Anil Mahajan · R. D. Gupta

Integrated Nutrient Management (INM) in a Sustainable Rice-Wheat Cropping System

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Dedication

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

Foreword

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.

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Preface

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.

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About the Authors

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 peered 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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We consider it our privilege to express our deep admiration and immense gratitude to Mr. Amit Trikha, National Manager, Bayer Bioscience Pvt. Ltd., Hyderabad (Andhra Pradesh, India), for his sustained support and encouragement for this important publication. Dr. Rohit Sharma is also gratefully acknowledged for his contribution in Chapter 2 related to 'Organic Farming in Sustainable Agriculture'. He has the research experience of approximately 1 year in an International Research Project based on 'Organic Farming' and has also attended an IFOAM Training on the same topic. He obtained his Ph.D. in Agronomy from CSK Himachal Pradesh Krishi Vishvavidyalaya, Palampur (Kangra, Himachal Pradesh, India).

Dr. Anil Mahajan, is extremely grateful to his respected and revered advisers Dr. S. K. Sharma, Former Professor (Training) and Krishi Vigyan Kendra In-charge, Sundernagar (Mandi, Himachal Pradesh, India), and Dr. R. M. Bhagat, Head, Production Division and Consultant, Tea Research Association, Tocklai Experimental Station, Jorhat (Assam, India), in MSc and Ph.D. programmes for their constant inspiration during the writing of this book. Dr. Mahajan can never forget the constant inspiration and support given by his guru, Advocate Sarvir Singh Jamwal; his gracious father, Mr. Arvind Mahajan, and affectionate mother, Mrs. Parkash Gupta; his grandmother, Mrs. Puspa Devi; his loving and caring elder brother, Mr. Narinder Mahajan, and sister-in-law, Mrs. Shivani Mahajan;

his brother-in-law, Dr. Mrityunjay Gupta, and sister, Mrs. Archana Gupta; his cousin, Mr. Ashish Kaistha and sister-in-law Mrs. Charu Kaistha; his uncles, Mr. R. L. Kaistha, Dr. B. L. Kaistha, Mr. B. K. Abrol and Mr. M. M. Rai Sharma; and his dearest friends, Mr. Sidharth Chug, Mr. Ankur Saini, Dr. Anil Choudhary, Dr. Rajesh Dogra, Dr. Amit Sharma, Dr. Ruchi Sharma and Dr. Susheel Sharma. Further, Dr. Mahajan is also deeply indebted to his uncle, late Mr. Puspinder Singh Jamwal, for inspiring the documentation of this book.

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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–wheat cropping system • Green Revolution • sustainability • chemical fertilizer • plant protection chemicals • soil health • environment degradation • organic manures • integrated nutrient management system

A. Mahajan and R.D. Gupta, *Integrated Nutrient Management (INM) in a Sustainable Rice–Wheat Cropping 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 $N/P_2O_5/K_2O$ 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, 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.

1.1.4 Growing Indebtedness

Among the farming community, the indebtedness is growing at an alarming rate leading to distress. Nearly half of the farmers of the country are in debt. About half of them belong to the seven states of Tamil Nadu, Uttar Pradesh, Andhra Pradesh, Maharashtra, West Bengal, Madhya Pradesh and Punjab. Relatively, Andhra Pradesh ranks first in the list, having 82% of the indebted farmer households, followed by Tamil Nadu with 74.5% and Punjab with 65.4%.

A recent survey revealed that about 49% of the farmers were indebted in 2003 (Joshi, 2007). On an average, an Indian farmer's household has a debt of Rs 12,585. The Punjab farmer tops the list with a debt of Rs 41,576, followed by Kerala, Haryana, Andhra Pradesh and Tamil Nadu with a debt of Rs 33,907, Rs 26,007, Rs 23,965 and Rs 23,963, respectively. The available estimates indicate that about 40% of the credit needs of the peasants are met by the informal sector (money lenders), which charges much higher rates of interest (normally two to three times) than what is offered by the cooperative or commercial banks.

1.2 Dr. Swaminathan's Views in 1968 on Intensive Agriculture

Intensive agriculture may be defined as 'harnessing of soil and water resources, genetic potential of plants and other inputs like chemical fertilizers, weedicides, fungicides/bactericides and insecticides to a large extent'. This concept is firmly rooted in the irrigated areas of India and will no doubt succeed in getting the country out of the 'food trap'. The 'ship to mouth' existence of the early 1950s has been transformed into one of 'farm to ship' reality (Subba Rao, 1999). India can now boast of an enviable buffer stock of about 40 million tonnes of food grains with a quantum jump in productivity and production of rice and wheat. Thus, introduction of high-yielding varieties of rice and wheat, responding to high doses of chemical fertilizers and susceptible to more diseases and insect/pest attacks, has succeeded in ushering in an era of self-sufficiency in food grain production. This is more often referred to as the Green Revolution. However, it has also brought about several environmental problems because of the indiscriminate use of chemical fertilizers and pesticides in the cultivation of rice and wheat crops which has not only made the soil resources sick but has also rendered the water resources polluted and posed health hazards to both human beings and animals. Flora and fauna have also been affected. Details of these environmental problems due to indiscriminate use of fertilizers have been mentioned elsewhere (Gupta and Singh, 2006).

According to Subba Rao (1999), excessive use of chemical fertilizers and pesticides appears to be the most daunting feature having varying impacts on agriculture and environment. In a large measure, the problem was aggravated with nitrogenous fertilizers, which always exceeded the recommended doses without due regard to balanced nutrition. Similarly, pesticides were not used for a targeted pest but as a preventive measure to avert a possible problem of pest attack.

In this context, the following extract of Dr. M.S. Swaminathan, father of the Green Revolution, Ex-DARE and Director General, ICAR, New Delhi, India, in his address to the Science Congress held at Varanasi in January, 1968, explains the gravity and seriousness of indiscriminate exploitation of agricultural base and inputs:

> Intensive cultivation of land without conservation of soil fertility and soil structure would lead ultimately to the springing up of deserts. Irrigation without arrangements for drainage would result in soils getting alkaline or saline. Indiscriminate use of pesticides, fungicides and herbicides could cause adverse changes in biological balance as well as lead to an increase in the incidence of cancer and other diseases, through the toxic residues present in grains or other edible parts. Unscientific tapping of underground water would lead to the rapid exhaustion of this wonderful capital resource left to us, through ages of natural farming. The rapid replacement of numerous locally adapted varieties with one or two high yielding strains in large contiguous areas would result in the spread of serious diseases capable of wiping out entire crops, as happened prior to the Irish potato famine of 1845 and Bengal rice famine of 1942. Therefore, the practice of exploitative agriculture without a proper understanding of the various consequences of every one of the changes introduced into traditional agriculture and without first building-up a proper scientific and training base to sustain it, may only lead us into an era of agriculture disaster in the long run, rather than to an era of agricultural prosperity.

1.3 Remedies

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 (Mahajan et al., 2002). It has tremendously helped the socio-economic development of the rural population in India. Rice and wheat are the staple food crops of a great majority of the country's people. However, many of the farmers have now realized the sustainability issues concerning the rice–wheat cropping system such as yield plateauing, decline in water tables, decline in soil fertility and physical properties, deterioration of soil biological activities and toxicity of heavy metals and contamination of ground water with nitrate which have already been stated. These important sustainability issues or barriers must be broken down in the light of the demand for food commodities which is increasing rapidly with increasing population, growing economy, rising income and growing urbanization.

Out of the various remedies responsible for the breakdown of sustainability issues concerning maintenance of the rice–wheat cropping system, some of the very important ones are described hereunder.

1.3.1 Use of Organic Manures

Application of well-decomposed organic manures like farmyard manure, digested cow dung and compost (urban and rural) was usually neglected by the farmers with the advent of the Green Revolution, whereafter chemical fertilizers became the potent source of plant nutrients. Addition of these manures must now be revived. Organic manures besides having primary and secondary nutrients also contain micronutrients vis-à-vis growth-stimulating and growth-regulating substances. However, some materials used in the preparation of farmyard manure, rural compost or town waste compost contain toxic substances such as the heavy metals Zn, Cu, Ni, Cr, Cd, etc., which if present in excessive amounts in the organic manures can adversely affect the plant growth.

It is worthwhile to mention that although organic manures ameliorate the physical, chemical and biological properties of the soils, they cannot substitute chemical fertilizers because of the low amount of plant nutrients present in them and because their bulky nature involves high transport cost. Thus, we cannot wholly and solely depend upon manures for increasing the yield of the rice–wheat cropping system.

1.3.2 Use of Green Manure

Growing legume as green manure for improving the following crop's productivity and the quality of the soil is one of the oldest practices. It becomes more beneficial particularly for light soils having sandy and loamy sand texture and also for sandy loam soils or those having loam/silty loam texture. Under such conditions, growing of dhaincha (*Sesbania aculeata*) and burying it into the soil before the flowering stage at the time of transplanting rice has been found useful not only to increase the yield of rice but also to enhance the yield of wheat (Gupta et al., 2005). The main influence of green manuring is to augment the supply of nitrogen and other nutrients. The other benefits are protection of soil from erosion and reduced loss of nutrients by leaching (Gupta and Sharma, 2004).

In the light of the above, it is stressed that, wherever possible, green manuring should be practised. This practice alone, however, like other organic manures, cannot fully meet the plant nutrient requirement of the rice–wheat cropping system.

1.3.3 Use of Rural Wastes and Crop Residues

Rural wastes like paddy straw, wheat straw and residues of other crops like sorghum, pearl millet, sugar cane and pulses have lot of potential as plant nutrients. However, their use as such or after composting in sustaining rice and wheat yields cannot equal that of chemical fertilizers in view of the burgeoning population requiring more food grain production. Another constraint of these organic residues is their high C/N ratio which is sometimes 100:1 or even more. This results in the occurrence of immobilization of nitrogen.

Apart from the above, sewage and industrial effluents contain variable quantities of plant nutrients and organic matter depending upon the source of origin (Chhonkar, 2003) as well as some toxic elements. Waste water generated from various industries contains a considerable amount of plant nutrients (Chhonkar, 2001).

1.3.4 Use of Bio-Fertilizers

The main bio-fertilizers which can be used as supplement to chemical fertilizers are blue-green algae (BGA) and *Azolla* for rice. BGA are capable of fixing atmospheric nitrogen, particularly under puddled rice soils, contributing about 50–100 kg N ha^{-1}. They also produce growth-promoting substances (Mahajan et al., 2003a).

Azolla is a floating freshwater fern. It is ubiquitous in distribution in lowland rice fields and freshwater bodies. The fern harbours a nitrogen-fixing BGA – *Anabaena azollae*. Due to its prolific growth character and association with nitrogen-fixing BGA, it can be used as a bio-fertilizer in rice cultivation. *Azolla* can contribute about 100–150 kg N ha^{-1} $year^{-1}$ (Mahajan et al., 2003b).

Azotobacter culture, prepared from *Azotobacter chroococcum* or other species, can be used as bio-fertilizer for direct-seeded rice and wheat crops (Mahajan et al., 2008a).

1.3.5 Use of Vermicompost

Vermicompost prepared from earthworms, known as the *tillers of the earth*, is a natural organic manure. It is also called bio-fertilizer. Vermicompost is a mixture of worm castings and organic matter including humus, live earthworms, their cocoons and other organisms. The earthworm species which are presently being extensively used for vermicomposting are *Eisenia foetida*, *Eudrilus Eugenia*, *Eudrillus eugeniae*, *Pheritima elongata* and *Perionyx excavatus*. However, *Eisenia foetida* is the most widely adopted species across the world. It is a rich source of plant nutrients, like N, P and K, as well as micronutrients and vitamins/enzymes (Mahajan et al., 2008c). Vermicompost has been found five times richer in N, seven times in P, 11 times in K, two times in Mg and Ca, and seven times in actinomycetes than in the ordinary soil. As such, it can be used as manure for both rice and wheat crops and others to supplement the chemical fertilizers.

1.3.6 Use of Both Organics and Inorganics

From the foregoing literature emerges the fact that the application of neither inorganics – chemical fertilizers (Gupta and Singh, 2006) – nor organics alone (Gupta, 2005b; Mahajan and Sharma, 2005; Mahajan et al., 2007a, b) can assist in sustaining the yield of the rice–wheat cropping system. This problem, however, can be resolved using both these sources of nutrients in view of the increased population and has already been substantiated by the following studies:

- The Fertilizer Association of India has reported the removal of major plant nutrients (NPK) to the extent of 24 million tonnes, which exceeds its addition through fertilizer application (14 million tonnes) resulting in a wide gap of 10 million tonnes year^{-1} (Pathak, 1998). This gap is likely to continue in the future also due to the continuous removal of nutrients under intensive cropping system.
- Another study conducted by the Indian Farmers Fertilizer Co-operative Limited Organization and Food Agricultural Organization has shown that 37.5% of the farmers have difficulty with regard to availability of farmyard manure or compost. So, the need of the future is to tap all the organic sources to meet the increasing consumption of plant nutrients.

A point to be mentioned here is that India uses both organic manures (2 t ha^{-1}) and NPK fertilizer nutrients (108 kg ha^{-1}) far less when compared to other agrarian countries like China where organic manure and NPK fertilizer consumptions are 10 t ha^{-1} and 760 kg ha^{-1}, respectively.

- There is a huge potential of organic resources in Indian farms which could be effectively made use of. As per the estimate made, nearly 7.5 million tonnes of NPK could be used for increasing the organic components of the fertilizer inputs to sustain the availability in agricultural production. The challenge before us is to develop a suitable technology package to make full use of organic manures and other sources along with inorganics to improve food production without impairing soil health. This would ensure sustainability in agricultural production, especially in the rice–wheat cropping system.

1.4 Integrated Nutrient Management System

Use of both organics and inorganics to increase crop production is called *Integrated Nutrient Management (INM) System.*

INM system will also be an alternative to the total uptake of plant nutrients which has been projected to the order of 37.46 million tonnes by 2025, requiring 301 million tonnes of food grains for the growing population of 1,504 million, whereas the total availability of plant nutrients from organic sources would be only 7.75 million tonnes as reported by Gupta and Singh (2006). Thus, roughly 30 million tonnes of plant nutrients will have to be met through chemical fertilizers.

In simple terms, *INM system refers to a balanced use of chemical fertilizers in combination with organic manures, crop residues, bio-fertilizers and other biological sources*. Because of much economic significance, recommendations were made for adopting and strengthening INM system during the Ninth Five Year Plan.

The main aim of INM system is to have sustainability in the productivity of the rice–wheat cropping sequence or that of maize and wheat with minimum deleterious effects of chemical fertilizers on soil health and environment ecology.

In the International Seminar organized by Food and Agricultural Organization and Indian Farmers Fertilizer Corporation Limited Organization on INM system for ‘Sustainable Agriculture’, the former Union Agriculture Minister advocated the use of various organic sources for Indian Farming System with emphasis on the rice–wheat cropping system. *Former Secretary of 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 of the twenty-first century. He stressed upon demonstrating sustained agricultural production through high input of inorganic and organic fertilizers*.

Now after demonstration on farmers’ fields, a number of models of INM system concerning rice–wheat crop rotation have come into the fore in many states like Himachal Pradesh, Madhya Pradesh, Orissa, Punjab, Haryana, Uttar Pradesh, Rajasthan and West Bengal which can be utilized for increasing crop production in rice–wheat cropping sequence.

Impact Points to Remember

- 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.
- The crisis of the rice–wheat cropping system in India is mainly due to the decline of the annual average growth rate, the Green Revolution and environmental degradation, the Green Revolution and inequality and growing indebtedness.
- 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 as low as 1.7% during the Tenth Five Year Plan.
- The share of agriculture in gross domestic product has declined to 18% but the dependence on agriculture is still hovering around 60%.
- The intensive use of fertilizers has polluted the soil in many parts of Punjab, Haryana and western Uttar Pradesh, while the uncontrolled use of irrigation has caused salinity as a consequence of waterlogging.
- 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) and secondary (Ca, Mg, S) nutrients and micronutrients (Zn, Cu, Mn, Fe, etc.).
- The Green Revolution has contributed towards inequality in the distribution of income and the landholding 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 farmer as the agriculture sector has become an unviable proposition for him.
- Indiscriminate use of chemical fertilizers has not only made the soil resources sick but has also rendered the water resources polluted and posed health hazards to both human beings and animals.
- Nearly half of the farmers of the country are in debt and belong to the seven states of Tamil Nadu, Uttar Pradesh, Andhra Pradesh, Maharashtra, West Bengal, Madhya Pradesh and Punjab. Relatively, Andhra Pradesh ranks first in the list having 82% of the indebted farmer's households, followed by Tamil Nadu with 74.5% and Punjab with 65.4%.
- The various remedies responsible to break 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.
- Some materials used in the preparation of farmyard manure, rural compost or town waste compost contain toxic substances such as the heavy metals – Zn, Cu, Ni, Cr, Cd, etc. – which if present in excessive amount in the organic manures can adversely affect plant growth.
- The constraint of organic residues is their high C/N ratio which is sometimes 100:1 or even more. This results in the occurrence of immobilization of nitrogen.
- The main bio-fertilizers which can be used as supplement to chemical fertilizers are blue-green algae (BGA) and *Azolla* for rice.
- *Azotobacter* culture, prepared from *Azotobacter chroococcum* or other species, can be used as a bio-fertilizer for indirect-seeded rice and wheat crops.
- Use of both organics and inorganics to increase crop production is called *Integrated Nutrient Management System*.
- INM system refers to a balanced use of chemical fertilizers in combination with organic manures, crop residues, bio-fertilizers and other biological sources.

Study Questions

1. Define the following:
   - (a) Integrated nutrient management system
   - (b) Environmental degradation
   - (c) Green Revolution
   - (d) Vermicompost
   - (e) Crop residues
   - (f) Bio-fertilizers
2. Explain the various factors which are responsible for the crisis of rice–wheat cropping system in India?

3. What are the various remedies responsible to break down sustainability issues to maintain the rice–wheat cropping system?
4. Explain the need for integrated nutrient management in rice–wheat cropping system?
5. What are the views of Dr. Swaminathan in 1968 on intensive agriculture?

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Chapter 2
Concept of INM System

Abstract India accounts for 2.2% of the global land and 16% of the world's population. The country's population has crossed the one-billion mark in 2001. While the population is likely to further increase at an alarming rate and, side by side, as the land for cultivation of crops will decrease tremendously in the following decades, it will result in an increased demand for food, fodder, shelter, energy, employment, etc. The long-term fertilizer experiments have shown that continuous application of suboptimal doses of chemical fertilizers alone to soil has resulted in the deterioration of soil health, thereby culminating in environmental pollution and stagnation in crop productivity. Hence, integrated use of organic manures with optimal levels of NPK fertilizer is the need of the hour, as it will not only improve the nutrient status and soil health, but also prove to be a boon in stabilizing the crop yields over a period of time. Therefore, integrated nutrient management (INM) system is the only way to maintain and improve the nutrient status of Indian soils. In other words, INM system is an ecologically, socially and economically viable approach, which on the whole is non-hazardous.

Keywords Long-term fertilizer experiments • chemical fertilizer • soil health • environment pollution • crop productivity • organic manures • integrated nutrient management system

Agriculture is the main occupation of India, and over 75% of its population generally depends directly or indirectly on agriculture for their livelihood. It is the pivot around which the country's economy revolves and, by all means, it is the most predominant sector. Every year about 19 million Indians are added to the existing population, which is currently more than 1 billion (approximately 1.18 billion). It is estimated that by 2010 about 246 million tonnes of food grains will be needed annually, and to produce this quantity, about 25 million tonnes of plant nutrient ($N + P_2O_5 + K_2O$) as mineral fertilizers would be required (Prasad, 2000; Mahajan and Sharma, 2005). The demographic projections indicate that per capita land availability is also reducing, which would fall from the present figure of 0.14 to 0.10 ha in the year 2025 (Kanwar and Sekhon, 1998). In the absence

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of any significant scope for horizontal expansion and to meet the ever-increasing demand for the food needs of the rapidly growing population, vertical growth in agriculture through increased production per unit area is the only alternative which involves intensive use of resources coupled with modern agricultural technology. But, long-term experiments have indicated that continuous and intensive use of chemical fertilizers has resulted in numerous problems like micronutrient deficiencies, nutrient imbalances in soil and plant systems, pest infestation, environmental degradation, deterioration of soil health, stagnation of crop yields, etc. (Dubey et al., 1997; Jaggi et al., 2001), which are more in the case of rice–wheat cropping system. It is therefore imperative to supply the plant nutrients in an integrated manner to maintain soil fertility for sustaining the desired level of crop production and productivity through a judicious combination of chemical fertilizers and organic sources like organic manures, farmyard manures (FYM), compost, green manures, crop residues, recyclable waste, vermicompost, legumes and bio-fertilizers.

The rice–wheat cropping system plays a vital role in the world agricultural economy, supplying food for both humans and livestock. Cereals like *Oryza sativa* (rice), *Triticum aestivum* (wheat) and *Zea mays* (maize) have higher yield potentials than other cereals such as pulses and oilseeds. Therefore, to exploit the full yield potential of cereals and other crops grown in sequence, while maintaining both the level of crop production and soil fertility, an integrated nutrient management strategy is essential to suit a cropping system rather than individual crops (Mahajan et al., 2002).

INM system must take into account the effects of the previous crop on the fertilizer needs of the succeeding crop vis-à-vis the residual effects of fertilizers applied, the contribution of legumes in the cropping systems, the direct and residual effects of organic manures, bio-fertilizers and the management factor. Further, to protect the environment from further degradation, less use of chemical fertilizers by shifting from chemical to eco-friendly sources of nutrients is highly desirable. This is possible by building a strong organic environment in cultivated fields (Prasad, 2000). In recent years an interest has developed in the use of renewable sources of plant nutrients in INM system taking into consideration the ecology, escalating cost of chemical fertilizers, loss of soil productivity and yield instability (Singh, 1999).

2.1 Concept of IPNS Under Indian Soil Conditions

Generally three terminologies are used for conveying the same meaning, namely, Integrated Plant Nutrition System (IPNS), Integrated Plant Nutrient Supply System (IPNSS) and Integrated Nutrient Management (INM). Although all these three kinds of terminologies appear to be the same, they convey different meanings (Acharya et al., 1998), which are detailed here.

2.1.1 Integrated Plant Nutrition System (IPNS)

IPNS refers to the supply of nutrients to the plant from various sources. These sources consist of:

- Nutrient reserves in the soil
- Organic sources of nutrients – FYM, compost, green manure, crop residues and organic fertilizers

2.1.2 Integrated Plant Nutrient Supply System (IPNSS)

IPNSS mainly concerns the maintenance or adjustment of the soil fertility and plant nutrients to an optimum level for sustaining the desired crop productivity through optimization of benefits from all possible sources of plant nutrients in an integrated manner.

2.1.3 Integrated Nutrient Management (INM)

INM is actually the technical and managerial component of achieving the IPNS under farm conditions. As such it takes into account all the factors of soil and crop management, including management of all other inputs such as water, agrochemicals, etc., besides nutrients.

Its details and concept have been described in the preceding paragraphs.

