonates, chloride ion, nitrate-nitrogen, some micronutrients (Zn, Cu, Fe, Mn) and SAR were higher than in groundwater samples. Cu was not detected in groundwater samples. Although TDS was high in grey water, it was within safe limit for irrigation.

Irrigation impact of gray water on soil properties: Analysis of soil samples revealed higher pH (9.3) and EC (1.67 dS/m), slight increase in organic C, available N, available K, chloride ion (11.6 meq/l), sodium ion (76.0 mg/l), extractable Zn, Cu and B in post-harvest surface soil irrigated with 100% gray water in comparison to pre–harvest soil. Phosphate content was very high ranging from 34.4 to 61.2 kg/ha in both pre and post-harvest soils irrigated with 100% gray water. Micronutrients B and Zn slightly increased, with reduction in Cu, Mn and Fe. Reduction in bulk density was also observed may be due to accumulation of Na in surface soil.

Effect of gray water irrigation on yield of cabbage crop: Higher yield of 52.6 t/ha was obtained in plots irrigated with 50% fresh groundwater and 50% gray water. It was followed by yield of 49.6 t/ha from alternate irrigation with groundwater and gray water (Plate 5.5.1). The possible reason may be combination of 50% fresh water and gray water was responsible for enrichment of soil with nutrients without excessive accumulation of toxic elements in soil and plant.

DTPA extractable micronutrients concentration in cabbage plant: Maximum concentrations of Zn, Fe and Mn in cabbage were found under use of 50% fresh water and 50% gray water, but Cu was not detected. The study revealed that irrigation with 100% gray water thrice may increase soil salinity and alkalinity; reduction in the ability of soil to absorb and retain water; increase Na, K and P to some extent.

Uptake of micronutrients in cabbage plants: Uptake of Zn, Fe and Mn ranged from 6.08 to 43.97, 106.9 to 811.1 and 5.08 to 23.39 kg/ha, respectively under 50% groundwater and 50% gray water followed by alternate irrigation. The possible reason may be irrigation with gray and fresh water may have helped in optimum translocation of micronutrients to cabbage plants due to higher solubility of cations.

Thus efficient use of such combination of irrigation water can effectively increase water resource for irrigation and may prove to be a boon for agricultural production.

Plate 5.5.1. Cabbage crop grown with safe utilization of gray water in Pusa

5.6. Jammu (AESR 14.2)

5.6.1. Raised and sunken bed system for crop diversification within Jammu region

The project aimed to improve water productivity of waterlogged areas, diversify the existing cropping system and improve livelihood of the farmers of Jammu region. A physical model of raised and sunken bed was developed on 4.0 ha land with six raised beds of size 86.0x9.0 m each, six sunken beds of size 86.0x9.0x1.5-2.0 m each and one farm pond of size 90.0x30.0x2.0 m. Area of the farm pond was 540 m^2 with depth 3 feet. Cropping systems like rice (Basmati 370)-wheat and rice (Basmati 370)-berseem were used as checks. Results of test trials on multiple use of water in *zaid*, *kharif*, *rabi* seasons, conducted on raised beds of the physical model in lowlands, showed satisfactory trends for crop diversification (Table 5.6.1). In the sunken beds, Indian major carps (Catla, Rohu and Mrigal) and exotic carps (Silver carp, Grass carp and Common carp) were grown with stocking density of 600 fingerlings per pond. Fish carps of 50 kg were harvested.

Table 5.6.1. Crop diversification in raised and sunken bed system in Jammu

Crop	Variety	Yield (t/ha)	Fertilizer (N:P:K)	Irrigation (mm)	Rainfall (mm)	TWA (mm)	WUE (kg/ha-mm)
***Zaid* 2016**							
Tomato	Samrudhi (F_1)	7.64	120:60:60	360	46.8	406.8	18.77
Okra	F_1	8.18	100:60:60	360	196.8	556.8	14.69
Radish	F_1 (Silky White)	4.64	60:30:50	60	60.2	120.2	38.56
***Kharif* 2016**							
Okra	F_1	5.09	100:60:60	-	784.2	784.2	6.49
Rice (Transplanted)	Basmati 370	2.33	30:20:10	150	442.4	592.4	3.93
Rice (Direct seeded)	Basmati 370	1.97	30:20:10	-	820.8	820.8	2.40
***Rabi* 2016-17**							
Cauliflower	Girja White	4.24	-	180	180	180.0	23.56
Spinach	Local	2.72	-	54.3	180	234.3	11.59
Knol khol	SJKK-01 (G-40)	3.64	100:50:50	-	180	180.0	20.2

Operational Research Project (ORP)

Theme 1 - ORP

Bathinda (AESR 2.1)

1. Matching and reconciliation of water supply with crop water demands in consideration of crop diversification and water application

Balluana minor (length 10.8 km) of the Behman distributary of Bathinda branch was selected to evaluate irrigation system performance, to work out intervention for improvement of irrigation system, and improve crop and water productivity under "On Farm Development". The Balluana minor has 11 outlets with discharge capacity of 24.63 cusec. Only nine outlets were selected for this study. Total cultivable command area under the minor is 6223.5 ha. Total canal running days from November, 2015 to October 2016 were 274 days for the ORP area. During *rabi* season, total canal running days were 112 days on each outlet with total discharge of 51131.5 ha from the outlets. Total cropped area during *rabi* season was 6111.52 ha, wheat being the main crop at all outlets. Overall relative water supply of the system for *rabi* 2016 was 0.28 (Table B1). So, there is a need to replace large part of the area under wheat by barley, gram and raya, which require less water to match crop water requirement with water supply at the outlets. During *kharif* season, total canal running days was 162 days for each outlet with total discharge of 73958.0 ha from the outlets. Overall relative water supply of the system for *kharif* 2016 was 0.74. Total cropped area during *kharif* was 6111.52 ha, rice covering maximum area. So there is need to either increase the supply of water or replace high water requiring crops with low water requiring crops like cotton, guar and bajra.

Table B1. Relative water supply from canal during *rabi* 2015-16 and *kharif* 2016

Outlet no.	Canal water diverted (ha-cm)		Effective rainfall (ha-cm)		Total water supply (ha-cm)		Crop water requirement (ha-cm)		Relative water supply	
	Rabi	*Kharif*	*Rabi*	*Kharif*	*Rabi*	*Kharif*	*Rabi*	*Kharif*	*Rabi*	*Kharif*
3758/R	5617.3	8125.1	4003.4	36889.0	9620.7	45014.1	33490.7	66029.9	0.287	0.682
14025/L	5041.9	7292.8	3653.3	33663.7	8695.2	40956.5	30475.9	62570.5	0.285	0.655
14040/R	4850.1	7015.3	3517.8	32415.1	8367.9	39430.4	29345.5	60249.8	0.285	0.654
18163/R	4822.7	6975.7	3490.6	32163.8	8313.2	39139.5	29118.0	59782.7	0.286	0.655
20170/L	7124.4	10305.0	5176.5	47699.1	12300.9	58004.1	43376.8	80016.0	0.284	0.725
25000/L	5973.6	8640.3	4347.2	40057.4	10320.8	48697.7	36565.3	58244.5	0.282	0.836
26630/L	6631.2	9591.6	4822.7	44439.1	11453.9	54030.7	40565.1	64615.7	0.282	0.836
35977/TL	6713.4	9710.5	4869.0	44865.2	11582.4	54575.3	40676.2	66766.7	0.285	0.817
35977/TR	4356.9	6301.9	3155.3	29074.8	7512.2	35376.7	26314.2	46082.5	0.285	0.768

Parbhani (AESR 6.2)

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

Twenty-five wells from the command (C) area of left bank canal of Jayakwadi Irrigation Project and five wells from the adjacent non command (NC) area were selected to monitor water table fluctuation and quality of groundwater (GW). Water table depth measured in selected dug wells during March 2017 showed that water table of C area ranged from 5.1 to 7.2 m, which was higher by 3.0 m in the NC area. Due to exploitation of well water for *rabi* summer crops such as sweet orange, water table depth increased to 6.08 m in the C area and 9.08 m in the NC area, despite release of canal water. From 1985 to 2017, annual fluctuations in the water table showed that water table in the C area raised due to recharge from canal water as compared to NC area (Table P1).

During March 2017, water quality parameters like pH, EC, CO_3^{2-}, HCO_3^-, Cl^-, $Ca^{2+} + Mg^{2+}$, Na^+ and SAR in the C area were higher than in the NC area. Based on SAR values, GW in both C and NC areas were rated with no sodium hazard (S_1). Thus the water can be used for all types of soils with little danger of exchangeable sodium. Quality of GW from the C area with high salinity (EC) (C_3) was categorized as C_3S_1 and that from the NC area with medium salinity (C_2) as C_2S_1. The former GW cannot be used on soils with restricted drainage.

Table P1. Annual water table fluctuation and water quality in Jayakwadi command (C) and non command (NC) area

Year	Water table depth (m)		pH		EC (dS/m)		SAR	
	C	NC	C	NC	C	NC	C	NC
1985	2.2	4.6	8.6	8.0	0.92	0.60	1.5	0.78
1986	3.2	9.0	8.9	8.1	0.82	0.8	0.7	0.50
1987	4.0	6.0	8.7	8.2	0.83	0.70	0.9	0.40
1988	5.8	7.73	8.5	8.0	0.92	0.60	1.5	0.98
1989	2.3	3.8	8.6	8.0	0.90	0.70	2.5	1.50
1990	3.2	5.3	8.6	8.0	1.8	0.70	3.5	2.10
1991	2.9	5.6	8.5	8.2	2.0	0.50	5.52	1.84
1992	2.9	13.0	9.0	8.4	1.8	1.0	0.91	0.77
1993	3.8	6.4	8.5	8.1	0.9	0.40	2.3	0.60
1994	4.6	8.1	8.34	8.0	0.8	0.30	0.9	0.50
1998	3.4	8.8	8.61	8.5	1.9	1.20	1.2	0.642
1999	3.2	4.1	7.65	7.59	1.2	0.56	0.76	0.70
2000	4.0	5.6	7.40	7.10	1.0	0.50	1.5	0.9
2001	4.5	6.8	7.81	7.65	1.13	0.52	2.8	1.20
2002	4.0	7.8	7.99	7.75	1.41	0.70	2.9	1.10
2003	9.9	12.8	7.98	7.91	1.40	1.10	1.53	0.164
2004	7.8	8.6	7.89	7.39	1.28	0.83	1.14	0.46
2005	5.9	9.2	8.0	7.58	1.02	0.82	1.52	1.17
2006	5.4	9.5	8.03	7.45	0.95	0.85	4.74	1.30
2007	5.1	7.9	7.63	7.53	1.01	0.95	2.88	2.70
2008	5.0	8.8	7.65	7.50	1.01	0.80	3.80	2.70
2009	4.0	8.9	7.66	7.60	1.3	0.70	4.10	3.70
2010	4.5	9.0	7.98	7.60	1.4	0.80	3.50	3.10
2011	4.0	8.7	7.83	7.57	1.59	0.67	5.95	3.61
2012	6.8	10.2	7.71	7.52	1.58	0.91	5.45	2.73
2013	15.1	15.1	7.72	7.37	2.31	1.91	3.82	1.84
2014	6.9	8.9	7.63	7.26	1.91	0.85	4.70	2.76
2015	9.4	14.3	7.56	7.23	1.25	0.66	5.66	3.46
2017	6.1	9.1	7.40	7.15	1.82	0.85	4.84	3.60

Gayeshpur (AESR 15.1)

1. Arsenic contamination and mitigation in shallow tubewell command

The study was conducted in village Ghetugachi, Chakdah block, Nadia district of West Bengal. Arsenic (As) concentration in shallow tubewell water was 0.21 ppm. Three water management options were selected i) continuous submergence (CS) was maintained with 4 cm ponded water, ii) saturation was maintained after subsidence of ponded water (SAT), and iii) irrigation was applied when soil metric potential at 20 cm soil depth reached -0.03 MPa after disappearance of ponded water to simulate alternate wetting and drying situation (AWD). The goal was to understand As mitigation naturally through water management practices in different rice varieties. Among the water management practices, alternate wetting and drying method resulted in lowest As accumulation in all plant parts of the rice varieties. Among the varieties, Gontera Bidhan 1 showed lowest As accumulation in rice root, shoot and grain when alternate wetting and drying was applied. Grain yield of the variety (4.13 t/ha) was least compromised (19.85%) compared to yield (4.95 t/ha) under continuous submergence. Arsenic accumulation in various parts of rice varieties just before harvest, available As in soil and economic returns after harvest is presented in Table G1.

Table G1. Arsenic accumulation in rice cultivars at harvesting stage, yield and economics under simulated irrigation situations

Treatment	Root As (mg/kg)	Stem As (mg/kg)	Leaf As (mg/kg)	Grain As (mg/kg)	Available As in soil (mg/kg)	Grain yield (t/ha)	Profit (Rs./ha)	B:C
IET 4786, CS	16.13	4.85	4.59	1.31	1.57	4.24	22657	0.57
IET 4786, SAT	15.80	4.11	2.72	0.89	1.32	4.10	22215	0.59
IET 4786, AWD	4.36	4.14	3.47	0.84	1.09	3.94	21655	0.59
IR 36, CS	13.89	3.47	6.98	1.15	1.69	4.10	22204	0.56
IR 36, SAT	8.07	3.18	3.05	0.90	1.40	3.85	18099	0.48
IR 36, AWD	10.13	3.54	3.45	0.40	1.30	3.66	16951	0.46
GB 1, CS	13.39	5.93	6.70	2.03	1.40	4.95	35190	0.89
GB 1, SAT	13.21	4.33	4.04	1.12	1.40	4.75	32064	0.85
GB 1, AWD	13.26	5.08	2.31	0.14	1.33	4.13	23566	0.64
SEm (±)	0.15	0.05	0.15	0.02	0.06	0.10	-	-
$CD_{0.05}$	0.46	0.14	0.44	0.05	0.18	0.29	-	-

As-Arsenic; CS-Continuous submergence; SAT-Saturation; AWD-Alternate wetting and drying; Calculations were made with figures upscaled to one hectare; GB 1- Gontera Bidhan 1

Theme 2 - ORP

Hisar (AESR 2.3)

1. Demonstration of efficient water management technologies

During *rabi* season of 2015-16, trials were conducted on farmers' fields located at two outlets (10000R and 14920L) of Sarsana minor of Balsamand distributary. Wheat crop grown under FIRBS showed average grain yield of 4.51 t/ha at 14920L outlet. The yield was 6.4% higher with 12.6% or 3.1 cm water saving over conventional sowing and flood irrigation (Table H1). Water productivity (WP) ranged from 164.9 to 191.7 kg/ha-cm with flood irrigation and 202.1 to 234.1 kg/ha-cm with FIRBS (Fig. H1). The average increase in WP was 36.6 kg grain/ha-cm under FIRBS.

Table H1. Performance of wheat grown with FIRBS and flood irrigation (*Rabi* 2015-16)

Field No.	Grain yield (t/ha)		Irrigation water applied (cm)		Increase in yield (%)	Water saved (%)	Increase in WP (%)
	Flood	FIRBS	Flood	FIRBS			
1	4.78	5.08	25.3	22.2	6.1	12.3	20.9
2	4.64	4.89	28.1	24.2	5.5	13.9	22.5
3	4.43	4.75	23.1	20.3	7.3	12.1	22.1
4	4.28	4.60	23.3	20.5	7.3	12.0	21.9
5	4.23	4.50	22.5	19.8	6.3	12.0	20.8
6	4.70	4.99	25.8	22.6	6.1	12.4	21.2
Mean	4.51	4.80	24.7	21.6	6.4	12.6	21.7

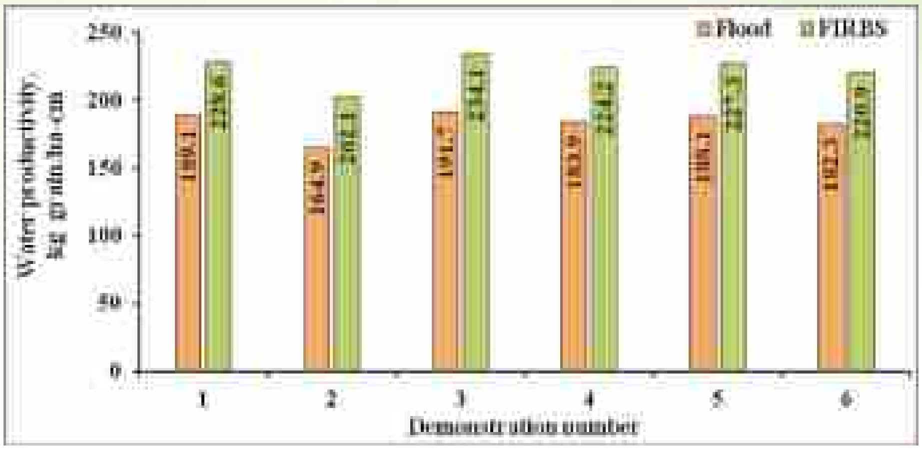


Fig. H1. Water productivity of wheat at farmers' field during *Rabi* 2015-16

Coimbatore (AESR 8.1)

1. Operational research project on improved water management in LBP command

Technology of improved irrigation management was demonstrated at three farmers' field (selected at random) each at head, middle and tail reaches of Lower Bhavani Project (LBP) command area. The improved water management is referred to applying irrigation at 0.6 IW/CPE once in 12-14 days along with gypsum application in splits. It was compared with farmers' practice of applying irrigation once in 8-10 days. Irrigation water applied for improved and farmers' practices were 450 and 600 mm. The demonstration showed that there was 19.6 to 29.4% water saving and 12.1 to 17.1% increase in yield when groundnut var. CO 2 was grown with the improved practice under groundnut-rice cropping system during 2016 (Table C1).

