*Volume 6*
Innovations and Challenges in Micro Irrigation

# Micro Irrigation Engineering for Horticultural Crops

## Policy Options, Scheduling, and Design



*editors*
Ajai Singh
Megh R. Goyal

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# MICRO IRRIGATION ENGINEERING FOR HORTICULTURAL CROPS

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*Edited by*
**Ajai Singh, PhD, FIE**
**Megh R. Goyal, PhD, PE**

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# LIST OF ABBREVIATIONS

| | |
|---|---|
| AP | Andhra Pradesh |
| APMIP | Andhra Pradesh Micro Irrigation Project |
| ASAE | American Society of Agricultural Engineers |
| bcm | billion cubic meters |
| BCR | benefit cost ratio |
| CPE | cumulative pan evaporation |
| CRF | capital recovery factor |
| CSS | central sponsored scheme |
| CSWI | canopy water stress index |
| CWP | crop water productivity |
| CWR | crop water requirement |
| DBTL | direct benefit transfer for loan |
| DDP | Desert Development Program |
| DI | drip irrigation |
| DPAP | Drought-Prone Area Program |
| EC | electrical conductivity |
| ET | evapotranspiration |
| FAO | Food and Agriculture Organization |
| FUE | fertilizer use efficiency |
| GH | greenhouse |
| GGRC | Gujarat Green Revolution Company Ltd. |
| GOI | Government of India |
| HDPE | high-density polyethylene |
| HSPA | Hawaiian Sugar Planter's Association |
| ICU | irrigation control unit |
| INCID | Indian Committee on Irrigation and Drainage |
| INR | Indian Rupees |
| IPE | irrigation production efficiency |
| IRR | internal rate of return |
| IWMI | International Water Management Institute |
| LDPE | low-density polyethylene |
| MI | micro irrigation |

| | |
|---|---|
| NCPAH | National Committee on Plasticulture Application in Horticulture |
| NMMI | National Mission on Micro Irrigation |
| NMSA | National Mission on Sustainable Agriculture |
| NUE | nutrient use efficiency |
| NWP | nutritional water productivity |
| OBC | other backward classes |
| OFWM | on-farm water management |
| PMKSY | Pradhan Manthri Krishi Sinchayee Yojana |
| PVC | polyvinyl chloride |
| SC | scheduled caste |
| SDI | subsurface drip irrigation |
| SMP | soil moisture potential |
| SPV | special-purpose vehicle |
| SRI | System of Rice Intensification |
| TN | Tamil Nadu |
| UCH | Hart uniformity coefficient |
| WUE | water use efficiency |

# FOREWORD

This book, under the book series "Innovations and Challenges in Micro Irrigation," encompasses the relevant research work on micro irrigation and can be quite useful for graduate students and practicing engineers. We need to focus on innovation and evolving new paradigms for efficient utilization of water resources as a means of socioeconomic development of humankind. Water is an essential natural resource for life-supporting systems of all living beings. It is the single most important input in agriculture and has a major role in providing stability and enhancement of agricultural production, leading to self-sufficiency and sustainability. Therefore, application of micro irrigation systems can play an important role to achieve the aim of sustainable development and healthy ecosystems. The per capita availability of water is dwindling and approaching the scarcity levels not far in the future. There is immense need to conserve and use most efficiently both surface water and groundwater resources.

Prof. Megh R. Goyal, Senior Editor-in-Chief of 20 books on micro irrigation by Apple Academic Press Inc. (AAP) and Father of Irrigation Engineering of 21st Century in Puerto Rico, has edited this book volume. I am happy to learn that Dr. Ajai Singh of Central University of Jharkhand, Ranchi, India, has joined him, and both the editors have made commendable efforts to bring this book volume. I also like to commend efforts by AAP to publish quality books on micro irrigation.

I wish the authors all the success in this as well as in future endeavor in this direction.

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# PREFACE 1

Adoption of micro irrigation systems can be a panacea in irrigation-related problems and will increase the area under cultivation. In this technology, the cropped field is irrigated in the close vicinity of root zone of crop. It reduces the water loss occurring through evaporation, conveyance, and distribution. Therefore, high water use efficiency can be achieved. The rain-fed cropped area can be increased with this technology, and potential sources of food production for the benefit of world's food security could be augmented. This edited book has chapters ranging from policy intervention to application of systems to different crops and even under different land conditions. This has been a continued effort of Prof. Goyal to compile the research works in a form of a book series and provide an opportunity for the large scientific community to have easy access.