2.2 What Is INM System?

Integrated nutrient management (INM) system or integrated nutrient supply (INS) system aims at achieving a harmony in the judicial and efficient use of chemical fertilizers in conjunction with organic manures, use of well-decomposed crop residues, recyclable waste, green manures, compost including vermicompost, inserting of legumes in cropping systems, use of bio-fertilizers and other locally available nutrient sources for sustaining soil health and amelioration of environment as well as crop productivity on long-term basis (Mahajan and Sharma, 2005). The increase in crop productivity results from the combined effect of chemical fertilizers and organic manures which also helps in the improvement of physical, chemical and biological properties and consequently the soil organic matter and nutrient status. The basic objectives of the INM system are to make balanced nutrient supply to crop, to maintain and improve the soil fertility as well as soil health for sustained high productivity on a long-term basis and also to reduce fertilizer input cost. As plant nutrient sources differ markedly in their nutrient contents, release efficiency or fixation, crop specificity and farmers' acceptability, their appropriate combinations to a production system for optimum and balanced nutrient supply depend on the land use, ecological, social and economic conditions.

For INM system to have a desirable progress and wide acceptability, nutrient supply packages for important agroecological environments need to be developed. These should be technically sound, practically feasible, economically attractive and socially acceptable (Swarup, 1998). INM system can ensure long-term sustainability of agricultural growth through improvement in soil health by narrowing down the gap between nutrient removal and supply, and will significantly reduce the need for chemical fertilizers. The complementary use of chemical and organic fertilizers may increase the efficiency of the former in order to maintain a high level of crop productivity. Long-term fertilizer experiments involving intensive cereal-based cropping systems reveal a declining trend in productivity even with the application of recommended levels of N, P and K fertilizers. Thus, INM system holds promise in sustaining higher crop yields besides improving soil health (Kaushal, 2002).

2.3 Concept Underlying INM System

The continuous use of high doses of chemical fertilizers is adversely affecting the sustainability of agricultural production and causing environmental pollution (Virmani, 1994). In the coming decades, a major issue in designing a sustainable agricultural system will be the management of soil organic matter and the rational use of organic inputs such as animal manures, crop residues, green manures, sewage sludge and food industry wastes. However, organic manures cannot meet the total needs of modern agriculture; therefore, integrated use of nutrients from fertilizers and organic resources seems to be the need of the time. Following are the two basic concepts underlying INM system (Mahajan and Sharma, 2005; Roy and Ange, 1991; Subba Rao and Sammi Reddy, 2005):

1. The maintenance or adjustment of plant nutrients supply to achieve a given level of crop production by optimizing the benefits from all possible sources of plant nutrients in an integrated manner, appropriate to each cropping system and farming situation in its ecological, social and economical possibilities.
2. Upgrading the productivity of all sources of plant nutrients and reducing plant nutrient losses. If the soil fertility has already eroded to a high degree by inappropriate management practices, one major task of INM system will be at least to stop the unfavourable ongoing loss of surface or top soil nutrients.

Thus, in a nutshell, the fundamental concept of INM system is the continuous improvement of soil fertility for sustained productivity on long-term basis through judicious and efficient use of inorganic fertilizers and various organic sources, which helps in the improvement of physical, chemical and biological properties of soil, and consequently their optimum nutrient supply to different crops and cropping systems in specific agroecological situations.

2.4 Definition of INM System

INM system may be defined as 'an intelligent use of optimum combination of organic, inorganic and biological nutrient sources in a specific crop rotation or cropping system to achieve and sustain optimum yield without harming soil ecosystem'. Such a package of plant nutrients formulated must be technically sound, economically viable, practically feasible, socially acceptable and environmentally safe. Briefly, INM system is a holistic approach and may be defined as 'maintenance of soil fertility and plant nutrient supply to an optimum level for sustaining the crop productivity at desired level'.

2.5 Principles Underlying INM System

Six basic principles of sustainable INM system laid out by Dennis Greenland (quoted by Meelu, 1996) include:

1. Nutrients removed by crops must be returned to the soil.
2. Soil physical conditions should be maintained and upgraded.
3. Organic carbon levels of soils should be maintained and enhanced.
4. Build-up of abiotic stress should be minimal.
5. Degradation of land occurring due to soil erosion must be controlled.
6. Soil quality with respect to soil acidity, salinity and sodicity or toxic elements build-up must be minimized.

These principles emerge when one compares a natural ecosystem with an agricultural ecosystem. An agricultural ecosystem differs from a natural one in that plant nutrients are constantly being removed and exported and in that sources of plant nutrients outside the cropped area may be used to increase crop production.

2.6 Maintenance of Soil Health Through INM System

As already stated, the main aim of INM system is to manage the soil fertility, sustain the agricultural productivity and improve the farmer's profitability through the judicious and efficient use of chemical fertilizers, organic manures, crop residues and bio-fertilizers. However, this does not mean adding everything everywhere, rather it is a well-considered, practical and efficient blend of diverse nutrient sources which can produce desired yields and maintain soil health on long-term basis (Roy and Dudal, 1993). Thus, INM system practises efficient and judicious use of all the major sources of plant nutrients through fertilizers, organic and other biological sources in an integrated manner so as to maximize economic yield for a given cropping system as well as to maintain soil health. Simultaneously, it helps to restore and sustain soil fertility and crop productivity as well as helping to check the emerging micronutrient deficiencies. Moreover, it brings economy and efficiency into fertilizer use and positively affects the physical, chemical and biological properties of soil. Consequently, the increase in soil organic matter and optimum nutrient supply to the plants is ensured (Singh and Yadav, 1992; Swarup, 1998; Ravankar et al., 2003). In other words, it takes into account all the factors of soil and crop management, including management of all inputs such as water, agrochemicals, nutrients, etc.

2.7 Advantages of INM System

INM system is the key to enhance soil productivity and its sustainability. It not only aims at supplying plant nutrients in balanced form, but also lowers the dependency on fossil fuels used in the manufacture of chemical fertilizers. The main advantages of INM system include:

- To maintain soil fertility status, soil health as well as environment for attaining higher crop productivity, thereby meeting the present and future food supply needs
- To increase organic matter content by using all available organic sources which enhance the physical, chemical and biological properties of the soil
- To prevent soil degradation
- To enrich soil microflora and microfauna as well as soil fauna
- To increase fertilizer use efficiency and to generate profit for the farmers through the judicious and efficient use of chemical fertilizers, organic manures, crop residues and bio-fertilizers
- To make effective use of resource cycling and nutrient movement within the farm
- To maintain positive nutrient balance in soil and to develop eco-friendly sustainable agriculture
- To meet the social and economic aspirations of the farmers by lowering the cost of inputs and enhancing productivity as well as profitability

2.8 Organic Farming

There is no doubt that the Green Revolution during 1967/68 accompanied by the White Revolution, Yellow Revolution and Golden Revolution made the country self-sufficient in food production. However, the use of chemical fertilizers, pesticides, salts in the feed of animals and excess irrigation water created a lot of trouble not only in the physical environment (land, air and water), but also in the biological environment (animals including human beings and plants). Thus, the need for organic farming was realized. Moreover, people have now become health-conscious and a growing awareness about environmental issues is also contributing to increased demand for organic foods (Gupta et al., 2005; Gupta, 2005b; Mahajan et al., 2007a).

> Organic farming or organic agriculture may be defined as that type of farming, which favours maximum use of organic materials and generally shun[s] the use of synthetically produced agro-products like fertilizers, pesticides, growth regulators and livestock feed additives for maintaining soil productivity and fertility, and also opposes the use of genetically modified organisms and does not harm the environment.

Although the main aim of organic farming is to develop viable and sustainable agriculture, a number of farm management practices or methods are now available in this field. They mostly comprise cultural or diversified agricultural techniques like crop rotation; mixed cropping or intercropping; tillage operations and trap crops; green manuring; organic manures (FYM and compost); vermicompost; organic residues; use of botanical pesticides, biocides and microbial inoculants to control insects and other pests; bio-fertilizers, etc. This farming is directed towards enhancing natural life cycles rather than suppressing them. In other words, organic farming is based on the dynamic interaction between the soil, plants, animals, humans, ecosystem and environment.

2.8.1 Concept of Organic Farming

According to popular notion, ‘organic farming’ is an agriculture system which is rendered without the addition of artificial external inputs such as chemical fertilizers and pesticides. Due to the ill effects caused by the Green Revolution like human health hazards, environment pollution, biodiversity erosion, water depletion and desertification of soils, the concept of organic farming came into existence. Moreover, many farmers committed suicide because of the debt incurred due to the convergence of rising costs of various inputs and falling prices of agricultural commodities as a result of unjust and unfair trade patterns (Gupta, 2005b). The concept of organic farming originated with the establishment of *International Federation of Organic Agriculture Movement* (IFOAM) on 6 November 1972 in Versailles, France. Today, nobody can deny the fact that organic food is growing into a reality all over the world. Globally, there has been a rapid growth in organic farming in the past decade, and presently there are more than 100 countries where it is being practised.

In India, National Standard Committee also drafted the concept and principles of basic standards of organic farming in 1996. India is a member of IFOAM (headquarters in Germany), which has over 750 organizational members from 130 countries across the world. *All India Federation of Organic Farming* (AIFOF) is a member of IFOAM in India, having in its fold a spectrum of non-governmental organizations (NGOs), farmers' organizations, promotional bodies and cooperative units. The main objective of organic farming is to reduce or eliminate external agricultural inputs, especially synthetic ones and rely on eco-friendly management system.

2.8.2 Organic Farming – Indian Scenario

The key principles of organic farming consist of sustainability (ecological, economical, and social), traceability and natural productivity. There is great scope for organic farming in India because only 35% of India's total cultivable area is covered with fertilizers, i.e. where irrigation facilities are available; in the remaining 65% of arable land, which is mainly rain-fed, negligible amounts of fertilizers are being used. As per the study conducted by Food and Agriculture Organization (FAO) in mid-2003, India has 1,426 certified organic farms, producing approximately 14,000 t of organic produce annually (Singh, 2004). During 2002, 11,925 t of organic produce were exported, which mainly consisted of tea, coffee, spices, basmati rice, oilseeds, vegetables, fruits, cotton and herbal plant products. Pineapple, pepper, turmeric and walnut are the other products which are being produced organically. The major products of organic farming in India are shown in Table 2.1.

There are large numbers of farmers in India, who have either never cultivated their lands using chemical fertilizers or have reverted to organic farming due to their beliefs or purely for economic reasons. These farmers are cultivating hundreds of thousands of hectares of land, but are not classified as organic growers although they are following this method. Their produce generally sells either

Table 2.1 Major products produced by organic farming in India (Adapted from Mahajan et al. [2007b])

Sr. No.	Type of products	Products
1.	Fruits	Mango, banana, pineapple, passion fruit, orange, papaya, sapota, custard apple, sugarcane, cashew nut, walnut
2.	Vegetables	Okra, brinjal, garlic, onion, tomato, potato, cucurbits, cole crops, leafy vegetables
3.	Cereals	Rice, wheat, maize, jowar, bajra
4.	Pulses	Pigeon pea, chickpea, green gram, black gram, red gram, white gram, chana
5.	Oilseeds	Mustard, groundnut, sesame, castor, sunflower
6.	Plantation crops	Tea, coffee
7.	Spices	Cardamom, black pepper, white pepper, ginger, turmeric, vanilla, tamarind, cloves, cinnamon, nutmeg, mace, chillies
8.	Others	Cotton, herbal extracts

in the open market along with the other grown foodstuffs at the same price, or purely on goodwill and trust as organic through select outlets and regular specialist bazaars. These farmers are not keen to opt for certification because of additional costs involved vis-à-vis extensive documentation required for such certification (Gupta et al., 2005).

Asia has about 13% of the world's organic land, dominated by China ranking second in the world after Australia, followed by India and Russia. Organic farming is becoming more popular in India, especially in southern states like Karnataka, Tamil Nadu and Andhra Pradesh, and now it has also been initiated in many other states of the country like Assam, Madhya Pradesh, Uttarakhand, Uttar Pradesh, Meghalaya, Jammu & Kashmir, Himachal Pradesh, etc. In Kerala, the Department of Agriculture is encouraging an expansion of organic farming to cover banana, cashew nut and mango, whereas the north-eastern region provides considerable opportunity for organic farming due to least utilization of chemical inputs. The major organic food markets for India are Europe, the United States, Japan and the Middle East. The EXIM Bank has reported that the annual growth rate of organic food has increased from 15% to 30% during the last 5 years and it has a bright future, which indicates impressive opportunities for export of different organic food products by India. Thus, organic farming is gaining more momentum in India, and the World Bank has sanctioned different projects designed to allow rural populations to export organic produce.

2.8.3 Organic Farming – World Scenario

The concept of organic agriculture for food production and biodiversity conservation is considered favourably at the international level. International Union for Conservation of Nature (IUCN) recognizes the potential of organic agriculture in several protected-area categories. There are about 8,000 organic farmers in Germany, and in Switzerland the share of organic farming has reached about 7%, with the largest share being 30% in Kanton Graubünden. In Austria, there are more than 20,000 organic farmers, constituting around 10% of the total. Sweden and Finland have come up to the level of Switzerland, and Italy is also progressing towards organic farming. In Uganda, 7,000 farmers have chosen to cultivate organic crops, whereas in Mexico innumerable small farmers have started to produce organic coffee and other staple foods. Although worldwide markets for organic foods are expanding, the concentration of growth has been mainly in Europe, the United States and Japan. All these three markets have recorded annual growth rates of 15–30% in the past 5 years. According to the International Trade Centre projections, the organic market size would be around US$46 billion in the European Union, US$45 billion in the United States and US$11 billion in Japan in 2010, thereby indicating that the organic food market would grow substantially in most of the European countries, the United States and Japan (Mahajan et al., 2007b).

2.8.4 Principle of Organic Farming

The basic principle of organic farming is to enhance organic matter content of the soil as this has a profound impact on soil quality, by improving soil structure and fertility and increasing water infiltration and storage capacities. Moreover, soil erosion is reduced due to the production of more humus in soils. Organic farming maintains soil biological activities at a high level. Above all, organic farming maintains environment quality (Gupta and Sharma, 2002). Generally, organic farming is based on four principles.

2.8.4.1 Principle of Health

Organic farming should sustain the agricultural productivity and enhance the health of soil, plant, animal and human beings. It is intended to produce high-quality, nutritious food that contributes to preventive health care and well-being both of the farmers and the general public.

2.8.4.2 Principle of Ecology

Organic farming states that production is to be based on ecological processes, and various processes of recycling. Nourishment and well-being are achieved through the ecology of the specific production environment. For example, in the case of crops, organic farming constitutes the base of the living soil both for lower and higher plants as well as animals.

2.8.4.3 Principle of Fairness

Organic farming should build on relationships that ensure fairness with regard to the common environment and life opportunities. It should provide everyone involved with a good quality of life, and contribute to food sovereignty and reduction of poverty.

2.8.4.4 Principle of Care

Organic farming should be managed in a precautionary and responsible manner to protect the health and well-being of current and future generations and the environment.

2.8.5 Benefits of Organic Farming

Organic farming is the backbone of sustainable agriculture and mainly depends upon organic recycling. It is a healthy, safe, ecologically sound and sustainable way of substantially increasing food production. Nowadays, it has drawn attention of a large section of planners and scientists at the global level. The main benefits derived from organic farming are as follows.

2.8.5.1 Food Safety

It produces high-quality, nutritious food that contributes to preventive health care and well-being. Further, there is a scope of increase in concentrations of vitamin C and minerals with lower nitrate levels in organic foods as compared to conventionally grown food. For instance, occurrence of blue baby disease caused by excessive nitrate can be minimized by following organic farming.

The kitchen garden behind grandma's small village cottage which follows organic farming is a source of the best veggies ever tasted. They are naturally delicious, pure and devoid of pesticides, harmful chemicals and noxious fertilizers. That is real organic food.

2.8.5.2 Reduction in Environmental Pollution

There is reduction in environmental pollution by proper use of well-decomposed organic manures, such as FYM, green manures, compost, vermicompost, biofertilizers, organic residues, etc. It saves the soil from being further polluted and improves its physical condition, supplements the soil nutrient reserves, besides enhancing the production of many of the field crops sustainably.

2.8.5.3 Reduction in Pesticide Residues

Pesticide residues in food become minimized, which otherwise might have adverse effects on plants, animals and finally on the health of human beings. Further, organic farming makes food free from the bad effects of chemical-based farming, especially of pesticides like dichlorodiphenyltrichloroethane (DDT), benzene hexachloride (BHC) and others, which otherwise have been found to enter the various foodstuffs through the food chain.

2.8.5.4 Reduction in Metals and Antibiotics in Organic Foodstuffs

Food materials grown organically are mostly free from heavy metals, hormones and antibiotics compared to those which are grown chemically (Gupta, 2005a). In a recent survey it has been tested that 17 countries, including India, had the highest level of dioxins in eggs of hens (Dahatonde and Khambalkar, 2007). This is because dioxins are created when garbage, plastics, metal-treated wood and other materials are burnt.

2.8.5.5 Shelf Life

There is an improvement in the shelf life of produce by adopting the practices of organic farming as compared to conventional farming/chemicalized agriculture. For example, hitherto, apple produced from organic farming in the valley of Kashmir, India, has a much better shelf life than that produced from inorganic farming.

2.8.5.6 Soil Properties

Organic farming maintains and boosts the long-term natural fertility of soils. It increases the organic matter content of soil, thus reducing the bulk density and mechanical impedance, decreasing compaction and improving water-holding capacity.

2.8.5.7 Soil Erosion

Organic farming, which is also resisting soil erosion and improving percolation of water to a greater depth by using practices such as crop rotations, cover crops, green manure crops and organic matter, helps in water conservation (groundwater, river, lakes) and effective soil moisture conservation. Crop rotation and cover crops also make life difficult for pests because they are discouraged from invading the fields every year as their feeding habits are disturbed.

2.8.5.8 Nutrient Balance

It sustains nutrient balance in soils by supplying the entire primary, secondary and micronutrients in a balanced form and does not leave much residual effects of chemical fertilizers as these are used in conjunction with organics. Unlike fertilizers, the organics contain secondary and micronutrients.

2.8.5.9 Animal Macro- and Micro-organisms Welfare

There is protection of wildlife like birds, frogs, insects, etc. with organic farming. Moreover, it also avoids harming soil macro- and micro-organisms. Beneficial macro-organisms, especially earthworms, are encouraged. Similarly, ammonifying bacteria along with cellulose and starch-decomposing bacteria are encouraged.

2.8.5.10 Good Returns

Organically farm produce fetches premium prices in the national and international market. Although not much research has been carried out so far regarding the effect of organic practices on the quality of foods, it is believed that various foods obtained from organic farming taste better. Whether this is a fact or a myth is still to be proved. However, this is the reason for good returns on organic foods.

2.8.5.11 Generation of Employment

It generates more income and employment in rural areas, which results in reduction of poverty and improvement of lifestyle. Organic farming aims at reducing the costs of production and helps the farmers to get reasonable returns. Organic products promise better prospects for market and trade, e.g. growing of mushroom from farm wastes like wheat straw and rearing of silkworms and honeybees with purely organic-farming components generates employment for the rural youth.

2.8.5.12 Less Use of Inputs

There is less utilization of non-renewable external inputs and energy sources like fossil fuels and rock phosphates, etc. for organic farming, which totally relies upon organic sources of plant nutrients such as organic manures, compost, green manures, vermicompost, crop residues, bio-fertilizers, etc.

2.8.5.13 Crop Yield

It is eco-friendly and as such sustains crop yield over a long run. Although in the initial years of inception of organic farming, the yield of the crops is less, in the long run it gets stabilized. It is because, unlike chemicalized agriculture, organic farming solely depends on the use of on- and off-farm animal manure, compost, green manure, crop residues and residual effect in maintaining soil health and crop growth.

2.8.6 Constraints of Organic Farming

Although organic farming is one of the best approaches to get sustainability in crop production, some constraints are prevalent in its adoption which are as follows:

- The organic crop growers in India are facing great difficulties due to a limited market and lack of market information for selling their produce. This problem is more so in north-western Himalayan states like Uttarakhand, Himachal Pradesh and Jammu & Kashmir.
- There are varied nutrient contents in organic materials and so it becomes difficult for the farmers to calculate the actual amount of organic materials to be added to the soil.

- Bulkiness of organic materials like FYM and compost, which involve high cost of transportation, is another constraint for its use.
- There is a lack of appropriate training for organic growers.
- There is a non-availability of packages of organic practices for all agriculture and horticulture crops based on locally available inputs.
- There is an inadequate availability of organic inputs such as FYM, crop residues, compost, vermicompost, bio-fertilizers, etc.
- There is a lack in farmers' adoption of this practice because of chances of low yield during the initial 1–3 years of crop adoption.
- There is an increasing adoption of genetically modified crops at an alarming rate in the world from 3.8 million hectares in 1995/96 to 58 million hectares in 2003.
- There is still no awareness in farmers and NGOs of the impact of organic farming.
- There is a slow release of nutrients from organic sources which does not match the nutritional demand of high-yielding varieties.
- Regulatory mechanism on quality control is missing.
- It is a time-consuming and labour-intensive process.
- There are high costs involved in existing inspection and certification processes which are not affordable by the farmers.
- There are no local- and state-level certification agencies.

Although a number of countries have moved away from the inorganic or chemicalized farming to organic farming, it is still not possible for India to depend entirely upon this system of farming due to the increase in human population. As total availability of plant nutrients from different organic sources is projected to be 7.75 million tonnes (Tandon, 1997) by 2025 against the total requirement of 37.50 million tonnes (Katyal, 2001) for 1,504 million population (Sekhon, 1997), it means that if we depend on organic sources there would be a deficiency of about 30 million tonnes of nutrients. Hence, it becomes imperative to use both organic and inorganic sources of plant nutrients, i.e. INM system to enhance food production for the increasing population. However, in our country the contribution of organic sources, which was 80–100% in 1949/50, reduced to about 32% in 1993/94 and 20–25% in 2004/05. So, the need of the hour is to enhance the contribution of organic sources in total nutrient consumption (Gupta and Sharma, 2006).

Impact Points to Remember

- The INM system comprises the judicial and efficient use of chemical fertilizers in conjunction with organic manures like FYM and compost, green manures, crop residues, recyclable waste, introducing legumes in cropping systems and bio-fertilizers for sustaining soil health and environment as well as crop productivity on a long-term basis.