Table C1. Comparison of the performance of groundnut under improved and farmers' water management practices

Parameter	Location	Grain yield (t/ha)		WUE (kg/ha-mm)		Net return (Rs./ha)		B:C	
		T_1	T_2	T_1	T_2	T_1	T_2	T_1	T_2
Head Reach	Location 1	1.65	1.85	2.50	3.63	44190	58700	2.15	2.74
	Location 2	1.57	1.83	2.38	3.59	41100	56600	2.10	2.62
	Location 3	1.50	1.75	2.27	3.43	39400	54400	2.11	2.64
Middle Reach	Location 1	1.73	2.03	2.84	3.97	51100	68050	2.44	3.05
	Location 2	1.60	1.85	2.42	3.63	44550	59550	2.26	2.81
	Location 3	1.75	2.00	2.87	3.92	51240	65940	2.41	2.94
Tail Reach	Location 1	1.70	1.98	2.79	3.87	47950	63900	2.29	2.83
	Location 2	1.63	1.90	2.67	3.73	45200	60900	2.25	2.79
	Location 3	1.50	1.75	2.46	3.43	38300	53450	2.04	2.57

T_1: Farmers' practice, T_2: Improved practice, Rainfall = 60 mm

2. Operational research project on drip fertigation in sugarcane and banana

Sugarcane: The experiment was conducted in three villages, Kullampalayam, Ellamadai and Konnamadai in Tamil Nadu, all having sandy loam soil. During 2015 and 2016, sugarcane var. Co 86032 was grown with drip fertigation at three random farmers' fields in head, middle and tail reaches of the LBP command. Drip lateral spacing was 1.5 m, dripper spacing was 0.6 m and dripper discharge was 4 lph. Depth of irrigation varied according to CPE at every three days. Paired row planting i.e. 60 cm between two rows in a pair and 90 cm between two pairs of rows was chosen. Interventions to the crop were i) drip irrigation once in three days at 80% PE, ii) application of full dose of P (62.5 kg/ha) as basal and iii) fertigation of N (275 kg/ha) and K (112.5 kg/ha) in 14 equal splits, with 15 days interval from 15 DAP. Recommended dose of fertilizer was 275:62.5:112.5 kg NPK/ha.

Banana: Farmers were selected at random from three locations *viz.*, Kullampalayam, Vellalapalayam and Pulavakalipalayam, one each at head, middle and tail reaches of the distributary. Soil texture was sandy loam. Banana var. Kathali was grown using drip fertigation. Drip lateral spacing was 1.8 m, dripper spacing was 0.6 m and dripper discharge was 4 lph. Plant spacing was 1.8 m x 1.8 m i.e. triangular geometry planting. Interventions to the crop were i) application of entire P (35 g/plant) in the 3rd month through band placement and ii) N (110 g/plant) and K (330 g/plant) in 30 equal splits from 6th week to 35th week after planting. Recommended dose of fertilizer was 110:35:330 g NPK/plant. Response of sugarcane and banana to drip fertigation is compared with farmers' practice in Table C2.

Table C2. Comparison of drip fertigation and conventional method of sugarcane and banana cultivation

Parameter	Year	Head reach		Middle reach		Tail reach	
		T_1	T_2	T_1	T_2	T_1	T_2
Sugarcane							
Total water applied (mm)	2015	2230	1600	2150	1810	2100	1625
	2016	2150	1572	2200	1578	2250	1677
Yield (t/ha)	2015	89.0	121.0	91.0	125.0	85.0	115.0
	2016	90.0	120.5	-	-	88.0	121.5
WUE (kg/ha-mm)	2015	39.9	75.6	42.3	69.1	40.5	70.8
	2016	41.9	76.7	-	-	39.1	72.5
Net return (Rs./ha)	2015	94200	149800	94200	165500	82000	135500
	2016	92000	146650	-	-	83900	147450
B:C	2015	1.85	2.17	1.82	2.36	1.72	2.05
	2016	1.80	2.12	-	-	1.71	2.12
Banana							
Total water applied (mm)	2015	-	-	2100	1620	2050	1580
	2016	2100	1640	-	-	-	-
Yield (t/ha)	2015	-	-	17.0	21.5	17.5	22.0
	2016	15.5	20.0	-	-	-	-
WUE (kg/ha-mm)	2015	8.10	13.27	-	-	8.54	13.92
	2016	7.38	12.20	-	-	-	-
Net return (Rs./ha)	2015	545500	713000	-	-	564000	731000
	2016	484250	651000	-	-	-	-
B:C	2015	5.06	5.85	-	-	5.15	5.91
	2016	4.57	5.37	-	-	-	-

T_1-Conventional method, T_2-Drip fertigation in sugarcane and banana; Total water applied=Irrigation+Rainfall; Average sale price of banana was Rs.40/kg

Jammu (AESR 14.2)

1. Managing agriculture water demand through pressurized irrigation system

The study was undertaken to improve water use efficiency of vegetable crops in canal command areas of Jammu under PMKSY project entitled "More crop per drop of water" and to strengthen farmers' reliability in pressurized irrigation system. Pargwal canal project (2860 ha) and Ramban cluster canal project (2692 ha) were selected with an aim to cover 10% area under each project under mini-sprinkler and drip irrigation systems. Design of microirrigation system for vegetable crops was made for plot size of 100 x 100 m (1.0 ha) by standardizing components like capacity of tank, power of pump and specifications of micro-sprinkler and in-line drip irrigation systems. This was done to run the system covering 1.0 ha of selected farmers' fields on cyclic basis of 0.25 ha/2500 m^2. For the micro-sprinkler system, capacity of water storage tank is 10000 *l* in order to meet water requirement per half hour per cycle to apply 4 mm depth of water within 0.25 ha. Pump size is 7.5 hp. Therefore, time required to irrigate 1.0 ha area with 4 mm water depth is 80 to 100 minutes. For the drip irrigation system, lateral spacing is 1.0 m with 0.3 m/30 cm dripper spacing. Water required to provide irrigation to a depth of 4.4 mm is 20 minutes/cycle. Total number of drippers required for one hectare is 33332. Guidelines for adopting the microirrigation system (mini-sprinkler and drip irrigation system) are forwarded to the Project Officer, Soil and Water Management, Command Area Development (CAD), Jammu. Agriculture department/CAD may execute the programme as per their approved components and evolve the rates as per subsidized rates.

Jorhat (AESR 15.4)

1. Demonstration and ORP on irrigation management in different crops in farmers' field in different location of Assam

Brinjal: Sangro 33 and BE 706 varieties showed that improved practice resulted in 20.2% increase in yield and 40% water saving compared to farmers' practice.

Tomato: Rocky, Trishul and Nayak varieties showed that improved practice resulted in 18.5% increase in yield and 40% water saving compared to farmers' practice.

Yellow sarson: B9 variety of yellow sarson grown after winter rice resulted in 13.8, 43.6 and 15.6% higher seed yield in Nalbari, Sonitpur and Jorhat districts, respectively over farmers' practice (rainfed). On an average, two irrigations at flowering and siliqua formation stages recorded 21.2% higher yield of yellow sarson over farmers' practice. It is also evident that instead of keeping the land fallow after winter rice, yellow sarson is one of the most feasible and remunerative *rabi* crops in areas of DTW/STW commands of Assam.

Broccoli: Early 07 variety showed that improved practice resulted in 9.6% increase in yield and 33.3% water saving compared to farmers' practice.

Gladiolus: Novalux variety showed that irrigated crop recorded 32.8, 52.9, 17.3 and 21.2% higher spike length, spike weight, number of spike and number of corms, respectively than the corresponding rainfed crop.

Autumn rice: Dishang variety showed that improved practice resulted in 8% increase in yield and 38.5% water saving compared to farmers' practice.

Aerobic rice: Englongkiri and Banglami varieties showed that improved practice resulted in 12.3-14.0% increase in yield compared to farmers' practice.

Sugarcane: Dhansiri and Doria varieties showed that improved practice resulted in 30.5-60.3% and 30.0-60.8% increase in cane yields of main crop and first ratoon crop, respectively compared to farmers' practice in three districts. All the results are summarized in Table J1.

Table J1. Performances of different crops under farmers' and improved practices in Assam

Crop	Treatment	Farmers' practice[#]	Improved practice[#]
Brinjal	Fruit yield (t/ha)	17.80 (Nalbari)	19.50 (Nalbari)
		16.59 (Jorhat)	21.86 (Jorhat)
	Total irrigation water used	20.0	12.0
	IWUE (kg/ha-cm)	860.0	1723.0
Tomato	Fruit yield (t/ha)	21.24	25.17
	Total irrigation water used	20.0	12.0
	IWUE (kg/ha-cm)	1062.0	2097.5
Yellow sarson	Seed yield (t/ha)	1.25 (Nalbari)	1.09 (Nalbari)
		0.79 (Sonitpur)	0.55 (Sonitpur)
		0.92 (Jorhat)	0.79 (Jorhat)
Broccoli	Head yield (t/ha)	9.90	10.85
	Total irrigation water used (cm)	24.0	16.0
	IWUE (kg/ha-cm)	412.5	678.1
Gladiolus	Spike length (cm)	70.2	93.2
	Spike weight (g)	79.6	121.7
	Numbers of spikes/ha	120400	141200
	Number of corms/ha	115600	140120
Aerobic rice	Grain yield (t/ha)	3.10 (Nalbari)	3.48 (Nalbari)
		1.25 (Chirang)	1.43 (Chirang)

Autumn rice	Grain yield (t/ha)	0.50	0.54
	Total irrigation water used (cm)	65.0	40.0
	IWUE (kg/ha-cm)	76.9	135.0
Sugarcane	Cane yield of main crop (t/ha)	51.4 (Sonitpur)	67.1 (Sonitpur)
		42.1 (Golaghat)	67.5 (Golaghat)
		57.3 (Jorhat)	78.7 (Jorhat)
	Cane yield of first ratoon crop (t/ha)	54.9	71.2
		47.2	75.9
		62.1	83.6

[#]Please refer to the improved and farmers' practices from the original report of Jorhat centre

Dapoli (AESR 19.2)

1. Performance evaluation of low pressure in-line drip irrigation system to jasmine (*Jasminum* sp.) on tribal farmers' fields

The study was conducted to determine water requirement of jasmine crop, study hydraulics of low pressure in-line drip system and evaluate response of jasmine crop to the irrigation system. Four tribal farmers' fields at Jawhar and Vikramgad talukas of Palghar district, Maharashtra were chosen. A plastic tank of 1000 litre capacity was installed over the MS angle stand to develop the required pressure head. The drip system was installed as per spacing using LDP sub main of 25 mm diameter and 12 mm in-line lateral with in-line emitters having recommended discharge of 1.6 lph at 10 m operating pressure. Pressure head of range 1.5-5.0 m gave discharge of 0.56-1.09 l/h. Water requirement calculated for jasmine crop varied from 4 to 10 l/day/plant with total evaporation being 1589.4 mm during 2016. Flow condition in the sub main and lateral of drip system was considered as steady with lateral outflow. Hydraulics of the drip system was evaluated. Estimated values of hydraulic performance parameters *viz.*, coefficient of variation, statistical uniformity coefficient, field emission uniformity and absolute emission uniformity were 0.002, 0.99, 90.97 and 90.27, respectively. After assessment of the drip system, perennial jasmine crop was grown with the system. Maximum yield and WUE of jasmine were observed in December 2016 (Table D1).

Table D1. Month-wise average yield of jasmine flower during the year 2016

Month	Average flower yield (t/ha)	Water requirement (ha-cm)	Water use efficiency (kg/ha-cm)
January	1.10	8.75	125.7
February	1.35	9.01	149.8
March	1.15	11.70	98.3
April	0.95	14.38	66.0
May	0.40	14.81	27.0
June	0.40	12.42	32.2
July	-	-	-
August	-	-	-
September	0.10	6.06	165.0
October	1.40	9.20	152.0
November	1.45	10.62	136.5
December	1.70	9.44	180.0

Theme 3 - ORP

Udaipur (AESR 4.2)

1. Assessment of groundwater recharge through farm pond constructed at farmers' field

Three previously constructed farm ponds of sizes 40x30x3 m^3, 20x20x3 m^3, 20x20x3 m^3 at farmers' fields in Bhinder block of Udaipur district were selected for the study. Topographical survey of the submergence area was conducted. Depth capacity curves for the ponds were prepared (Fig. U1). Water level and impact of the ponds on groundwater recharge in open well were monitored (Plate U1). Average groundwater recharge rate through the ponds was 17.1 mm/day. During the year 2016, total recharge in the ponds was 4811 m^3, out of which 1750 m^3 was pumped out and net recharge was 3061 m^3 (Total evaporation=404 m^3). Thus irrigation water from the farm ponds may help to enhance crop productivity in the region.

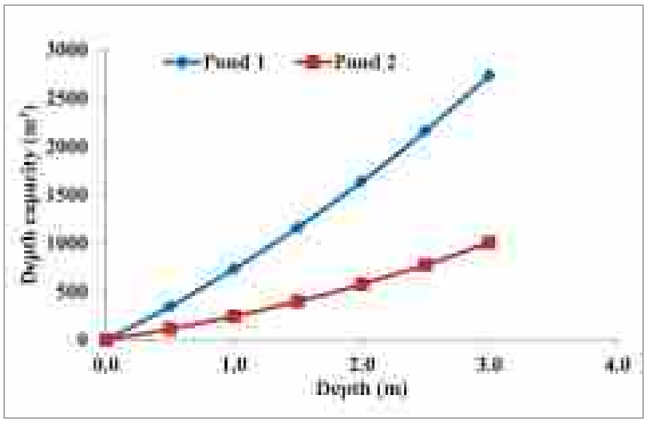


Fig. U1. Depth capacity curves of two farm ponds

Plate U1. Impact of farm pond on groundwater recharge

Navsari (AESR 19.1)

1. Survey related to feedback on sub surface drainage (SSD)

Since 2003, about 156 ha have been brought under SSD covering 75 farmers of south Gujarat. Out of 66 farmers, 77, 14, 7 and 2% farmers from districts of Surat, Bharuch, Navsari and Tapi have installed drainage system due to serious waterlogging and salinity problems in the region. Majority (74%) of the respondents have installed drain pipe at a spacing of 45 m and depth of 90 to 120 cm in their fields as per recommendation given in 2003-04. Major benefits obtained by the farmers through adoption of the drainage technology is that >59% farmers have seen improvement in the salt affected soils within two years, and 64% farmers found its benefit in waterlogged fields within one year. According to the opinions of 54% and 40% farmers, cultivation of sugarcane crop could recover the total cost of drainage installation within one and two years, respectively. Moreover, with adoption of the drainage technology, time range required for getting *vaspa* condition in field has reduced from 25-30 days to 5-7 days. Also, sugarcane yield has increased from 60-80 t/ha to 100-140 t/ha. Additional benefits of the technology are that 76% farmers needed less planting material due to better germination in drained fields, 71% farmers could irrigate their fields frequently, and 36% farmers experienced increase in land value due to reclamation of the affected soils. Most of the farmers in south Gujarat are convinced that it is the best technology for reclamation of waterlogged and salt affected soils. But there is scope for research to reduce cost of the drainage system.

