Integrated Nutrient Management (INM) in a Sustainable Rice–Wheat Cropping System
Integrated Nutrient Management (INM) in a Sustainable Rice–Wheat Cropping System
Dedicated to my beloved uncle, late Mr. Hira Lal Chadha, who has been a source of constant inspiration and encouragement in my life

Dr. Anil Mahajan
Agriculture is the main occupation in India and about 75% of its population depends directly or indirectly on agriculture for their livelihood. It is the dominant sector that contributes 18% of the gross domestic product. Thus, agriculture is the foundation of the Indian economy. The maximum share of Indian exports is also from the agriculture sector. As the population of the country is increasing tremendously, approximately at the rate of 19 million every year over the existing population of more than 1 billion (approximately 1.18 billion), the food grain production must necessarily be increased. This can be done by increasing crop production to match the population growth rate of 2.2% per annum, which is expected to stabilize at 1.53 billion around 2050.

There is no doubt that the Green Revolution in India during the late 1960s brought self-sufficiency in food grain production, mainly through the increase in rice and wheat crop yields – the two main crops of the country which play an important role from food security point of view. However, the excessive use of fertilizers and pesticides, and the neglect of organic manures for these crops, has resulted in the deterioration of physical, chemical and biological health of the rice- and wheat-growing soils. Owing to the deterioration of the health of these soils, the productivity of the rice–wheat cropping system has now either got reduced or in some places has become constant for the last decade. The solution of this problem is merely through the proper use of both organics and inorganics, i.e. Integrated Nutrient Management (INM) system. This system holds promise in sustaining crop yields and improving soil health. Holistic use of manures (farmyard manures, compost, green manures, vermicompost), crop residues and bio-fertilizers alone or in combination with chemical fertilizers would result in 25–50% economy in fertilizers (N, P and K) applied to the rice–wheat sequence. Their use has proved a potential tool for maintaining soil fertility and crop productivity in the rice–wheat cropping system in the long run. There is limited information with regard to INM system, especially in rice and wheat crops in which the difference between their potential and their actual yield has widened due to the increasing cost of fertilizers and other inputs. Even if one achieves higher yield by paying higher costs, profitability of the farmers decreases progressively. Moreover, there will be no amelioration in the soil health. Due to all these factors affecting these two crops,
INM information is very much required. This necessity encouraged the authors to compile such information on INM system in the form of a book.

The book entitled *Integrated Nutrient Management (INM) in Sustainable Rice–Wheat Cropping System*, by Dr. Anil Mahajan and Dr. R. D. Gupta, is a vast assemblage on Integrated Nutrient Management for rice and wheat cropping pattern in terms of latest technologies developed which can reduce the cost of production without impairing the yield and sustaining soil health/environment.

The book consists of an introduction and chapters on the need and components of INM system and bio-fertilizers – their varieties and requirements in India. In the chapter on bio-fertilizers, the role of asymbiotic and symbiotic nitrogen-fixing bacteria, including blue-green algae and mycorrhizal fungi, in INM system has been mentioned along with the role of phosphate-dissolving organisms, like bacteria and fungi. The potential of organic resources as plant nutrients in India, their characteristics and the use of balanced fertilizers; the efficient use of fertilizers and water management and the role of INM in the sustainable rice–wheat cropping system; soil-related constraints in the rice and wheat production; constraints in the adoption of INM system and future research strategies/priorities are the other crucial topics which have been explained extensively.

In my opinion, this publication, probably the first of its kind, presents a good blending of our economic requirements and soil ecological necessities. The authors have successfully established compatibility between the organics and inorganics. They have thus developed a two-pronged approach of using organic manures – FYM, compost, vermicompost, bio-fertilizers and crop residues, and chemical fertilizers in the rice and wheat cropping system. This is the need of the hour to help the farmers overcome the critical period of disaster through which they are passing and struggling for their survival from the uneconomical farm holdings.

Last but not the least, I extend my appreciation to Dr. Anil Mahajan and Dr. R. D. Gupta for this laudable attempt, and wish them all the success in their novel, noble and praiseworthy task. Undoubtedly, this book will need revisions from time to time, as and when more literature becomes available on this topic. The glossary and the appendices of this book give further valuable information pertaining to agriculture.