- The basic objective of the INM system is to make a balanced nutrient supply to crops, to maintain and improve soil fertility as well as soil health for sustained high productivity on a long-term basis and also to reduce fertilizer input cost.
- The main aim of INM system is to manage soil fertility, sustain agricultural productivity and improve the farmer's profitability through the judicious and efficient use of chemical fertilizers, organic manures, crop residues and biofertilizers.
- The fundamental concept of INM system involves the maintenance or adjustment of plant nutrient supply to achieve a given level of crop production by optimizing the benefits from all possible sources of plant nutrients in an integrated manner, appropriate to each cropping system and farming situation in its ecological, social and economical possibilities.
- The main principles of INM system are that nutrients removed by crops must be returned to the soil, organic carbon levels should be maintained, soil physical conditions and soil quality must be upgraded and sustained, and degradation of land due to soil erosion must be controlled.
- Organic farming is that type of farming which favours the maximum use of organic materials and generally shuns the use of synthetically produced agro-products like fertilizers, pesticides, growth regulators and livestock feed additives.
- The concept of organic farming originated with the establishment of *International Federation of Organic Agriculture Movement* (IFOAM) on 6 November 1972 in France.
- Asia has about 13% of the world's organic land, dominated by China ranking second in the world after Australia, followed by India and Russia.
- In India, National Standard Committee also drafted the concept and principles of basic standards of organic farming in 1996 and its member in India is *All India Federation of Organic Farming* (AIFOF).
- Organic farming is becoming more popularized in India, especially in southern states like Karnataka, Tamil Nadu and Andhra Pradesh and now it has also been initiated in many other states of the country like Assam, Madhya Pradesh, Uttarakhand, Uttar Pradesh, Meghalaya, Jammu & Kashmir, Himachal Pradesh, etc.
- According to the International Trade Centre projections, the organic crop market size would be around US$46 billion in the European Union, US$45 billion the United States and US$11 billion in Japan in 2010.
- There are four principles of organic farming – *Principle of Health*, *Principle of Ecology*, *Principle of Fairness* and *Principle of Care*.
- Organic farm produce fetches premium price in the national and international market.
- There is less utilization of non-renewable external inputs and energy sources like fossil fuel and rock phosphates, etc. in the case of organic farming.
- Growing of mushroom from farm wastes like wheat straw and rearing of silkworms and honeybees in the farm, which are purely organic farming components, generate employment to the rural youths.

- The main drawback with organic farming is that organic crop growers in India are facing great difficulties due to a limited market and lack of market information for selling their produce.

Study Questions

1. Define the following:
    - (a) Integrated nutrient management system
    - (b) Long-term fertilizer experiments
    - (c) Cereals
    - (d) Pulses
    - (e) Oilseeds
    - (f) Soil health
    - (g) Trap crops
    - (h) Desertification
    - (i) Ecosystem
    - (j) Amelioration
    - (k) Mixed cropping
    - (l) Intercropping
    - (m) Pesticides
    - (n) Crop productivity
2. Explain integrated nutrient management system and differentiate it from organic farming.
3. What is the basic concept underlying integrated nutrient management system?
4. What are the aims and principles underlying integrated nutrient management system?
5. Differentiate between natural ecosystem and agricultural ecosystem.
6. Define organic farming. What are the benefits and constraints encountered in the adoption of organic farming?
7. What is the basic aim and principle of organic farming?
8. What will be the impact of organic movement on fertilizer nutrients?
9. Write a short note on sustainable agriculture.
10. Enlist the major products produced by organic farming in India.
11. Is organic farming feasible in India or not? Discuss it.
12. What can be used in organic farming?
13. Explain the concept of IPNS under Indian soil conditions.

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Chapter 3
Need of INM System in Modern Agriculture

Abstract Recent studies have revealed that continuous use of suboptimal doses of nutrients in the intensive cropping system has led to severe depletion of nutrient reserves in soil, causing multiple nutrient deficiencies. The use of high-analysis fertilizers devoid of micronutrients has also aggravated micronutrient deficiencies causing significant decline in crop productivity. No single dose of plant nutrient applied through chemical fertilizers, organic manures, crop residues or bio-fertilizers can meet the entire nutrient need of a crop in modern intensive agriculture. Rather, these need to be used in an integrated manner following a management technology which is practicable, economically viable, socially acceptable and ecologically sound. In this chapter, the rising need for INM system due to escalating prices of chemical fertilizers, imbalances in the ratio of NPK consumption, imbalances between consumption and domestic production, deterioration of soil health, consumption of non-renewable energy by inorganic fertilizers, deterioration in soil health, pollution hazards of chemical fertilizers, loss of chemical productivity, deterioration in soil physical properties and biological activity, additive effects of organic fertilizers as a source of secondary nutrients and micronutrients, and decline in crop productivity through inorganics have been discussed.

Keywords Intensive cropping system • high-analysis fertilizers • micronutrients • organic manures • crop residues • bio-fertilizers • INM system • crop productivity • soil health • soil physical properties

The world population is expected to double within the next 3–5 decades, thus making the task of several national agricultural systems more difficult to provide the needed food security. This is likely to be further complicated by environmental problems which are cropping up due to intense use of chemicals like inorganic fertilizers, insecticides, fungicides, bactericides and weedicides. Therefore, sustainability of national agricultural systems is a major concern today. For the solution of the above concern, the management of soil fertility and soil health through INM system is the key for the development of sustainable agriculture.

A. Mahajan and R.D. Gupta, *Integrated Nutrient Management (INM) in a Sustainable Rice–Wheat Cropping System*,

INM system is an age-old concept but its importance was not realized earlier as nutrient removal by the crops was very low due to subsistence farming. At present, INM system has a great significance because of intensive farming being practised (Mahajan and Sharma, 2005). Moreover, for realization of higher crop yields from a system on an economic basis, judicious and efficient blending of organic and inorganic sources of plant nutrients is essential. The need of INM system has arisen due to the following reasons.

3.1 Escalating Prices of Chemical Fertilizers

The feedstocks for manufacture of nitrogenous fertilizers, such as natural gas, naphtha, fuel oil, coal, etc., are available from indigenous sources. However, the bulk of the requirement of raw material intermediates for manufacture of phosphatic and complex fertilizers is met through imports. About 20% requirement of NH_4 and 80% of H_2PO_4 is met through imports. Similarly for manufacturing phosphatic fertilizers, nearly 80% requirement of rock phosphate and entire requirement of S is met through imports. Prices of these intermediate raw materials play a vital role in the cost of production of phosphatic fertilizers. In spite of domestic production, some amount of nitrogenous and phosphatic fertilizer and the entire amount of potassic fertilizers are imported every year causing an expansion in large amounts of foreign exchange, and resulting in higher prices of chemical fertilizers as shown in Table 3.1 (Anonymous, 2005–06). It is therefore all the more important to supplement the addition of NPK and S fertilizers through organic sources such as FYM, green manures, bio-fertilizers and introduction of legumes in the crop rotation. Such agricultural practices will take care of micronutrient demands of the plants in addition to improving physical, chemical and biological properties. These practices will also ameliorate better soil health with less environment pollution (Jaggi et al., 2001).

3.2 Imbalances in the Ratio of NPK Consumption

Although fertilizer application has played a big role in bringing about a Green Revolution in India, a disturbing feature in its consumption was discernible from imbalance in N, P_2O_5 and K_2O fertilizer ratio. This ratio has been worked out to

Table 3.1 Imports of urea, DAP and MOP from 1999/2000 to 2004/05 (Adapted from Anonymous, 2005–06)

	Imports (thousand tonnes)					
Fertilizers	1999/2000	2000/01	2001/02	2002/03	2003/04	2004/05
Urea	533.0	–	222.0	119.4	143.1	641.0
DAP	3,268.0	861.0	932.7	383.2	734.1	643.6
MOP	2,946.1	2,646.0	2,810.2	2,603.2	2,579.3	3,409.5

Table 3.2 Consumption ratio of $N/P_2O_5/K_2O$ from 1991/92 and 1999/2000 to 2004/05 (Adapted from Anonymous, 2005–06)

	$N/P_2O_5/K_2O$ consumption ratio					
Zones	1991/92	1999/2000	2000/01	2002/03	2003/04	2004/05
East	3.7:1.5:1	3.6:1.7:1	3.9:1.5:1	4.1:1.6:1	3.6:1.4:1	3.8:1.4:1
West	6.2:3.2:1	8.2:3.9:1	7.6:3.5:1	6.6:3.2:1	8.9:4.1:1	6.7:3.3:1
North	24.9:7.7:1	28.8:10.9:1	29.1:8.7:1	21.7:6.5:1	16.2:6.1:1	17.3:5.1:1
South	3.0:1.5:1	3.5:1.5:1	3.3:1.6:1	3.3:1.4:1	8.9:4.1:1	2.7:1.3:1
All India	5.9:2.4:1	6.8:2.9:1	6.8:2.6:1	6.5:2.5:1	6.6:2.7:1	5.7:2.2:1

be 5.9:2.4:1 for 1991/92 and 6.6:2.7:1 for 2003/04 as against the required 4:2:1 (Anonymous, 2005–06; Gupta and Sharma, 2006b). Balanced use of fertilizers in the country has had a serious setback due to decontrol and price escalation of chemical fertilizers, a non-renewable source of energy, as well as subsidy on urea. In the northern states except Himachal Pradesh, in the eastern states except West Bengal and Orissa, and in the western states except Rajasthan, there was great indiscriminate use of N, P_2O_5 and K_2O fertilizers as was evident from their ratios (Table 3.2).

With continuous use of NPK, several other nutrients like Zn, S, Ca and Mg had become the yield-limiting factors. Also, the farmers were using relatively more N fertilizers which resulted in poor nutrient balance in the soil as the use of P and K fertilizers by the farmers was not added strictly according to the soil needs. So, to increase the production we must use all these nutrients in a balanced and right proportion through appropriate methods.

3.3 Imbalances Between Consumption and Domestic Production

Fertilizer consumption of all nutrients increased from 16.80 million tonnes during 2003/04 to 18.39 million tonnes during 2004/05. The consumption of N increased from 11.08 million tonnes during 2003/04 to 11.71 million tonnes during 2004/05 with an increase of only 0.63 million tonnes. In sharp contrast, the consumption of P increased only marginally from 4.12 million tonnes during 2003/04 to 4.62 million tonnes during 2004/05, i.e. an increase of only 0.50 million tonnes. Consumption of K increased from 1.60 million tonnes during 2003/04 to 2.06 million tonnes during 2004/05, i.e. an increase of 0.46 million tonnes as shown in Table 3.3 (Anonymous, 2005–06).

In contrast to fertilizer consumption, fertilizer production has recorded a nominal growth. The production of N at 11.30 million tonnes and P_2O_5 at 4.03 million tonnes represented an increase of 0.74 and 0.41 million tonnes, respectively (Table 3.3). Similarly, total consumption of fertilizer nutrients per hectare of gross

Table 3.3 All India consumption, production and surplus/deficit of N, P_2O_5 and K_2O (million tonnes) in 2003/04 and 2004/05 (Adapted from Anonymous, 2005–06)

	N		P_2O_5		K_2O		All nutrients ($N + P_2O_5 + K_2O$)	
Variables	2003/04	2004/05	2003/04	2004/05	2003/04	2004/05	2003/04	2004/05
Consumption	11.08	11.71	4.12	4.62	1.60	2.06	16.80	18.39
Production	10.56	11.30	3.62	4.03	–	–	14.18	15.33
Surplus (+)/deficit (−)	(−)0.52	(−)0.41	(−)0.50	(−)0.59	(−)1.60	(−)2.06	(−)2.62	(−)3.06

cropped area increased marginally from 88.29 kg during 2003/04 to 96.69 kg during 2004/05 (Anonymous, 2005–06). According to Tandon (1997), organic sources of plant nutrients like animal manure, urban wastes and crop residues have a total tapable nutrient potential of 5.05 million tonnes. Thus, INM system can cope with the challenges to produce and supply such an enormous quantity of fertilizers in view of the fast-dwindling petroleum resources and other raw materials needed for fertilizer manufacturing, as well as to check the heavy fertilizer imports.

3.4 Deterioration of Soil Health

India produced about 202 million tonnes of food grains during 1998/99 with fertilizer ($N + P_2O_5 + K_2O$) consumption of 16.75 million tonnes. The estimated nutrient removal is 25–27 million tonnes, leaving a gap of about 10 million tonnes. To meet the demands of the current population of more than one billion, the estimated minimum food grain production target is 230 million tonnes. The estimated nutrient removal to produce the targeted food grains and other agricultural commodities is around 34.3 million tonnes as against the estimated fertilizer consumption of about 18 million tonnes leaving a gap of about 16.3 million tonnes. Thus, the widening gap between nutrient addition and crop removal had resulted in deterioration of soil health. The long-term fertilizer experiments (LTFEs) in progress from 1970 in India have shown that continuous application of suboptimal doses of chemical fertilizers to soils had a deleterious effect on soil productivity. However, integrated use of organic manures with optimum levels of NPK fertilizers not only improved the nutrient status and soil health but also stabilized the crop yields at a higher level (Prasad, 2000). In a long-term fertilizer study at Palampur, Himachal Pradesh (India), in maize–wheat cropping sequence, integrated use of fertilizer (100% N, P_2O_5 and K_2O) and FYM maintained the productivity of the system against N, P_2O_5 and K_2O alone. Similar was the situation in the case of Jammu (Jammu & Kashmir) where use of N, P_2O_5 and K_2O and FYM has given good results in rice–wheat cropping system.

3.5 Inorganic Fertilizers Consume Non-renewable Energy Sources

Inorganic fertilizer manufacture involves the use of non-renewable sources of energy like fossil fuel and rock phosphates, which appear to be depleting at a faster rate, and also adds to the cost of production. It has now therefore become necessary to use the other sources of plant nutrients like organic manures and bio-fertilizers to maintain soil fertility and crop productivity (Singh, 1999).

Among organic manures, FYM and compost (urban and rural) are the main components. Wherever it is possible, green manuring must be practised. *Azotobacter* inoculants, blue-green algae (BGA) and *Azolla* are the main bio-fertilizers which can be utilized for wheat and rice crops. Vermicompost and compost are another source of organic fertilizers.

3.6 Pollution Hazards of Chemical Fertilizers

Use of high-analysis fertilizers alone leads to pollution of air, soil and water and contributes to global warming. There is an accumulation of heavy metals such as Cd, Cr, Ni and Pb in soils up to toxic level. Groundwater has also been contaminated with heavy metals. Application of nitrogenous fertilizers alone without using phosphate and potassic fertilizers renders the formation of some specific types of compounds that are carcinogenic. Indiscriminate use of nitrogenous fertilizers without phosphate or potash has damaged the productivity of agricultural land in the long run, spoiling the reputation of fertilizers (Gupta and Singh, 2006). Indiscriminate consumption of N, P_2O_5 and K_2O has made the soils sick. For example, in the rice-growing areas of Haryana and Punjab, the organic C content in the soils has declined to 0.2% from 0.5% during 20 years of intensive cropping. Intensive cropping has already exhausted the secondary nutrients and micronutrients (Gupta and Singh, 2006). Organic farming is a practical way of addressing some major environmental problems (Mahajan et al., 2007a, b). The integrated use of organics, inorganics and bio-fertilizers not only avoids pollution hazards of soil, water, air, crop and food but also lowers farmers' fertilizer expenses and sustains the soil's productivity (Pathak et al., 2002).

3.7 Loss of Soil Productivity

The indiscriminate use of nitrogenous fertilizer without phosphate or potash has damaged the productivity of the agricultural land in the long run. Moreover, indiscriminate use of fertilizers has not only decreased the soil productivity but has also created a number of health hazards both to the soils and to human beings.

3.7.1 Loss of Chemical Fertility

The results from over 5,000 manurial trails in India have shown that the nutrient supplying power of many soils has declined steadily under continuous and intensive farming, and the soil fertility seems to have been stabilized at a comparatively low level. The research under LTFEs in India (Singh and Swarup, 2000) has generated the following results:

- Imbalanced use of chemical fertilizers alone leads to the deficiency of one or the other nutrient in the soil. The use of N alone failed to respond in the absence of P in certain cases. Long-term use of N alone reduced soil productivity even below the control (without NPK application). The use of N alone probably promoted imbalanced removal of soil nutrients, while in control nutrient depletion was in a natural proportion.
- Long-term use of high-analysis NPK fertilizers leads to the deficiency of secondary nutrients (Ca, Mg and S) and micronutrients like Zn, Cu, Mn and Fe in the soil and will become a yield-limiting factor after a number of years.
- Continuous application of N alone may lead to soil acidification. This has been proved in the soils of the Kandi belt of Jammu, Jammu & Kashmir, where continuous use of urea has reduced pH from 7.5 to 6.5 (Gupta et al., 1992a) or 5.5.
- Continuous use of inorganic fertilizers may lower soil organic matter content. LTFEs conducted at Barackpore and Pantnagar showed that there was a decline in soil organic matter with intensive rice cropping over a period of 12 years with chemical fertilizers alone. Thus, application of organic manures along with recommended levels of fertilizers enables to maintain the organic matter in the soil compared to fertilizer alone.
- The integrated use of NPK in conjunction with FYM holds promise in sustaining higher crop yields besides improving soil health and corrects some nutrient deficiencies. A similar result has been found in the soils of Palampur, Himachal Pradesh (Kaushal, 2002).
- Without balanced use of NPK fertilizers, the deficiency of Co and Mo in legumes has become a serious problem.

3.7.2 Deterioration in Soil Physical Properties

The continuous use of chemical fertilizers may increase bulk density and mechanical impedance; decrease soil porosity, infiltration rate and hydraulic conductivity; and reduce water-stable aggregates and water-holding capacity of some soils (Amgain and Singh, 2001). In a silty loam soil at Palampur (Himachal Pradesh), addition of N alone for 13 years lowered available water capacity from 12.3% to 11.1% in the control, while NPK + FYM increased it to 15.7% (Acharya et al., 1988). Thus, INM system improves the soil physical conditions, soil structure, aggregate stability, soil moisture rententivity and hydraulic conductivity. Such improvement in soil physical conditions contributes to soil fertility as well as to crop productivity.

3.7.3 Deterioration in Biological Activity

Chemical fertilizers when applied in higher doses may prove harmful to soil life, especially when used in concentrated and water-soluble form. For example, use of fertilizers at 50% of the recommended dose enhanced the counts of bacteria, actinomycetes and fungi. On the other hand, their application at 100% and 150% of the recommended dose adversely affected the microbial population, particularly that of actinomycetes (Yaduvanshi and Gupta, 1983). In another study, Gupta et al. (1983a) observed that use of organic manures increased not only the population of bacteria but also atmospheric N fixation by *Azotobacter* in soil. Acidification of soil caused by continuous use of N alone is very harmful to microbes, which often depend upon sole enzymes; enzymes are active in a very specific pH range. Changes in pH slow down enzyme reaction, and microbes have to enter into rest, encysting, or may die of hunger. However, micronutrients are the activators of enzymes.

$(NH_4)_2SO_4$ is a very strong biocide, hindering N fixation and killing bacteria and actinomycetes (Gupta et al., 1983a) vis-à-vis nematodes and earthworms, while superphosphate has a negative effect on free-living N-fixing bacteria. They are favoured by mild P fertilizers like basic slag, thermo phosphate or bonemeal when added to stubble mulch or straw.

3.8 Organic and Mineral Fertilizers Show Additive Effects

The efficiency of fertilizers increases when used in combination with organic matter (Yadav et al., 1998). For example, Chaudhary and Singh (1989) revealed that FYM + P was efficient in improving soil structure, while FYM alone failed to do so. The integrated use of organic and inorganic fertilizers at optimum levels as determined by soil tests in LTFEs indicates the build-up of micronutrient/secondary nutrient reserves such as Zn and S (Prasad, 2000). Thus, integrated use of organic manures and mineral fertilizers would not only give significantly higher yields, but also help to maintain soil health by narrowing down the gap between nutrient removal and supply.

3.9 Organic Materials as a Source of Secondary Nutrients and Micronutrients

Unlike high-analysis fertilizers, organic manures, in addition to NPK, supply secondary nutrients and micronutrients like S, Zn, Cu, Fe and Mn as well (Roy and Dudal, 1993; Yadav and Kumar, 2000). BGA, in addition to supplying N, also produce vitamin B_{12}, vitamin C, amino acid compounds, auxins and ascorbic acid, which contribute to growth and development of rice plants and reduce sulfide injury (Venkataraman, 1982). Similarly, *Azotobacter* is well known for producing growth-promoting substances which favourably enhance plant growth and development (Gupta and Dogra, 1999).

3.10 Interaction Benefits for Crops

A strong interaction exists in soil among factors like plant nutrition, soil physical properties, soil life, environmental conditions and crop production. Periodical return of organic materials to soil improves soil chemically, physically and biologically. Plant growth in such a soil is good even if chemical input is low and water problems decrease greatly.

3.11 Reduction in Crop Productivity

The farmer studies in cereal-based cropping system, particularly in rice–wheat cropping system, have indicated the detrimental effects of continuous application of high amounts of chemical fertilizers leading to decline in crop productivity. This is due to nutrient imbalances and deficiency of micronutrients (Hedge, 1992; Nambair and Abrol, 1989). Under such conditions, organic manures can play an important role in sustaining the soil productivity under rice–wheat cropping system (Amgain and Singh, 2001; De Datta and Barker, 1978; Roy and Dudal, 1993). In order to endorse the crop productivity and soil health, integrated use of organic manures and chemical fertilizers assumes greater significance in the rice–wheat cropping system because the use of organics also suffers from the drawbacks of having essential nutrient elements in very small amounts, as they are bulky in nature, and release of nutrients is slow and thus they are not enough to meet out the nutritional requirements of the growing crops. On the other hand, chemical fertilizers alone do not provide all the nutrients in balanced quantities as required by plants and also encourage the depletion of soil organic matter content and affect the physical, chemical and biological properties of the soil.

Thus, to make agriculture more successful and sustainable in the future era, it is desirable to supplement chemical fertilizers through reliable, native, pollution-free, renewable, eco-friendly, economically viable, socially acceptable and self-replicating sources such as organic manures (FYM and compost), green manures, crop residues, vermicomposting, legumes, enriched compost and biofertilizers. This concept is to be applied by optimal combination of all sources, based on their availability and sustainability for different crops, soil types and cropping systems in specific agro-ecological situations.

Impact Points to Remember

- INM system is an age-old concept but its importance was not realized earlier due to subsistence farming; however, at present it has great significance because of intensive farming being practised.
- India has imported every year some amount of nitrogenous and phosphatic fertilizer and the entire amount of potassic fertilizers causing an expansion in large amounts of foreign exchange, which resulted in escalating prices of chemical fertilizers.
- Inorganic fertilizer manufacture involves the use of non-renewable sources of energy like fossil fuel and rock phosphates, which appear to be depleting at a faster rate.
- Use of high-analysis fertilizers alone leads to pollution of air, soil and water and contributes to global warming.
- Imbalanced use of chemical fertilizers alone leads to the deficiency of one or the other nutrient in the soil.
- Continuous application of N alone may lead to soil acidification, and continuous use of inorganic fertilizers may lower soil organic matter content.
- Indiscriminate consumption of N, P_2O_5 and K_2O has made the soils sick. For example, in the rice-growing areas of Haryana and Punjab, the organic C content in the soils has declined to 0.2% from 0.5% during 20 years of intensive cropping.
- The continuous use of chemical fertilizers may increase bulk density and mechanical impedance; decrease soil porosity, infiltration rate and hydraulic conductivity; and reduce water-stable aggregates and water-holding capacity of some soils.
- Acidification of soil caused by continuous use, especially of N alone, is very harmful to microbes, which often depend upon sole enzymes that are active in a very specific pH range.
- $(NH_4)_2SO_4$ is a very strong biocide, hindering N fixation and killing nematodes and earthworms, while superphosphate has a negative effect on free-living N-fixing bacteria.
- Unlike high-analysis fertilizers, organic manures, in addition to NPK, supply micronutrients like Zn, Cu, Fe and Mn as well, though in small amounts.
- BGA, in addition to supplying N, also produce vitamin B_{12}, amino acid compounds, auxins and ascorbic acid, which contribute to growth of rice plants.