Theme 4 - ORP

Kota (AESR 5.2)

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

The study was conducted at Manasgaon distributary of Right Main Canal (RMC) and Andhed distributary of Left Main Canal (LMC). Under each distributary, nine farmers' fields, three each at the head, middle and tail reaches were chosen. Thus there were total eighteen demonstrations of wheat crop covering 0.1 ha for every canal reach. Test block was irrigated with boarder strip method with 6 cm ponded water compared to random flood irrigation in control block (farmers' practice). Results showed that grain yields of wheat var. Raj 4037 were 8.6 and 8.8% higher with 16 cm water saving in the test block compared to the control block at LMC and RMC, respectively (Table K1).

Table K1. Effect of improved water management on wheat crop

Particulars		*Rabi* 2015-16	
		Test block	Control block
Irrigation practice		**Recommended:** Four irrigations at CRI, tillering, flowering and milk stages by border strip method (6 x 50 m)	Farmers' practice (Flood irrigation)
Number of irrigations		4	4
Depth of irrigation applied(cm)		6	10
Total water applied (cm)		34	50
Saving of water over control (cm)		16	-
Grain yield (t/ha)	Andhed (LMC)	5.21	4.80
	Manasgaon (RMC)	5.16	4.74
Increase in yield (%)	Andhed (LMC)	8.60	-
	Manasgaon (RMC)	8.80	-
Water expense efficiency (kg/ha-cm)	Andhed (LMC)	153.30	96.00
	Manasgaon (RMC)	151.60	94.70

2. Transfer of newly generated water management practices in soybean and paddy at farmer's fields

Location of the present demonstration is same as the previous one. Under each distributary, nine farmers' fields were chosen for soybean, three each at the head, middle and tail reaches. Six farmers' fields were chosen for paddy, three each at the head and middle reaches. Thus there were total fifteen demonstrations covering 0.1 ha for every canal reach.

Soybean var. JS-95-60: In the test blocks under Andhed distributary, application of total 6 cm of irrigation water resulted in 7.27, 6.88 and 9.17% increase in soybean seed yield at the head, middle and tail reaches, respectively compared to the corresponding control blocks, where total 10 cm water was applied. At the test blocks under Manasgaon distributary, application of total 6 cm of irrigation water resulted in 7.69, 5.46 and 7.08% increase in soybean yield at the head, middle and tail reaches, respectively compared to the control blocks, along with 66.7% water saving (Table K2).

Paddy var. Pusa Sugandha 4: In the test blocks at Andhed distributary, application of total 45 cm irrigation water resulted in 9.6 and 9.8% increase in rice grain yield at the head and middle reaches, respectively compared to the control blocks, where total 60 cm of irrigation water was applied. In the test blocks at Manasgaon distributary, application of total 45 cm irrigation water resulted in 11.2 and 13.1% increase in rice yield at the head and middle reaches, respectively compared to the control blocks, where 60 cm of irrigation water was applied. Thus 33.3% water was saved with the improved water management (Table K2).

Table K2. Effect of improved water management on soybean and paddy crops

Particulars	*Kharif* 2015-16			
	Soybean		Paddy	
Irrigation practice	**Test block** Recommended: 6 cm depth of irrigation at flowering and pod formation stage by border strip method	**Control block** Farmers' practice: 10 cm by flood method	**Test block** Recommended: 5±2 cm standing water and refilling it 1-3 days after disappearance of ponding water	**Control block** Farmers' practice: 10-12 cm depth of irrigation by flood irrigation, i.e. continuous submergence
Number of irrigations	1	1	5	5
Depth of irrigation applied (cm)	6	10	7	10

Depth of pre-sowing applied (cm)		-	-	10	10
Total water applied (cm)		6	10	45	60
Saving of water over control (cm)		4	-	15	-
Crop yield (t/ha)	Andhed	1.25	1.16	4.98	4.54
	Manasgaon	1.37	1.29	4.89	4.36
Increase in yield (%)	Andhed	7.75	-	9.7	-
	Manasgaon	6.20	-	12.1	-
WEE (kg/ha-cm)	Andhed	208.3	116.0	110.7	75.7
	Manasgaon	228.3	129.0	108.7	72.7

3. Poor quality irrigation water, nitrogen and zinc of wheat crop in the salt affected area of the Zone V

From *Rabi* 2013-14 to 2015-16, trial was conducted with application of poor quality irrigation water, and different doses of nitrogen and zinc to wheat var. Raj 3077 at a farmer's field. Results showed that application of N @ 150 kg/ha gave significantly higher grain yield and WUE of wheat than yield with N dose of 120 kg/ha. Nitrogen doses of 150 kg/ha and 180 kg/ha showed statistically similar grain yield and WUE (Table K3).

Table K3. Pooled result on performance of wheat under poor quality irrigation and doses of nitrogen and zinc

Treatment	Grain yield (t/ha)	Straw yield (t/ha)	WUE (kg/ha-mm)	Net return (Rs./ha)
Nitrogen level				
120 (kg/ha)	4.02	5.38	56.3	53737
150 (kg/ha)	4.41	5.91	61.7	59967
180 (kg/ha)	4.53	5.99	63.4	61346
$CD_{0.05}$	0.18	0.25	2.62	3299
Zinc sulphate level				
20 (kg/ha)	4.28	5.69	2.62	58156
40 (kg/ha)	4.36	5.84	59.9	58778
$CD_{0.05}$	NS	NS	NS	NS

4. On farm experiment on soybean+maize intercropping system

The trail was conducted to popularize soybean+maize intercropping system in the command area of Manasgaon distributary of Right Main Canal (RMC) and Andhed distributary of Left Main Canal (LMC). Soybean and maize crops were planted in the ratio of 4:2. Results of the trial are shown in Table K4.

Table K4. Effect of improved water management on soybean+maize

Particulars		*Kharif* 2016	
		Test block	Control block
Irrigation practice		Recommended: Soybean + maize intercropping system with irrigation at flowering and pod development stage by border strip method	Farmers' practice (Sole soybean)
Number of irrigations		1	1
Depth of irrigation applied (cm)		6	10
Total water applied (cm)		6	10
Saving of water over control (cm)		4	-
Soybean equivalent yield (t/ha)	Andhed (LMC)	1.38	1.20
	Manasgaon (RMC)	1.47	1.30
Increase in yield (%)	Andhed (LMC)	14.63	-
	Manasgaon (RMC)	13.28	-
Water productivity (kg/m3)	Andhed (LMC)	47.60	23.00
	Manasgaon (RMC)	54.88	25.20
Net return (Rs./ha)	Andhed (LMC)	28574	23000
	Manasgaon (RMC)	32929	19000

Sale price of soybean (Rs./kg) = 35 and 34 at LMC and RMC, respectively
Sale price of maize (Rs./kg) = 15 and 14 at LMC and RMC, respectively

5. On farm experiment on System of Rice Intensification (SRI) technique

Manasgaon distributary of Right Main Canal (RMC) and Andhed distributary of Left Main Canal (LMC) were selected for demonstration of rice var. Pusa Sugandha 4. The goal was to popularize SRI among farmers of the region. About 10-12 days old seedlings were planted under SRI against 25-30 days old seedlings under conventional practice by farmers. Plant spacing was 25x25 cm under SRI against 10x12 cm under conventional practice. Results of the demonstration are shown in Table K5.

Table K5. Performance of rice grown under SRI technique at farmers' field

Particulars	*Kharif* 2016	
	SRI	Control block
Irrigation practice	Saturated condition by intermittent light irrigations up to panicle initiation and then shallow standing water	Farmers' practice
Number of irrigations	2+4 (6)	6
Depth of irrigation applied (cm)	2 cm before transplanting and 4 cm after transplanting	10
Depth of pre-sowing irrigation applied (cm)	15	15
Total water applied (cm)	35	75
Saving of water over control (cm)	40	-

Grain yield (t/ha)	(LMC) Andhed	6.12	4.89
	(RMC) Manasgaon	6.25	4.86
Increase in yield (%)	(LMC) Andhed	25.1	-
	(RMC) Manasgaon	28.6	-
Water expense efficiency (kg/ha-cm)	(LMC) Andhed	174.8	64.8
	(RMC) Manasgaon	178.6	65.0

Rahuri (AESR 6.2)

1. Comparative performance of improved layouts with scheduling of irrigation under fertilizer management to individual crop vis-a-vis farmers' practice

During *Kharif* 2016 season, soybean showed yield increase with recommended practice ranging from 15.4 - 21.1% as compared to traditional practice by farmers (Table R1). Water use efficiency ranged from 124.44 to 135.61 kg/ha-cm with the recommended practice against lower WUEs with farmers' practice. During *Rabi* 2016-17, chickpea and wheat showed yield increase by 24.4 - 24.0% and 21.1 - 21.2%, respectively over traditional practices. Respective ranges of WUE for chickpea and wheat were 149.4 - 153.6 kg/ha-cm and 85.8 - 87.9 kg/ha-cm in plots under recommended practices against lower WUEs in the control plot. Water saved over farmers' practice is 25% during *kharif* and 14.29% during *rabi* season.

Table R1. Effect of adoption of improved packages of practices on performance of individual crop and its economic benefits

Name of farmer	Treatment	Crop & Variety	Yield (t/ha)	Total water applied (cm)	WUE (kg/ha-cm)	Yield increase over C (%)	Cost of cultivation (Rs./ha)	Net monetary return (Rs./ha)	B:C
***Kharif* 2016**									
Changdev Kawade	L+I+F (R)	Soybean JS-335	2.24	18	124.44	15.40	39975	24985	1.63
Shivaji Bhaval	FP (C)	Soybean JS-335	1.90	24	78.96	-	38680	16275	1.42
Balasaheb Pawar	L+I+F (R)	Soybean JS-335	2.44	18	135.61	21.14	40010	24960	1.77
Rambhau Nishane	FP (C)	Soybean JS-335	1.93	24	80.21	-	38570	17255	1.45
***Rabi* 2016-17**									
Balasaheb Pawar	L+I+F (R)	Chickpea Vishal	2.69	18	149.44	24.54	45975	83145	2.81
Ganesh Nishane	FP (C)	Chickpea Vishal	2.03	21	96.67	-	41610	55830	2.34
Nanasaheb Pawar	L+I+F (R)	Chickpea Vishal	2.77	18	153.61	24.44	46250	86470	2.87
Rajendra Pawar	FP (C)	Chickpea Vishal	2.09	21	99.52	-	41235	59085	2.43
Changdev Kawade	L+I+F (R)	Wheat Trimbak	3.19	36	87.92	21.19	43890	10255	1.23
Jalindar Nishane	FP (C)	Wheat Trimbak	2.51	42	59.76	-	39180	3490	1.10
Bhausaheb Jadhav	L+I+F (R)	Wheat Trimbak	3.09	36	85.78	21.11	43250	9246	1.21
Shivaji Bhaval	FP (C)	Wheat Trimbak	2.44	42	58.00	-	38240	3172	1.08

R- Recommended practice; FP- Farmers' practice; C- Control; Market rate (Rs./q): Wheat Rs.1700, Chickpea Rs.4800, Soybean Rs.2900

2. Effect of irrigation scheduling over farmers' practice on *Bt* cotton

The trial was conducted in four farmers' fields for the fifth year to compare recommended irrigation scheduling at 75 mm CPE and RDF of 125:65:65 with farmers' practice. Ridges and furrows were prepared. Seeds of *Bt* cotton were sown by dibbling. Results showed that seed cotton yield in test plots increased by 15.9 to 16.3% over the control plots. The recommended practice plots also showed higher WUE, net return and benefit-cost ratio (Table R2).

Table R2. Comparison of recommended and farmers' practice for growing *Bt* cotton

Sl. no.	Name of farmer	Practice	Yield (t/ha)	Water applied (cm)	WUE (kg/ha-cm)	Water saving (%)	Increase in yield (%)	Net return (Rs./ha)	B:C
1	Jalindar Nishane	R	2.75	30.00	24.88	16.73	15.89	59300	1.82
	Dharmaji Jadhav	C	2.31	52.20	17.43	-	-	41274	1.59
2	Rajendra Pawar	R	2.63	22.50	26.72	23.18	16.31	54440	1.76
	Rambhau Nishane	C	2.20	52.20	17.18	-	-	36748	1.53

R-Recommended practice, C-Control/Farmers' practice, Effective rainfall was 80.52 cm for Sl.no.1 and 75.92 cm for Sl. no.2

Coimbatore (AESR 8.1)

1. Operational Research Project on improved water management practices in the system tank of Periyar Vaigai command area

Ten demonstrations were laid out in village Arumbanur to demonstrate four water saving technologies on five acres of system tank command area having sandy clay loam soil. Ten farmers having access to groundwater source for irrigation in the command area were randomly chosen for the demonstrations. There were four demonstrations for SRI technology, and two demonstrations each for alternate wetting and drying (AWD), AWD through water tube device and terminal stress management through KCl and PPFM spray (Table C1). The farmers utilized groundwater source for cultivation of rice crop due to 60% deficit rainfall. This caused the groundwater table to fluctuate. It was 12-15 m or sometimes deeper in the open wells in the command area. In the fourth technology demonstration plots, due to drastic depletion of groundwater without any sufficient recharge, the rice crop faced water stress at advanced growth phase. Terminal stress management was carried out with spray of PPFM twice at flowering @ 500 ml/ha/spray. The crop was provided limited water. Though yield level was very low due to severe stress, the management practice helped to overcome the terminal stress. Yield in the treated plot increased by 7 - 8% compared to untreated plot (Table C1).

Table C1. Yield, water saving and water use efficiency through water saving implemented on applied to rice crop

Water saving technology	Grain yield (t/ha)		Yield increase (%)	Total water used (mm)		Water saving (%)	Water use efficiency (kg/ha-mm)	
	Improved practice	Conven-tional		Improved technology	Conven-tional		Improved technology	Conven-tional
SRI	5.42	4.73	14.7	945	1200	21.3	5.74	2.94
SRI	5.82	4.99	16.7	970	1200	19.2	6.00	3.16
SRI	5.44	4.82	12.9	930	1200	22.5	5.85	3.01
SRI	4.99	4.22	18.2	950	1200	20.8	5.25	2.52
AWD irrigation (AWDI)	4.75	4.33	9.7	995	1200	17.1	3.77	2.60
AWDI	4.51	4.12	9.7	980	1200	18.3	3.60	2.42
AWDI through water tube device	5.04	4.67	7.81	945	1200	21.2	4.32	2.89
AWDI through water tube device	5.27	4.79	10.0	960	1200	20.0	4.48	2.99
Terminal stress management	4.65	4.33	7.51	1050	1200	12.5	3.42	2.60
Terminal stress management	4.82	4.48	7.58	1050	1200	12.5	3.59	2.73

Faizabad (AESR 9.2)

1. Improved water management practices in rice (*Kharif*) and wheat (*Rabi*) at head, middle and tail end of the minors in ORP area

Improved water management practice, i.e. 7 cm water applied at 1-3 days after disappearance of ponded water (DADPW) through check basin method (10 m x10 m) gave 15.8-22.0% higher grain yield of rice in comparison to farmers' practice (application of 10–12 cm water by flooding/field to field irrigation). From head to tail reaches, improved water management practice recorded higher WEE (61.52 to 63.55 kg/ha-cm) against the farmer's practice (38.68 to 37.56 kg/ha-cm). With this improved practice, total water saving 35% at all the reaches at Chandpur distributary (Table F1).

Similarly, application of 6.0 cm irrigation in wheat crop at critical stages (CRI, late jointing and milking stage) by check basin method (100 m^2) increased grain yield by 30.28-34.73% compared to farmers' practice at head, middle and tail end of the distributary (Table F1). But increase in yield was more at head and tail ends compared to middle end of the distributary. Respective WEEs with improved water management practice at the canal reaches were 163.08, 161.30 and 158.22 kg/ha-cm.