I feel very fortunate to work with Dr. Megh R. Goyal, who indeed made a serious effort to invite quality chapters. I owe my deepest gratitude to Prof. Nand Kumar Yadav "Indu," Vice Chancellor at Central University of Jharkhand for his support and encouragement. The editors are grateful to many individuals who have contributed their works in the form of chapters.

I feel profound privilege in expressing my heartfelt reverence to my parents, brothers and sister, in-laws for their blessings and moral support to achieve this goal. Last but not the least, I acknowledge with heartfelt indebtedness, the patience and the generous support rendered by my wife, Punam, and our daughter, Anushka, who always allowed me to work continuously and relentlessly.

**—Ajai Singh, PhD, FIE**

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# PREFACE 2

During October 22 through November 4, 2015, I along with my wife visited UNESCO World Heritage archeological sites in Athens (Ἀθῆναι *Athēnai*), Corinthia (Greek: Κορινθία-*Korinthía*), Ephesus, Malta, and Rome.

My vision for micro irrigation technology has expanded globally. I am surprised to observe how this is expanding to tourist regions and especially to archeological sites with number of visitors exceeding 1 million per year. Although no emphasis is made to draw attention of visitors to this valuable technology, yet there is a potential audience. At one of these sites, I started my own initiative to explain this water-saving technique to a small group along with the administrator of this site, who happened to be a civil engineer. He promised me to promote this through a short presentation, of course at a nominal cost.

Water being the limited resource, its efficient use is essential in order to increase agricultural production per unit volume of water and per unit area of crop land. Due to increase in the population, the competition of limited water resources for domestic, industrial, and agricultural needs is increasing considerably. Water for irrigation is becoming scarce and expensive due to depletion of surface and subsurface water caused by erratic rainfall and overexploitation. Therefore, it is essential to formulate economically viable water and other input management strategies in order to irrigate more land area with existing water resources and to enhance crop productivity. Improper distribution lowers the conveyance efficiency and ultimately causes water loss. Therefore, right amount at right time and frequency of irrigation is vital for optimum use of limited water resources for crop production and management.

The aim of irrigation scheduling is to increase efficiencies by applying the exact amount of water needed to replenish the soil moisture to the desired level. Appropriate irrigation scheduling saves water and energy. Therefore, it is important to develop irrigation scheduling techniques under prevailing climatic conditions in order to utilize scarce water resources effectively for crop production. Numerous studies have been carried out in the past in the development and evaluation of irrigation scheduling under a wide range of irrigation systems and management, soil, crop, and agroclimatic conditions. Climate-based irrigation scheduling approaches (such as pan evaporation replenishment and cumulative pan evaporation and ratio of irrigation water to cumulative pan evaporation) have been used by many researchers due to simplicity, data availability, and higher degree of adaptability at the farmer's field. Surface irrigation is the most common method for field/vegetable/fruit crops and ornamental plants. The overall efficiency of surface irrigation method is considerably low compared to modern pressurized irrigation systems: drip, micro-sprinkler,

and sprinkler. Drip irrigation can potentially provide high application efficiency and application uniformity.

This book volume presents policy adoption methods, irrigation scheduling, and design procedures in micro irrigation engineering for horticultural crops.

The mission of this book volume is to serve as a reference manual for graduate and undergraduate students of agricultural, biological, and civil engineering; horticulture, soil science, crop science, and agronomy. I hope that it will be a valuable reference for professionals that work with micro irrigation and water management; for professional training institutes, technical agricultural centers, irrigation centers, agricultural extension services, and other agencies that work with micro irrigation programs.

After my first textbook, *Drip/Trickle or Micro Irrigation Management* by Apple Academic Press Inc., and response from international readers, Apple Academic Press Inc. has published for the world community the 10-volume series on *Research Advances in Sustainable Micro Irrigation* edited by M. R. Goyal. The website <appleacademicpress.com> gives details on these 10 book volumes.

This book is volume six of the book series *Innovations and Challenges in Micro Irrigation.* Both books series are a must for those interested in irrigation planning and management, namely, researchers, scientists, educators, and students.