Study Questions

1. Define the following:
   (a) Global warming
   (b) Total porosity
   (c) Modern agriculture
   (d) Enzyme
   (e) Mechanical impedance

   (f) Water-holding capacity
   (g) Infiltration
   (h) Water-stable aggregates

2. Why has the need arisen for integrated nutrient management system in modern agriculture?

3. How does long-term use of chemical fertilizers alone lead to deterioration in soil productivity – physical, chemical and biological?

4. Differentiate the following:
   (a) Subsistence farming and intensive farming
   (b) Low-analysis fertilizers and high-analysis fertilizers
   (c) Renewable energy sources and non-renewable energy sources
   (d) Bulk density and particle density
   (e) Infiltration rate and hydraulic conductivity
   (f) Organic manures and inorganic manures

5. Explain with suitable examples how various organic materials act as a source of secondary nutrients and micronutrients.

6. Explain with suitable examples how chemical fertilizers may prove harmful to soil life.

7. Soil health is deteriorating day by day. How can we overcome this upcoming threat?

8. Write a short note on the following:
   (a) Escalating prices of chemical fertilizers
   (b) Pollution hazards of chemical fertilizers
   (c) Imbalances between consumption and domestic production
   (d) Pollution and its types
   (e) Interaction benefit crops

9. Justify the following statements:
   (a) Inorganic fertilizers consume non-renewable sources and organic fertilizers consume renewable sources
   (b) Organic and mineral fertilizers show additive effects
   (c) Chemical fertilizers affect soil physical properties

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Chapter 4
Components of INM System

Abstract The main objective behind INM system is to manage and sustain the agricultural productivity and improve the farmer's profitability through the judicious and efficient use of chemical fertilizers, organic manures, green manures, and compost including vermicompost, crop residues and bio-fertilizers. However, this does not mean adding everything everywhere; rather, a well-considered practical and efficient blend of diverse nutrient sources is required which can produce desired yields and maintain soil health on long-term basis. INM system helps to restore and sustain crop productivity, and also assists in checking the emerging micronutrient deficiencies. Further, it brings economy and efficiency in the use of fertilizers. In this chapter, the main components of INM system are discussed.

Keywords INM system • soil fertility • chemical fertilizers • organic manures • crop residues • compost • vermicompost • bio-fertilizers • soil health • crop productivity

The rice–wheat cropping sequence is a heavy nutrient feeder with almost twice the quantity of plant nutrients being removed from soil than what is added through the fertilizers and manures, thus posing a major threat to sustain soil health and crop productivity (Hedge et al., 1999). The continuous use of chemical fertilizers has resulted in the deterioration of soil health, environmental pollution and stagnation of productivity; hence, crop productivity under rice–wheat cropping system can only be maintained and improved by INM system (Jaggi et al., 2001; Mahajan and Sharma, 2005). Inorganic fertilizers, organic manures (FYM, compost, green manures and vermicompost), crop residues/wastes, legumes and bio-fertilizers are the main components of INM system which have been shown in Fig. 4.1.

The components of INM system not only include the use of organic fertilizer in the form of FYM, compost, green manure, vermicompost, bio-fertilizers and crop residues, but also possess a suitable crop variety, use of optimum cultural management, soil and water use for efficient and suitable crop production.

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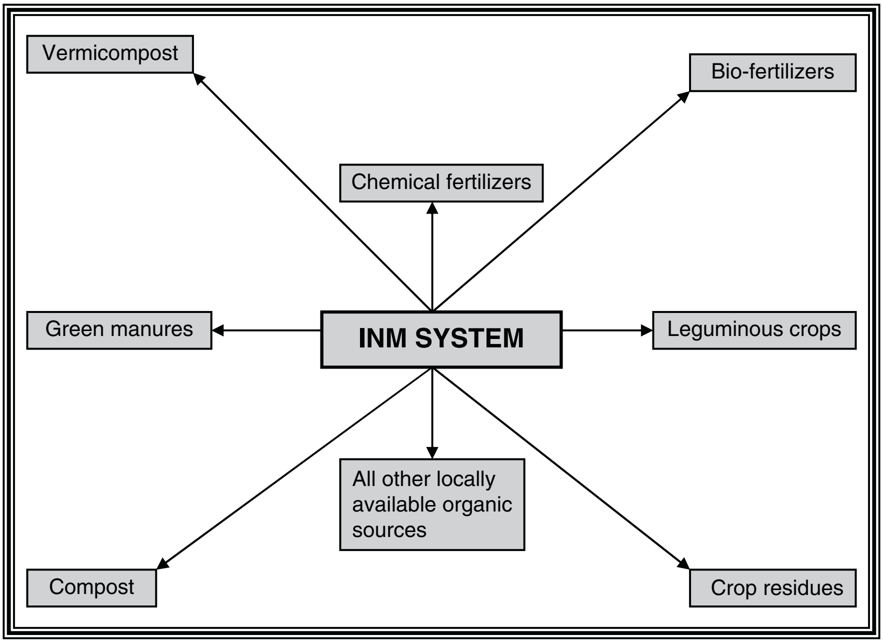

Fig. 4.1 Flow chart showing the different components of INM system

4.1 Chemical Fertilizer

> If HYVs were the catalyst that ignited the green revolution then chemical fertilizer was the fuel that powered its forward thrust. (Norman E. Borlaug)

When the history of human progress will be written, the use of fertilizers to fight against hunger will not be forgotten. When soils become poor, fertilizers act as additives that help the agricultural systems to sustain themselves. Thus, fertilizers are the most important monetary input used in crop production. Plant nutrient supply from the chemical fertilizers is the key to increasing agricultural production by enhancing the land productivity. Since 1950, the fertilizer consumption in India has increased remarkably. India is now the third largest in the world in terms of both production and consumption of fertilizers. Although fertilizer use in food grains production is of recent origin, the dependence on fertilizers is increasing rapidly due to the need to supply large amounts of nutrients in intensive farming systems, because soil nutrient resources alone cannot support such systems.

Use of chemical fertilizers in balanced proportions and recommended amounts is the quickest way of boosting crop production. Hardly 30–40% of the applied fertilizer nutrient is utilized by the crop; the rest is lost through various pathways like leaching, surface run-off, volatilization, denitrification, soil erosion and the fixation mechanism in soil. Therefore, efforts are to be made to increase the fertilizer-use efficiency. Further, chemical fertilizers alone are unable to maintain and sustain the long-term soil health and crop productivity (Subba Rao and Srivastava, 1998) because they are unable to supply minor and trace elements. Hence, the integrated use of inorganic fertilizers with organics, including bio-fertilizers, can greatly increase the efficiency of applied nutrients without causing any ill effects on the soil health and therefore appears to be an ideal way for sustained crop production and pollution-free environment (Mahajan et al., 2002; Ram, 2000).

4.1.1 Advantages of Chemical Fertilizer

Fertilizers are an important tool or key input for increased agricultural production in modern era. It is because they are the major contributors for enhancing crop production and maintaining soil productivity. Some of the advantages of chemical fertilizers include:

- They are easy and quick sources of plant nutrients.
- They contain nutrients in higher and definite concentrations compared to other sources.
- Use of balanced fertilization, however, based on soil test recommendations increases the fertilizer use efficiency and pays back to the farmer more profit per rupee invested.
- Chemical fertilizers are less bulky in nature and can be easily transported.
- Time and labour costs can be saved.

4.2 Organic Manures

The manures which are prepared from plant residues and animal remains are referred to as organic manures, and were traditionally and preferentially used in developing countries until the 1960s when chemical fertilizers began to gain popularity. Organic manures are generally of two types – bulky organic manures and concentrated organic manures. The manures that are applied in large quantities and contain low amounts of plant nutrients are known as bulky organic manures such as farmyard manure (FYM), compost (village and town compost), vermicompost, night soil, biogas slurry, sewage and sludge, etc.; concentrated organic manures contain higher percentages of major plant nutrients than bulky organic manures (Mahajan et al., 2002). The important concentrated organic manures are edible oil cakes (mustard, groundnut, sesame and linseed cakes), non-edible cakes (castor, neem, sunflower, mahua and karanj cakes) and non-vegetarian sources (blood meal, bonemeal, fishmeal, chicken manure), etc. These concentrated organic manures are made from raw materials of animal or plant origin. Bulky organic manure contains nutrients in small quantities; therefore, large quantities of these are required per hectare. They have direct effect on the plant growth, like any other commercial fertilizer. Besides the major nutrients, bulky organic manures also contain traces of micronutrients. It should be kept in mind that organic manures should be well decomposed. Nutrient content of different organic manures are given in Table 4.1. By using this table we can calculate the amount of organic matter to be applied in the soil.

Organic manures like FYM, compost, vermicompost, green manures, crop residues and bio-fertilizers are important inputs for maintaining soil fertility and ensuring yield stability. FYM is the most important and commonly used organic manure in India. As it is a general manure and it supplies all the constituents of plant food vis-à-vis micronutrients, FYM has been commonly used as a source of plant nutrition from time immemorial (Plate 4.1). It has three main constituents, namely dung, urine and litter. Moreover, the application of FYM along with the recommended level of chemical fertilizers enables to maintain the organic matter content and augments the water-holding capacity of the soil in comparison to fertilizer application alone. The organic sources can help to increase overall nutrient supply for agricultural crops and also increase the soil organic matter content which performs different functions at its different stages of decomposition. Build-up in soil organic matter, i.e. humus, produced due to an application of organic manures improves the physical properties of the soil, while at later stages it is mineralized and nutrients are released in the soil ecosystem. Therefore, it is imperative to study the direct and residual effects of organic manuring in a cropping system as a whole. Thus, organic manures also play a vital role in maintaining long-term soil fertility and sustainability.

Table 4.1 Nutrient content of different organic manures (Adapted from Mahajan et al. [2007])

	Nutrient content (%)		
Organic manure	N	P_2O_5	K_2O
A. Bulky organic manures			
FYM	0.5	0.20	0.5
Farm compost	0.5	0.15	0.5
Town compost	1.4	1.0	1.4
Night soil	5.5	4.0	2.0
Sewage and sludge	3–6	2.0	1.0
Poultry manure	3.03	2.63	1.4
B. Concentrated organic manures			
Fish manure	4–10	3–9	0.3–1.5
Neem cake	5.22	1.08	1.48
Linseed cake	5.56	1.44	1.28
Groundnut cake	7.29	1.53	1.33
Mustard oil cake	5.21	1.84	1.19
Safflower oil cake	7.88	2.20	1.92
Cotton oil cake	6.50	2.89	2.17
Raw bonemeal	3–4	20–25	–
Steamed bonemeal	1–2	25–30	–
Blood meal	10–12	1–2	1.0

Plate 4.1 Farmyard manure (FYM)

4.2.1 Distinction Between Organic Manures and Fertilizers

A distinction between the correct meaning of the terms manures and fertilizers can be made from the following:

- Precisely speaking, manure is comprised of some natural products such as FYM, compost, seabird excreta (guano) and green manures, containing all the three essential elements NPK as well as organic carbon required to be supplied to the soil in different quantities. Apart from these, manures also contain secondary nutrients and micronutrients in small amounts. Manures are also called natural manures, general manures or organic manures.
- A fertilizer, on the other hand, is artificial manure as it is the product of some manufacturing processes. Commonly it contains only one of the essential elements, but might contain more than one also. The examples are urea, ammonium sulphate ($(NH_4)_2SO_4$), diammonium phosphate ($(NH_4)_2HPO_4$) and potash (K_2O). Fertilizers are also called artificial manures, special manures or inorganic manures.

4.2.2 Potential of Farmyard Manure (FYM) in India

The total potential of FYM in India, as reported by Raychaudhuri in 1972, was estimated to be 10.8 million tonnes (Raychaudhuri, 1972). However, with the increasing population of human beings, now a sizeable proportion of animal dung is used as fuel, especially in the villages in the form of dried dung cakes. However, later on the country yielded about 500 million tonnes of FYM produced from about 1,000 million tonnes of animal dung annually (Bhardwaj et al., 1998). When distributed over the net cultivated area of 145 million hectares, the quantity of FYM for 1 ha of land works out to be about 3.5 t. Presently, India is producing more than 1,500 million tonnes of dung.

4.2.3 Various Forms of Organic Wastes

The various forms of organic wastes are listed below.

4.2.3.1 Livestock and Human Wastes

The organic wastes from livestock and humans include:

- Cattle-shed wastes such as cattle dung and urine
- Human excreta and other livestock wastes of goat, sheep, pigs, poultry, etc.
- By-products of slaughter houses, blood and meat wastes, bones, horns and hooves, leather and their wastes
- Urban solid wastes, sewage and sludge, rural and urban compost and biogas slurry

4.2.3.2 Crop Residues, Tree Wastes and Aquatic Weeds

Some additional sources of organic wastes include:

- Crop wastes of cereals, pulses and oilseeds, fibre and sugar crops
- Stalks of maize, cotton, tree leaves and forest litter
- Marine wastes such as sea and aquatic weeds like water hyacinth, fishmeal, etc.

4.2.3.3 Agro-industrial Wastes

Agro-industrial wastes are available in significant quantities at processing sites and can be effectively utilized as manures. These include pressmud, coir pith from coconut industry, rice husk, paper and pulp waste, oil cakes, sawdust, groundnut husk, distillery waste, fruit and vegetable industry waste, and wastes of tobacco and coffee industry, etc. Their N, P_2O_5 and K_2O contents vary from 0.5–1.5%, 0.5–2.5% and 0.5–3.0% respectively, depending on the waste. The nutrients in agro-industrial waste materials make them important in respect of their use and economic value. These wastes can be put to various uses because (i) they are sources of energy and power; (ii) they act as animal feed and fodder and (iii) they can be used for farm development such as improvement of soil health, soil fertility, soil physical conditions and plant protection.

4.2.3.4 Poultry Manure

Poultry manure is the excreta of farm fowl which decomposes gradually. It contains higher N and P compared to other organic manures and the average nutrient contents in poultry manure are 3.03% N, 2.63% P_2O_5 and 1.4% K_2O. Experiments have confirmed that the application of poultry manure, even as top dressing in cereals (rice and wheat), has resulted in perceivable yield increase. Poultry manure can substitute FYM as well as chemical fertilizer, because it is approximately four times richer in N, ten times in P and twice in K_2O than FYM (Gupta and Sharma, 1970). However, the farmers are not fully aware of this fact. Therefore, it is imperative to educate the farmers not only about the values of N, P_2O_5 and K_2O in poultry manure, but also that it is a good source of micronutrients like Zn, Cu, Mn, Fe, etc.

4.2.4 Advantages of Organic Manures

Organic manure utilization can help in many ways:

- It bridges the fertilizer gap (ranging to about 25%) and saves foreign exchange.
- It supplies other essential nutrients in addition to NPK in a balanced form to the soil.
- It reduces leaching or erosion of nutrients and helps in the slow release process.
- It has successive residual effects.
- Organic acids released from decomposing organic matter help reduce alkalinity in soils.
- It improves soil quality by supplying humus-forming organic materials.
- It prevents soil pollution caused by inorganic fertilizer.
- It improves the buffering capacity of the soil.
- Rate of infiltration, percolation and drainage of water is enhanced.
- It results in an increase in water-retention capacity due to the increase in the humus content.
- It serves as a source of energy for the growth of macro- and micro-organisms, which help in performing beneficial functions in soil.

4.2.5 Compost

Organic manures prepared mainly from plant residues (leaves, stalks, twigs, barks, etc.) with small quantities of animal waste products like dung and urine are termed composts, and the process of making compost is known as composting. Thus, composting is largely a biological process in which micro-organisms of both types, namely aerobic (which require air or oxygen for their development) and anaerobic (which function in absence of air or free oxygen), decompose the organic matter and lower the C/N ratio of the refuse. On an average, compost contains 1.01% N,

Plate 4.2 Compost placed in the field

0.5% P_2O_5 and 0.8–0.9% K_2O. In comparison to FYM, compost has a high percentage of humus and is free from pathogenic diseases and weed seeds.

Briefly stated, compost is a manure similar in properties to FYM and is mainly made by the decomposition of plant residues with small amounts of dung, urine, sewage, etc. (Plate 4.2). Dung, urine and sewage are added during its preparation to provide N.

4.2.5.1 Types of Compost

Compost generally prepared in India is of the following two types.

Urban or Town Compost

Urban compost is prepared from night soil and street and dustbin refuse, and is rich in nutrients (1.0–2.0% N, 1.0% P_2O_5 and 1.5% K_2O) as compared to FYM and rural compost.

Rural or Village Compost

Rural compost is prepared from farm waste products, e.g. straw; crop stubbles; crop residues such as sugarcane trash, groundnut husks and leaves, cotton stalks, etc.; weeds; waste fodder; urine-soaked earth; litter from cowshed and hedge clippings. It contains 0.4–0.8% N, 0.3–0.6% P_2O_5 and 0.7–1.0% K_2O.

4.2.5.2 Principle of Composting

Composting is a controlled biological decomposition process that converts organic matter to a stable, humus-like product. The process depends upon micro-organisms, which utilize decomposable organic waste both as energy and food source. The composting process converts materials with potential odour and other offensive or harmful substances into a stabilized product that has reasonably less odour and is pathogen-free, and which is a poor breeding substrate for flies and other insects. In addition to this, the volume and weight of the composted product becomes less than that of the original raw waste because composting converts much of the carbonaceous material to gaseous carbon dioxide. Heat generated during the process destroys pathogenic organisms and weed seeds that might be present in the raw waste, and helps reduce moisture. In turn, because of the reduced volume and weight, hauling and spreading cost is less than that required for the raw wastes.

4.2.5.3 Methods of Preparation of Composts

Composting is the time-tested practice of decomposition of organic materials by micro-organisms. It is a potential route for recycling of a variety of wastes in agriculture. Agricultural rural wastes mostly consist of crop residues of rice, wheat, sorghum, pearl millet, maize, sugarcane, etc. Urban and agro-industrial wastes are the other category of potential materials which can be used for composting.

In India, two recommended methods – the 'Indore method' (aerobic) and the 'Bangalore method' (initially aerobic and later on anaerobic) – have been widely used. The Indore method was introduced by Howard and Ward at the Indian Institute of Plant Industry, Indore, while the Bangalore method was devised by C. N. Acharya, through his experiments at the Indian Institute of Science, Bangalore.

Indore Method

In the Indore method, a pit is dug near the cattle shed on a site which is totally free from water-logging conditions (Gupta et al., 1998). From the cattle shed, the wet bedding material consisting of shredded crop residues along with animal excreta are removed and spread in a layer in the pit. Then cattle dung is spread over this layer which is sprinkled with water to maintain optimum moisture. The process is repeated until layers of residues reach 30 cm above ground level. A shed may be erected over the pit to prevent soaking by rains. Residues are turned every fortnight and good-quality compost is ready in about 12–16 weeks. The advantages of the Indore method are listed below:

- The compost is prepared in rural areas by this method.
- Cow dung is used as a starter. As a result, decomposition becomes quick and good-quality manure is produced.
- The manure becomes ready for application in the field within 3–4 months.

Bangalore Method

In the Bangalore method, conservation of nutrients is attempted (Gupta et al., 1998). Heaps are prepared as in the Indore method except that each heap is sealed with a plaster of mud which increases the temperature due to anaerobic fermentation. By this method, an N-rich compost is prepared within 32 weeks. Compost gets ready when the temperature in the pile approaches that of the surrounding air. The final product is dark or dark brown in colour, finally divided, rich in humus and has a C/N ratio in the range of 10:1 to 20:1. The advantages of the Bangalore method are listed below:

- It is simple to use, needs little labour and water, and there is less nutrient loss than in the Indore method.
- It effectively controls foul smell.
- As trenches are used for composting, there is a reduction in the loss of moisture and N.
- It minimizes fly nuisance by destroying fly larvae and also kills the pathogenic organisms.
- Compost is prepared from town waste, so the cost of the manure is less.
- Compost prepared by this method contains more amount of N and P, so it is good organic manure.
- It is a suitable manure for vegetable cultivation in urban areas.

Since pathogenic organisms remain in the Bangalore manure, it should be sterilized before application in the field.

The average available nutrients composition of compost prepared by these two methods is given in Table 4.2.

Hot Fermentation Method

Pioneering work on preparation of compost in pits by hot fermentation method was carried out in India by Dr. Acharya, particularly using town refuse and night soil; it consists of the following main steps:

- The compost production depot should be located just on the outskirts for convenient transport of street refuse and night soil to the site. In large cities and towns, there may be a number of such depots for serving various localities. The compost depot should accommodate more than 200 pits or trenches. The dimensions of the pits are 1.0 × 2.5 × 1.0 m for the towns having a population of more than 50,000, which can take the dumping for about a year.

Table 4.2 Average composition of compost

Nutrients	Indore method	Bangalore method
Available N (%)	0.8	1.0
Available P (%)	0.3	0.5
Available K (%)	1.5	1.7

- The pits are dug in rows with a space of 1.5 m between trenches. Roads of suitable width are provided for the carts to approach and unload the materials inside the trenches.
- The refuse is dumped into the trench and spread out with rakes to make a layer of about 15 cm.
- Night soil brought in closed containers is discharged over the layer of refuse. If necessary, it is spread out with long wooden spades in a layer of about 5 cm. This is then covered again with another 15 cm layer of refuse.
- Night soil and refuse are piled in alternate layers until the pit is filled and extended to 15 cm above ground level with a final layer of refuse on the top. This may be dome-shaped and covered with a thin layer of soil.
- The decomposition of dumped material in pits takes place largely in the absence of sufficient air except in the surface 10–12 cm layer or so.
- The percentage of recovery of organic matter and N obtained by this method is higher compared to the aerobic method in overground heaps, as shown below in Table 4.3.

4.2.5.4 Advantages of Composting

Composting is one way in which some of the pathogens associated with the utilization of various wastes such as odours, human pathogens and storage and handling constraints can be resolved. The advantages of composting are listed below:

- An ancient practice whereby farmers have converted organic wastes into a farm resource that provides nutrients to crops and enhances soil tilth, fertility and productivity.
- Acts as an excellent soil-conditioning agent.
- During the composting process, some organic matter is transferred into humic substances, which are relatively resistant to microbial decomposition. Thus, composting helps to maintain or increase soil organic matter content.
- Improves the texture, permeability and water-holding capacity of the soils.
- There is an improvement in humus content, hygroscopic moisture, water-retention capacity and absorption capacity when organic matter is added to the soil.
- Ameliorates the fertility of marginal and arable land and can also be used for restoration of land that has been severely eroded or strip-mined.
- An excellent material for litter or bedding. It is moisture-absorbent and odourless and eliminates the need to purchase bedding from an outside source.