Table F1. Performance of rice and wheat crops at head, middle and tail ends of Chandpur distributary (2016)

Treatment	Head End		Middle End		Tail End	
	Grain yield (t/ha)	WEE (kg/ha-cm)	Grain yield (t/ha)	WEE (kg/ha-cm)	Grain yield (t/ha)	WEE (kg/ha-cm)
Rice						
Farmers' practice	3.83	38.68	3.64	37.99	3.46	37.56
Improved practice (IP)	4.44	63.55	4.44	63.51	4.15	61.52
Increase under IP (%)	15.84	-	22.03	-	19.91	-
Wheat						
Farmers' practice	3.18	89.93	3.16	90.12	3.03	86.59
Improved practice	4.29	163.08	4.12	161.30	4.02	158.22
Increase under IP (%)	34.73	-	30.28	-	32.93	-

Pantnagar (AESR 14.5)

1. Effect of mulch and earthing up on green cob and water productivity of spring maize in *Bhabhar* area of Uttarakhand

A field demonstration was carried out in a farmer's field in *Bhabhar* area of Uttarakhand to assess the impact of straw mulch and earthing up practices on productivity of spring maize var. Pioneer 31Y45. The cultivation was done from February to May in sandy loam soil having poor water holding capacity. Yellow sarson fine straw material @ 6 t/ha was used for mulching immediately after crop sowing. At 35 DAS, earthing up was done at knee high stage. Base of the plant was covered with soil up to plant height of 15 cm. Fertilization was done with recommended dose (120:60:40). Total eight irrigations were applied to the plots following conventional practice (flat bed sowing) and flat bed sowing + earthing up treatment. But in the mulched plots, only six irrigations were applied during the crop growth period. The irrigation depth was maintained at 6 cm; however after earthing up it was reduced from to 4.5 cm. Compiled results of two years showed that green cob yield in mulched plots was 36.1% higher than with conventional sowing and 20.2% higher than with conventional sowing + earthing up. Conventional sowing + mulch also resulted in higher WUE and economic return than the remaining two treatments (Table P1). It was concluded that application of fine straw of either rice or yellow sarson (generally burned or wasted) can save 12 cm water and earn Rs.30519 higher net return than the conventional sowing method. Fine straw (small sized pieces) facilitated crop emergence and uniform spreading.

Table P1. Crop yield, water use efficiency and monetary advantages of maize as influenced by different treatments (mean data of 2 years)

Treatment	Green cob yield (t/ha)	Irrigation depth (cm)	Irrigation WUE (kg/ha-cm)	Net return (Rs./ha)	B:C
Conventional sowing (Flat bed sowing)	9.97	42	231	83195	2.95
Conventional + earthing up at knee high stage	11.29	33	337	92422	3.06
Conventional + straw mulch @ 6 t/ha	13.57	30	444	113714	3.86

Powarkheda (AESR 10.1)

1. Demonstration of performance of different crop/varieties with ridge–furrow methods of sowing

The demonstration was carried out to find out the possibility of growing advanced varieties of different crops as an alternate to soybean under upland condition in deep black soil. Results showed that maize hybrid DKC 7074 maturing in 95 days and having yield of 4.87 t/ha with net return of Rs.37652/ha and B:C ratio of 2.07 may be the best alternative crop for soybean (Table P1). Arhar variety TT 401 having seed yield of 2.67 t/ha with net return of Rs.85340, B:C ratio of 2.73 and maturing in 160 days was ranked as the second best alternative.

Table P1. Performance of maize, arhar and sesame crops as alternatives to soybean crop under upland condition in deep black soil (Powarkheda)

Crop	Varieties	Seed yield (t/ha)	Cost of cultivation (Rs./ha)	Net return (Rs./ha)	B:C
Maize	JM 216	3.78	35353	21317	1.60
	CHH 215	3.82	35353	21977	1.62
	CHH 218	3.22	35353	12977	1.37
	DKC 7074	4.87	35353	37652	2.07
Arhar	TT 401	2.67	49344	85340	2.73
	ICPL 88039	2.44	49344	73674	2.49
Sesame	JTS – 8	0.58	38500	8140	1.21
Soybean	JS 20 – 29	1.22	46500	-9840	-
	JS 20 – 34	0.67	46500	-26490	-
	RVS 2001 – 04	1.29	46500	-7830	-

Bilsapur (AESR 11.0)

1. Effect of different levels of water on growth and yield of rice–wheat crop sequence under tubewell command at cultivator's field

- One farmer from village Risda was selected to compare recommended practice with farmers' practice for growing wheat var. GW 273 on 1.0 ha during *rabi* 2015-16. Table B1 shows that application of four irrigations at CRI, tillering, flowering and milk stages of wheat resulted in 24% higher grain yield compared to two irrigations at CRI and flowering. Recommended agronomic practices including RDF (100:60:40 NPK) gave 26.7% higher grain yield of wheat over the farmers' dose (78:38:12 NPK). Water expense efficiency was also higher under recommended practice compared to farmers' practice.
- One farmer from village Risda was selected for growing rice var. Karma Masuri on 2 ha during *kharif* 2016. Improved practice i.e. irrigation at 3 DADPW recorded 5.75% and 7.17% higher grain yield compared to continuous submergence (CS) with farmers' dose of fertilizer (75:34:10) and CS with application of RDF (100:60:40 NPK), respectively. Again, CS with RDF and improved irrigation with RDF resulted in 19.77 and 20.97% higher grain yield compared to CS with farmers' dose of fertilizer and improved irrigation with farmers' dose of fertilizer (Table B1).

Table B1. Comparison of recommended and farmers' methods of irrigation and fertilizer managements on performance of wheat and rice under tubewell command

Irrigation level	Method of Irrigation					
	Farmers' practice			Recommended practice		
	No. of irrigations	Yield (t/ha)	WEE (kg/ha-cm)	No. of irrigation	Yield (t/ha)	WEE (kg/ha-cm)
Wheat						
Irrigations at four growth stages	4	2.37	62.69	4	2.89	96.97
Irrigations at two growth stages	2	1.82	91.91	2	2.14	135.44
Rice						
Continuous submergence (5±2 cm)	-	4.26	31.79	-	5.31	56.48
Irrigation at 3 DADPW	-	4.52	37.98	-	5.72	65.74

Chiplima (AESR 12.1)

1. Demonstration in water saving through system of rice intensification (SRI)

Rice variety MTU-1001 was grown in village Basantpur, district Sambalpur, Odisha to compare conventional practice with SRI method of rice cultivation in Hirakud command area. It was observed that number of effective tillers per hill (21.9) was 253% higher under SRI method than the conventional method (6.2). Yield components i.e. number of spikelets per panicle, filled grain percentage and grain yield were 23.9, 16.7 and 42.3% higher than the conventional method. There was 31% less water consumed and 105% more water productivity with the SRI method (Table C1). Thus SRI proved to be a better method than farmers' conventional practice of cultivating rice.

Table C1. Relative performance of SRI and conventional method of rice cultivation in a farmer's field under Hirakud command

Parameter	SRI method	Conventional practice	Advantage over conventional (%)
Rice variety	MTU-1001	MTU-1001	-
Spacing	25 × 25 cm	20 × 10 cm	-
Nutrient management	100% RD (80:40:40)	100% RD (80:40:40)	-
Water management	Maintenance of water in channels	Shallow submergence (5 ± 2 cm)	-
Weed management	Mechanical weeding thrice	Hand weeding twice	-
Number of hills/m^2	16	50	-
Average no. of effective tillers/hill	21.90	6.20	253.23
No. of spikelets/panicle	95.70	77.20	23.96
Filled grain percentage	91.00	78.00	16.67
Test weight (g)	23.80	23.80	0.00
Grain yield (t/ha)	6.02	4.23	42.32
Cost of cultivation (Rs./ha)	36700	28900	26.99
Irrigation water requirement (cm)	90.00	130.00	-30.77
Water productivity (kg/ha-cm)	66.89	32.54	105.57
B:C	2.39	2.14	12.07

Pusa (AESR 13.1)

1. On farm water management for wheat and rice

- Improved water management practice for wheat (after harvest of rice) was tested in five farmers' field at village Katraw, block Gaunaha, district West Champaran, Bihar, and compared with conventional method of irrigation by farmers. Improved practice involved application of three irrigations each of depth 6 cm at 25, 65 and 95 DAS by border method of irrigation with 75% cut-off; while farmers' practice involved application of three irrigations each of depth 8 cm by flooding. Compared to farmers' practice, mean grain yield of wheat increased by 9.6% with 25% water saving when the crop was irrigated with improved practice (Table P1).
- Improved water management practice for rice under SRI was tested at five farmers' fields at village Narha Panapur, block Tetaria, district East Champaran, Bihar. In the improved practice, 3 days drying after disappearance of 3 cm of ponded water (DADPW) was used with recommended dose (RD) of NPK for rice var. Arize 6444. In control block, farmers' own practice of water management was used with RD of NPK for rice var. Rajendra Bhagwati. Yield increased by 25.7% with 28.6% water saving under improved water management (Table P1).

Table P1. Effect of improved water management practice on wheat during (*Rabi* 2015-16) and rice (*Kharif* 2016)

Observation block	Range of yield in 5 fields (t/ha)	Standard deviation	No. of irrigations	Total depth of water applied (cm)	WUE (kg/ha-cm)
Wheat (*Rabi* 2015-16)					
Study block	3.50-4.11	0.24	3	18	209.83
Control block	3.13-3.81	0.27	3	24	142.33
Rice (*Kharif* 2016-17)					
Study block	5.84-6.92	0.43	10	30	207.67
Control block	4.13-5.23	0.47	7	42	110.29

Gayeshpur (AESR 15.1)

1. Reconnaissance survey of arsenic contamination in soil-irrigation water-plant (rice) in villages of Nadia district (West Bengal) selected through staggered random sampling

Out of 30,000 shallow tubewells in 17 blocks of Nadia district (West Bengal), 20,000 tubewells in 10 blocks have been found to discharge arsenic (As) contaminated water beyond WHO permissible limit for drinking water i.e. 0.01 ppm. Six random villages across three administrative blocks were selected during 2014-15 and three random villages of two blocks were selected for survey during 2015-16. Ten replicated samples were collected from the command area of five shallow tubewells (STWs) in a village. The As contamination database is presented in Table G1.

Table G1. Arsenic contamination in soil, crop (*boro* rice cv. IET 4786) and irrigation water in district Nadia, West Bengal

Block	Village	Geographic location of village	Arsenic loading in water (mg/l) soil (mg/kg), plant (mg/kg)		
			Irrigation water	Available soil As	As in rice grain
Chakdah	Panchpota	N 23°00.232'E 88°36.271'	0.077	0.580.22	0.440.20
Haringhata	Haripukuria	N 22°56.473'E 88°36.979'	0.112	0.870.31	0.540.12
Haringhata	Dasdia	N 22°57.463'E 88°36.312'	0.269	2.150.94	1.430.46
Karimpur II	Gomakhali	N 23°57.532'E 88°33.941'	0.162	0.840.16	0.630.08
Karimpur II	Sadhipur	N 23°53.094'E 88°29.444'	0.247	0.590.18	0.540.36
Karimpur I	Tarapur	N 24°04.819'E 88°41.556'	0.165	1.090.61	0.760.57

Note: The village that had As content in irrigation water closest to the mean of the 5 STW water samples collected from the same village is presented here

Theme 5 - ORP

Morena (AESR 4.4)

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

Interventions for the three reaches of Chambal canal were carried out with land shaping (natural field, traditional levelling and precise levelling), sowing methods (conventional, zero tillage and broad bed and furrow), irrigation methods (traditional flood; broader strip; each furrow, alternate and skip furrow) and different crop rotations. Irrigation water (canal water and groundwater) was used conjunctively for six on farm trials, each trial being conducted at five locations. Table M1 shows that improved practice resulted in 9.2 to 18.4% increase in grain yield of paddy with 1098 m^3 of water saving compared to farmers' practice. Wheat crop also showed 14.9 to 18.3% increase in yield with 577 to 590 m^3 water saving compared to farmers' practice. For mustard, improved production technology (sowing just after paddy, zero tillage) showed 27.4% increase in seed yield, with higher net profit, B:C ratio, water productivity. Zero tillage also saved the cost of cultivation and reduced weed population that aided in increasing production and profit compared to farmers' practice. Direct seeding improved yield, net profit and B:C ratio by 9.2% for paddy compared to transplanted paddy. In pigeon pea, there was 13.4% increase in seed yield and 400 m^3 water saving in comparison to farmers' practice. Pearl millet showed increase in grain yield by 39.3%, water saving by 347 m^3 and water productivity by 54.2%. Chickpea showed 76.3% higher seed yield than traditional method. Precise land leveling and broad bed furrow sowing for clusterbean and greengram crops proved to be more profitable and helped in saving resources. Thus the newly developed technologies helped the farmers to increase crop production and fetch higher profit compared to their traditional practices.

Table M1. Assessment of effects of improved practices on crops under various cropping systems at the three reaches of Chambal canal command

Trial no./ Reach	On farm trial	Practice	Variety	No. and source of irrigation	Method of irrigation	Grain yield (t/ha)	Net profit (Rs./ha)	B:C	Total water use (m^3)	WP (kg/m^3)
1/Head	Pigeon pea (K2016)	FP	Pusa 992	1C+1G	Flood	1.68	59901	3.19	632	0.27
		IM	Pusa 992	2C+1G	BS	1.90	68574	3.26	612	0.31
	Wheat (R2015)	FP	MP1203	3C+1G	Flood	4.03	40648	2.06	374	1.08
		IM	MP1203	3C+1G	BS	4.38	52790	2.46	309	1.42
2/Head	Paddy (K2016)	FP	Pusa1509	C+G	Flood	4.43	33400	1.92	775	0.57
		IM	Pusa1509	C+G	CB	5.02	47100	2.32	703	0.71
	Wheat (R2015)	FP	MP1203	C	Flood	3.85	37110	1.94	343	1.12
		IM	MP1203	C	BS	4.43	55760	2.67	309	1.43
3/Mid	Paddy (K2016)	T	Pusa1509	C+G	Flood	5.33	38300	1.91	938	0.57
		DS	Pusa1509	C+G	CB	4.88	43600	2.45	732	0.67
	Mustard (R2015)	FP	NRCDR-2	C	Flood	1.52	28040	2.31	225	0.68
		IM	NRCDR-2	C	BS	1.94	41160	3.44	185	1.05
4/Tail	Pearl millet (K2016)	FP	Hybrid	C+TW	Flood	2.85	23680	1.84	512	0.56
		IM	Hybrid	C+TW	RF	3.97	39780	2.91	485	0.82
	Chickpea (R2016)	FP	JG-130	C-only pre-irrgn	BS	0.92	90800	1.38	141	0.65
		IM	JG-130	C-only pre-irrgn	BBF	1.62	32920	2.38	113	1.43
5/Tail	Clusterbean	FP	HG 560	TW	BS	1.52	39765	2.61	512	0.30
		BBF	HG 560	TW	BBF	1.85	54416	3.25	485	0.38
		PLL+BBF	HG 560	TW	BBF	2.02	61179	2.50	469	0.43
6/Tail	Greengram	FP	TJM 3	TW	BS	0.89	25138	2.30	495	0.18
		BBF	TJM 3	TW	BBF	1.05	32953	2.71	472	0.22
		PLL+BBF	TJM 3	TW	BBF	1.20	39489	2.96	469	0.26

K, R-*Kharif*, *Rabi*; FP-Farmers' practice; IM-Improved practice; T-Transplanting; DS-Direct seeding; PLL- Precision land levelling; BBF-Broad bed furrow sowing; C-Canal water; G-Groundwater; TW-Tubewell water; BS-Border strip; CB-Check basin; RF-Ridge and furrow; irrgn-irrigation

Kota (AESR 5.2)

1. Conjunctive use of water and improvement in soil health at farmer's field in problematic area

Pooled data of three years (2013 to 2016) revealed that significantly higher grain yield (4.81 t/ha), straw yield (7.05 t/ha), WUE (67.42 kg/ha-mm) and net return (Rs.63573/ha) of wheat var. Raj 3077 were observed when pre-sowing and first irrigation was applied with CW and subsequent irrigations applied alternately with CW and TW along with gypsum @ 250 kg/ha + FYM @ 5 t/ha compared to other treatments at farmer's field. After harvest of wheat, EC (1.15 dS/m) and pH (8.2) of soil in the treatment (T_4) were lowest in among the treatments (Table K1).

Table K1. Effects of conjunctive use of water on wheat and soil amendments on soil chemical properties

Treatment	Grain yield (t/ha)	Straw yield (t/ha)	WUE (kg/ha-mm)	Net return (Rs./ha)	EC (dS/m)	pH
T_1- Pre-sowing and first irrigation with CW and then alternate irrigation with TW	4.16	6.06	58.33	57406	1.21	8.32
T_2- T_1+250 kg/ha gypsum	4.42	6.47	61.91	61299	1.18	8.27
T_3- T_1+5 t/ha FYM	4.45	6.51	62.42	57787	1.18	8.28
T_4- T_2+T_3	4.81	7.05	67.42	63573	1.16	8.20
$CD_{0.05}$	0.17	0.14	2.3	NS	-	-

CW-Canal water, TW-Tubewell water, FYM-Farm yard manure

Madurai (AESR 8.1)

Several meetings were organized in the ORP area under canal command of Madurai district. Objective of the meeting was to interact with 25-30 farmers from seven villages of the district. The topics chosen for intercation are shown in Table M1.