The contributions by the cooperating authors to this book series have been most valuable in the compilation of this volume. Their names are mentioned in each chapter and in the list of contributors. This book would not have been written without the valuable cooperation of Dr. Ajai Singh and the investigators, many of whom are renowned scientists who have worked in the field of micro irrigation throughout their professional careers.

I would like to thank editorial staff, Sandy Jones Sickels, Vice President, and Ashish Kumar, Publisher and President at Apple Academic Press, Inc., for making every effort to publish the book when the diminishing water resources are a major issue worldwide. Special thanks are due to the AAP production staff for the quality production of this book.

We request the reader to offer us your constructive suggestions that may help to improve the next edition.

I express my deep admiration to my wife, Subhadra Devi Goyal, for understanding and collaboration during the preparation of this book. I

dedicate this book volume to research scientists at the Water Technology Centre of Tamil Nadu Agricultural University, who made earnest efforts to water conservation practices in Southern India.

As an educator, there is a piece of advice to one and all in the world: "Permit that our almighty God, our Creator, excellent Teacher and Micro Irrigation Designer, irrigate our life with His Grace of rain trickle by trickle, because our life must continue trickling on…."

**—Megh R. Goyal, PhD, PE**
Senior Editor-in-Chief

# WARNING/DISCLAIMER

**PLEASE READ CAREFULLY**

The goal of this compendium, *Micro Irrigation Engineering for Horticultural Crops,* is to guide the world engineering community on how to efficiently employ micro irrigation engineering for horticultural agriculture. The reader must be aware that the dedication, commitment, honesty, and sincerity are most important factors in a dynamic manner for a complete success.

The editors, the contributing authors, the publisher and the printer have made every effort to make this book as complete and as accurate as possible. However, there still may be grammatical errors or mistakes in the content or typography. Therefore, the contents in this book should be considered as a general guide and not a complete solution to address any specific situation in irrigation. For example, fruit or vegetable or meat or grain, etc. requires a different type of engineering intervention to process such produce.

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# ABOUT THE LEAD EDITOR

**Ajai Singh, PhD,** FIE, is an Associate Professor and Head of the Centre for Water Engineering and Management at the Central University of Jharkhand in Ranchi, India. He is a Fellow of the Institution of Engineers (India) and a life member of the Indian Society of Agricultural Engineers, the Indian Water Resources Society, the Indian Association of Hydrologist, the Indian Meteorological Society, and the Crop and Weed Science Society. Formerly he has worked as junior project officer at the Indian Institute of Technology (IIT) Kharagpur; and then as Assistant Professor at North Bengal Agricultural University, West Bengal.

Dr. Singh has authored more than 30 articles in technical journals and textbooks, including the book *Introduction to Drip Irrigation.* He has also written the books *Hydrological Modelling Using Process Based and Data Driven Models* and *Finite Element Analysis and Optimal Design of Drip Irrigation Sub-main.* His area of active research is hydrological modeling, micro irrigation engineering, water resources planning and management, and groundwater hydrology. He has been conferred the Distinguished Services Certificate (2012) by Indian Society of Agricultural Engineers, New Delhi.

His area of active research is hydrological modeling, micro irrigation engineering, water resources planning and management, and groundwater hydrology. He has been conferred Distinguished Services Certificate (2012) by Indian Society of Agricultural Engineers, New Delhi.

Dr. Singh received a BTech degree in Agricultural Engineering in 1995 and completed his MTech. in 1997. He obtained his PhD degree in 2011.

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# ABOUT THE SENIOR EDITOR-IN-CHIEF

Megh R. Goyal, PhD, PE, is, at present, a Retired Professor in Agricultural and Biomedical Engineering from the General Engineering Department in the College of Engineering at University of Puerto Rico, Mayaguez Campus; and Senior Acquisitions Editor and Senior Technical Editor-in-Chief in Agricultural and Biomedical Engineering for Apple Academic Press Inc.

He received his BSc degree in Engineering in 1971 from Punjab Agricultural University, Ludhiana, India; his MSc degree in 1977; and PhD degree in 1979 from the Ohio State University, Columbus; his Master of Divinity degree in 2001 from Puerto Rico Evangelical Seminary, Hato Rey, Puerto Rico, USA.