Dr. C. L. Acharya  
FISSS, FNAAS, F.N.A.Sc., FISWM  
Former Director Extension Education (HPAU), Palampur (H.P.)  
Former Director Indian Institute of Soil Science (ICAR), Bhopal (MP)  
28, Nagarkot Colony, Thakurdwara, P.O. Maranda,  
Palampur – 176 102 (H.P.),  
India
India accounts for 2.2% of the global land and 16% of the world’s population. Agriculture is the backbone of the Indian economy. It is, in fact, the pivot around which the country’s economy revolves. The country is primarily agrarian, and this sector provides livelihood to a very large majority of the population. To meet the ever-increasing demand for food to feed the population of more than 1 billion, and to exploit the high-yielding varieties’ potential, there is a requirement of higher fertilizer doses, which are a non-renewable source of energy, along with the use of pesticides, especially in areas where the rice (Oryza sativa L.) and wheat (Triticum aestivum L.) cropping system is being followed. The rice and wheat cropping system, which came into prominence only during the post-Green Revolution period, is the most widely adopted cropping system in India, contributing substantially to the National Food Production. Presently about 10.5 million hectare area is under this cropping system, providing approximately 75% of the total food grain production. About 33% of India’s rice and 42% of its wheat is grown by this cropping system. Although this cropping system gave an impressive increase in per capita production, particularly in irrigated areas from the late 1960s to the late 1980s, this increase declined in partial or total factor productivity. This declining trend began during early 2000 and is still going on. Hence the need of the hour is to enhance sustainability of the rice–wheat cropping system. Among the various factors responsible for causing reduction in yield of rice and wheat the use of chemical fertilizers and pesticides is one of them. These inputs, however, have not only deteriorated the soil health in terms of physical properties – destruction of soil aggregation, change in bulk density, etc. – but have also caused deficiency in micronutrients and secondary plant nutrients. It is therefore essential to improve the soil health of the rice and wheat cropping system and thereby maintaining the sustainability of rice and wheat crops. This can be done only by adding both organic and inorganic sources of nutrients in soils growing rice and wheat. Hence, the authors Dr. Anil Mahajan and Dr. R.D. Gupta intended to write this book entitled A Textbook on Integrated Nutrient Management (INM) in Sustainable Rice–Wheat Cropping System. This book, the first of its kind, has been embodied to present the importance and beneficial effects of various organic sources and their utilization in inorganic or chemical fertilizers to supplement plant nutrients in rice and wheat cropping systems.

This book consists of 13 chapters. Chapter 1, Introduction, indicates the crises of the rice–wheat cropping system and their remedies. Chapter 2 provides the
definition and concept of the INM system, its principles, aims and advantages, as well as the definition of organic farming, its concept, Indian and World scenarios, principles of organic farming, its benefits and constraints, and impact points to remember. Chapter 3 is devoted to the need of INM system in modern agriculture, namely the escalating prices of chemical fertilizers, imbalances in NPK fertilizers consumption ratio and their consumption and production ratio, deterioration of soil health, pollution hazards of chemical fertilizers, loss of soil productivity, and additive effects on inorganic and organic fertilizers. Chapter 4 elucidates various components of INM system. These consist of advantages of organic manures and inorganic fertilizers, green manuring, compost, vermicompost, bio-fertilizers and biogas slurry. Chapter 5 lists the major bio-fertilizer groups and their requirement in India, prospects and constraints in the use of bio-fertilizers vis-à-vis their precautions. Chapter 6 describes the potential of organic resources, namely animal dung, crop residues, green manures and legumes, bio-fertilizers, compost and vermicompost, biogas slurry, as plant nutrients in India. Chapter 7 gives the distribution of the rice–wheat cropping system and contribution to food grain security in South Asian countries, its characteristics and nutritional values. Chapter 8 presents the concept, definition and aims of balanced fertilization, and balanced NPK fertilization in the rice–wheat cropping system and their ratio. Chapter 9 speaks about the effective use of fertilizers and water management practices for rice and wheat crops. Chapter 10 describes the role of INM in the sustainable rice–wheat cropping system with respect to chemical fertilizers and organic manures including enriched compost, vermicompost and micronutrients/plant growth regulators, crop residues, green manure, legumes and bio-fertilizers. Chapter 11 elaborates on the soil-related constraints in the rice and wheat production, namely Indian rice and wheat ecosystem, soil-related constraints in rice and wheat production and their management practices for increasing production and suggestion for the future. Chapters 12 and 13 deal with the constraints in the adoption of INM system and the future research strategies/priorities respectively. In each of the chapters, an abstract, impact points to remember, study questions and references have been provided. A Glossary, which is the result of the assimilation of knowledge and work of different authors and publishers, has also been compiled.