Table M1. Meetings organized in ORP area under canal command of Madurai district

Date	Venue	No. of farmers	Topic
05.01.2016	Arumbanur pudur	30	Water saving technologies in paddy cultivation
11.01.2016	Arumbanur	30	System Rice Intensification and cono-weeding techniques
21.01.2016	Kodikkulam	20	Water saving technology and System of Rice Intensification
28.03.2017	Arumbanur	25	Water saving technologies in paddy cultivation
16.11.2016	Arumbanur	25	About OPR activities and demonstration of water saving technologies
17.11.2016	Kodikullam	25	About OPR activities and demonstration of water saving technologies
04.01.2017	Arumbanur pudur	30	Water conservation and stress management technologies to improve rice yield

Faizabad (AESR 9.2)

1. Conjunctive use of surface and groundwater at middle of Chandpur distributary for optimum production

Use of canal water (CW) and tubewell water (TW) to apply 6 cm water with check basin method at critical growth stages (CRI, late jointing and milking stage) of wheat produced significantly higher grain yield of 4.32 t/ha compared to farmers' practice (3.24 t/ha) of applying 10-12 cm water twice by flooding, field to field method as and when CW is available (Table F1). Trial at 14 farmers' fields in the middle of distributary showed that conjunctive use of water increased yield and WEE of wheat by 34.95 and 49.94%, respectively compared to sole use of CW.

Table F1. Effects of conjunctive use of water on performance of wheat at middle end of distributary during 2015-16

Field no.	Number of irrigations			Total water applied (cm)	Grain yield (t/ha)	WEE (kg/ha-cm)
	Canal	Tubewell	Total			
Farmers' practice						
Field 1	2	-	2	20	3.22	160.75
Field 2	2	-	2	20	3.33	166.25
Field 3	2	-	2	20	3.40	170.00
Field 4	2	-	2	20	3.10	155.00
Field 5	2	-	2	20	3.00	150.00
Field 6	2	-	2	20	3.41	170.50
Field 7	2	-	2	20	3.21	160.50
Improved practice						
Field 8	2	1	3	18	4.67	259.44
Field 9	2	1	3	18	4.25	236.11
Field 10	2	1	3	18	4.16	231.11
Field 11	2	1	3	18	4.30	238.89
Field 12	2	1	3	18	4.35	241.67
Field 13	2	1	3	18	4.20	233.33
Field 14	2	1	3	18	4.65	258.33
Increase in yield (%) w.r.t. farmers' practice					34.95	49.94

Almora (AESR 14.2)

1. Micro water resource development at farmers' field and their multiple water utilization

Tanks of capacity 20 to 198 m^3 were constructed as micro-water resources at locations 79^{0}56'E & 29^{0}37'N (near Almora) and village Challar Mussoli of block Hawalbagh. Rainfall, runoff or spring water was stored in the structures. Experiments on multiple use of water were carried out at five farmers' fields. Harvested water from these tanks was delivered with gravity fed drip or sprinkler systems to irrigate high value crops. LDPE and poly tanks were installed at farmers' field and joined with drip irrigation system for small terraces to utilize the water efficiently. Results obtained with components of multiple water use system are as follows:

Fruit Cultivation (Kiwi): Kiwi cultivation became popular among farmers within five years and many Kiwi orchards are established in Jageshwer watershed. A new refined system of Kiwi plantation along with vermicomposting was introduced in the area to enhance farmers' income and sustain livelihood.

Vermicomposting: A very low cost vermicompost unit (without shed) of capacity 88.18 m^3 was constructed under the kiwi plants. The kiwi plants could directly absorbed nutrients from the vermicompost and provide shade to the unit. About 79.18 m^3 was estimated to yield about 498 q vermicompost and earn Rs.1,49,400 if sold at Rs.3 per kg. To avoid problem of rats and mixing of soil with vermicompost, a low cost *Paccka* vermicompost pit was made with slope 1:1, width 2.5 m and depth 1.0 m, length 1.0 m as per terrace length and farmers' requirement. The pit was then lined with low cost locally made blocks often used to make water tanks.

Fish: Fingerlings of silver carp, grass carp and common carp were cultivated in the ratio 30:40:30. During 2015 and 2016, two farmers earned Rs.10000 and Rs.8000 by selling fish cultivated in 142 m^3 and 70 m^3 tank, respectively.

Vegetables: Out of nine vegetables, onion and garlic found more suitable crops during *rabi* season, and tomato, capsicum, summer squash during *kharif* season for higher hills. In mid hills all the above mentioned crops found suitable including okra as it is very remunerative crop for mid hills. Tomato and capsicum should be planted in March and April in higher hills otherwise these crops get rotten due to higher rains, if sown late. The late crop can be grown only under polyhouse. Low tunnels were constructed for growing nursery and protect crop damage by wild animals and save tomato and capsicum fruits from rottening during rainy season.

Poultry/Duckery: Three farmers started construction of houses for poultry/duckery. Twenty birds of crawler variety poultry were given to one farmer.

Azolla cultivation: Azolla production was 3 to 4 kg/m^2/month. It was used as feed for poultry and fish and fertilizer.

Therefore in the multiple water use model, product and bi-product of one system served as feed for another which will ultimately reduce cost, enhance income and sustain livelihood of farmers. In two years, gross income was estimated to be Rs.60,000 by cultivating fish in 100 m^3, net profit of Rs.66071 from dairy with four cows, Rs.1.2 lakhs/year from kiwi fruit from fourth year onwards, gross income of Rs.3.90 lakh through vermicomposting in six pits (size 3x1.5x0.7 m) using cow dung and biomass from forest areas. Azolla grown in tank area of 12 m^2 can yield 864 kg/year. This was used as feed for poultry, fish and cattle. Azolla can also be used to make manure which may act as carbon sink and make the system resilient against climate change. This income can be achieved in 4000 m^2 area. Thus, the model can increase farmers' income from 2-3.23 times compared to the gross income of Rs.36000 with the traditional system. Water availability intensified agriculture, improved livelihood and helped in poverty alleviation in hills.

Jammu (AESR 14.2)

1. Modelling for planning the conjunctive use of water at basin level within the canal commands of Jammu

The study was carried out to quantify demand and supply in distributaries D-10 and D-10A of Ranbir canal water, and find the possibility of meeting deficit irrigation by augmenting groundwater resource in a conjunctive mode. Water demand for rice variety Basmati-370 during *kharif* 2016 was worked out to be 4879 to 539560 ha-cm having relative water supply (RWS) from 0.41 to 0.58 in various major and minors of the distributaries (Table J1). Prospect of water supply through groundwater in a conjunctive mode was 45 to 60% to meet up the deficit irrigation under each major and minor for growing Basmati-370 during *kharif* season. Status of GW in the region showed that aquifers at shallow depths within different reaches of the canal have fine sand/silt deposits. This results in reduction of discharge within two to three years and clogging of shallow tubewells (*bambi*). This restricts the farmers from using groundwater (Table J2).

Table J1. Relative water supply (RWS) during *Kharif* 2016 in distributaries of Ranbir canal command

Distributary	Canal water diverted (ha-cm)	Water available at field (ha-cm)	Effective rainfall (ha-cm)	Total water supply (ha-cm)	Water requirement (ha-cm)	RWS
Kotlishah Dowla, Tanda Minor	2972.7	2080.8	1914	3994.8	8610	0.46
Ratian head to Kapoor pur	172530	120771	119944	240715	539560	0.44
Musachak minor	11826	8278.2	7656	15928.2	34440	0.46
Main Tanda minor	187920	131544	80732.5	212276.5	363169.8	0.58
Chakroi minor	45603	31922.1	29501.1	61423.2	132708.8	0.46
Katyal minor	49410	34587	31900	66487	143500	0.46
Badyal-A	1620	1134	1276	2410	5740	0.41
Badyal-B	1539	1077.3	1084.6	2161.9	4879	0.44
Ratian head to Koratana	197640	138348	92382.4	230730.4	415576	0.55
SKUAST Channel	4860	3402	3190	6592	14350	0.46
Khanna chak minor	29160	20412	19140	39552	86100	0.46
Samka minor	17820	12474	8613	21087	38745	0.55
Chandu chak minor	45360	31752	29348	61100	132020	0.46

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

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

Name of village	Aquiclude depth (m bgl)	Aquifer depth (m bgl)	Requirement of GW as per RWS	Constraints in using GW use at farmer level
Badyal Brahmna	0-50	25	55-60%	• Average depth of aquiclude ranges from 50 to 100/200 m. Aquifer/perched water table ranges between 20 to 80 m bgl. • Aquifers at shallow depth at middle and tail ends, except R. S. Pura village, have fine sand/silt and give small discharge. Within 2 to 3 years, the farmer level tubewells get clogged. • Farmers have marginal land holdings.
Badyal-B	0-100	>50		
Kotli-Shah-Daula	0-50	25	55%	
Korotana-Khurd	0-100	20	45%	
Kapoorpur	0-50	20	56%	
Chakroi	0-100	100	54%	–
Chakroi (Tubewell No. 8)	0-50	50		
Mulachak	0-100	80	54%	
Agrachak	0-200	50-200	–	
R.S. Pura	0-50	10-20	–	Farmers have constructed shallow tubewells in R.S. Pura

Gayeshpur (AESR 15.1)

1. Arsenic mitigation in broccoli through conjunctive use of contaminated groundwater and safe surface (pond) water

The intervention was untaken to assess the efficiency of conjunctive use of As contaminated shallow tubewell water (STW) water and relatively safe pond water (PW). Arsenic content of STW and PW was 0.23 and 0.08 mg/l, respectively. A remunerative crop of broccoli var. Green Magic F_1 hybrid grown with different combinations of STW and PW showed that use of 100% PW/surface water significantly reduced As accumulation (4.76 mg/kg) in broccoli head (edible). But this was significantly similar to As content in broccoli head using 50 STW:50 PW (Table G1). Total water used for every treatment was 398.5 mm.

Table G1. Effect of quality of irrigation water on As accumulation in broccoli head, available As in soil after harvest and crop response

Intervention	As content at harvest (mg/kg)		Yield (t/ha)	Water productivity (kg/m^3)
	Broccoli head	Soil		
100% STW (T_1)	6.11^{a}	0.318^{a}	15.58^{a}	3.908
25% STW + 75% PW (T_2)	5.25^{b}	0.174^{cd}	14.50^{a}	3.639
75% STW + 25% PW (T_3)	5.28^{b}	0.294^{ab}	13.79^{a}	3.460
50% STW + 50% PW (T_4)	4.77^{b}	0.235^{bc}	14.78^{a}	3.708
100% PW (T_5)	4.67^{b}	0.164^{d}	13.67^{a}	3.430
SEm(±)	0.14	0.02	0.36	-

Chalakudy (AESR 19.2)

Farmer-Scientist interaction was organized in ORP area under canal command.

Date	Venue	No. of farmers	Topic
Dr. S. Anitha, Professor (Agronomy)			
06.02.2016	Punnayurkulam	40	Micro nutrient management in Agriculture
16.03.2016	Adatt	30	Organic Cultivation
22.03.2016	Directorate of extension, Mannuthy	53	Water use Efficiency
07.10.2016	Paraly Panchayath	35	Organic farming in paddy cultivation
26.10.2016	KVK, Thrissur	46	Organic Waste Management
17.12.2016	Muriyard Krishi Bhavan	35	Organic Paddy cultivation
E.B. Gilsha Bai, Assistant Professor (Agriculture Engineering)			
25.04.2016	Water Technology Centre, KAU, Vellanikkara	25	Microirrigation
Dr. Mini Abraham, Associate Professor			
03.01.2016	Valayanchirangara, Perumbavoor	25	Microirrigation
27.01.2016	ARS, Chalakudy (Karshakasangham, Pothanikade, Kothamangalam)	48	Rice cultivation
25.05.2016	Jeevagramam, Perumbavoor	26	Mushroom Cultivation
22.07.2016	ARS, Chalakudy (Kudumbasree Master Trainees)	22	Organic Cultivation
20.09.2016	Farmers, Mullassery Block	45	Microirrigation & Fertigation
28.09.2016	Farmers, Manjappra Panchayath	22	Mushroom cultivation
18.10.2016	Trichy Block, Tamilnadu	36	Irrigation methods
28.10.2016	Panthalam Block Panchyath Farmers	42	Precision methods
30.11.2016	farmers of Chavakkad block	48	Water management
Dr. Deepa Thomas, Assistant Professor			
11.01.2016	Farmers, Thrissur & Ernakulam (RATTC, Vyttila)	30	INM in rice cultivation
28.01.2016	Alangad Block, Ernakulam	30	Weed management in rice
02.02.2016	Farmers, Koratty	35	Banana cultivation
22.02.2016	Farmers, Thrissur & Ernakulam (RATTC, Vyttila)	30	INM in rice cultivation
19.03.2016	Labour Force Thrissur & Ernakulam (RATTC, Vyttila)	30	Organic cultivation
20.02.2016	Bharath Matha College, Trikkakkara	25	Organic cultivation
Dr. Mary Regina F., Professor			
21.10.2016	Perakom	20	Water Management & Microirrigation Systems
25.10.16	Mullassery	25	Water Management & Microirrigation Systems
02.11.16	WTC, Vellanikkara	28	Water Management & Microirrigation Systems
03.11.16	Mithradam, Aluva	35	Water Management & Microirrigation Systems
04.11.16	Chelakkara	32	Water Management & Microirrigation Systems
15.11.16	Pattikkad	28	Water Management & Microirrigation Systems
16.11.16	Chazhoor	25	Water Management & Microirrigation Systems
21.11.16	Perumbavoor	32	Water Management & Microirrigation Systems
05.12.16	Ernakulam	27	Water Management & Microirrigation Systems
08.12.16	Muvattupuzha	24	Water Management & Microirrigation Systems
14.12.16	Perumbavoor	31	Water Management & Microirrigation Systems
20.12.16	Nedumbassery	28	Water Management & Microirrigation Systems
22.12.16	Piravom	29	Water Management & Microirrigation Systems
23.12.16	Alagappanagar	36	Water Management & Microirrigation Systems

Technology Assessed Refined and Transferred

East India

Pusa

- Irrigation should be applied at 10% moisture depletion of field capacity along with three foliar applications of 1% $FeSO_4$ at tillering, pre-flowering and flowering stages under aerobic condition of rice to obtain higher grain yield, WUE, net return and B:C ratio
- Papaya fruit crop should be cultivated under drip irrigation with mulch at the irrigation regime of 100% PE
- Maize-maize cropping system in calcareous soils grown with irrigation at IW/CPE 0.8 and mulching with sugarcane trash or maize stubble mulch @ 10 t/ha in *rabi* and *kharif* maize was found to be the best
- Irrigation should be applied with in-line drip irrigation at an operating pressure of 1.4 kg/cm^2 to obtain significantly higher tuber yield of potato, WUE, net return and B:C ratio. It showed better results compared to lower operating pressures but was at par with operating pressure of 1.6 kg/cm^2

Shillong

- Zero tillage for both *kharif* and *rabi* crops resulted in higher grain yield as compared to conventional tillage. Significantly higher grain yield of rice (33.8%) and succeeding *rabi* crops, *viz.*, pea (14.6%), toria (50.5%) and buckwheat (21.3%) as well as the water use efficiency were recorded under zero tillage for both crops as compared to conventional tillage
- Zero tillage resulted in higher maize equivalent yield (MEY) (6.10 t ha^{-1}) as compared to conventional tillage. Among the intercropping system/residue management treatments, MEY was highest under intercropping of maize+groundnut paired row (residue retention) (7.18 t ha^{-1}), which was 32.7% more as compared to sole maize. Yield of succeeding toria crop was also higher under the intercropping (0.73 t ha^{-1}) compared to sole maize
- Residue management practice maize stalk cover + poultry manure + *Ambrosia* @ 5 t ha^{-1} proved to be best for maize var. DA 61-A (6.55 t ha^{-1}) and toria var. M-27 (1.25 t ha^{-1}), with 34.1% and 81.3% higher yields compared to their respective controls
- Turmeric grown in terrace condition with FYM @ 5 t ha^{-1} + straw mulching @ 5 t ha^{-1} resulted in 176.7% increase in rhizome yield (10.15 t ha^{-1}) compared to control