Since 1971, he has worked as Soil Conservation Inspector (1971); Research Assistant at Haryana Agricultural University (1972–1975) and the Ohio State University (1975–1979); Research Agricultural Engineer/ Professor at Department of Agricultural Engineering of UPRM (1979–1997); and Professor in Agricultural and Biomedical Engineering at General Engineering Department of UPRM (1997–2012). He spent 1-year sabbatical leave in 2002–2003 at Biomedical Engineering Department, Florida International University, Miami, USA.

He was the first agricultural engineer to receive the professional license in Agricultural Engineering in 1986 from College of Engineers and Surveyors of Puerto Rico. On September 16, 2005, he was proclaimed as "Father of Irrigation Engineering in Puerto Rico for the Twentieth Century" by the ASABE, Puerto Rico Section, for his pioneer work on micro irrigation, evapotranspiration, agroclimatology, and soil and water engineering. During his professional career of 45 years, he has received awards such as: Scientist of the Year, Blue Ribbon Extension Award, Research Paper Award, Nolan Mitchell Young Extension Worker Award,

Agricultural Engineer of the Year, Citations by Mayors of Juana Diaz and Ponce, Membership Grand Prize for ASAE Campaign, Felix Castro Rodriguez Academic Excellence, Rashtrya Ratan Award and Bharat Excellence Award and Gold Medal, Domingo Marrero Navarro Prize, Adopted son of Moca, Irrigation Protagonist of UPRM, Man of Drip Irrigation by Mayor of Municipalities of Mayaguez/Caguas/Ponce, and Senate/Secretary of Agriculture of ELA, Puerto Rico.

Dr. Megh R. Goyal has been recognized as one of the experts "who rendered meritorious service for the development of [the] irrigation sector in India." This honor was bestowed by the Water Technology Centre of Tamil Nadu Agricultural University in Coimbatore, India, to Dr. Goyal during the inaugural session of the National Congress on "New Challenges and Advances in Sustainable Micro Irrigation" on March 1, 2017.

He has authored more than 200 journal articles and edited more than 45 books including *Elements of Agroclimatology* (Spanish) by UNISARC, Colombia; two *Bibliographies on Drip Irrigation*.

Apple Academic Press Inc. (AAP) has published his books, namely: *Management of Drip/Trickle or Micro Irrigation*, and *Evapotranspiration: Principles and Applications for Water Management*. During 2014–2016, AAP has published his 10-volume set on *Research Advances in Sustainable Micro Irrigation*. During 2016–2017, AAP will be publishing book volumes on emerging technologies/issues/challenges under two book series, *Innovations and Challenges in Micro Irrigation*, and *Innovations in Agricultural & Biological Engineering*. Readers may contact him at: <goyalmegh@gmail.com>

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# PART I

# Policy Options: Drip Irrigation Among Adopters

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## CHAPTER 1

# OPINION OF ADOPTERS AND NONADOPTERS TOWARD DRIP IRRIGATION: INSIGHTS FOR MARKETING

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## ABSTRACT

This chapter highlights some consumer perceptions and focuses on the differences between the adopters and nonadopters. The results indicate that there are many myths about drip irrigation and these usually make the nonadopters have very high expectations from the technology and thereby suppress the satisfaction levels post-adoption. Marketing needs to take into consideration such myths and educate the prospective customers about these and also take up activities to ensure that customers are better prepared and taken care of better to deal with the actual events post-adoption. There are many other aspects of drip irrigation that marketers need to focus: drip irrigation helps in timely and adequate availability of irrigation; it is costly and difficult to master; it enhances the chances for increasing incomes and increase in water tables, and also enables agriculture with very limited water availability while effecting a reduction in the usage of water and power consumed for irrigation and provision of very good quality after-sales service.

## 1.1 INTRODUCTION

A global crisis about water and its management is significantly about availability of water for use and its characteristic of highly uneven spatial distribution. Enhancing water availability and making it amenable for use and managing the distribution are challenges of a tall order due to the dynamic nature of the resource and its usage. Agriculture accounts for majority of global freshwater withdrawals and almost all in some fast-growing economies [13]. At the global level, more than two-thirds of the blue water withdrawals are for irrigation. Irrigated agriculture represents almost a fifth of the total cultivated land but contributes more than one-third of the total food produced worldwide [13] and therefore it is of critical importance of sustenance for the human race.