Table 4.3 Percentage recovery (Adapted from Garg et al. [1971] and Gupta et al. [1998])

Constituent	Heap method	Trench or pit method
Organic matter	53	78
Nitrogen	54	74

4.2.6 Green Manures

Green manure is the cheapest way to fertilize the cereal crops where sufficient quantity of FYM or compost is not available. The practice of ploughing or intermittently adding un-decomposed green plant material into the soil for the purpose of improving the physical condition and fertility of the soil is called green manuring and the manure obtained by this method is known as green manure (Mahajan et al., 2002). Before the introduction of chemical fertilizers, green manuring was consistently practised for crops like rice, wheat, etc. For green manuring, generally leguminous crops are preferred because they have an additional advantage of fixing atmospheric N (Gupta et al., 2005).

Green manuring, in fact, is the easiest and quickest way of supplying readily decomposable organic matter to soils, and thereby the release of plant nutrients (Plate 4.3). The magnitude of green manure has been known in periods as far back as 1000 BC because references to the use of stalks and stems of sesame as manure have been found in ‘*Atharva Veda*’ (Gupta and Sharma, 2004). This practice, however, decreased in India after 1960 due to introduction of intensive farming systems and easy availability of chemical fertilizers.

4.2.6.1 Green Manure Crops

The crops mainly used for green manuring are: (a) non-leguminous crops such as *Cannabis sativa* (bhang), *Vernonia cenerea* (kodogira), *Brassica* spp. (Mustard),

Plate 4.3 Green manures incorporated in the field

Triticum aestivum (wheat), *Zea mays* (maize), *Sorghum vulgare* (jowar), *Daucus carota* (carrot) and *Raphanus sativas* (radish); and (b) leguminous crops such as *Sesbania aculeata* (dhaincha), *Vigna unguiculata* (cowpea), *Phaseolus aureus* (mung), *Crotolaria juncea* (sunn hemp), *V. radiata* (green gram), *Cyanopsis tetragonoloba* (cluster bean), *P. vulgaris* (French bean), *Trifolium alexandrinum* (berseem), *Meliolotus alba* (Senji) and other short-duration legume crops.

The non-legumes used as green manuring crops provide organic matter but do not fix atmospheric N into the soil, while the legumes provide organic matter to the soil besides fixing atmospheric N. The legumes have the ability of acquiring N from the air with the help of its root bacteria nodule. The growing of *S. aculeata* and *C. juncea* as green manures has been found very effective in Indian soils. Green manure incorporation adds plenty of fresh biomass and maintains nutrient reserves and physical condition of soil. A green manure crop improves the structure of the subsoil by a deep-rooting system and increases the water-holding capacity of the soil. It may also be useful in reclamation of saline, alkaline and sodic soils (Najar and Gupta, 1996). On an average, it generally adds 60–80 kg N ha^{-1} to different crops. Apart from this, green manure crops also provide a shielding action against erosion and leaching. At present, about 6.3 million hectares are estimated to be under green manuring. The practice of green manuring is adopted in various ways in different states of India to suit soil and climatic conditions (Gupta et al., 2005). In Bharmour area of Chamba and in some areas of Kangra, Una, Kullu and Mandi districts of Himachal Pradesh green manuring with leaves and twigs of wild bushes such as Basooti (*Vasica indica*), Eupatorium (*Eupatorium adenophorum*), Subabool (*Leucaena leucocephala*), etc. is done (Acharya et al., 2001). The green material is applied to the paddy fields before transplanting. The plant nutrient content of certain green manure crops is presented in Table 4.4 (Ravuri and Mosha, 2005).

4.2.6.2 Methods of Green Manuring

Green manuring is mostly practised in Karnataka, West Bengal, Andhra Pradesh, Orissa, Madhya Pradesh, Punjab and Uttar Pradesh, and less in other Indian states. The adoption of green manuring primarily depends upon the agro-climatic conditions. The two methods of green manuring are as follows.

Table 4.4 Nutrient content of certain green manure crops (Adapted from Ravuri and Mosha [2005])

	Approximately quantity present in 1 t of fresh weight (kg)		
Green manure crops	N	P_20_5	K_20
Sunn hemp	6–9	1.0–2.0	7–10
Dhaincha	5–7	1.0–1.5	7–8
Pillipesara	9–11	1.5–2.0	8–10
Cowpea	5–6	1.5–2.0	7–8
Green gram	4–6	1.0–1.5	7–8

Green Leaf Manuring

In this method, green leafy materials, such as *Glyricidia maculata* (Glyricidia), *Pongamia glabra* (karanj), *Ipomoea cornea* (Ipomoea), *S. speciosa* (wild dhaincha) etc., are collected from other places and added to the soil at the time of puddling a paddy field. This system is common in the eastern, southern and central parts of India.

Green Manuring In Situ

In this method, green manure crops are grown in situ and buried in the same field while ploughing, which on decomposition supplies nutrients to the grown crops which are generally legumes. The green manuring crop may be grown as a pure crop or be intercropped with the main crop. Generally, annual legumes such as *S. aculeata*, *V. unguiculata* and *C. juncea*, etc. are used for in situ green manuring. This system of green manuring is commonly followed in northern India.

4.2.6.3 Advantages of Green Manure Crops

As already stated, green manuring is a very old farm practice and has been used from early times as a source of supplementing animal manure. In India, favourable climatic conditions prevail for extensive cultivation of green manuring, to make up for the shortage of available cattle dung manure, much of which is burnt as fuel. Several trees and shrubs are also available which have been found useful to serve as green leaf manuring. Green manuring is therefore an important source of soil fertility, under Indian conditions. The following are the main advantages of green manure crops:

- They supply organic matter to the soil which provides the stability to the soil structure needed for optimum plant growth. Moreover, organic matter added through green manure serves as an energy source for soil micro-organisms which transform nutrients from unavailable form to available form.
- They increase the adsorptive capacity of soil and promote aeration, drainage and granulation, which eventually increase crop growth.
- Leguminous green manure crops add more N to the soil.
- They increase the availability of nutrients like P, Ca, K, Mg and Fe, the decomposing organic matter liberates CO_2, leading to lowering of soil pH, especially of calcareous, saline and sodic soils, which helps in solubilization of these nutrients.
- Decomposition of green manures increases the ionic-exchange capacity of soils, i.e. cation- and anion-exchange capacity.
- They check the growth of weeds because green manure crops grow very quickly and tend to suppress the growth of weeds and also grasses.
- They act as a cover crop and protect the soil from erosion and nutrient loss by taking up soluble nutrients which might have otherwise been lost in drainage water or due to erosion or run-off.

- They add green matter, which stimulates the activity of the micro-organisms, and further stimulate the biochemical changes accordingly.
- The soil conservation benefits provided by green manure crops extend beyond protection of bare soil during non-crop periods. The mulch that results from a chemically or mechanically incorporated green manure crop increases infiltration and reduces water evaporation from the soil surface.
- They take up soluble substances containing essential plant nutrients, which otherwise might be lost in drainage water. In other words we can say that besides actively fixing N in the root nodules, green manuring crops also reduce the leaching losses of mineral N because of their vigorous root system.
- Mineral constituents of soil in combination with humus of green manure are in a more suitable form for assimilation by the succeeding crops.
- They aid in the reclamation of saline, alkaline and sodic soils by the release of organic acids.
- The greatest benefit of green manuring lies in its being a cheaper source of plant nutrients. This kind of manure also helps in keeping the soil well managed.

4.2.6.4 Characteristics of Green Manure Crops

For green manure crops to be agronomically attractive and economically viable, the plants should possess the following characteristics:

- They should have profuse leaves and rapid growth early in their life cycle. For example, *C. juncea* and *P. aureus*.
- They should have abundant and succulent tops and be capable of making good stands even on poor and exhausted soils.
- They should yield large quantities of green material in a short period. For example, *S. aculeata*.
- They should be leguminous with good nodular growth habit, which is indicative of rapid N fixation even under unfavourable soil conditions.
- They should have a deep root system which can open the subsoil compaction for the supply of plant nutrients.
- They should be easy to manage during the establishment and incorporation into the soil.
- They should be tender (more leafy than woody growth) so that their decomposition is rapid. For example, *T. alexandrinum*.
- They should be tolerant to drought, shade, adverse temperature, insect–pest attack, diseases, etc., so that they can be easily incorporated.
- They should have the capacity to recycle nutrients.
- They should have the ability to produce seeds in sufficient quantities to increase the areas under the crop.
- They should not invade and cause difficulties for the succeeding crop in the crop rotation.

4.2.7 Vermicompost and Vermicasts

Vermicomposting is derived from the Latin word *vermis*, meaning worms. Vermicomposting or vermistabilization is a method of making compost using earthworms, which generally thrive well in soil, eat biomass and excrete in digested form, and convert solid wastes of animals and plants into valuable organic manure under aerobic conditions. This organic manure or compost is generally called vermicompost (Plate 4.4). The art of rearing earthworms is called vermiculture. In other words, the use of earthworms in organic waste management has been termed 'vermicomposting'.

Vermicomposting is, in fact, the process in which earthworms feed on waste organic substances, convert them into compost by passing them through their digestive system and excrete them in a granular form called vermicasts. Thus, vermicompost is a mixture of vermicasts or faecal excretions and organic matter including humus, live earthworms, their cocoons and other organisms. It is worthwhile to mention that vermicasts are rich in calcium carbonate ($CaCO_3$) and to some extent magnesium carbonate ($MgCO_3$) also. Owing to the presence of these carbonates, the amount of exchangeable Ca^{2+}, Mg^{2+}, K^+ and available N, P and K is higher in the vermicasts. The nutrients present in vermicasts are readily soluble in water for the uptake of plants. Various steps involved in the preparation of vermicomposting are described separately. Organic wastes such as kitchen wastes, city wastes, sewage wastes, etc., can also be utilized in vermicomposting. On an average, it contains 1.6% N, 5.04% P_2O_5 and 0.8% K_2O. Apart from these, vermicompost

Plate 4.4 Vermicompost

also contains hormones like auxins and cytokinins, enzymes, vitamins and useful micro-organisms like bacteria, actinomycetes, protozoa, fungi and others. They are also rich in macronutrients and micronutrients, vitamins and growth hormones.

The C/N ratio of vermicompost is much lower (16:1) than that of FYM (30:1). The best pH for preparing vermicompost is 6.5 to 7.5, and it can grow at a wide range of temperature varying from 0°C to 40°C. It is estimated that 1,800 worms, which is an ideal population for 1 m^2, can feed on 80 t of humus per year. The worms commonly used for this purpose are *Eisenia foetida* (red worms), *Eudrillus eugeniae* (African night crawler) and *Pheritima elongata*, which are potential agents in breaking down animal wastes. The nutrient status of vermicast prepared by these species was assessed and it was found that FYM and vermicompost have comparable contents of N but vermicompost possessed higher C/N ratio (Gupta and Bhagat, 2004).

4.2.7.1 Vermicomposting Materials

Almost all types of biological, degradable and decomposable organic wastes can be used in vermicomposting. Commonly used composting materials are animal dung, agricultural wastes, forestry wastes, city leaf litter, biogas slurry, city refuse, industrial wastes, wastepaper, cotton cloth, etc.

4.2.7.2 Composition of Vermicompost

Vermicompost is a mixture of earthworm casts, which are a rich source of both macronutrients and micronutrients, as well as vitamins, growth hormones and microflora. Vermicompost holds promise to play a significant role in the building up of soil fertility and improving soil health for sustainable agriculture. The composition of vermicompost is given in Table 4.5.

Table 4.5 Composition of vermicompost

Sr. No.	Nutrients	Contents
1.	Organic carbon (%)	9.15–17.98
2.	Total nitrogen (%)	0.5–1.5
3.	Available phosphorous (%)	0.1–0.3
4.	Total phosphorous (%)	1.34–2.20
5.	Available potassium (%)	0.15–0.56
6.	Total potassium (%)	0.40–0.67
7.	Available sodium (%)	0.06–0.30
8.	Calcium and magnesium (meq/100 g)	22.67–70.00
9.	Copper (ppm)	2.0–9.5
10.	Iron (ppm)	2.0–9.3
11.	Zinc (ppm)	5.7–11.5
12.	Available sulphur (ppm)	128.0–546.0

4.2.7.3 Types of Earthworms Suitable for Vermicomposting

Dr. R. D. Gupta, Former Associate Dean, Sher-e-Kashmir University of Agricultural Sciences and Technology, Jammu, Jammu & Kashmir, has rightly quoted about earthworms:

> Enhance the dwindling earthworm's population in the soils. They will increase their fertility and productivity and thereby, assist in the sustainability of agriculture.

Earthworms are found worldwide and their contribution in improving soil fertility is well known since a long time. They are long and cylindrical in shape, and have a large number of grooves. They belong to the order oligochaeta, class chaetopoda, phylum Annelids or Annelida of the animal kingdom. There are about 3,320 species of earthworms in the world which have adapted to a wide range of environment. More than 550 species have been identified in India. Normally, the average lifespan of an earthworm is about 1 year during which it may reproduce about ten times. Earthworm species which are presently being extensively used for vermicomposting are *E. foetida*, *E. eugenia* and *Perionyx excavatus* (Kumar, 2005). However, *E. foetida* is the world's most widely adopted species. These earthworms are red, brown or purple in colour, up to 15 cm long and weigh 0.5–1.5 g. These earthworms are commercially known as pink worms, red worms and purple worms.

> All the fertile areas of this planet have at least once passed through the bodies of earthworms. (Charles Darwin)

Activities of earthworms in the soil show that they are of great economic importance. They feed on decayed organic matter and leaves which are dragged into their burrows, thereby acting as decomposers. They ingest large quantities of soil during their life cycle and enrich the soil by bringing subsoil to the surface to mix with topsoil. Thus, they are truly soil-dwelling organisms and their bodies are in direct contact with soils throughout their life cycle. They help to improve soil drainage, aeration and root growth and have a high biomass in soil. Earthworms can be categorized into the three following types.

Epigeic

These worms live on the surface of the soil, i.e. they are surface dwellers (within 1 m soil depth), and are active for a limited period. They have a high reproductive rate with a short lifespan. As per their dietary habits they require high organic contents. These are very useful for vermicomposting due to their high metabolic activities. This category includes *E. foetida*, *Pheritima elongata*, *Engulus engineer*, *Perionyx arboricola*, etc.

Endogeic

These make deeper tunnels and lie below 3 m depth in the soil. Such species reside beneath the top soil surface and feed on humified organic matter which is at different levels of degradation. They make extensive tunnels oriented obliquely and horizontally to soil surface, resulting in enhanced soil aeration. Further, by mixing leached microbial or organic matter with clay, silt and sand particles they improve texture and structure of soil.

Diageic

This type prefers 1–3 m soil depth and has characteristics of both epigeic and endogeic types of earthworms. Diageic worms are deep-dwellers. They make extensive and permanent burrows. They line the burrows with their excrement and collect litter from the surface and store it in their burrows for feeding. Therefore, they are beneficial for loosening and mixing soil surfaces and organic matter into subterranean soil strata.

4.2.7.4 Steps in Vermicomposting

Vermicomposting is an essential tool of sustainable agriculture; it may be more helpful in increasing crop productivity, quality produce, reducing cost of agricultural inputs in addition to improving soil health. The various steps involved in the preparation of vermicomposting are shown in Fig. 4.2.

4.2.7.5 Methods for Preparing Vermicomposts

Vermicompost can be prepared by a number of methods, which are briefly described below.

Heap Method

In this method, vermicomposting is done in the field or on the ground. The field is well levelled and a platform of manageable size is prepared, about 12–15 cm above the ground. It can be 10–20 m long and 1 m wide. This platform is plastered with soil free of stones, glass or any form of chemical contaminants. Over the platform, a 15 cm feed layer of partly digested material is made. After watering the platform, earthworms are spread on it. A few more layers of pretreated waste materials can also be heaped.

The plant wastes are mixed with small quantities of well-decomposed cow dung manure, i.e. roughly 0.5 kg FYM for 10–20 kg of plant material. This is done to give bacterial inoculums for enhancing decomposition process and ultimately vermicomposting. The heaps are sprinkled with a little water, i.e. 5 l for 10–20 kg waste or plant material. The whole waste heap should be kept moist for 3–7 days and periodically turned for proper mixing. If platforms are already under thatched-roof shade, heaps can also be covered with broad leaves locally available. Heaps may be circular or rectangular in shape.

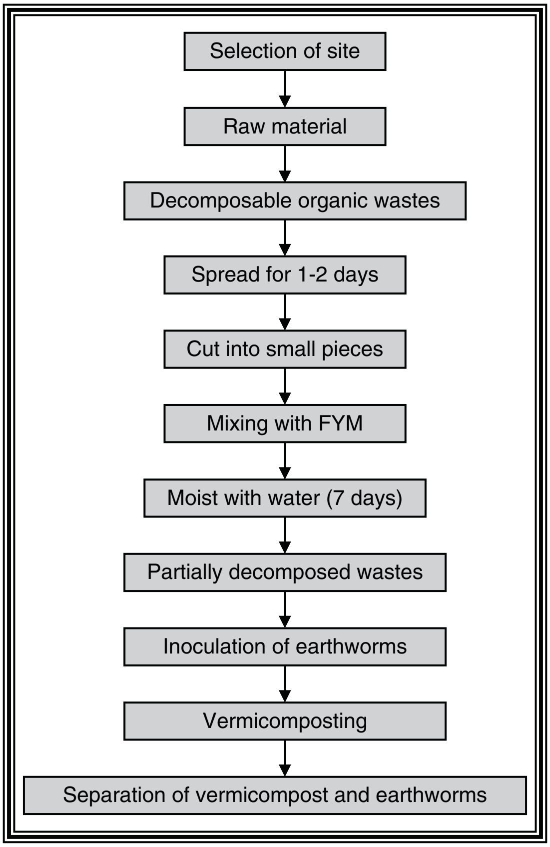

Fig. 4.2 Steps involved in the preparation of vermicomposting

Vermicompost becomes ready within 60–70 days when top layers seem somewhat dark brown in colour and granular in texture. Watering should then be stopped for 2–3 days and gently vermicompost should be scraped from the top layers. This vermicompost should then be kept to a side and left undisturbed for about 1 day. If there are adult worms present these would move down or away from the vermicompost.

Pile/Bed Method

This method is useful where farmers cannot afford a cemented structure, as it can be taken up under the shade of a tree and without any structure. The materials required are 3–4 q of dry grass, sufficient amount of FYM, 7–8 q of waste of crops and 8,500–10,000 earthworms per metre. First of all, a 15 cm layer of dry waste is spread and then another 15 cm layer of FYM is placed over it. Water is sprinkled to retain proper moisture for 24 hr; 300–350 red worms are then placed in 1 m^2 area and covered with a 20 cm layer of crop residue waste. About 60% relative humidity is maintained for about 60–65 days and the pile is protected from the attack of birds. With these amounts of input, 3–4 q of compost and 20,000–25,000 red worms can be obtained within 2 months. Similarly, another 3–4 q of compost can be obtained within the next 45–50 days. In this way, 2.0–2.5 t of vermicompost can be obtained within a year. The size of the unit depends on the availability of the material but the ideal one should be 1.0–1.5 m.

Pit Method

This method is comparatively better than the pile method. Cemented twin pits of 4 × 1.25 × 0.75 m each are made. At every 30 cm, there is a hole made in the wall of the pit. Filling is done by the same method as has been mentioned in the pile method. However, the ratio of crop residue to FYM is 2:1. While filling the two, one pit should be left empty to allow earthworms to move into it after preparation. If waste is available in less quantity, soil can be mixed with FYM. After 15 days of filling, 8,000–10,000 worms are placed there and a temperature of 20–30°C and relative humidity of 60% are maintained. After 60–65 days, vermicompost is ready.

Another pit method of 1.2 × 1.2 × 1.2 m size with sloping floor may be constructed with bricks and cement at a high level, so that rain water cannot enter in the pit. The pit should be made under shade but should be near a source of water. At the bottom of the pit broken bricks are laid (3–4 cm), followed by a layer of top soil from an arable field up to a thickness of 15 cm. This bed is followed by a layer of small lumps of cattle dung. The bed is then inoculated with 100 earthworms.

Over the earthworms N-rich green leaves and kitchen wastes are applied every day up to 1 week. The pits are left as such but covered with dried leaves for about 10 days. Watering is done from time to time. When new baby earthworms are seen addition of vegetable waste is continued until the pit becomes full. After 45–50 days the contents from the pit are taken out and heaped on the ground in open sunlight. Due to the sun's heat, the earthworms move to the bottom of the heap and settle there. The top portion of the heap is collected and passed through sand sieves. The soft dark-brown or black-brown material so obtained is called vermicompost.

The unsieved material together with the earthworms obtained from the bottom of the heap is again used for vermicomposting. About 2.5 t moist vermicompost in three pits is available and after drying it attains the weight of about 1 t.

4.2.7.6 Advantages of Vermicompost

Vermicompost serves as an eco-friendly fertilizer, which is made of organic wastes such as farm and organic residues, with the help of earthworms. It is one of the best methods of recycling organic wastes to improve soil fertility as well as disposing of these wastes to check environmental pollution and health hazards. The advantages of vermicompost are given below:

- Vermicomposting is an environmentally safe, cost-effective and easy method of preparing better-quality compost within a very short period of time.
- It is a quick method of disposal of garbage without using external energy in an eco-friendly way and leaves no harmful effect on soil and crop plants.
- Huge quantities of domestic, agricultural and rural industrial organic wastes can be recycled into manure free of pollution.
- It is rich in microflora like *Azospirillum*, Actinomycetes, *Phospho bacillus*, which multiply fast in the digestive system of the earthworms.
- Vermicompost is a rich source of nutrients such as macronutrients and micronutrients, vitamins, enzymes and growth hormones which are suitable for all crops in addition to improving physical and chemical properties as well as microbial environment of the soil.
- It also contains antibiotics and thus enhances the resistance capacity of plants against pests and diseases.
- Leaching of nutrients from chemical fertilizers in the soils is reduced considerably, especially from N fertilizers.
- There is greater water absorption and conservation due to burrowing activity of earthworms and increased humus content.
- Produce obtained using vermicompost has a better lustre, taste and shelf life.
- It upgrades the value of original waste material.
- Buffering action of vermicompost neutralizes the pH of the soil and helps in the availability of minerals and trace elements more easily to crops.
- It helps in the multiplication of earthworms, which reduces the incidence of nematodes.
- It is effectively utilized as a carrier formation for *Rhizobium*, *Azospirillum* and phosphate solubilizers, which are recommended with FYM.
- It reduces fertilizer input to a greater extent.
- The use of vermicompost eliminates odour and fly problem.
- It prevents soil degradation, enhances soil fertility status and reduces toxicity.
- It avoids the demerits of chemical fertilizers.