Faizabad

- Multiple use of water should be adopted by renovating old ponds or constructing new ponds in areas where water is available through canal and rainfall. Pisiculture and duckery may be practiced in the ponds. Banana, vegetables and fuel trees may be grown on bunds of the ponds. This will help in achieving highest net profit and B:C ratio for the farmers compared to present cropping system of rice-wheat+rai. Farmers of ORP area are very much convinced with this system
- Improved water management in rice i.e. 7 cm water, 1-3 days after disappearance of ponded water applied with check basin method (10 m x 10 m) should be practiced instead of continuous ponding through plot to plot or field to field wild irrigation method
- Improved water management in wheat i.e. 6 cm water at CRI, late jointing and milking stages by check basin method (10 m x 5 m) should be practiced instead of heavy irrigation through plot to plot or field to field wild irrigation method
- At tail end of canal command, pigeon pea should be grown on raised bed in paired rows at 50 cm spacing intercropped with either five rows of short duration rice (NDR-97) in sunken beds or three rows of urd (blackgram) on raised beds during *kharif* season for getting more profits
- Under poor availability of canal water during *rabi* season, intercropping of gram and mustard in the ratio 4:2 was more economical
- Rice-potato-okra and maize-potato-okra were found most remunerative cropping systems under head and tail end of distributary, respectively. As okra crop grown in summer needs more irrigation, it should be sown on raised beds and 5-6 cm water should be given at 7 days interval after the first irrigation at 20 DAS
- Application of 75% recommended dose of fertilizers (NPK) + 25% N through biocompost was found suitable with five irrigations at critical growth stages of wheat
- Sowing of greengram on raised beds in paired rows along with furrow irrigation at 1.0 IW/CPE or irrigation at 10 days interval is recommended
- Drip fertigation at 80% wetted surface with 75% N was found suitable in aonla orchard

- Drip fertigation at 80% PE with 100% N proved to be high yielding and remunerative irrigation system for sugarcane crop
- Drip fertigation at 80% PE with 100% N resulted in higher production and gave higher income for marigold flower
- 7 cm irrigation at 3 DADPW before panicle initiation (PI) and at 1 DADPW from PI to milking stage of scented rice with 75% RDF + 25% N through biocompost fetched higher yield and income
- For zaid cowpea, drip irrigation @ 80% PE every third day in rice straw mulched plot (5 t/ha) was high yielding and most remunerative irrigation system
- 15-25 October has been found optimum period for planting of *rabi* maize with 1.0 IW/CPE moisture regime to obtain maximum production and higher net return
- Irrigation level 0.8 IW/CPE with integrated nutrient supply system (75% RDF + 25% N through biocompost) has been found most suitable for getting higher production and economic return from broccoli
- Sowing of wheat crop may be delayed maximum up to 25th December and irrigated at 1.0 IW/CPE for high production of the crop under late sown condition
- Irrigation schedule 7 cm water at 4 DADPW has been found high yielding and economical for drum seeded rice in puddled soil
- Irrigation schedule 1.0 IW/CPE with raised bed paired row planting of mentha on 70 cm beds and 20 cm furrow has been found high oil yielding and economical

Bilaspur

- Delaying irrigation up to 3-5 days after subsidence of ponded water can be considered to be the best water regime for paddy in clay-loam to clay soil as about 40-60 % of irrigation water can be saved without any loss in yield in comparison to continuous submergence (± 5 cm ponded water)
- In Madagascar system of rice cultivation, delaying irrigation up to 3 DADPW (after tillering stage) can be considered to be the best water regime that saved 12-13% irrigation water without any yield loss compared to continuous shallow submergence (±3 cm ponded water) after tillering
- Rice cultivation under SRI system gave higher grain yield and net return with irrigation at 3 DADPW and interculture operation done twice with Ambika paddy weeder
- Sprinkler irrigation up to vegetative stage and surface irrigation after vegetative stage gave higher grain yield of wheat with lower water expanse and maximum net return as compared to border strip irrigation
- Irrigation at IW/CPE 0.8 or four irrigations at 25, 54, 82 and 102 days after sowing gives higher yield of *rabi* sunflower and higher WEE
- Irrigation at IW/CPE 0.9 (or 8-9 irrigations) is recommended for summer groundnut as it gave higher yield and WEE
- Use of sprinkler irrigation gives higher yield of onion and potato with yield increase of 26% and 18% and water saving of 42% and 36% over surface irrigation, respectively
- Brinjal (var. Mukta Keshi) crop had better growth and green fruiting with irrigation at IW/CPE 0.8 (about 7 irrigations at an interval of 20-25 days) and application of 200 kg/ha N in sandy loam soil
- Drip irrigation at 0.6 PE on alternate day with application of boron @ 2.0 kg/ha gives maximum yield of tomato (var. Pusa ruby) and benefit-cost ratio compared to drip irrigations at 1.0, 0.8 and 0.4 PE. Yield increased by 74% yield with 45% water saving over traditional surface (alternate furrow) irrigation
- Drip irrigation at 80% PE with paired row planting at 60 cm is recommended for sugarcane var. CO 1305, because it gives maximum yield with yield increase of 24.8% and water saving of 43.3% over traditional surface irrigation and planting method
- Higher yield of banana was obtained under drip at 80% PE with 43.62% increase in yield and 27.63% water saving compared to surface irrigation. There was an additional water saving of 20.3% on use of mulch
- Buch (*Acorus calamus*) recorded higher rhizome yield with high net return with a spacing of 30x20 cm. When irrigation is provided at 1 DADPW, the crop consumes 288 cm water in its cropping period of 10-11 months. Buch can be well adopted in waterlogged areas
- Higher bulb yield of onion (24.01 t/ha) was recorded with irrigation at 60% CPE and application of micronutrient Zn @ 5 kg/ha + S @ 20 kg/ha. Water expanse efficiency and net return with this technology was 585.84 kg/ha-cm and Rs.1,93,565/ha, respectively

Jorhat

- Demonstrations conducted at farmers' field under ORP recorded superior results over the existing practices of farmers. In case of autumn rice, recommended irrigation practice (5 cm irrigation 3 DADPW) could save about 38.5% irrigation water over farmer's practice with significant increase in yield. This has indicated the scope in increasing the irrigated area to an extent of 38.5% usnig the same volume of irrigation water for growing autumn rice

- In Assam, brinjal and tomato as *rabi* vegetables occupy large area. The irrigation practices adopted are unscientific i.e. frequently applied with unmeasured depth. Proper irrigation practice increased brinjal yield by 20.2% and tomato yield by 18.5% with considerable water saving i.e. 40%
- Rice follow in farmers' field was utilized by growing yellow sarson with the provision of irrigation. On an average two irrigations at flowering and siliqua formation stages have showed 21.2% higher yield over farmers' practice of growing yellow sarson
- Proper on farm irrigation management experiments showed that yield of broccoli and gladiolus may be increased by 9.6 and 17.3%, respectively and about 33.3% water may be saved
- Chewing type sugarcane has drawn attention of farmers because of its market demand. *In situ* rainwater harvesting technique like ridge mulched by plastic film and furrow with sugarcane trash/weed or only plastic mulching in ridge increased yield of chewing type sugarcane upto 60%. For rice field, increasing bund height to 30 cm was found to be an *in situ* rainwater harvesting technique
- Studies on Meleng watershed in Jorhat district helped to formulate strategies for conservation of resources and devise need based site specific interventions
- Assam lemon being a shallow rooted high value specialized crop, provision of drainage is important. Sub-surface drainage through pipe made from split bamboo with mineral envelope was found to be beneficial and superior for drainage. The same pipe can also be utilized for irrigation during winter

West India

Junagadh

- A mathematical model and nomograph developed for deriving rainfall intensity-duration-frequency (I-D-F) relationship is recommended for design of water harvesting-cum groundwater recharging structures by scientific communities/NGOs/government sectors working on implementation of projects on water harvesting-cum-groundwater recharge
- Runoff coefficient derived, and mathematical model and nomograph developed for deriving rainfall I-D-F relationship are recommended for hydrologic design of flood control and water conservation structures for scientific communities/NGOs/government sectors working on implementation of projects on flood control and well water conservation in Mahi basin
- Under conjunctive water use planning for wheat crop in Junagadh region, groundwater draft of 533.94 m^3/ha can be reduced (by 7.72%) per irrigation given from check dam. Thus 123.8 kWh/ha (4.9%) power can be saved on irrigation given from check dam. It is economical when at least two irrigations are given from surface source. If second irrigation onwards is applied through conjunctive use of water, benefit-cost ratio rises by 0.04 against irrigation given from check dam
- The aquifer properties for different talukas of the Junagadh district recommended for the scientific community/Government/Non-Government Organizations are useful for groundwater recharge/development planning and management as well simulating groundwater behavior for adopted cropping pattern. It can also be useful for finance institution for the loan sanctions on groundwater development projects
- Contour maps of GW quality parameter like EC, TDS, pH, Ca, Mg, Na, Fe, Mn, carbonate, bicarbonate, chloride, sulphate, Nitrate-N and water hardness were prepared based on analysis of samples from 391 wells in 73 talukas of 11 districts of Saurashtra region during *rabi* season of 2012 and 2013. These maps can be useful for the farmers for operation and maintenance of drip irrigation. The scientific information along with GW quality maps are released for the scientific community
- Impact of seawater intrusion on GW quality in South Saurashtra coast was studied. Water quality parameters *viz.*, EC, pH, Ca, Mg, Na, K, CO_3^{++}, HCO_3^- and Cl^-, SAR, ESP, RSC, RSBC, SSP, TDS, Puri's Salt index, total hardness, LSI, sodium hazard, potential salinity, permeability index, Mg/Ca, MAR, Kelli's ratio, Ca^{++}/HCO_3^-, Na^+/Cl^-, Mg^{++}/Cl^- and HCO_3^-/Ca^{++} analyzed for the coastal belt. Analysis was done at distances of 5, 10, 15 and 20 km from the sea coast before/after monsoon period. Mathematical models relating rainfall and groundwater EC are developed for the scientific communities/line departments of state/central governments/NGOs. The information is also useful for selection of cropping patterns and irrigation water management strategies by the farmers
- Groundwater quality in coastal belt area has been improved through water harvesting measures compared to non-treated area
- To avoid groundwater pollution surrounding the industrial area of Jetpur town it is suggested that the effluent from the textile dying industry should be added to river after proper effluent treatment

- Policy makes, farmers, agricultural pesticide manufacturers/importers, agricultural produce purchasers/exporters, agro industries, state government/central government line departments/ NGOs and academic/research institutes were informed of the fact that GW of Junagadh region contains nitrate-nitrogen more than the permissible limit of 50 ppm indicating that the water is harmful for drinking
- From aquifer mapping of Uben river basin it was suggested that about 200 km^2 arc shaped area from Evenagar - Chobari - Sakkarbaugh - Vadal - Makhiyala - up to Fareni has good GW potential. Therefore this arc shaped area is suitable for augmentation of water resources and water resource development activities compared to other parts of Uben basin

Kota

Extension activities and transfer of technologies undertaken

Under the ORP, 62 field demonstrations were conducted out of which 18 were at head reach, 18 at middle reach and 12 at tail reach of selected distributaries. Besides these, six demonstrations each on SRI and soybean+maize intercropping system were carried out. On farm trial (OFT) on conjunctive use of water was conducted to disseminate the technology. Staff of the project has given advice to government officials on water management on regular basis. In addition to this, lectures on soil, water and new irrigation methods have been delivered to government officials. The project staff also participated in the agriculture technology *mela* to disseminate awareness of various technologies among farmers and other stakeholders. Some of the technologies are mentioned below:

Crop	Technologies undertaken
Wheat and soybean	Border strip method of irrigation (5x50 m) with 80% cut off ratio
Soybean + maize intercropping	Intercropping of soybean + maize (4:2) and irrigation at critical stages i.e. flowering and pod development (need based)
Paddy	Irrigation of 7 cm (5±2) depth of irrigation with 1-3 days after disappearance of ponding water
Paddy	System of rice intensification
Wheat	Conjunctive use of water i.e cyclic irrigation with canal and brackish water or blending
Coriander	Sprinkler irrigation

Parbhani

- In-line drip irrigation at 1.0 ET_c on alternate day should be practiced by farmers for better and quality yield of *rabi* onion
- For better and quality produce of *rabi* onion application of 75 kg/ha N through water soluble fertilizers in drip system with five equal splits at 15, 30, 45, 60 and 75 days after planting should be adopted
- For better and quality produce of *rabi* brinjal in-line drip irrigation system with one lateral for paired row (0.6 x 0.6 m) is recommended to operate at alternate day with 60% PE
- To get higher yield, quality produce and economic return from turmeric it is recommended to apply irrigation of 60 mm when CPE reaches 75 mm at 0.8 IW/CPE and fertilizer @ 150:50:50
- For higher yield, net monetary return and B:C ratio, it is recommended to irrigate *Bt* cotton crop after every two days with 0.5 CPE depth using in-line drip irrigation system for paired planting at 60 x 60-120 cm as sole crop or 180 x 30 cm with greengram as intercrop
- For higher yield, net monetary return and B:C ratio of *rabi* sorghum, it is recommended to apply in-line drip irrigation system scheduled at 1.0 ET_c for paired row planting of 45x15-75 cm. The fertilizer dose should be 80:40:40 kg/ha NPK applied in 3, 2 and 3 splits, respectively till 60 days after sowing
- For higher yield, net monetary return and B:C ratio of *rabi* okra, in-line drip irrigation system laid at alternate row and scheduled at alternate day with depth of water equal to 40% PE along with 75% RD of water soluble fertilizers at 75, 37.5 and 37.5 kg/ha NPK, respectively in 5,3 and 5 splits from 0 to 75 days after sowing is recommended
- For higher yields, gross monetary returns, net monetary returns and B:C ratio of sweet orange, in-line drip system forming a loop around the tree canopy is recommended along with application of 75% recommended dose of fertilizers (600:300:300 g/plant NPK) in 12 splits till 240 days after stress withdrawal of *Mrug bahar*

- Paired row planting of turmeric at 45 x 15 cm spacing on raised beds of 150 cm with alternate day drip irrigation at 0.5 PE is recommended for obtaining higher rhizome yield, economic benefit and WUE.