The authors fervently hope that this book will invoke an awareness about the wealth of ideas, information and comments presented in it. These ideas and information will be guidelines and will serve as a useful scientific tool for students, researchers, teachers and extension personnel working in state agricultural universities, central research institutes and state departments of agriculture.

The authors would welcome suggestions, if any, for further improvement in the subsequent editions.

Anil Mahajan
Bayer BioScience Pvt. Ltd.
Hyderabad (Andhra Pradesh), India

R.D. Gupta
Sher-e-Kashmir University of Agricultural Sciences and Technology,
Jammu (Jammu & Kashmir), India
Dr. Anil Mahajan completed his B.Sc. Agriculture (with specialization in Plant Protection) in June 1999, M.Sc. Agriculture (Soil Chemistry and Fertility) in December 2001 and Ph.D. Agriculture (Soil Physics) in January 2006 with distinction from Chaudhary Sarwan Kumar Himachal Pradesh Krishi Vishvavidyalaya (CSK HPKV), Palampur, India. He also holds a Diploma in Computer Applications from Institute of Computer Education and Sciences Training, Palampur. It is pertinent to mention that he has studied minor subjects such as Agricultural Engineering and Agronomy during his Ph.D. Agriculture, and Agronomy during his M.Sc. Agriculture. He has worked as Senior Research Fellow (from 27 July 2005 to 31 August 2007) under the Indian Council of Agricultural Research (ICAR), Government of India, in a Geographic Information System-based research project entitled ‘Developing Mountain Agriculture System Information Files for Planning Niche-based Agriculture Developing in Kangra and Mandi Districts of Himachal Pradesh’ at Centre for Geo-informatics Research and Training, CSK HPKV, Palampur. He has also worked as Research Associate under ICAR-aided research project, ‘Modeling Impact and Adaptation for Major Crops in Himachal Pradesh’ (from 1 September to 2 December 2007) at Centre for Geo-informatics Research and Training, CSK HPKV, Palampur, and as Research Associate at Horticulture Technology Mission Mode Project, ‘Integrated Nutrient Management for Major Fruit Crops of Kandi Region of Jammu’ (from 3 December 2007 to 3 January 2008) in the Division of Soil Science and Agricultural Chemistry, Sher-e-Kashmir University of Agricultural Sciences and Technology (SKUAST), Jammu. Presently, he is working as Territory Manager, Business Development for rice crop (from 4 January 2008 till date) in a German Multinational Company, Bayer BioScience Pvt. Ltd. (wholly owned subsidiary of Bayer CropScience Pvt. Ltd., India).

Dr. Anil Mahajan has done remarkable research work in the rice–wheat cropping system during his doctoral programme, and also in rice, maize and vegetables in master’s research work. He was a recipient of the University Merit Scholarship during his B.Sc. and Ph.D. programmes, and was awarded Honours Certificate in
M.Sc. degree and Best Poster Award at National Workshop on Natural Resource Management for Sustainable Agriculture organized by SKUAST, Jammu, and Soil Conservation Society of India in November 2006. He has 30 publications (research, review and extension papers) to his credit and has attended several national and international training sessions and workshops. It needs to mention that he twice qualified ICAR National Eligibility Test conducted by Agricultural Scientists Recruitment Board, New Delhi, in the following professional subjects: Soil Science – Soil Chemistry/Fertility/Microbiology and Soil Science – Soil Physics, Soil and Water Conservation.

Dr. Rameshwar Dass Gupta is a leading soil scientist and noted environmentalist, having specialized in Soil Microbiology and Pedology. He did his B.Sc. Agriculture in 1965 with specialization in Agricultural Chemistry from Jammu & Kashmir University, India, securing third position; M.Sc. Agriculture (Agricultural Chemistry) in 1968 from Ranchi University, India, achieving second rank at the university among the students of Agricultural Chemistry and Soil Science; and Ph.D. Agriculture (Soil Science and Water Management) in 1980 from Chaudhary Sarwan Kumar Himachal Pradesh Krishi Vishvavidyalaya, Palampur, India. It is worthwhile to mention that Dr. Gupta has studied special subjects such as Plant Biochemistry, Crop Physiology and Soil Microbiology during his M.Sc. Agriculture; and General Bacteriology, Inorganic Nutrition, Chemistry of Soil Organic Matter and Analytical/Physical Chemistry during his Ph.D. Agriculture. He also holds a Postgraduate Diploma in Ecology and Environment from Indian Institute of Ecology and Environment, New Delhi.