4.2.7.7 Precautions Taken for Vermicomposting

The following precautions should be taken into account while preparing vermicompost:

- Vermicompost heap or bed should not be covered with plastic or polythene sheets or bags because these may trap heat and gases. Only gunny bags have to be used.
- Vermicomposting should be done under shade because it protects the vermicompost and earthworms from rain and the sun’s heat. Low-cost shade may be

made with straw, palm leaves, date palm leaves or leaves of flame tree (*Butea monosperma*) and kachnar (*Bauhinia variegate*), etc.
- Earthworms should not be added to fresh cow dung because the latter generates a huge amount of heat that may kill the earthworms.
- Approximately 50% crop residues, green leaves, etc. should be used with animal dung.
- Addition of larger quantities of acid-rich substances such as tomatoes and citrus wastes should be avoided.
- Dry conditions kill the worms and water-logging drives them away. Thus, optimum moisture levels should be maintained. Watering should be done daily in summer and on every third day in rainy and winter seasons.
- Earthworms may grow in a wide range of temperature varying from 0°C to 40°C. However, 25–30°C is ideal for their normal growth and multiplication.
- Vermicomposting heap should not be overloaded so that high temperatures that will adversely affect their population can be avoided.
- A drainage channel should be created around the heap to avoid stagnation of water, particularly in high rainfall areas in rainy season.
- Chemical fertilizers/pesticides should not be applied over the heap.
- Precautions against attack of red ants and rats should be taken as they feed on cocoons.
- The earthworms should be protected from poultry birds by fencing the vermicomposting area with wire net of 2.5″ square.
- To protect the earthworms from termites, 0.2% chloropyriphos solution or 4% solution of neem seed kernel should be sprayed. Neem-based formulations should be preferred.

4.2.8 Bio-Fertilizers

Bio-fertilizers are carrier-based preparations containing primarily active strains of micro-organisms which either fix atmospheric N or solubilize plant nutrients like phosphate. They stimulate plant growth through synthesis of growth-promoting substances to increase the availability of nutrients that can be easily assimilated by plants (Mahajan et al., 2003a). In other words, any biological material which is used as a source of supplying plant nutrients through various biological sources in soils or plants is a bio-fertilizer (Gupta and Khajuria, 1996; Gupta, 2006). Bio-fertilizers can be used for the treatment of seeds, seedlings and application to soil or composting to increase soil fertility, improved crop growth, and high yield by quick multiplication and efficient biological activities. Preparations containing micro-organisms can also be considered as microbial fertilizers. *Azotobacter* inoculants, *Rhizobium* culture, *Phosphobacterin*, blue-green algae (BGA) and *Azolla* are the main bio-fertilizers. At present, an area of about 2 million hectares has been estimated under bio-fertilizer (Mahajan et al., 2003a, b). Various kinds of bio-fertilizers are described below.

4.2.8.1 N-Fixing Micro-organisms

Nitrogen is the most important primary plant nutrient required by plants in large quantities for successful crop production. Most of the Indian soils are deficient in it. Microbes such as bacteria and BGA have a biochemical process by which atmospheric triple-bound elemental N is converted into organic form, which subsequently becomes available to plants. They are again divided into three subgroups.

Symbiotic N-Fixing Bio-Fertilizers

This refers to the fixation of atmospheric N by the leguminous plants with the help of root nodule bacteria such as *Rhizobium* and *Azolla*. In the symbiotic relationship, the bacteria receive the products of photosynthesis as energy source and, in return, they fix N from the air for their host.

Asymbiotic N-Fixing Bio-Fertilizers

This refers to the fixation of molecular N by free-living organisms like various species of *Clostridium*, *Azotobacter* and BGA independently. They can be categorized into obligate aerobic, facultative or anaerobic organisms.

Associative N-Fixing Bio-Fertilizers

This refers to the loose association between the roots of non-legumes (grass, maize, sorghum, wheat, barley, pearl millet, etc.) and N-fixing bacteria, *Azospirillum*.

4.2.8.2 P-Solubilizing Micro-organisms

Phosphorous is the second most important macronutrient after N required by plants and micro-organisms for their growth and development. Soils in India are poor to medium in available P status. The efficiency of utilization of P fertilizers is very low (20–25%) due to physical or chemical adsorption.

Thus, P become unavailable to crops because of its low solubility and chemical adsorption in soil. Further, there is build-up of insoluble phosphates in soil where P fertilizers have been applied over long periods. Some heterotrophic bacteria and fungi are, however, capable of having the ability to solubilize inorganic P from insoluble sources (Gupta et al., 1986), which include the following.

P-Solubilizing Fungi

Aspergillus awamori, *Aspergillus niger*, *Aspergillus flavus*, *Trichoderma viridi*, *Penicillium digitatum* and *Penicillium oxysporum*.

P-Solubilizing Bacteria

Pseudomonas striata, *Pseudomonas rathonis*, *Pseudomonas calicus*, *Bacillus polymyxa*, *B. subtilis*, *B. circulans*, *B. pulvifaciens* and *B. megaterium* or *megatherium*.

The solubilization effect of P-solubilizing micro-organism (PSM) is generally due to the production of organic acids produced by the above-mentioned P-solubilizing bacteria and fungi. They are also known to produce vitamins, amino acids, growth-promoting substances such as indole acetic acid (IAA) and gibberellic acid (GA), which help in better growth and development of plants.

4.2.8.3 P Absorbers

Ectomycorrhizae

'Ecto' means outside, and therefore signifies the fungus that does not grow inside the cortical cells. A type of mycorrhizal relationship exists in which the fungi invade all the cells of the root cortex. Fungi belonging to Basidiomycotina and a few Ascomycotina form the ectomycorrhizae. They are generally present in evergreen trees, especially conifers belonging to the Pinaceae family (Gupta and Banerjee, 1991), and shrubs and some deciduous trees. Moreover, they are easily visible to the naked eye without any special preparation.

Endomycorrhizae

'Ento' means the growth of fungi in association inside the cortical cells. This is an association between the fungus and the roots of a plant in which fungal hyphae infect the roots and remain up to the cortical region (parenchyma of roots) by secreting cellulolytic enzymes. They are particularly useful on deciduous shrubs and citruses. Vesicular arbuscular mycorrhiza (VAM) fall under the endomycorrhizae category.

Vesicular Arbuscular Mycorrhizae (VAM)

VAM is the symbiotic association of fungi with roots of vesicular plants. It has a great potential, especially in the acquisition of phosphorous in P-deficient soils, and is an effective tool which helps in the solubilization of the unavailable P in the soil. A VAM fungus not only improves crop yields but also saves P fertilizer to the tune of 25–30% (Tandon, 1997) and increases the uptake of nutrients such as P, Cu, Zn, Mn and Fe. A survey of Indian soils showed that out of 363 districts, 2.2% were high, 51.5% medium and 46.3% were low in P content (Ghosh, 1982). Therefore, 98% of the cultivated area in the country requires phosphatic fertilization to get high productivity and profitable yield.

VAM differs from phosphate solubilizers in a way that it does not solubilize the insoluble/unavailable P but assimilates and translocates it to the host roots. The use of VAM has been found very effective in increasing the grain yield of rice and wheat (Majjigudda and Sreenivassa, 1997; Solaiman and Hirata, 1997). It also has the ability to withstand high soil temperatures, acid rain and biocide treatments, and to protect plants from pH extremes. About 90% of plants, including the most important agricultural crops, are known to be associated with VAM fungi. These are formed by fungi belonging to genera *Glomus*, *Gigaspora*, *Acaulospora*, *Entrophospora*, *Scutellospora* and *Sclerocystis*, and have been found to have extremely wide host range. The availability of VAM fungi culture is limited in India at present because it is an obligate symbiont, requires a living host plant for its multiplication and cannot be cultured on artificial media, like agar-agar etc. For this purpose IDRC, Canada, has supported a production unit at BAIF, Pune. Tata Research Institute, New Delhi, is also working for the same. VAM, therefore, can be regarded as an alternative strategy for a more rational agricultural programme in the near future.

Ectenomycorrhizae

Both ectomycorrhizae and endomycorrhizae are present in this category, as observed on roots of a pine tree. Varieties of both kinds of these mycorrhizae have been shown in Table 4.6, as reported by Gupta and Banerjee (1991).

4.2.8.4 Micro-organisms Suitable for Organic Matter Decomposition

The addition of un-decomposed organic materials in soil is detrimental. Their proper decomposition is very essential before adding in the field as insoluble

Table 4.6 Mycorrhizae in natural habitat and field conditions (Adapted from Gupta and Banerjee [1991])

Sr. No.	Type of mycorrhizae	Group/family of host plant	Mycorrhizae fungi
1.	Ectotropic	Pinaceae	Basidiomycetes
		Betulaceae	Deuteromycetes
		Fagaceae	Ascomycetes
2.	Endotropic	Non-septate endophytes	*Endogone* spp.
		(Vesicular arbuscular)	
		Bryophytes, Pteridophytes	
		Gymnosperms	
		(*Minus pinaceae*)	
		Angiosperms	
		Septate endophytes	*Basidomycetes*
		(Vesicular arbuscular)	*Rhizoctonia*
		Orchidaceae, Gentianaceae, Ericales	*Armilaria* and others
3.	Endo/Ectotropic (Joint group)	Salicaceae	VAM fungi
		Juglandaceae	
		Tiliaceae, Myrtaceae	(Phycomycetes)

constituents of organic matter are cellulose and lignin, which delay the process of composting. The decomposition of cellulose is primarily done by fungi such as *Aspergillus awamori*, *Trichoderma viridi* and *Penicillium digitatum*; bacteria including *Arthrobacter*, *Cellulomonas*, *Clostridium*, *Cytophaga*, *Sporocytophaga*, *Trichoderma* and *Paecilomyces*; and actinomycetes like *Nocardia* and *Streptomyces*. On the other hand, decomposition of lignin is carried out by the higher fungi belonging to Basidiomycetes like *Polyporus*, *Agaricus*, *Armillaria*, *Coprinus*, *Chrysosporium*, *Pleurotus* and *Phanerochaete*.

Based on the type of micro-organisms, the classifications of bio-fertilizers are given in Table 4.7.

Thus, it can be concluded from the foregoing discussion that bacterial cultures like *Rhizobium*, *Azospirillum*, *Azotobacter*, *Azolla* and BGA have the ability to fix atmospheric N, and *Psuedomonas striata* and *Aspergillus awamori* have the ability to convert insoluble phosphate into soluble phosphate. Similarly, fungi like VAM increase nutrient uptake particularly of P, Zn and other micronutrients. Bio-fertilizers are mostly cultured in the laboratory, except that BGA and *Azolla* can be mass-multiplied in the field. Thus, bio-fertilizers are now considered to be an important component of sustainable and viable agriculture.

4.2.9 Biogas and Biogas Slurry

Biogas is also called cow dung gas as it is derived from cow dung and other natural farmyard wastes by anaerobic fermentation. The composition of the fuel gas obtained from biogas plants is given in Table 4.8.

Biogas slurry is the end product of biogas plants when organic materials are converted into CH_4 and CO_2. The fuel gas can be used for heating, lighting or as motive power. The range of N, P_2O_5 and K_2O content of the residual slurry on dry basis is given in Table 4.9.

Table 4.7 Classification of bio-fertilizers (Adapted from Mahajan et al. [2008a])

Sr. No.	Micro-organisms	Examples
1.	Bacterial bio-fertilizers	*Rhizobium*, *Azospirillum*, *Azotobacter*, *Phosphobacteria*
2.	Fungal bio-fertilizers	Mycorrhiza
3.	Algal bio-fertilizers	Blue-green algae and *Azolla*
4.	Actinomycetes bio-fertilizers	*Frankia* in woody plants

Table 4.8 Composition of biogas

Sr. No.	Component	Percentage
1.	Methane	50–60
2.	Hydrogen	5–10
3.	Carbon dioxide	30–45
4.	Nitrogen	1–2

Table 4.9 Composition of biogas slurry

Sr. No.	Component	Percentage
1.	N	1.4–1.8
2.	P_2O_5	1.1–2.0
3.	K_2O	0.8–1.2

Table 4.10 Comparative annual advantages of utilization of 45 kg of fresh cattle dung per day

Sr. No.	Method of utilization	Amount of fuel	Effective heat value (million kilocalories)	Amount of manure (cartload[a])
1.	Composted in manure pit	–	–	7
2.	Converted into cakes for fuel	3.65 t	1.55	–
3.	Digested in biogas plant	620 m^3	1.87	10

[a] 1 Cartload = 2 t approximately

In addition, digested slurry contains a fair amount of essential micronutrients. The slurry is rich in humus and easily mixes with the soils. It prevents breeding of flies and is free from odour which is usually associated with compost-making, and can be used as manure to various crops.

The biogas plant thus produces fuel gas and manures and provides local sanitation. Comparative advantages of cow dung composted in manure pits, cakes for fuel and dung digested in biogas plant in 1 year from 45 kg of fresh cattle dung per day can be seen in Table 4.10.

4.2.9.1 Minimum Requirements for Setting Up Biogas Plant

It is not economically feasible to set up even the smallest size biogas plant (2 m^3) unless 40 kg fresh dung is available daily. The cow dung should be mixed with an equal quantity of water before it is fed into the gas plant. The gas plant should be located near the kitchen in an open area exposed to the sun for the greater part of the day. The groundwater level at the site should be at least 4 m below the surface throughout the year.

Impact Points to Remember

- Fertilizer consumption in India has increased remarkably since 1950. India is the world's fourth-largest consumer and producer of fertilizers.
- Hardly 30–40% of the applied fertilizer nutrient is utilized by the crop and the rest is lost through various pathways like leaching, surface run-off, volatilization, denitrification, soil erosion and fixation in soil.
- The manures that are applied in large quantities contain low amount of plant nutrients and, therefore, are known as bulky organic manures such as FYM, compost, night soil, etc.

- The concentrated organic manures contain higher percentage of major plant nutrients than bulky organic manures. The important concentrated organic manures are edible oil cakes (mustard, sesame, groundnut and linseed); non-edible cakes (neem or nim, mahua, karanj, etc.); blood meal; bonemeal; fish-meal; etc.
- FYM is the most important and commonly used organic manure in India. The application of FYM along with the recommended level of chemical fertilizers maintains the organic matter content and augments the water-holding and ionic-exchange capacity of the soil in comparison to fertilizer application alone.
- The practice of ploughing or intermittently adding un-decomposed green plant material into the soil for the purpose of improving the physical condition as well as fertility of the soil is called green manuring and the manure obtained by this method is known as green manure.
- For green manuring, generally leguminous crops are preferred because they have an additional advantage of fixing atmospheric N.
- There are two methods of green manuring – green-leaf manuring and green manuring in situ.
- Organic manures prepared artificially from plant residues (leaves, stalks, twigs, bark, etc.) and animal waste products are termed compost, and the process of making compost is known as composting. On an average, it contains 1.01% N, 0.5% P_2O_5 and 0.8–0.9% K_2O.
- Vermicomposting is a method of making compost with the use of earthworms and their C/N ratio is much lower (16:1) than that of FYM which is usually 30:1 or less.
- In India, compost is commonly of two types – urban or town compost and rural or village compost.
- In India two recommended methods – ‘Indore method’ (aerobic) and ‘Bangalore method’ (initially aerobic and later on anaerobic) – have been widely used. The Indore method was introduced by Howard and Ward at the Indian Institute of Plant Industry, Indore, whereas, the Bangalore method was devised by C. N. Acharya as a result of his experiments at the Indian Institute of Science, Bangalore.
- During composting earthworms need to be protected from poultry birds by fencing the pit with wire net of 2.5 cm^2.
- In vermicomposting, earthworms can be categorized into three types – epigeic, endogeic and diageic.
- The quantity of well-decomposed vermicompost recommended is 5 t ha^{-1}, i.e. 2.5 t ha^{-1} broadcast before sowing and 2.5 t ha^{-1} added 1 month after sowing of crop.
- Any biological material which is used as a source of supplying plant nutrients through various biological reactions in soils or plants is a bio-fertilizer.
- Bio-fertilizers are mostly cultured in the laboratory, except BGA and *Azolla*, which can be mass-multiplied in the field.
- N-fixing microbes such as bacteria, actinomycetes and blue-green algae (BGA) have a biochemical process by which elemental N is converted into organic form which is available to plants such as *Rhizobium*, *Azolla*, *Azotobacter*, BGA and *Azospirillum*.

- The solubilization of insoluble P is generally due to the production of organic acids produced by phosphate-solubilizing bacteria and fungi.
- VAM differs from phosphate solubilizers in a way that it does not solubilize the insoluble/unavailable P, but assimilates and translocates it to the host roots.
- The decomposition of cellulose is primarily done by fungi such as *Aspergillus awamori*, *Trichoderma viridi* and *Penicillium digitatum*; bacteria including *Arthrobacter*, *Cellulomonas*, *Clostridium*, *Cytophaga*, *Trichoderma*, and *Paecilomyces*; and actinomycetes like *Nocardia* and *Streptomyces*, while the decomposition of lignin is carried out by higher fungi like *Polyporus*, *Chrysosporium*, *Pleurotus* and *Phanerochaete*.

Study Questions

1. Define the following:
    (a) Soil
    (b) Farmyard manure
    (c) Night soil
    (d) Crop residues
    (e) Green manures
    (f) Shrubs
    (g) Microbial fertilizers
    (h) Poultry manure
    (i) Biogas slurry
    (j) Micro-organisms
    (k) Organic manures
    (l) Fishmeal
2. Differentiate the following:
    (a) Sewage and sludge
    (b) Soil fertility and soil productivity
    (c) Blood meal and bonemeal
    (d) Ectomycorrhizae and endomycorrhizae
    (e) Urban compost and rural compost
    (f) Chemical fertilizers and bio-fertilizers
    (g) PSM and VAM
    (h) Leguminous crops and non-leguminous crops
    (i) Bacterial bio-fertilizers and algal bio-fertilizers
    (j) Symbiotic N-fixing bio-fertilizers and asymbiotic N-fixing bio-fertilizers
3. Explain briefly the different components of INM system.
4. How can fertilizers play a dominant role in enhancing productivity?
5. What are bulky and concentrated organic manures? Name four of them each.
6. Explain vermicomposting and what types of earthworms are suitable for it.

7. List the different advantages of vermicomposting in sustainable agriculture.
8. What are the different methods for the preparation of composts?
9. What are the different methods of green manuring practised in India?
10. How is green manure different from compost?
11. What are the precautions taken while preparing for vermicomposting?
12. What are the various steps involved in the preparation of vermicomposting?
13. List the various advantages of composting and green manuring.
14. Explain the different methods used for the preparation of vermicompost.
15. What characteristics make the green manure crops more desirable?
16. Write a short note on the following:
    (a) Chemical fertilizers
    (b) Agro-industrial wastes
    (c) Classification of bio-fertilizers
    (d) Types of compost
    (e) Heap method
    (f) Advantages of Indore and Bangalore methods
    (g) Biogas slurry

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Chapter 5

Bio-Fertilizers: Their Kinds and Requirement in India

Abstract After the Green Revolution agriculture was mainly based upon a package of various agricultural inputs, namely the use of high-yielding varieties of different crops, water, pesticides and chemical fertilizers. Excessive use of nitrogenous fertilizers in many rice- and wheat-producing states in comparison to phosphatic and potassic fertilizers has not only deteriorated the soil health but has also impaired the health of human beings and animals (Gupta and Singh, 2006). Similarly indiscriminate and excessive use of pesticides produced health hazards in animals and human beings and soil macro/micro flora and fauna (Gupta and Singh, 2008). Thus, to reinforce the development of sustainable agriculture, use of bio-fertilizers has assured great promise to mete out the nutrient demand. The term 'bio-fertilizers' denotes nutrient supplement inputs for plant growth which are biological in origin. The role of bio-fertilizers in agricultural production assumes special significance, particularly in the present context of expensive chemical fertilizers. Moreover, it can provide the farmers with a new strategy which is helpful for achieving the goal of increasing productivity. Keeping in mind the environment safety, food security and availability of resources, it becomes obligatory to harness the full potential of the available bio-fertilizers.

Keywords Soil health • crop yields • chemical fertilizers • food grain production • sustainable agriculture • bio-fertilizers

The Green Revolution in India during the late 1960s has no doubt brought about self-sufficiency in food production. However, excessive use of nitrogenous fertilizers without phosphate and potassic fertilizers, and plant protection chemicals for maximizing crop yield has resulted in the deterioration of physical, chemical and biological health of soils in respect of cultivated lands. Bio-fertilizer use has therefore become an essential input along with the use of other organics in intensive agriculture due to its crucial role in augmenting nutrient supply to crops, by increasing the nutrient availability through exploitation of natural processes like biological N fixation, solubilization of insoluble P, decomposition and recycling of organic wastes, etc. It has become more so at a time when excessive use of chemical ferti-

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lizers and their increasing demand in intensive farming have increased, but pose a serious threat to soil health, environment and sustainability in food grain production. In contrast to chemical fertilizers, bio-fertilizers release nutrients slowly to the soil. Thus, the management of long-term soil fertility and sustaining crop productivity through biological fertilizers is a very important component of agriculture (Mahajan et al., 2002, 2008a; Mahajan and Sharma, 2005).

> Bio-fertilizers refer to various inoculants or cultures containing a specific micro-organisms in concentrated form, which are derived either from nodules of plant roots or from the soil of root zone (rhizosphere). And posses unique ability to fix atmospheric N either by living symbiotically with the roots of leguminous plants or non-symbiotically (free living) or to transfer native soil nutrients such as P, Zn, Cu, Fe, S etc. from the non-usable (fixed) form to usable form through biological processes.

5.1 Bio-Fertilizer Requirement in India

India is one of the most important countries in bio-fertilizer production and consumption in the world. The present production capacity of different bio-fertilizer production units in the country is more than 10,000 t year^{-1}. At present there are 151 bio-fertilizer production units representing both government and non-government agencies in the country that are producing and supplying different bio-fertilizers, out of which, the Government of India has supported 71 units. Based on cultivated areas of the country and treatment of the seed sown at the rate of 200 g bio-fertilizer per 10 kg seed, the National Bio-fertilizer Development Centre (NBDC), Ghaziabad, has worked out the requirement of total bio-fertilizers as given in Table 5.1.

The systematic study on bio-fertilizers in India was first started by N. V. Joshi in 1920, followed by many more scientists with the changing times. The first bio-fertilizer unit was started by the Gujarat State Fertilizer Company (GSFC), Vadodara, in 1985, and many more followed thereafter. Among the different states, the maximum production capacity is in Tamil Nadu followed by Madhya Pradesh, Uttar Pradesh, Gujarat and Maharashtra. At present, about a dozen fertilizer companies are engaged in bio-fertilizer production, marketing and promotion (Table 5.2).