In India, for example, the area irrigated with groundwater has increased to 500% since 1960. As on 2009, annual groundwater withdrawal for irrigation has been estimated as 221 billion cubic meters (bcm). The overall irrigation efficiency in India is often quite low compared to global standards. It is believed that this is mainly because the efficiency of conventional flood irrigation technique, practiced in large parts of India, is itself

very low. Thus, micro irrigation (MI) technology, including drip and sprinkler irrigation, was introduced as a water-saving technology [8]. It was expected to make a contribution to conservation of the water resources in India [9]. A minimalist expectation was to save water from the quantum used in irrigation and it was expected to promote sustainable water use [2, 8]. Various field experiments have shown this technique to increase water use efficiency up to 80–90% depending on the crop and soil type [2, 11].

Drip irrigation is one of the most efficient methods of irrigation [3]. It is also seen as a promising technology in terms of its ability to support the farmer in raising incomes and reducing poverty [14]. The benefits of MI include water saving, increased yield and productivity of certain crops (especially spaced crops), labor cost savings, electricity savings, lesser pumping hours and hence easier irrigation, better crop growth and also better soil health. A lot of evidence exists claiming economic benefits on the adoption of MI. However, there exists little or sparing evidence of socioeconomic benefits from the adoption of MI.

The rapid commercialization, of agriculture enabled by MI in various regions of India and across a variety of plantations and field crops, is resulting in higher adoption rates of MI in such areas. In spite of these advantages, the spread of MI has been restricted to only a few pockets across India.

Exploring the marketing and impact of adoption of MI is crucial as different states of India such as Gujarat, Andhra Pradesh, and Rajasthan are giving a massive push to MI due to water resource conservation. The Andhra Pradesh Micro Irrigation Project (APMIP) claimed to have brought 0.166 million ha of area under MI during 2.5 years [10]. At the same time, there are pockets like Jalgaon and Nashik in Maharashtra, Narsinghpur and Maikaal in Madhya Pradesh where the market forces are leading to high adoption rates. In some pockets, the high adoption rate is observed even in the absence of government subsidies [14].

The marketers increasingly want to sell and promote drip irrigation without subsidies as they see the potential to expand the market much faster and to more users than possible with subsidies. Therefore, they are looking for insights into consumers' attitude and understanding of drip irrigation to evolve better marketing practices.

There are several such issues related to MI in India. Understanding perception of drip irrigation system, the differences among the adopters and nonadopters is an important stepping-stone toward formulating better

marketing of drip irrigation. This chapter outlines the details on differences of opinions among users and nonusers across three different states and proposes certain marketing insights based on the analyses.

## 1.2 REVIEW OF LITERATURE

### *1.2.1 THE GLOBAL WATER MANAGEMENT CRISIS AND MICRO IRRIGATION*

According to the UN estimates, the volume of global freshwater resources is around 35 million $km^3$, or about 2.5% of the total volume. Around 30% of the world's freshwater is stored in the form of groundwater (shallow and deep groundwater basins up to 2000 m, soil moisture, swamp water, and permafrost). This constitutes about 97% of all freshwater that is potentially available for human use. Freshwater lakes and rivers contain an estimated 105,000 $km^3$ or around 0.3% of the world's freshwater [11, 12, 13].

In 1989, 63% of the world's irrigated area was in Asia, compared with 64% in 1994. Also 37% of arable land of Asia was irrigated in 1994. Among Asian countries, India has the largest arable land, which is close to 39% of Asia's arable land. Irrigated agriculture represents 20% of the total cultivated land but contributes 40% of the total food produced worldwide [12, 13]. Agriculture accounts for around 70% of global freshwater withdrawals, even up to 90% in some fast-growing economies [13].

In India, for example, the area irrigated with groundwater has increased 500% since 1960. In developing and transforming nations, this "global boom" has occurred at various economic levels: subsistence farming, staple-crop production, and commercial cash crop cultivation. It has brought major socioeconomic benefits to many rural communities in Asia, the Middle East and North Africa and Latin America—with numerous countries establishing large groundwater-dependent economies [16]. The countries with the largest extent of areas equipped for irrigation with groundwater, in absolute terms, are India (39 million ha), China (19 million ha), and the USA (17 million ha). Figure 1.1 shows that 91% of the water withdrawal in the country is for irrigation and livestock purposes.