Dr. R. D. Gupta started his professional career as an Assistant Extension Specialist (Soil Science) in Punjab Agricultural University, Ludhiana, in 1968 and has served in various capacities as Assistant Scientist, Associate Professor, Deputy Director Extension Education (Training) and Chief Scientist, Krishi Vigyan Kendra, SKUAST, Jammu. He has served as Chief Scientist and Head, Regional Agricultural Research Station, SKUAST, and was the Founding Associate Dean, Faculty of Agriculture, SKUAST, Jammu, and Head, Divisions of Agricultural Chemistry and Soil Sciences and Agroforestry. He has over 150 peer-reviewed publications like research papers, review and research papers as various book chapters and three books to his credit, namely Problems and Management of Soil and Forest Resources of Northwest Himalayas (1991); Environmental Degradation of Jammu & Kashmir Himalayas and Their Control (2005) and Environment Pollution: Hazards and Control (2006). He has also contributed a number of extension papers in Intensive Agriculture, Agriculture Today, Farmers’ Forum, Indian Farmers’ Digest, Farmers and Parliament, Agrobios Newsletter, Gram Vikas Jyoti and daily newspapers.
Dr. Gupta is associated with learned societies like Indian Society of Soil Science, Soil Conservation Society of India, Association of Rice Research Workers, Society of Soil Survey and Land Use Planning, Clay Minerals Society of India, Indian Society of Ecology, Society for Environment and People and Indian Society of Tree Scientists. He has guided a number of M.Sc. Agriculture students in Agricultural Chemistry and Soil Science and remained an advisory committee member of many M.Sc. and Ph.D. Agriculture students in various disciplines at the Faculty of Agriculture.
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Chapter 1
Introduction

Abstract The rice–wheat cropping system of Indian agriculture is the cornerstone of the nation’s food security. This system contributes about 75% of the nation’s total food grain production. It has tremendously helped the socio-economic development of the rural population in India. The Green Revolution in India during the late 1960s has no doubt brought about self-sufficiency in food grain production. However, imbalanced use of inorganic fertilizers and plant protection chemicals for maximizing crop yield has resulted in the deterioration of physical, chemical and biological health of the rice–wheat growing soils. Currently, there is a growing concern about the sustainability of the rice–wheat cropping system as the growth rates of rice and wheat yields have either become stagnant or declined in rice–wheat growing states like Punjab, Haryana, eastern Uttar Pradesh, Madhya Pradesh, Bihar, Himachal Pradesh, Jammu & Kashmir, as well as southern and other states. The crisis of the rice–wheat cropping system in India is mainly due to the decline in the annual average growth rate, the Green Revolution and environmental degradation, the Green Revolution and inequality, and growing indebtedness. The various remedies responsible for breaking down sustainability issues to maintain the rice–wheat cropping system, some of which are very important, are use of organic manures, green manures, rural wastes and crop residues, bio-fertilizers, vermicompost and use of organics and inorganics. The one and only solution for the above-mentioned crisis for the rice–wheat cropping system is the use of both organics and inorganics, i.e. Integrated Nutrient Management (INM) System. Moreover, our former Secretary of the Department of Agricultural Research and Education (DARE) and Director General of Indian Council of Agricultural Research (ICAR), Dr. R.S. Paroda, declared INM system as a mission for the twenty-first century. He stressed upon demonstrating sustained agricultural production through high input of inorganic and organic fertilizers.

Keywords Rice–wheatcroppingsystem • GreenRevolution • sustainability • chemical fertilizer • plant protection chemicals • soil health • environment degradation • organic manures • integrated nutrient management system
The rice–wheat cropping system is the principal cropping system occupying 24 million hectares of cultivated land in the Asian subtropics. The system is prevalent in about 13.5 million hectares in the Indo-Gangetic Plains, of which 10 million hectares lies in India, 2.2 million hectares in Pakistan, 0.8 million hectares in Bangladesh and 0.5 million hectares in Nepal, and about 10.5 million hectares in China. This system covers about 33% of the total rice area and 42% of the total wheat area in these four South Asian countries, and account for one quarter to one third of the total rice and wheat production. China and India produce more than half of the world’s rice, thereby generating the highest employment for the rural Asian population. About half of the irrigated wheat production in South Asia comes from rice–wheat rotation (Pillai, 1994; Mahajan, 2006).