Table 5.1 Bio-fertilizers and their estimated requirement in India

Bio-fertilizers	Estimated requirement (tonnes)
Rhizobium	34,999
Azotobacter	145,953
Azospirillum	74,342
Blue-green algae	251,378
P solubilizer	25,534

Table 5.2 Capacity and production of bio-fertilizers manufactured by major fertilizer companies (1998/99) (Adapted from Biswas et al. [2001])

		Production (tonnes)					
Company	Capacity	*Rhizobium*	*Azotobacter*	*Azospirillum*	*Acetobacter*	PSM	Total
Ajay Biotech (Mkt. ZIL)	2,400	–	–	–	–	769.8	769.8
HFC	750	[a]	[a]	[a]	[a]	[a]	97.6
GSFC	500	34.8	59.2	47.3	–	118.7	260.0
MFL	343	8.9	–	116.7	–	201.7	327.3
MAIDC	300	17.7	0.8	–	–	27.8	46.3
KRIBHCO	250	23.6	122.3	–	–	104.1	250.0
Kisan Agro (Nima Ltd.)	240	[a]	[a]	[a]	[a]	[a]	14.5
RCF	150	–	–	–	–	63.7	63.7
SPIC	100	7.7	–	47.8	3.0	35.3	93.8
GFCL	75	0.9	–	1.9	–	2.8	5.6
MLN (IFFCO)	75	8.4	34.5	–	–	47.6	90.5
PPCL	75	0.4	–	–	–	–	0.4
Total	5,258	102.4	216.8	213.7	3.0	1,371.5	2,019.5

[a] Breakup is not available

5.2 Major Bio-Fertilizer Groups

Long-term fertility experiments have shown that continuous use of suboptimal doses of chemical fertilizers has resulted in the sickness of soil, environmental degradation and decline in crop yields. Bio-fertilizers are able to cope with these problems besides being eco-friendly and environmentally safe low-cost inputs that reduce the farmers' fertilizer bill vis-à-vis maintenance of soil health (Gupta and Khajuria, 1996). The major bio-fertilizer groups which can be used in different agricultural crops are described below.

5.2.1 Rhizobium

The first commercial bio-fertilizer was developed as a *Rhizobium* culture in 1895 with the product 'Nitragin' in the United States. In India, the use of *Rhizobium* inoculants was initiated in 1920, but its systematic production began after 1950 with gradual introduction of other bio-fertilizers.

The most widely studied and extensively used bio-fertilizer is *Rhizobium* inoculant, which colonizes the roots of specific legumes to form tumour-like growths called root nodules (Plate 5.1). These nodules act as mini factories of NH_3 production. *Rhizobium* inoculants help in establishing efficient symbiotic association with leguminous pulse and fodder crops that can fix 50–100 kg N ha^{-1} or even more, depending upon the cross-inoculation group, the *Rhizobium* spp. and the kind of soil.

Plate 5.1 *Rhizobium*

Recently, Gupta and Kher (2006) and Gupta (2007) have reported that N fixation by different legumes varied widely, ranging from as low as 10 kg ha^{-1} $year^{-1}$ to as high as 500 kg ha^{-1} $year^{-1}$. The data further indicated that cultivation of peas in grasslands fixed highest N, varying from 400 to 500 kg ha^{-1} $year^{-1}$ (Gupta, 2007).

5.2.1.1 Legume – *Rhizobium* Symbiosis

The most important plant group involved in symbiotic N fixation comprises dicotyledonous plants of the family leguminoseae. There are about 10,000 species of legumes, and out of these nearly 200 are cultivated by humans and have been divided into three subfamilies, namely *Papilionaceae*, *Caesalpinioideae* and *Mimosoideae*. The largest of the three is *Papilionaceae*. In this subfamily important cultivated plants like *Trifolium*, *Melilotus*, *Medicago*, *Phaseolus*, *Crotalaria*, *Pisum*, *Dolichos*, *Cajanus*, *Vigna*, *Lathyrus*, etc. are found.

It is generally believed that most of the leguminous plants bear nodules. However, it has been found that hardly 10–12% of the leguminoseae have been studied for nodulation. It has also been found that legumes belonging to *Papilionaceae* and *Mimosoideae* are more often nodulated.

The fact that legumes increase the fertility of soil was observed by several scientists and they postulated N fixation by these legumes. This was found to be true and was proved by later scientists. In 1889, Beijerinck isolated the bacterium from the root nodules of legumes. It was later well established that the bacterium by itself is incapable of fixing atmospheric N (N_2 – triply bound, i.e. $N{\equiv}N$), and that

N is accumulated by the leguminous plants only in symbiosis with the bacterium. The importance given to legume *Rhizobium* symbiosis is so much that *Rhizobia* are classified based on the ability of the organism to nodulate the test legume plant. The specification within the genus *Rhizobium* is based mainly, for the present at least, upon host specificity. Based upon this, more than 20 cross-inoculation groups have been established, but out of them only seven have achieved prominence (Alexander, 1978).

5.2.1.2 How Is a Cross-Inoculation Group Defined

A cross-inoculation group can be defined as a '[c]ollection of leguminous species which develop nodules when exposed to bacteria obtained from the nodules of any member of that particular plant group'. Consequently, a single cross-inoculation group ideally includes all host species which are infected by an individual bacterial strain. However, many legumes of agricultural importance vis-à-vis non-cultivated plants are not inoculated by bacteria of six main types of cross-inoculation groups. Black locust (*Robinia pseudoacacia*), garbanzo (*Cicer arietinum*), hemp sesbania (*Sesbania exaltata*) and others do not fit into the established categories. They require distinctly different bacterial strains. The cross-inoculation groups and *Rhizobium* legume association are listed in Table 5.3.

5.2.1.3 Nature of the Microsymbiont

Members of the genus *Rhizobium*, after infecting an appropriate legume, form the nodules and take part in symbiotic N fixation. *Rhizobia* are Gram-negative, non-spore-forming aerobic motile rods varying in size from 0.5 to 0.9 μm wide and 1.2 to 3.0 μm long. They can utilize several carbohydrates, sometimes with an accumulation of acid but not of gas. They are facultative symbionts, capable of living freely in the soil and in the root region of leguminous plants. However, they can only infect the roots of selective leguminous plants and form nodules.

Table 5.3 Cross-inoculation groups and *Rhizobium* legume association (Adapted from Alexander [1978])

Genus	Species	Crops
Alfalfa group	*R. meliloti*	*Medicago*, *Melilotus*, *Trigonella*
Clover group	*R. trifolii*	*Clovers*
Pea group	*R. leguminosarum*	*Pisum*, *Vicia*, *Lathyrus*, *Lens*
Bean group	*R. phaseoli*	*Phaseolus*
Lupine group	*R. lupini*	*Lupinus*, *Ornithopus*
Soybean group	*R. japonicum*	*Glycine*
Cowpea group	–	*Vigna*, *Crotalaria*, *Arachis*, *Cajanus*, *Phaseolus*, *Dolichos*

5.2.1.4 Methods of *Rhizobium* Inoculations Application

Several procedures have been developed to ensure beneficial nodular associations. One of the most familiar and primitive methods is the application of soil from a field previously cropped with legumes. This technique, however, is not good because soil weeds, pathogens as well as other microbes are added to the soil, which causes inefficiency to the nodule bacteria. On the other hand, seed inoculation of specific *Rhizobium* spp. in legumes, under different Indian soil conditions, has been proved very useful. On the farmers' fields in different parts of south India, seed inoculation with *Rhizobium* has proved essential in increasing the yield of groundnut and Bengal gram. There were, however, variations in yields from place to place due to several factors like soil, climate, cultural practices, etc., and recently soil-based carriers have replaced the early inoculants.

Treatment of seeds with the slurry of *Rhizobium* culture is the most effective method of its application for obtaining maximum response. This method consists of the following steps:

1. Slurry of the required quantity of culture or inoculant is prepared. Generally, 400–500 ml of water is required for 200 g of culture.
2. Ten per cent jaggery or gur, i.e. 40–50 g, is added in the amount of water mentioned above. The solution is boiled and cooled.
3. The prepared slurry is poured over the heap of seeds required to be treated. The seeds are mixed homogeneously with hands. Thereafter, the treated seeds are spread over a clean floor or on a plastic or gunny bag for drying.
4. The treated seeds are sown immediately.
5. The seeds are never dried directly in the sun as some of the rays may kill the *Rhizobia*.

Usually, 10 kg of normal-sized seeds such as green gram (mung), black gram (urd), cowpea, lentil and berseem are treated with 200 g of *Rhizobium* culture by the above-mentioned method. However, seeds of groundnut, chickpea, soybean and pea, being bigger in size, require 400–500 g of culture for 10–12 kg of seeds.

5.2.2 *Azotobacter*

Azotobacter is an aerobic free-living, N-fixing bacterium that fixes the atmospheric N in soil without any association, which means it is a non-symbiotic N-fixing bacterium that benefits the plants by growing in their rhizosphere (Plate 5.2). There are six species of *Azotobacter*, namely *A. chroococcum*, *A. nigricans*, *A. paspali*, *A. vinelandii*, *A. beijerinckii* and *A. armeniacus*, of which *A. chroococcum* is the one most commonly found in arable soils. It is generally present in neutral or alkaline soils. The population of *A. chroococcum* in Indian soils rarely exceeds 10^4–10^5 g^{-1} of soil. The population of *Azotobacter* in soils of Jammu & Kashmir ranged from 6.5 to 45.0 × 10^3 g^{-1} of soil (Gupta et al., 1977), with dominance of *A. chroococcum*. However, the number of these bacteria was in the range of

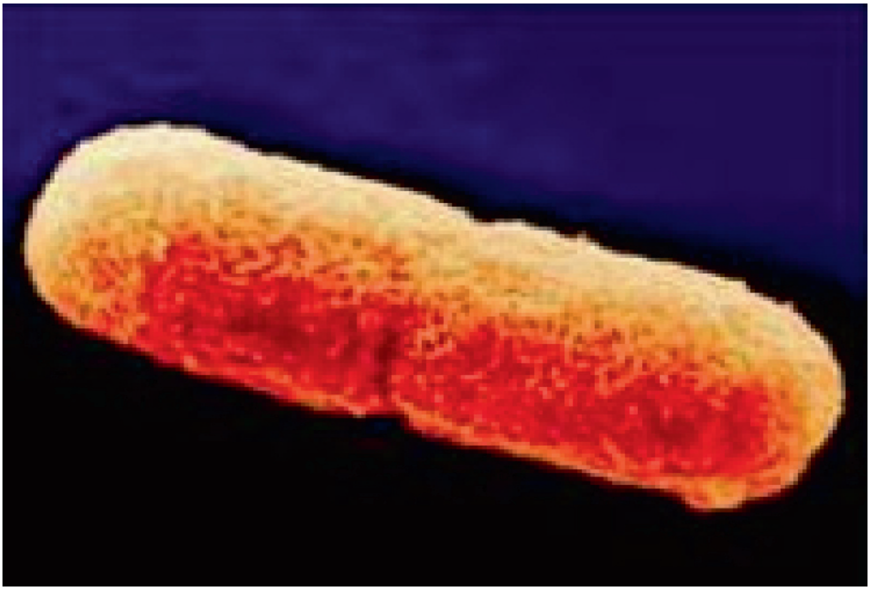

Plate 5.2 *Azotobacter*

51×10^3 to 76×10^3 g^{-1} of soil on floating islands of Kashmir (Gupta et al., 1983a). In great soil groups of the north-west Himalayas, the population of *Azotobacter* was 6.7–62.3 g^{-1} of soil (Gandotra et al., 1998). In these soils three species of *Azotobacter*, namely *A. chroococcum*, *A. vinelandii* and *A. beijerinckii*, were observed. *A. chroococcum* inoculants can save N to the tune of 15–20 kg ha^{-1} in cereals and millets. Use of *Azotobacter* culture has been found to be effective for a variety of non-leguminous crops such as directly seed-sown paddy and wheat. Its use has shown an increase in the yield of rice, ranging from 1% to 20% and that of wheat from 10% to 30% (Singh and Dixit, 2001). In Russia, with the use of *Azotobacterin* culture, 8–10% increase in the yield of non-leguminous crops like wheat and paddy has been reported. The Australian experience is more or less similar in that *Azotobacters* can colonize the N-poor wheat fields. In India too, treatment with this culture has proved to be beneficial not only for wheat and paddy but also for other crops (Bajpai, 2003). Commercial preparations of *Azotobacters* have also been found useful in other crops like sugarcane, cotton, maize, pearl millet (bajra), finger millet (ragi) and a number of vegetables such as tomato, brinjal (aubergine), chillies, cabbage, and potato (Mahajan et al., 2003a). Besides these crops, use of *Azotobacter* is also being recommended for plantation crops – coffee, tea, cocoa, coconut, cardamom, etc.

Apart from N fixation, this organism is also capable of producing antibacterial and antifungal compounds, vitamins and growth hormones (IAA and GA_3) in rhizosphere, leading to increased germination, plant growth and yield. In general, the use of *Azotobacter* reduces the inorganic fertilizer requirements to the tune of 25–50% (Venkataraman, 1982).

5.2.2.1 Methods of *Azotobacter* Inoculation Application

Azotobacter is a broad-spectrum inoculant which has proved to be useful for a number of non-leguminous crops, including vegetables, fruit trees and other crops. The inoculant can be used in different ways as described below.

Seed Treatment

The *Azotobacter* inoculant is coated to the seeds. A total of 25 kg of medium-sized seeds such as wheat, oats, cotton, maize and rice (to be sown directly) can be treated with 500 g of *Azotobacter* inoculant, whereas 250 g ha^{-1} inoculant is enough for treatment of small-sized seeds like mustard.

Seedling Treatment

Seedling treatment method is useful where transplanting of seedlings is required. For this purpose, the required amount of inoculant is prepared in water as suspension at a ratio of 1:10 or 1:15. The roots of seedlings in suspension are dipped and kept immersed for about 10–15 min. Treated seedlings should be planted immediately. Suspension of 2.5 kg inoculant in 25.0–37.5 l of water is enough for treatment of seedlings meant for 1 ha.

Setts/Tuber Treatment

This kind of application is beneficial to sugarcane setts and tubers of potato, where 1 kg *Azotobacter* inoculant is prepared in 40–50 l of water and the setts/tubers dipped in this for 5–10 min. The treated setts/tubers are then sown immediately.

Suspension of 2.5 kg *Azotobacter* inoculant is required for treatment of setts/tubers for 1 ha.

Soil Treatment

In the soil treatment method, a mixture of 5.0–7.5 kg of *Azotobacterial* inoculant is prepared in 100–150 kg of soil or FYM/compost for short-duration crops. The mixture is then broadcast in 1 ha of land either at sowing time or about 24 hr prior to sowing. This dose is doubled when required for long-duration (perennial) crops.

5.2.3 Azospirillum

Azospirillum is a common inhabitant in the tropics and is widespread in soils. It grows even inside the roots of grasses, some of which are economically important.

The association of this micro-organism with graminaceous plants like wheat, oats, pearl millet, sorghum and maize indicates an associative symbiosis. The recent terminology, however, used to describe this type of association of *Azospirillum* with plants is 'diazotrophic biocoenosis'. It colonizes the root mass and fixes N in loose association with plants and has positive interaction with cereal crops with an average response equivalent to 15–20 kg ha^{-1} of applied N. It fixes N in an environment of low oxygen tension because this bacterium induces the plant roots to secrete mucilage, which creates low oxygen environment and helps to fix atmospheric N. *Azospirillum* inoculations are found beneficial and are recommended for maize, wheat, barley, sorghum, pear millet and forage crops. Their application increases grain yield of cereals by 5–20%, millets by 30% and forage crops by over 50%. They are tolerant to high temperature ranging from 30°C to 40°C, and also supply growth regulators and secrete antibiotics which act as pesticides. Use of *Azospirillum* inoculation under saline–alkaline conditions is also possible because their strains are known to maintain high nitrogenase activity under stress conditions. It can be noticed that application of organic manure along with *Azospirillum* enhances N fixation ranging from 20 to 40 kg N ha^{-1} (Verma and Bhattacharya, 1990).

Use of *Azospirillum brasilense* has proved better than applying 30 kg N ha^{-1} to paddy in the Indo-Gangetic alluvium soil of Varanasi. Similar results were also reported in the case of sorghum and pearl millet in the field. Basal application of N (30, 45 and 90 kg ha^{-1}) showed a detrimental effect on *Azospirillum*. So an application of *Azospirillum* alone with no basal application of N should be advocated to the peasants.

Although its benefits have been reported with mostly graminaceous plants, *Azospirillum* can be inoculated to cotton, jute vegetables, potato, oilseed crops, flowers and horticulture crops also (Prasad, 2006). To study the effect of seed inoculation with *Azospirillum brasilense*, field trails were conducted in Nagpur district, Maharashtra, during 2004 on sorghum crop. The results indicated that sorghum responded well to N and the increase in yield was more than 40% in different soils compared to the control group (Prasad, 2006). However, the response of N and *Azospirillum* was relatively higher in moderately deep soils than in shallow and very deep soils.

5.2.3.1 Methods of Azospirillum Inoculation Application

The methods of application of *Azospirillum* inoculum are the same as have been described with the *Azotobacter* inoculant. However, the application of the former in the case of rice is done twice. First at the time of seed sowing to raise the nursery. For this purpose, the required quantity of *Azospirillum* inoculant (20 g kg^{-1} of seeds) is applied on to the seeds. The suspension is prepared by mixing about 200 g of inoculant in 300–400 ml freshwater or in 10% gur solution. The cooled inoculant slurry is then mixed thoroughly with the seeds in order to place a uniform coating over each seed. Usually a packet of 200 g *Azospirillum* inoculant is sufficient to treat 10 kg of seeds.

Azospirillum inoculant can also be applied at the time of transplanting. For this purpose, suspension of *Azospirillum* is prepared by mixing 1 kg of inoculant in 15–201 water and roots of the seedlings are dipped in it for 10–15 min before transplanting.

5.2.4 *Azolla*

The name *Azolla* has been derived from two Greek words *azo*, which mean to dry and *allyo*, which means to kill, inferring thereby that the plant dies under dry conditions. It is an aquatic, floating, freshwater fern that has a symbiotic relationship with N-fixing blue-green algae (BGA) known as cyanobacteria and belongs to the family Azollaceae. *Azolla* is widely found in temperate and tropical/subtropical natural ecosystems as well as in lowland rice-growing regions of the world, mainly popular in India, Vietnam, China, Thailand and Philippines. It has six species, i.e. *Azolla filiculoides*, *Azolla caroliniana*, *Azolla mexicana*, *Azolla microphylla*, *Azolla nilotica* and *Azolla pinnata*. They are triangular or polygonal in shape, and float on the water surface individually or in mats (Plate 5.3). On an average, a well-decomposed *Azolla* contains N (4–6%), P (0.5–0.9%), K (2–6%), Ca (0.4–1.0%), Mg (0.5%), Mn (0.11–0.16%), Fe (0.06–0.16%) and H_2O (>80%). Apart from this, it is very rich in proteins,

Plate 5.3 *Azolla*

essential amino acids, vitamins (vitamin A, vitamin B_{12}, beta carotene) and growth-promoter intermediaries.

In India, *Azolla* is commonly found in ponds, pools, tanks, shallow ditches, channels and in rice fields at several locations. Nitrogen-fixing BGA – *Anabaena azolla*, which has been found the most suitable with Indian rice culture, is always present in the cavities on dorsal leaves and also fixes atmospheric N. This fern–alga system is unique since both photosynthesis and N fixation occur in the leaves and, therefore, is an attractive resource for photosynthetic production of N fertilizer. *Azolla pinnata* has also been found commonly in India (Singh, 1982).

5.2.4.1 Requirements of Nutrients for *Azolla* and Factors Responsible for Its Production

The major nutrient requirement of *Azolla i*s phosphate (10–15 kg P_20_5 ha^{-1}) which multiplies at a fast rate and becomes almost double in 3–5 days. This makes it a good source of organic matter in the field, and thereby improves soil texture, structure, aggregation and water-holding capacity. It can be produced in nursery plots, ponds, tanks, polythene-lined sheets and earthen ditches. *Azolla* is established by vegetative propagation and used as a bio-fertilizer as well as a green manure in rice crop. The most important characteristic of *Azolla* is to release plant nutrients slowly and uniformly like slow-releasing fertilizers, and eventually reducing leaching losses in rice fields. The major limitations in the use of *Azolla* as a bio-fertilizer include the lack of water, particularly in north India, and temperature sensitiveness of the species. Maintenance of *Azolla* in ponds during winter is a big problem due to low temperatures. Higher temperature more than 40°C is also harmful to the fern. Their production is thus affected by several factors which are given below.

Temperature

The optimum temperature for better growth of *Azolla* ranges from 20°C to 30°C. Above or below this optimum temperature both the growth and the N-fixation capacity are adversely affected. The optimum N fixation was reported at pH 6.0 and temperature 20°C. *Azolla* can be protected from high temperature by providing shade, which can be achieved by growing *Sesbania* on field edges or by adopting intercropping and draining the field.

Water

Water is essentially required for existence of the *Azolla*. *Azolla* grows well in standing water or wet mud, but optimum condition is in standing water. *Azolla* dies when the soil surface starts drying. A minimum depth of 5–10 cm of water is desirable for good *Azolla* growth, with its tip touching the soil and a rise of water level up to 30 cm has no adverse effect. Shallow depth favours better nutrition since roots are near the soil.

Sunlight

Relative growth and nitrogenase activity will be at their maximum potential at 50% of full sunlight, while heavy shading decreases *Azolla* growth to almost zero.

Soil pH

Azolla can survive within a pH range of 3.5–10.0, but optimum growth will be in the range of 4.5–8.0. Strongly acidic and alkaline soils are not suitable for *Azolla* cultivation without proper amendments. According to Singh et al. (1982), although *Azolla* grows in soils with slightly acidic (pH 6.0) to alkaline (pH 8.0) reaction, yet optimum growth is attained at neutral pH (6.5 to 7.5), and low pH ranging from 2.9 to 3.6 does not support its growth.

Relative Humidity

The optimum relative humidity needed for normal *Azolla* growth is 80–90%. *Azolla* fronds (leaves) become dry, turn fragile and become susceptible to adverse conditions when relative humidity is less than 60%. Higher relative humidity (more than 90%) causing a longer dew point period makes the plant susceptible to diseases as well as encourage insect infestation.

Nutrients

Phosphorus is the most common limiting factor in the growth of *Azolla*. If fronds of *Azolla* are placed in P-deficient solution, their growth slows down or stops and they become reddish-brown and develop curled roots. Water containing 20 ppm P is optimum for *Azolla* growth.

Salinity

Azolla growth stops in the presence of 1.3% salts and it dies totally at higher salt concentration. Optimum salt concentration is 90–150 mg l^{-1} of water, but there is a lot of variability amongst different species.

Wind

The *Azolla* is also affected by wind, as the latter tends to push all the fronds together on the same part of the water surface. It is possible to reduce the influence of this factor by providing bunds and *Azolla*–rice intercrop.

5.2.4.2 Methods of *Azolla* Inoculation Application

Azolla can be used in two ways for paddy cultivation which are explained as under.

Azolla as a Green Manure

About 10–15 t of *Azolla* inoculum is used per hectare in the paddy fields nearly 1 week after transplanting. Approximately 10 kg P_2O_5 ha^{-1} in the form of superphosphate is required for the growth of *Azolla*.

Azolla as Dual Cropping

If water is not available before transplanting, inoculate *Azolla* on standing water at the rate of 500 kg fresh *Azolla* per hectare after about 1 week of planting the crop.

The recommended quantity of superphosphate should be applied in split doses, i.e. half as basal and half during addition of *Azolla*.