Sriganganagar

- *Kharif* brinjal should be grown with drip irrigation scheduled at 0.8 ET_c, fertigation scheduled as 96 kg/ha N, 64 kg/ha P_2O_5 and 48 kg/ha K_2O in 12 equal splits each at an interval of 10 days crop and 30 micron bicolour (gray and black) mulch. The treatment saved 34.1% irrigation water over surface irrigation and 15.7% irrigation water over drip irrigation scheduled at 1.0 ET_c without plastic mulch. It gave 12.2% higher fruit yield of brinjal in comparison to surface irrigation. The treatment gave net income of Rs.7,32,916 with incremental benefit-cost ratio of 2.43. It saved fertilizer by 20%
- Drip irrigation at 0.8 ET_c (Low tunnel) was found optimum irrigation schedule for bitter gourd as it gave 14.5% higher fruit yield and saved 52.6% irrigation water over surface irrigation (LT). This treatment gave net seasonal income worth Rs.7,51,384 with B:C ratio 3.40. In case of scarce irrigation water, drip irrigation at 0.6 ET_c (LT) has been recommended, because it maintained fruit yield and saved 60.7% water compared to flood irrigation. Fertigation schedule of 80 kg/ha N, 32 kg/ha P_2O_5 and 32 kg/ha K_2O in 12 splits each at an interval of 11 days has been recommended. This saved 20% fertilizers and gave 11.5% higher yield compared to conventional surface irrigation. This treatment gave net seasonal income worth Rs.7,03,773 with B:C ratio of 3.20
- The application of 180 kg N, 120 kg P_2O_5 and 80 kg K_2O/ha (RDF) with drip irrigation in 9 equal splits each at an interval of 11 days has been recommended as an optimum fertigation schedule for tomato. It gave 24.3% higher fruit yield and saved 24.2% irrigation water over surface or flood irrigation (LT). It gave net seasonal income of Rs.3,39,200 with B:C ratio of 3.40. Alternatively, 40% fertilizer can be saved without reduction in yield on application of 108 kg N, 72 kg P_2O_5 and 48 kg K_2O/ha with drip irrigation in 9 equal splits each at an interval of 11 days, because yield was at par with 100% RDF with flood irrigation
- If timely sowing (15th May) of cotton is not possible due to canal closure or some other reason, then cotton seedlings may be raised in plastic bags and transplanted in field up to 30th May with drip irrigation without any yield loss. It gave net seasonal income of Rs. 86,589/ha with B:C ratio of 1.95. Transplantion of cotton crop on 30th May, 10th June and 20th June, and irrigation with drip gave 15.4, 24.2 and 47.0% higher seed cotton yield over direct sown crop on these dates, respectively

Udaipur

Global Rajasthan Agritech Meet, Jaipur and Technology Fair, Udaipur

Udaipur: Farmers training organized and desilted structure by AICRP on IWM at Chhali (MPUAT adopted) village

TV Talk

1. TV talk delivered by Dr. K.K. Yadav on water quality improvement through rainwater harvesting. The programme was telecasted by ETV Rajasthan on 28.06.2016
2. TV talk delivered by Dr. K.K. Yadav on groundwater recharge and water quality which is telecasted by ETV Rajasthan on 01.06.2016

Central India

Jabalpur

- A training program was organized during 5-7 May 2016 on "Increasing Agriculture water productivity" in MP at Depstment of Soil and Water Engineering, CAE, JNKVV, Jabalpur
- A program on *"Krishi Siksha Diwas"* was organized on 3 December 2016 in CAE, JNKVV, Jabalpur. Seventy-five students of Saraswati Shishu Mandir, Ramnagar and Suhagi of Jabalpur district participated in this programme

Jabalpur: Training programme (Left) and Krishi Siksha Diwas (Right)

Morena

- Fennel (Saunf) crop grown in alluvial soil with irrigation scheduling at 0.8 IW/CPE fetched highest net return (Rs. 61,954/ha) and benefit-cost ratio (3.24). The treatment and yielded 2.23 t/ha. This technology for getting higher yield and economic benefit has been adopted by farmers of ORP area, Department of Horticulture and KVK through demonstrations, lectures and training
- Integration of irrigation scheduling at 0.6 IW/CPE, sprinkler irrigation method in oilseed – pulse i.e. soybean-chickpea cropping system will help to obtained maximum production, net return and maintain soil health in place of fellow-mustard practice. This cropping system will also help in fulfilling the increasing demand of pulses and vegetable oils. Soybean-chickpea is a new cropping sequence in Morena region having alluvial soil
- Microirrigation applied through porous pipe, installed under ridges at the time of ridge preparation, saved 70-90% water over surface irrigation. As turmeric crop requires continuous wetted/moist soil for better growth, porous pipe helped in keeing soil moist. This improved the yield and quality of turmeric. Labour cost and weed population reduced. Porous pipe irrigation allowed fertilizers to be used optimally. This technology was demonstrated in the horticulture department and progressive farmers' fields. Farmers are satisfied and ready to adopt this new technology

North India

Pantnagar

- Farm trials were conducted to improve crop and water management technologies. Farmers of the area visited to see the impact of trials conducted
- Farmers from Afganistan, Uttarakhand visited the project site. Field demonstrations were laid to bring awareness among the farmers on water efficient crop production technologies *viz.*, drip, ridge and furrow sowing, etc.
- Lecture series on "Water conservation and irrigation - More crop per drop of water" was delivered in Kisan Mela held from 10-13 March, 2016 at Pantnagar

Almora

- LDPE lined ponds were constructed by harvesting water from rivulets, nala, spring or roof. Sewage, silt or other impurities were removed from the harvested water by constructing sand filter with the help of locally available sand, stones and gravels. Farmers were advised to make multiple use of the water to enhance water productivity. Ponds with covering of locally made blocks are gaining popularity due to low cost, capacity to fully protect ponds and provide better condition for fish cultivation. Space between locally made blocks was filled with mixture of sand and cement to protect the LDPE lining. Pond covered with net further increased suitability for the multiple water use model
- LDPE film lined tanks were built and demonstrated at farmer's field. Capacity of 386 m^3 was developed in one farmer's field in three villages of Almora district during 2016-17. It was constructed to harvest water from surface runoff and small streams. Net was used on tanks to prevent wild animal and children damage the tanks. Use of net increased acceptance of the tanks among farmers
- Azolla was introduced in multiple water use model. Azolla reduced evaporation from the ponds. It was also used as compost. It served as fodder for cattle, fish and poultry. It will also absorb carbon. It will reduce evaporation from water tank, weed problem and mosquito breeding in the ponds
- Farmers were advised to plant hybrid napier in the bunds of their fields and use it as feed for cattle and fish

Jammu

- Refinement of technology guidelines for adopting microirrigation system i.e. mini-sprinkler and drip irrigation system was forwarded to Project Officer, Soil and Water Management, Command Area Development, Jammu on 5-07-2016
- Design of microirrigation system for vegetable crops is refined for plot size of 100 x 100 m (1.0 ha) within farmer clusters. Capacity of water storage tank to meet water requirement per ½ hour per cycle for 4 mm water depth within 0.25 ha is equal to 10000 litres. Pump size with discharge capacity of pump is 7.5 HP having discharge of 470 l/min (7.8 l/s). Component-wise details of microirrigation system have been provided for implementation by CAD and Agriculture Department, Jammu
- Technology refinement/ recommendation on sprinkler method of irrigation for potato crop during RCM, 2016 has been approved for adoption through OFTs. Salient aspect of the recommendation is that in absence of sprinkler irrigation facility, furrow method of irrigation may be popularized or adopted. Water productivity under sprinkler irrigation method increased by 15% over skip furrow method and 66.4% over flood irrigation. Sprinkler irrigation

increased net return by Rs.9000/ha over skip furrow method and Rs.53,500/ha over flood irrigation method

- Action plan for technologies transferred to Director Planning, Agriculture Production Department on formulation of state water policy will be adopted at block and district levels by state department (I&FC) of Jammu

Palampur

- Potato crop should be raised with drip irrigation at 0.8 PE and fertigation with 75% RDF in order to save water and fertilizer and obtain higher economic return
- For better production and economics, onion crop should be irrigated at 0.6 CPE at interval of three days. Okra crop should be irrigated at 0.8 CPE at two days interval. Both the crops should be fertigated with 100% recommended dose of N with locally prepared liquid manure which enriched with 1% liquid biofertilizer (E100)
- Production, economics and WUE of brinjal can be improved by planting the crop after incorporation of FYM @ 10 t/ha and mulching with organic material. The crop should be irrigated with 4 cm of water depth

South India

Belavatagi

- Alternatively alternate furrow (AAF) technology has become very much popular in Malaprabha command and more farmers are adopting this to save irrigation water. The AAF technology can be adopted in any region of the country where maize and cotton are grown in vertisols. This technology saves water, time and labour. This avoids excessive irrigation in command area and checks soil salinity
- About 80% cutoff length for boarder strip irrigation is being covered with narrow spaced crops like wheat and chickpea to avoid irrigating entire length of the border strip. This proven technology will save water, time and labour. This avoids excessive irrigation in command area and checks soil salinity
- Combination of surface irrigation at flowering followed by sprinkler irrigation at pod formation stage is ideal for getting higher grain yield, net return and B:C ratio for chickpea in northern dry zone of Karnataka

Belavatagi: AAF irrigation technology for brinjal crop

- Apart from this, several trainings to Farmers / Extension Personnel / Others were conducted



Field day on irrigation and drip irrigation in rabi crops conducted at IWMRC, Belavatagi on 10-02-2017

Chalakudy

A. Classes given to farmers from different places

Topic	Date	Venue
Soil nutrient management including micro nutrient	06/02/2016	KB Punnayurkulam
Organic farming	16/03/2016	KB Adat
Measures to improve WUE	22/03/2016	DE, Mannuthy World water day
Organic farming practices and rice cultivation	07/10/2016	Parali Panchyayath
Organic waste management	26/10/2016	KVK Thrissur
Organic farming practices and rice cultivation	17/12/2016	Muriyad KB
Water management	02.12.2016	Farmers of Pooppathy Mala block
Water management	22.12.2016	Farmers of Irinjalakuda Muncipality
Nutmug cultivation	07.01.2016	Kodassery
Nutmug cultivation	08.01.2016	Meloor
Weed management in rice	10.11.2016	Farmers, Parakkadavu Panchayath
Water Management & Microirrigation Systems	02.12.16	Mala
Water Management& Microirrigation Systems	15.12.16	Kodassery
Water Management & Microirrigation Systems	21.12.16	Kodungallur

B. Training conducted

Date	Topic	Trainees
3.10.2016 to 6.10.2016	Empowering women on organic farming and water saving technologies	Master trainers of Kudumbasree Mission, Ernakulum district
6.9.2016	Soil and water conservation Vegetable cultivation	ITI students, Institute of Women ITI, Chalakudy
7.10.2016	Soil and water conservation Methods of irrigation	Engineering students, Deptt. of Environmental Engineering, SCMS College, Karukutty
28.10.16	Water management with respect to Climate change	Employees of Agriculture department,local bodies, politicians, NGO and farmers

Farm advisory services rendered:

1120 farmers visited the station for getting advice on insect pest management and water management

Tribal Sub Plan (TSP)

1. Raipur (AESR 11.0)

Performance evaluation of lift irrigation system designed and installed under TSP at tail end reach of Kodar canal command

The experiment was conducted to evaluate existing surface water and groundwater resources in Village - Parsadih, Block and District - Mahasamund (Madhya Pradesh) and to suggest appropriate conjunctive water use plan for the region. Surface water from the selected minor no. 2 (L) and sub-minor L (2) in the tail end of the Parsadih distributary is shown in Table 1a. Groundwater assessment showed that recharge from rainfall was 0.54 Mm^3. Total recharge in the study area was 0.27 Mm^3. Groundwater available during *rabi* and *kharif* seaons was 1.46 Mm^3. Groundwater drafts for *kharif* and *rabi* seasons were 0.11 and 0.13 Mm^3, respectively. Surface water potential was 0.77 Mm^3. Groundwater potential was 0.47 Mm^3. Stage of groundwater development was 31.78%. Results obtained from the study of season-wise demand-supply scenario of surface water and groundwater is shown in Table 1b. Overall deficit in water supply was found to be 0.365 Mm^3 (Table 1c).

Table 1a. Surface water from minor and sub-minor in *kharif* and *rabi* seasons

Year	2012	2013	2014	2015	2016
Average discharge (cusec)	1.79	1.18	1.71	0.93	1.15
No. of days running	79	81	207	128	33
Water release (Mm^3)	0.35	0.24	0.86	0.29	0.09

Mm^3- million m^3

Table 1b. Demand-supply scenario of surface water and groundwater

Source	Water quantity (Mm^3)					
	Available		Utilizable		Utilized	
	Kharif	*Rabi*	*Kharif*	*Rabi*	*Kharif*	*Rabi*
Surface water	0.86	-	0.77	-	0.24	-
Groundwater	0.73	0.73	0.47	0.47	0.11	0.13

Table1c. Deficit/surplus as per requirement of present cropping pattern

Season	Water quantity (Mm^3)		
	Water Use	Water Requirement	Surplus/Deficit (-)
Kharif	0.350	0.78	-0.430
Rabi	0.125	0.06	0.065
Total	0.475	0.84	-0.365

2. Dapoli (AESR 19.2)

- Total 367 *jalkund* and 10 plastic lines *bandhara* were constructed and 6 low pressure drip irrigation systems were installed in 57.9 ha land in Mahad, Vikramgad, Jawhar, Mokhada and Mandangad talukas. Rainwater stored in one *jalkund* during monsoon season ranged from 4100 to 4300 litres. There was about four-fold increase in area under horticulture crops like mango and cashew. Success rate of mango and cashew grafts ranged from 73.69 to 88.42% and 85.8 to 90.4%, respectively in the talukas. The retention period of rainwater storage in *jalkund* was from 116 to 141 days, which facilitated irrigation for crops up to end of April. Land utilization index doubled (0.27 to 0.61) and water storage capacity utilization index increased in the range of 48.1 to 57.1% in the talukas due to intervention of *jalkund* technology in tribal areas of Konkan region.

- Plastic lined check dams (*Bandhara*) named as 'Konkan Vijay Bhandara' helped in including additional area of 60 acres under vegetable cultivation.
- Low pressure in-line drip irrigation system installed in farmers' field had 91% field emission uniformity. Farmers got jasmine flowers throughout the year (except July and August 2016) with highest flower yield of 1.7 t/ha and maximum WUE of 180 kg/ha-cm during December 2016.

3. Junagadh (AESR 5.1)

- AICRP scientists of Junagadh center visited tribal farmers' fields on 21.04.2016 and guided farmers who have been given drip sets for mango plantation (Plate 1) or sprinkler sets at Jambur, Hadmatiya, Vadla, Surva and Sirvan villages of Gir-Somnath district.

Plate 1. AICRP scientist guiding tribal farmer cultivating mango with drip irrigation at Vadla village

4. Pusa (AESR 13.1)

- Process of construction work of graded check dam/diversion structure with sluice gate at Nawkatti (Jamunia), Block-Gaunaha, District-West Champaran is under progress (Plate 2). Revised estimated cost of construction is Rs.6,70,697. About 7000 farmers will be benefitted after construction of the check dam/diversion structure with sluice gate on a natural stream i.e. Budhia Nadi, most of water being wasted at present.
- A modern irrigation system consisting of a tubewell, a diesel pumping set and a modern underground pipeline system was laid in village Saidpur Ghat of Sitamarhi district, Bihar. The beneficiaries are a group of farmers belonging to scheduled tribe (ST). Earlier, they were hiring tubewell and pumping sets for Rs.200 to 250 per hour. A training programme on water saving techniques was also organized on 28.12.2016.

Plate 2. Location for check dam/diversion structure with sluice gate

5. Powarkheda (AESR 10.1)

During the year 2016-17, six stop dams were constructed in five villages before rainy season. The dams have potential of irrigating 8 to 50 ha. The dams contributed to recharge of groundwater. Crop diversification with improved varieties of sesame (JTS 8), maize (JM 216) and arhar (TT 401) was taken as an intervention. Seeds were provided to 52 farmers. The crops were grown on 10.5 ha land using water from the stop dam (Plate 3). The tribal farmers were trained. Further, five groups consisting of five farmers each, were formed for cooperative use of sprinkler sets. One set of sprinkler comprising of 10 pipes, 10 raisers, 10 nozzles, 2 stoppers and 2 bands was issued to each group (Plate 3).

Stop dam at Barrukhal Nala, Matapura

Demonstration of maize variety JM 216

Farmers' training at Matapura

Distribution of sprinkler set

Plate 3. Crop cultivation with water from stop dam and interaction with farmers

6. Parbhani (AESR 6.2)

Wai village from Kalamnuri Tahsil was selected to demonstrate the benefits of modern water management technologies under rainfed condition for sustainable crop production. The village has 100% tribal population comprising of 224 farmers with maximum share of small (124) and medium (100) farmers cultivating on 401 ha land out of the total geographical area of the village (537 ha). Major water sources for irrigation are well, borewell with small area under command and lift irrigation from minor dam - 'Devadhari'. The soil is light-medium with undulating topography, similar to hilly areas. Thus flood method of irrigation used by the farmers is not feasible. Productivity of major crops is low. Farmers are following conventional cropping pattern of the region i.e. Soybean/Pigeon pea/Cotton-Wheat/Chickpea and Groundnut in summer. Very few farmers are cultivating vegetables and fruit crops. Impacts of several interventions are mentioned below:

I) **Demonstration of sprinkler irrigation technology:** Fifty-three farmers experienced 30-40% water saving along with saving of time, labour and energy. They experienced uniform application of water even on undulating topography. Protective irrigation was applied to soybean, pigeon pea, turmeric and cotton during *kharif* season and higher yields were obtained although there was scanty rainfall during June to October 2014-15 (480 mm) and June to October 2015-16 (573.9 mm) with long dry spells. *Rabi* season crops were also taken. Three years of feedback (2014-15 to 2016-17) from the farmers showed that sprinkler irrigation was beneficial in ensuring livelihood security through conservation of water. No case of suicide of farmers was reported in the prevailing drought years.

ii) **Demonstration of bullock drawn multipurpose seed cum ferti drill:** Ninety bullock drawn multipurpose seed-cum-ferti drill were distributed to ninety farmers. Guidance to operate the same was given on the occasion of Kisan mela. Farmers experienced that sowing of crops like soybean, pigeon pea and cotton with the machine was very easy and handy. Seeds and fertilizers were placed at proper depth, which resulted in uniform germination and vigorous crop growth. They also performed harrowing, hoeing after making necessary adjustments in the implement with the provided blade harrow. This saved time, labour and energy. Field efficiency of the machine was higher with negligible maintenance cost compared to the local bullock drawn wooden seed drill.

iii) **Demonstration of improved varieties of soybean**: Total 4420 kg (170 bags) seeds of improved soybean varieties *viz.*, MAUS-81 and JS-93-05 were distributed to 177 ST farmers. From feedback collected from the farmers after *kharif* 2015, it was known that the seeds showed uniform germination and good plant vigour. Seed yields were 33 to 55% higher, shattering of seeds was less with the improved varieties compared to traditional varieties. The farmers could give supplemental irrigation to the crop when long dry spell prevailed in July and August 2015.

iv) **Demonstration of fertilizer and improved variety of wheat:** 2120 kg (53 bags)of seeds of improved wheat variety Lok-1 along with 100 kg of 10:26:26 NPK and 100 kg urea were distributed to 53 farmers. After *rabi* 2015-16, farmers reported uniform germination and good plant vigour, with improved yield ranging from 2.5 to 3.0 t/ha against 1.0 to 1.5 t/ha obtained with traditional varieties. Recommended dose of fertilizer provided by VNMKV, Parbhani proved beneficial in harvesting higher yields of the wheat crop.

v) **Demonstration of portable drip irrigation system for turmeric crop:** During 2015-16, field demonstration of the irrigation system was carried out for turmeric on 0.40 ha in Wai village. The system consisted of filter, portable HDPE main and submain lines with in-line drip laterals and venturi for fertigation. After crop harvest in March 2016, farmers experienced saving of water, fertilizer, labour and time. Dry rhizome yield of 4.5 t/ha was obtained against 2.5 t/ha under conventional (flood) irrigation method. The farmers opined that the system can be used for cotton crop due to its portability and design. The system can also irrigate more area for crops having similar plant spacing as turmeric.

vi) **Demonstration of sprinkler irrigation technology at village Javarla, Dist. Nanded:** Sprinkler sets were distributed to 13 farmers. Live demonstration of sprinkler irrigation technology was given to the farmers for practical experience.