1.1 Crisis of Rice–Wheat Cropping System

The Green Revolution in India during the late 1960s has no doubt brought about self-sufficiency in food grain production. However, indiscriminate use of inorganic fertilizers and plant protection chemicals for maximizing crop yield has resulted in the deterioration of the physical, chemical and biological health of the rice–wheat growing soils due to the imbalanced use of N/P2O5/K2O ratio in fertilizers. A glance at fertilizer ratio data shows that it has never been found to be used in its ideal proportion, which is 4:2:1. Currently, there is a growing concern about the sustainability of the rice–wheat cropping system as the growth rates of rice and wheat yields are either stagnant or have declined in a number of states such as Punjab, Haryana, eastern Uttar Pradesh, Madhya Pradesh, Bihar, Himachal Pradesh and Jammu & Kashmir (Chand and Haque, 1998; Ladha et al., 2000; Mahajan et al., 2002, 2008b; Paroda, 1996). The crisis of the rice–wheat cropping system in India is due to the following reasons.

1.1.1 Decline of Annual Average Growth Rate

These days, Indian agriculture has faced a lot of crisis which can be conjectured by studying the annual average growth rate. During the Eighth Five Year Plan, the annual average growth rate was 4.7%, which reduced to 2.1% during the Ninth Five Year Plan and was as low as 1.7% during the Tenth Five Year Plan. Another troublesome issue is that the share of agriculture in gross domestic product has declined to 18% but the dependence on agriculture is still hovering around 60% (Joshi, 2007). Moreover, there is a widespread unrest among the peasants because of the slowing down or stagnation of their income.

It is to be pointed out here that the Green Revolution, which started mostly with rice and wheat crops during 1967/68, has now reached a plateau and is sustained with diminishing returns and falling dividends. For example, at the national level,
1.1 Crisis of Rice–Wheat Cropping System

Rice yields are hovering between 1.9 t ha\(^{-1}\) in 2000/01 and 2.1 t ha\(^{-1}\) in 2004/05. Yields of wheat have already become static at 2.7 t ha\(^{-1}\) since 1999/2000.

1.1.2 Green Revolution and Environmental Degradation

There is no doubt that the Green Revolution made the country self-sufficient in food production. As a matter of fact, the Green Revolution created buffer stocks at times exceeding 60 million tonnes, which made the nation proud (Dhaliwal, 2005). However, use of high-yielding varieties of rice and wheat, which responded to more doses of fertilizers and pesticides, and requirement of large quantities of water have changed the environmental conditions. Intensive use of fertilizers and pesticides in the rice- and wheat-producing states, especially Punjab, Haryana and western Uttar Pradesh, which reaped the main benefits of the Green Revolution, has deteriorated the environment. While the intensive use of fertilizers has polluted the soil in many parts of Punjab, Haryana and western Uttar Pradesh, the uncontrolled use of irrigation has caused salinity as a consequence of waterlogging. Reckless use of pesticides has not only polluted the soil, but has also given rise to brown hopper insect, a very common pest of paddy crop which was not present before the Green Revolution.

Since rice crop requires plenty of water, its continuous cultivation in Punjab, Haryana, Andhra Pradesh and Maharashtra has led to overexploitation of the groundwater resources. Extraction of groundwater has caused its overexploitation in 73% and 25% blocks, respectively, in Punjab and Haryana alone (Dhaliwal, 2005). Depletion of underground water has resulted in contamination by heavy metals like Cd, Cr, Pb and others. Further, it has been found that in those states where the peasants are following rice–wheat crop rotation for years together there is a lot of soil sickness. The soils have become hungry for both primary (N, P, K)/secondary (Ca, Mg, S) nutrients and micronutrients (Zn, Cu, Mn, Fe, etc.). Deficiency of secondary and micro plant nutrients is mainly attributed to almost neglect of organic manures including green manure by the farmers after chemical fertilizers became available in the market with the arrival of new high-yielding varieties of various crops.

1.1.3 Green Revolution and Inequality

On another level, the Green Revolution has contributed towards inequality in the distribution of income and land-holding pattern. Since only the rich peasantry could afford the costly inputs (chemical fertilizers, pesticides), they also reaped the benefits in a proportional measure. The Green Revolution indeed has bypassed the small farmers as the agriculture sector has become an unviable proposition for them. Moreover, with the agricultural produce market within the rice-like grip of middlemen, small farmers find it very difficult to sell their yield at a remunerative rate.