7. Udaipur (AESR 4.2)

Impact assessment of low cost groundwater recharge structures constructed in hard rock regions of southern Rajasthan

A low cost water harvesting structure was built at Doongri pada village (Plate 4a,b). Construction cost of the structure was only Rs.1.30 lakhs. During monsoon season of 2015, storage capacity of the structure varied from 260 m^3 at 0.4 m to 3489 m^3 at 1.5 m soil depth. Water table was monitored during monsoon and post-monsoon periods to evaluate efficacy of the structure (Plate 4c). An additional recharge of about 8735 m^3 of groundwater was created in the village. The structure also showed excellent impact on improving productivity of *kharif* maize by providing life-saving irrigation to the crop during longer dry spell and erratic rainfall condition. An additional area of 2.2 ha under wheat was irrigated during *rabi* season, that used to remain fallow before the intervention. Additional annual incomes of Rs.6502 from *kharif* maize and Rs.48224 from wheat were obtained. The benefit-cost ratio was 1.91:1. Thus socioeconomic status of the tribal farmers were improved. In southern Rajasthan, dry spells are common phenomena. Therefore, such low cost recharge structures are quite effective in augmentation of water table. Being economically viable, the work needs to be disseminated at larger scale in the region.

Plate 4. Low cost water harvesting structure (a & b) and monitoring of water table in a well near the structure (c) at village-Doongri pada, district-Banswara, Rajasthan

8. Rahuri (AESR 6.2)

Drip and sprinkler irrigation sets were distributed to the ST tribal farmers of villages in Dhadgaon taluka of Nandurbar district, Maharashtra. Type of the drip was in-line with dripper spacing of 0.4 m, lateral diameter of 16 mm, emission uniformity ranging from 90-95% and discharge of emitters 4 lph. Performances of different crops grown with drip and sprinkler irrigations during *kharif* 2016 are shown in Table 2.

Table 2. Performances of crops grown by tribal farmers under the intervention

Name of farmer	Area (ha)	Irrigation system used	Sowing date	Harvesting date	Yield before intervention (t/ha)	Yield after intervention (t/ha)
Maize						
Gulabsing Saising Pawara	0.40	Sprinkler	10.6.2016	30.9.2016	2.06	2.43
Sorghum						
Vijay Buradya Pawara	0.40	Sprinkler	20.6.2016	03.10.2016	1.34	1.58
Greengram						
Dongarsingh Pisa Pawara	0.40	Drip	04.6.2016	17.9.2016	0.36	0.43

Cotton						
Suresh Bhika Pawara	0.40	Drip	09.6.2016	22.10.2016	0.85	1.00
Jatrya Limba Pawara	0.40	Drip	22.6.2016	01.11.2016	0.87	1.09
Bebibai Fakarya Pawara	0.40	Drip	19.6.2016	27.10.2016	1.04	1.23
Darasing Narya Pawara	0.40	Drip	13.6.2016	04.11.2016	0.89	1.13
Redgram (Pigeon pea)						
Dhakalsing Kalu Pawara	0.40	Drip	15.6.2016	20.10.2016	0.74	0.93
Natwar Mahadu Salve	0.40	Drip	10.6.2016	28.10.2016	0.64	0.80
Groundnut						
Tanaji Fadshya Pawara	0.40	Drip	08.6.2016	16.10.2016	1.44	1.80
Vulya Ugravnya Pawara	0.40	Drip	18.6.2016	12.10.2016	1.35	1.69

9. Navsari (AESR 19.1)

AICRP scientists delivered lectures and imparted training to the *GRAM MITRA* and tribal youth (GGRC) on soil and water management for the *kharif*, *rabi* and summer crops.

10. Jabalpur (AESR 10.1)

Demonstration and training of farmers in TSP villages

- Different trainings and demonstrations were organized for 34 farmers at Khapa, Magradha and Dhundwa tribal villages of Block - Bijadandee, District - Mandla on the following themes:
- Line sowing with RDF ($N:P_2O_5:K_2O$::80:40:20) for *rabi* cultivation
- Use of high yielding variety seeds requiring less number of irrigations (2-3)
- Improved surface irrigation methods and sprinkler irrigation were applied for wheat varieties *viz.*, GW 273, HD 2851 and local variety Lokman
- A program of demonstration on microirrigation was organized on "Vishwa Jal Diwas" on 22 March 2017 in CAE, JNKVV, Jabalpur. Thirty seven farmers belonging to TSP villages- Khapa, Magradha and Dhundwa, Block- Bijadandee, District- Mandla participated in this programme. The purpose of the program was to conserve water and increase water use efficiency of field crops.
- Water level fluctuations in Bundelkhand region were 5.49-14.88 m below ground level (bgl) in Chhatarpur district and 2.63-36.50 m bgl in Sagar district during pre-monsoon (2012). Post-monsoon phase showed water level fluctuations of 2.26-9.24 and 1.20-20.21 m bgl in the districts. Thus the stage of groundwater development ranged from 27-66%. The GW recharge structures benefitted agricultural fields by increasing soil moisture content and improving agriculture productivity, changed lives of the tribal community, and improved health of animals in the area.

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Belavatagi

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BUDGET 2016-17

(Rs. in lakhs)

S. No.	Name of the Centre (University/Centre/Institute)	Grant in aid Salary	Grant-in-aid General including TA	Total NEH	Total NTSP
1	Almora (VPKAS)	0	3	0	3
2	Ludhiana (PAU)	137	6	0	143
3	Belavatagi (UAS Dharwad)	75	4	0	79
4	Coimbatore (TNAU)	185	10	0	195
5	Raipur (IGKVV)	115	6	0	121
6	Chalakudy (KAU)	66	4	0	70
7	Chiplima (OUAT)	43	4	0	47
8	Dapoli (DBSKKV)	70	4	0	74
9	Faizabad (NDUAT)	44	3	0	47
10	Gayeshpur (BCKVV)	60	4	0	64
11	Hisar (CCSHAU)	35	2	0	37
12	Jammu (SKUAST)	76	4	0	80
13	Udaipur (MPUAT)	40	2	0	42
14	Kota (AU)	85	4	0	89
15	Junagadh (JAU)	40	2	0	42
16	Morena (RVSKVV)	80	4	0	84
17	Navsari (NAU)	70	4	0	74
18	Palampur (CSKHPKVV)	84	5.3	0	89.3
19	Pantnagar (GBPUAT)	118	6	0	124
20	Parbhani (VNMKV)	69	4	0	73
21	Jabalpur (JNKVV)	115	6	0	121
22	Pusa (RAU)	60	6	0	66
23	Rahuri (MPKV)	94	6	0	100
24	Sriganganagar (RAU)	77	3	0	80
25	Jorhat (AAU)	62	0	13	75
26	Shillong (ICAR-RCNEH)	0	0	12	12
27	PCU (ICAR-IIWM)	0	13.7	0	13.7
Total		**1900**	**120**	**25**	**2045**

STAFF POSITION

Almora	
Chief Scientist	Dr. S.C. Panday
Agronomist	Dr. Sher Singh
Soil Physicist	Dr. S.C. Panday
Agril. Engineer	Vacant
Jr. Agronomist	Dr. D. Mahanta
Belavatagi	
Chief Scientist	Dr. G.B. Shashidhara
Agronomist.	Vacant
Soil Physicist	Dr. Punitha B.C.
Agril. Engineer	Vacant
Jr. Agronomist	Dr. U.K. Shanawad
Coimbatore + Madurai + Bhavanisagar	
Associate Professor	Dr. A. Raviraj
Assistant Professor	Dr. A. Valliammai
Assistant Professor	Dr. Elayarajan
Agronomist Prof.	Dr.T. Ragavan
Agril. Engineer	Dr. M. Rajeswari
Soil Physicist	Dr. J. Prabhaharan
Jr. Agronomist	N.K. Sathiyamoorthy
Res. Engineer	Dr. N.K. Prabhakaran
Sr. Agronomist	Dr. S.K. Natarajan
Soil Physicist	Dr. S. Thenmozhi
Agril. Engineer	Vacant
Jr. Agronomist	Dr. J. Bhuvaneswari
Chalakudy	
Chief Scientist	Dr. E.K. Kurien
Sr. Agronomist	Dr. Anitha S.
Sr. Agronomist	Dr. Mini Abraham
Soil Physicist	Smt. Bhindhu P.S.
Agril. Engineer	Dr. Mary Regina F.
Chiplima	
Chief Scientist	Dr. A.K. Mohanty
Sr. Agronomist	Dr. Sanjukta Mohapatra
Soil Physicist	Vacant
Agril. Engineer	Dr. N. Panigrahy
Jr. Agronomist	Mrs. S. Lenka
Dapoli	
Chief Scientist	Dr. R.T. Thokal
Horticulturist	Dr. Smt. R.S. Patil
Soil Physicist	Dr. K.P. Vaidya
Agril. Engineer	Dr. B.L. Ayare
Jr. Agronomist	Dr. T.N. Thorat

Faizabad	
Chief Scientist	Vacant
Agronomist	Vacant
Soil Physicist	Vacant
Agril. Engineer	Er. R.C. Tiwari
Jr. Agronomist	Dr. B.N. Singh
Gayeshpur	
Chief Scientist	Dr. S.K. Patra
Agronomist	Dr. B. Biswas
Soil Physicist	Dr. K. Bhattacharya
Agril. Engineer	Er. S. Saha
Jr. Agronomist	Mr. R. Poddar
Hisar	
Chief Scientist	V.K. Phogat
Agronomist	Vacant
Soil Physicist	V.K. Phogat
Agril. Engineer	Vacant
Jr. Agronomist	Vacant
Jammu	
Chief Scientist	Dr. A.K. Raina
Sr. Agronomist	Vacant
Soil Physicist	Dr. Abhijit Samanta
Agril. Engineer	Er. N.K. Gupta
Jr. Agronomist	Dr. Vijay Bharti
Powarkheda + Jabalpur	
Chief Scientist	Dr. N.K. Seth
Sr. Agronomist	Dr. P.B. Sharma
Soil Physicist	Dr. P.S. Kulhare
Agril. Engineer	Vacant
Jr. Agronomist	Dr. Vinod Kumar
Irrigation Engineer	Dr. R.K. Nema
Junior Scientist	Dr. M.K. Awasthi
	Er. Y.K. Tiwari
Jorhat	
Chief Scientist	Dr. R.K. Thakuria
Agronomist	Dr. K. Pathak
	Dr. A. Sharma
Agril. Engineer	Dr. P. Barua
Soil Physicist	Dr. B.K. Medhi
Junagadh	
Chief Scientist	Dr. H.D. Rank
Agril. Engineer	Prof. P.B. Vekariya
Soil Physicist	Dr. M.S. Dulavat
Agronomist	Vacant

Kota	
Chief Scientist	Dr. Pratap Singh
Soil Physicist	Vacant
Sr. Agronomist	Dr. H.P. Meena
Agril. Engineer	Er. I.N. Mathur
Jr. Agronomist	Dr. R.S. Narolia
Ludhiana + Bhatinda	
Chief Scientist	Dr. Rajan Aggarwal
Asst. Res. Engineer	Dr. (Mrs.) Samanpreet Kaur
Asst. Res. Engineer	Dr. Sanjay Satpute
Asst. Res. Engineer	Er. Amina Raheja
Sr. Scientist (Irrigation)	Dr. A.S.Sidhu
Soil Physicist	Dr. K.S. Sekhon
Asst. Agronomist	Dr. Anureet Kaur
Asst.Agril. Engineer	Dr Sudhir Thaman
Morena	
Chief Scientist	Dr.Y.P. Singh
Soil Physicist	Dr. N.S. Yadav
Agril. Engineer	Er. S.K. Tiwari
Sr. Agronomist	Dr. Sandeep Singh Tomar
Jr. Agronomist	Dr. Janmejay Sharma
Navsari	
Chief Scientist	Dr. V.P. Usadadiya
Sr. Agronomist	Vacant
Soil Physicist	Dr. J.M. Patel
Agril. Engg	Er. N.G. Savani
Jr. Agronomist	Prof. R.B. Patel
Palampur	
Chief Scientist	Dr Sanjay K. Sharma
Agril. Engg	Vacant
Sr. Agronomist	Dr. Kapil Saroch
Soil Physicist	Dr. S.K. Sandal
Jr. Agronomist	Vacant
Pantnagar	
Chief Scientist	Dr. Subhash Chandra
Soil Physicist	Dr. H.S. Kushwaha
Senior Agril Engineer	Dr. Yogendra Kumar
Agronomist	Vacant
Agril. Engineer	Dr. Vinod Kumar
	Dr. H.C. Sharma
	Dr. Harish Chandra
	Dr. U.C. Lohni
Jr. Agronomist	Dr. Gurvinder Singh
Parbhani	
Chief Scientist	Vacant
Agril. Engineer	Dr. U.M. Khodke
Agronomist	Prof. G.D. Gadade
Soil Physicist	Prof. U.N. Karad
Jr. Agronomist	Vacant
Pusa	
Chief Scientist	Vacant
Agronomist	Dr. Vinod Kumar
Soil Physicist	Dr. Mukesh Kumar
Agril. Engg	Dr. S.K. Jain
	Dr. S.P. Gupta
Jr. Soil Chemist	Dr. A.K. Singh
Jr. Agril. Engineer	Dr. Ravish Chandra
Jr. Agronomist.	Dr. Rajan Kumar
Rahuri	
Chief Scientist	Dr. S.D. Gorantiwar
Agronomist	Prof. J.B. Shinde
Agril. Engineer	Dr. S.B. Gadge
Research Engineer	Dr. S.D. Dahiwalkar
Soil Physicist	Dr. B.D. Bhakare
Junior Agronomist	Prof. S.S. Tuwar
Asst. Res. Engineer	Er. S.A. Kadam
Junior Res. Asst.	Er. K.G. Pawar
Bilaspur	
Chief Scientist	Dr. A.K. Sahu
Agronomist	Dr. A.K. Swarnkar
	Dr. J.R. Patel
Soil Physicist	Sh. P.K. Keshry
Agricultural Engineer	Dr. Devesh Pandey
Junior Agronomist	Dr. Geet Sharma
Shillong	
Chief Scientist	Dr. U.S. Saikia
Agronomist	Vacant
Agril. Engineer	Vacant
Soil Physics	Vacant
Jr. Agronomist	Vacant
Jr. Soil Physicist	Vacant
Sriganganagar	
Chief Scientist	Vacant
Soil physicist	Dr. B.S. Yadav
Agronomist	Dr. R.P.S. Chauhan
Agril. Engineer	Vacant
Jr. Agronomist	Vacant
Udaipur	
Chief Scientist	Dr. P.K. Singh
Soil Physicist	Dr. K.K. Yadav
Agril. Engineer	Er. Manjeet Singh
Agronomist	Vacant
Jr. Agronomist	Vacant


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