5.2.5 Blue-Green Algae (BGA)

As reported by Gupta et al. (1983b), the first observation of the ability of BGA to assimilate molecular N was made by De (1936, 1938), Singh (1939, 1942) and Sulaiman (1944). Now there is an unequivocal evidence that the maintenance of soil fertility in rice fields is through N-fixing BGA (Singh et al., 1982; Venkataraman, 1982; Mishra, 1993; Singh and Dixit, 2001). In the rice fields of India, the most active N fixer is *Aulosira fertilissima*. BGA have been found to fix atmospheric N in the range of 12–80 kg ha^{-1} under various Indian soil conditions.

The beneficial effects of BGA on the yields of different rice varieties have been demonstrated in a number of countries, including India. It has been found that in USSR, inoculation with *Morphonostoc punctiforme* resulted in 13.2% increase in rice crop yield, while in China with *Anabaena azotica* it was about 24%. In Japan, the average rice yield increase due to algal inoculation (*Tolypothrix tenuis*) was 2% in first year, 8% in second year, 15% in third year and 19% in fourth year. In a large number of Indian trials, complemented with recommended doses of N by BGA, an increase of about 10% higher yield in various varieties of rice has been found.

5.2.5.1 Ideal Conditions for BGA, Their Main Genera in India and Their Advantages

BGA are free-living N fixers, distributed worldwide and are believed to contribute to fertility in many agricultural/soil ecosystems as stated above. They

Plate 5.4 Blue-green algae (BGA)

are photosynthetic prokaryotes capable of fixing atmospheric N, particularly under water-logged rice fields and constitute a major component of INM system. Although BGA are widely distributed in different ecosystems, yet water-logged rice fields provide ideal conditions for their growth and multiplication (Plate 5.4). The principal BGA-fixing genera found in Indian rice soils include *Anabaena*, *Nostoc*, *Aulosira*, *Calothrix* and *Tolypothrix*. *Cylindrospermum*, *Aphanotheca* and *Wollea* are the other genera of BGA found suitable in rice-growing soil. Neutral-to-alkaline soils (pH 7.5–10.0) rich in available P, low flood water N, turbidity-free shallow water depth, moderately high temperature (30–35°C), bright sunshine and less frequent rains favour growth and N fixation by BGA. Rice fields provide natural medium for proper growth of these micro-organisms and can fix 25–30 kg of atmospheric N per hectare or more in soil. Besides this, they also add organic matter (80–120 kg ha^{-1}) and amino acids in soil, and thus help to improve soil structure. They reduce the hardness of water and this is particularly helpful when rice is raised with borewell water. Apart from the parameters mentioned above, BGA are known to produce growth-promoting substances and vitamin B_{12} which benefit the rice plants. BGA inoculation increases the yield of rice also.

5.2.5.2 Symbiotic Associations of BGA

Although most of the N-fixing BGA are free-living, many are symbiotic with plants. For example, many lichens are symbiotic associations of BGA with fungi. Some genera like *Nostoc punctiforme* have been found in nodules of clover. Several bacteria like *Caulobacter* spp., *Bacillus megatherium* and *A. radiobacter*, living in the slimes of BGA, either double the vigour of N assimilation by *Nostoc* or stimulate N fixation.

5.2.5.3 Methods of BGA Inoculant Application

BGA is applied at the rate of 10 kg ha^{-1}. The BGA flakes are crushed into powder and this powder is then broadcast in the standing water of rice fields about 1 week before transplanting of rice. The fields are kept under water-logged conditions for 3–4 days immediately after BGA application.

5.2.6 Phosphate-Solubilizing Micro-organisms (PSMs)

Several soil bacteria (particularly *Pseudomonas striata* and *B. polymyxa*) and fungi (*Aspergillus awamori* and *Penicillium digitatum*) posses the ability to transform insoluble phosphates into soluble forms by secreting organic acids such as formic, acetic, oxalic, malic, gluconic, citric, propionic, lactic and succinic, acids etc. These acids lower down the pH and, in turn, bring about dissolution and immobilized forms of phosphates. Besides, some of the hydroxyl acids may chelate with Ca and Fe, resulting in effective solubilization and thereby higher utilization of soil phosphates by plants. These micro-organisms are recommended for wheat, paddy, cowpea, gram, soybean and potato crops and are found to increase the yield by 10–50%. Phospho micro-organisms when used in conjunction with rock phosphate can save about 40% of the crop requirement of superphosphate.

It is important to mention that phosphobacterin is the name given to bacterial culture of *B. megatherium* var. *phosphaticum* by the Russian and European scientists (Gupta, 1972, 2002). This bacterial fertilizer is manufactured in large tanks under aerobic conditions in the powder form. The recommended dose is 5–15 g ha^{-1}.

5.3 Prospects of the Use of Bio-Fertilizers

The increase in production and use of bio-fertilizers in India is the result of special attention given by the government and interest by entrepreneurs to set up bio-fertilizer production facilities. Farmers have now also realized the benefits of the use of bio-fertilizers. The prospects of bio-fertilizers are as follows:

- Due to escalating costs, the average consumption of chemical fertilizers is very low compared to the required level. Bio-fertilizers being cheap and non-bulky can fulfil the demand of fertilizer consumption.
- There are no ill-effects on the soil health and the environment since bio-fertilizers are natural products carrying living micro-organism derived from the plant root or cultivated soil.

- Besides their role in atmospheric N fixation and P solubilization, they also help in stimulating the plant growth through hormones, providing better nutrient uptake and increasing tolerance towards drought and moisture stress.
- A small dose of a bio-fertilizer (300–500 g of material per hectare) is sufficient to produce desirable results because each gram of carrier contains approximately 10 million viable cells of a specific strain.
- Bio-fertilizers reduce the pressure on the non-renewable nutrient sources and thus their help in conservation.
- They are harmless, improve soil properties and maintain soil fertility, so their use can play a vital role as a low-cost input for sustainable agriculture.
- Marginal farmers in India cannot afford chemical fertilizers, but the use of bio-fertilizers is affordable and economical for a wide variety of crops such as cereals, millets, legumes, oilseeds, spices, vegetables, fruits and plantation crops.
- The cost/benefit ratio of bio-fertilizers is always higher, so their use is acceptable in all places of cultivation.
- Bio-fertilizers also ensure the supply of essential micro-nutrients like Fe, Zn, Mn, Cu, etc. for the augments of crop yields.
- *Azospirillum* and phosphobacterin bio-fertilizers secrete plant growth hormones which favour germination and root growth. They also result in absorption of more nutrients from soil, leading to increase in nutrient use efficiency.
- Certain bio-fertilizers may also work as bio-pesticides. For example, *Azotobacterin* strain 1006 has shown potential to inhibit some seed-borne pathogens in some of the cereals, as was reported by Shah and Joshi (1986). The efficiency of *Azotobacterin* isolated from local conditions can be increased by its use along with fresh FYM (Gupta et al., 2007). The data indicated that the use of *Azotobacter* culture alone enhanced the maize grain yield in the order of 21–53% over the control. But its use with an application of FYM increased the maize yield up to the tune of 93–123% over the control.
- The wastelands and lowlands can be enriched and their productivity enhanced by the application of bio-fertilizers.
- Bio-fertilizers also enhance the chlorophyll content favouring a higher photosynthesis rate.
- Bio-fertilizers like *Azotobacter* and *Azospirillum* are very useful for dry-land and rain-fed farming as well as for irrigated areas. Seed inoculation of maize with *Azotobacter* culture increases plant height, dry matter production, grain and stover yield compared to the control (Gandotra et al., 1989).
- They enhance the level of secondary metabolites, like phenols, that offer resistance to pests and diseases.

5.4 Constraints in the Use of Bio-Fertilizer

The modern-day intensive crop cultivation requires the use of mineral fertilizers, but they are expensive and their indiscriminate use creates a number of ecological and environmental problems. At this critical juncture, there is a need to use bio-fertilizers, which are low-cost inputs, renewable and pollution-free. However, in spite of the usefulness of bio-fertilizers, the farming community does not accept this practice because the crop response to organic manures and bio-fertilizers is not as spectacular as with mineral fertilizers (Mahajan et al., 2003a, b). However, in the long run, the yield of crops becomes stabilized with continuous use of organics. Hence, the use of organic farming must be advocated to the farmers on these lines.

5.4.1 Biological Constraints

- First, the presence of native ineffective strains, which cannot be displaced easily by the inoculated strains, if they are not very effective
- Second, the presence of antagonism strains in the bio-inoculants, which minimize the number of biological N-fixing micro-organisms in the rhizosphere

5.4.2 Technical Constraints

- Mutation, which arises during fermentation, is a serious problem, because it results in reduction in effectiveness of bio-inoculants, thereby raising the cost of production and quality.
- Region-wise inadequate availability of soil-specific strains, which limits the popular use of bio-inoculants.
- Shelf life of bio-fertilizers is a major constraint in the development of adequate market. Lower shelf life of bio-fertilizers carries some risk of recycling if it is not used or sold before expiry and this will sustain monetary loss to the marketing agency.

5.4.3 Marketing Constraints

- Demand is limited because of poor and inadequate knowledge of the farmers about the usefulness of bio-fertilizers in increasing crop yields and soil productivity.
- Extension centres, by and large, do not have well-qualified technical staff who can handle all the problems.
- Unavailability of proper transportation and storage facilities is also a major constraint for development of an effective market.
- In practice, State Departments of Agriculture place supply orders mostly with their own production units from where packets are transported to district quarters. Before these packets reach the field they pass through a chain of extension workers and then to farmers from production units to the field; in this course, the micro-organisms are exposed to high temperatures (above 40°C), which

may result in their death, thereby making them poor-quality bio-fertilizers. Therefore, these substandard packets when used by farmers harm both the producers and users alike.

5.4.4 Field-Level Constraints

- Low level of acceptance of bio-fertilizers by the farmers is because the response is not immediately visible and many times erratic in nature.
- Existing soil conditions such as acidity, alkalinity, pesticides application and high nitrate level limit the N-fixing capacity of the inoculants, resulting in poor performance of the inoculants.
- Presence of certain toxic elements like Hg, Cr, Cd, etc. and deficiency of nutrients like P, Cu, Co and Mo in many soils render the bacterial fertilizers ineffective.
- Use of substandard inoculants or faulty inoculation techniques, and sometimes adverse effects of agro-chemicals and unfavourable conditions like waterlogging reduce the effectiveness of bio-fertilizers.

5.4.5 Resource Constraints

Manufacturers, especially small producers, do not have or cannot afford to have a distribution system of their own. Delayed distribution results in lowering of the quality of the product. Thus, resource constraint in production of bio-fertilizers on a commercial scale is also one of the main drawbacks.

5.4.6 Lack of Publicity

Lack of publicity is one major constraint in popularizing bio-fertilizers among the farming community. Massive publicity programmes should be carried out for disseminating key information on the urgency and usefulness of bio-fertilizers in the following ways:

- Field experiments to be conducted on farmers' fields
- Publicity through radio, TV, newspapers and advertisements
- Display of slogans or key information on signboards, hoardings and wall paintings at dealers' premises or training camps
- Distribution of literature containing key information and catchy slogans in regional languages
- Organization of field day/farmers rally on bio-fertilizers
- Farm youth training programmes

- Publicity through local newspapers/magazines
- Films on bio-fertilizer preparation, its use and performance to be shown at farmer's camps
- Special campaigns arranged before sowing season

5.4.7 Bio-Fertilizer Carrier

The lack of a suitable carrier, due to short shelf life, is also a major constraint for the use of bio-fertilizers. Peat, charcoal, lignite, etc. are regarded as ideal carrier materials for bio-fertilizers. But they are not available in India in sufficient quantities and in desirable quality, and among them only charcoal is used because it is readily available. Peat has been universally recognized as the most suitable carrier, but its shelf life is less than 6 months. The desired characteristics of a carrier for bio-inoculants are low cost, high organic matter, higher water-holding capacity, longer organism-retention capacity, nearly sterile, no heat or moisture, non-polluting, nearly neutral pH and one that does not lower the quality of bio-fertilizers.

5.4.8 Adverse Soil Conditions

5.4.8.1 High/Low pH

If the soils are highly acidic, saline/alkaline and sodic, they need to be neutralized by liming or adding gypsum before inoculation, otherwise there may be poor inoculation response.

5.4.8.2 High Available N

If the soil contains high N, there would be poor inoculation response that cannot usually be differentiated.

5.4.8.3 Low P, Mo and Fe Content

Mo and Fe constitute the functional part of the enzyme nitrogenase that is responsible for catalysing reduction of molecular N, whereas P being constituent of adenosine diphosphate (ADP) and adenosine triphosphate (ATP) is directly involved in the energetic demands of N fixation. Therefore, inadequacy of available P may adversely affect N fixation or inoculation response. Similarly, Fe being a constituent of ferridoxin and Mo being a component of nitrogenase enzyme are essential in the mechanism of N fixation by the N-fixing bacteria, and their deficiency in soils may affect the process considerably.

5.4.9 *Quality Control Constraints*

One of the major reasons of failure with the use of bio-fertilizers is the supply of spurious quality products. Therefore, their quality control is very essential to gain the farmers' trust, because it is a natural product carrying living micro-organisms having very short shelf life. At present there is no control order of bio-fertilizers and the whole quality control activity is confined to checks on voluntary basis in the country, which leads to poor popularity among the farmers. So, for sustainable agriculture, some quality control standards should be set up for bio-fertilizers to prove their effectiveness on the farmers' fields.

5.4.10 *Pricing Policy*

There is no appropriate price mechanism of bio-fertilizers either at national or international level. Consumers have no idea about ex-factory price of retail price. It has also been observed that some organizations are selling the same product at different prices, which is quite illegal. It is high time some strategy were formulated on pricing policy.

5.5 Guidance and Precautions for the Use of Bio-Fertilizers

The principal precautions/guidance required to be taken up prior to using bio-fertilizers are:

- It is necessary that the bio-fertilizer that is supplied be of good quality, containing minimum 10^7 g^{-1} viable cells and purchased from reputed sources and manufacturers only.
- A bio-fertilizer should only be used for the crop specified on the packet, especially in the case of *Rhizobium* culture.
- The name of the crop for which it has to be used should be mentioned on the culture bag.
- Excess culture should be used or leftovers can be put in furrows of the field so that micro-organisms live in the rhizosphere.
- Before use they should be stored in cool and shady places at room temperature (25–28°C) for better shelf life.
- Direct contact of bio-fertilizers with pesticides/weedicides/chemical fertilizers during storage or application should be avoided.
- A packet of 200 g bio-fertilizer is sufficient for 10 kg seed treatment.
- If soil conditions are not favourable, it is preferable to use some soil amendments like addition of lime or rock phosphate in strongly acidic soils or gypsum

or phosphorous–gypsum in saline–alkali soils along with bio-inoculants to produce higher crop yield.

- It is better to use a bio-fertilizer just before sowing or planting of the crop in the field because micro-organisms survive better in soil instead of seed/seedling surface after treatment.
- Making seeds too wet or mixing in excess water while using bio-fertilizer as well as rough handling of seeds during treatment should also be avoided.
- If seeds have to be treated with any fungicide or insecticide or any toxic chemicals, apply the *FIR* formula for treatment of bio-fertilizers, where *F* denotes fungicide, *I* denotes insecticide and *R* denotes bio-fertilizer.
- The culture should not be put in warm or hot water, which could destroy the living bacteria contained in the bio-fertilizers.
- The combined use of bio-fertilizers and full recommended dose of N chemical fertilizers should be avoided. There should be a 15–20-day gap in their application for better N fixation.
- The response of bio-fertilizers depends greatly on the quality of the inoculants and, therefore, farmers should purchase them from reliable sources only. Moreover, farmers should check the expiry date on the bio-fertilizer packets and not use them beyond this date.
- The pH of the soil should be near neutral (6.5–7.5), otherwise the efficiency of bio-fertilizers would be adversely affected.
- Adequate nutrition, for instance with P, K, Ca, etc., for the normal growth and activity of *Rhizobium* is a must, which should be restored. To meet the requirement of Ca and P, fertilizers like CAN and SSP should be favoured.
- It is necessary to follow up all the instructions mentioned on the packets prior to using the bio-fertilizers.

5.6 Government's Future Planning for the Promotion of Bio-Fertilizer Production

Bio-fertilizers, which have been indigenously manufactured for more than 2 decades, have great significance in India. They have a lot of potential, which is unfortunately unrealized due to various factors. However, in the last 5 to 6 years with the promotion of bio-fertilizer technology intensified by the *Department of Agriculture and Co-operation* (DAC), it is felt that if sustained efforts are applied bio-fertilizers could play a significant role in Indian agriculture. In order to promote bio-fertilizer technology in India, a Mission Mode Project has been chalked out by DAC with the following objectives:

- Encouragement to private industries, state governments, voluntary organizations, etc. for production, distribution and marketing of bio-fertilizers.
- Extension of financial and technical support to such manufacturers.
- Organization of massive field trials for different crops by the manufacturers and agriculture department of state governments.

- Development of agro-climate-specific strains and R&D works related to technology development.
- Intensive agricultural expansion by imparting training to extension workers, state government officers, farmers, producers and traders on various aspects of technology.
- Publicity programmes through mass and other media to create awareness among the farmers about bio-fertilizers.
- Establishment of new Regional Bio-fertilizer Development Centres in different parts of the country.
- Bringing all the production units under the control of a single umbrella organization, and the recognition of DAC as the nodal agency.
- Emphasis on judicious use of plant nutrition inputs to improve soil properties and maintain soil fertility.
- Creation of, and function as, quality testing and quality control units, and the formulation of bio-fertilizers Regulatory Act.

5.7 Economics of Bio-Fertilizer

- Saving of 40–50 kg inorganic N per hectare.
- One tonne of *Rhizobium* inoculated is equivalent to 100 t of N, considering minimum fixation of 50 kg N ha^{-1} from 0.5 kg N ha^{-1} application dose.
- One tonne of *Azotobacter* and *Azospirillum* each is equivalent to 40 t of N considering minimum fixation of 20 kg N ha^{-1} from 0.5 kg N ha^{-1} application dose.
- One tonne of BGA is equivalent to 2 t of N considering minimum fixation of 20 kg N ha^{-1} from 10 kg BGA ha^{-1} application dose.
- One tonne of phosphorous solubilization is equivalent to 24 t of phosphorous pentaoxide considering 30% solubilization at the minimum dose of 40 kg P_20_5 with 0.5 kg PSM ha^{-1} application dose.

5.8 How to Get Bio-Fertilizer

Realizing the importance of the development of sustainable agriculture, the Government of India has launched a ‘National Project on Development and Use of Bio-fertilizers’ in 1983 and established seven Bio-fertilizer Development Centres in different parts of the country namely at Hisar, Jabalpur, Bangalore, Bhubaneswar, Nagpur, Imphal and headquarters at Ghaziabad. (Bio-fertilizers of *Azotobacter* and BGA can be obtained from The Director, National Bio-fertilizer Development Centre, C.G.O. Complex 11204-B, Kamla Nehru Nagar, Ghaziabad (Uttar Pradesh) – 201 001 INDIA.)

The farmers must plan in advance and orders should be placed at least 3 months prior to planting/sowing date, so that bio-fertilizers may reach well in time. Information regarding the crop and area under the crop should be furnished clearly.

Impact Points to Remember

- The term ‘bio-fertilizer’ denotes nutrient inputs for plant growth which are biological in origin and have no ill effects on soil health and environment.
- India is one of the major countries in bio-fertilizer production and consumption in the world. At present there are more than 120 bio-fertilizer production units representing both government and non-governmental agencies in the country that are producing and supplying different bio-fertilizers.
- The systematic study on bio-fertilizers in India was first started by N. V. Joshi in 1920 and followed by many more scientists as the time progressed.
- The first bio-fertilizer unit in India was started by the Gujarat State Fertilizer Company (GSFC), Vadodara, in 1985, and at present, about a dozen fertilizer companies are engaged in bio-fertilizer production, marketing and promotion.
- *Rhizobium* inoculants help in establishing efficient symbiotic association with leguminous pulse and fodder crops that can fix 50–100 kg N ha^{-1} and also leave sufficient amount of N in the soil to meet a part of the requirement of the succeeding crop in rotation.
- The first commercial bio-fertilizer was developed as a *Rhizobium* culture in 1895 with the product ‘Nitragin’ in the United States.
- The number of *A. chroococcum* in Indian soils rarely exceeds 10^4–10^5 g^{-1} of soil and can save N to the tune of 25–50 kg ha^{-1} in cereals and millets. Apart from N fixation, this organism is also capable of producing antibacterial and antifungal compounds and growth hormones.
- There are six species of *Azotobacter*, namely *A. chroococcum*, *A. nigricans*, *A. paspali*, *A. vinelandii*, *A. beijerinckii* and *A. armeniacus*, of which *A. chroococcum* is the most commonly found in arable soils. *A. agilis* and *A. macrocytogenes* are the other species of *Azotobacter* found in soils.
- Use of *Azotobacter* culture has been found to be effective for a variety of non-leguminous crops such as directly seed-sown paddy and wheat. Its use has shown an increase in yield of rice, ranging from 1% to 20% and that of wheat from 10% to 30%.
- Use of *Azotobacter* reduces the inorganic fertilizer requirements to the tune of 25–50%.
- *Azospirillum* application increases grain productivity of cereals by 5–20%, millets by 30% and forage crops by over 50%.
- *Azospirillum* are tolerant to a high temperature range from 30°C to 40°C and also supply growth regulators and secrete antibiotics which act as pesticides.

- *Azolla* is an aquatic, floating, freshwater fern that has a symbiotic relationship with N-fixing bacteria. It has six species, i.e. *Azolla filiculoides*, *Azolla caroliniana*, *Azolla mexicana*, *Azolla microphylla*, *Azolla nilotica* and *Azolla pinnata*.
- On an average, decomposed *Azolla* contains N (4–6%), P (0.5–0.9%), K (2–6%), Ca (0.4–1.0%), Mg (0.5%), Mn (0.11–0.16%), Fe (0.06–0.16%) and H_2O (>80%).
- The major nutrient requirement of *Azolla i*s phosphate (10–15 kg P_2O_5 ha^{-1}), which multiplies at a fast rate and almost doubles in 3–5 days.
- The optimum temperature for better growth of *Azolla* ranges from 20°C to 30°C.
- *Azolla* can survive within a pH range of 3.5–10, but optimum growth will be in the range of 4.5–7.0.
- Optimum salt concentration for *Azolla* growth is 90–150 mg l^{-1} of water.
- BGA micro-organisms have chlorophyll in their cells and so they can synthesize their own food in the presence of sunlight.
- The principal BGA-fixing genera found in Indian rice soils include *Anabaena*, *Nostoc*, *Aulosuria*, *Calothrix* and *Tolypothrix*.
- The average consumption of chemical fertilizers is very low compared to the required level due to high prices; therefore, bio-fertilizers being cheap can fulfil the demand for fertilizers.
- If seeds have to be treated with any fungicide, insecticide or any toxic chemicals, apply *FIR* formula for treatment of bio-fertilizers where *F* denotes fungicide, *I* denotes insecticide and *R* denotes bio-fertilizer.

Study Questions

1. Explain the role of bio-fertilizers in context with sustainable agriculture.
2. Explain prospects and constraints for the use of bio-fertilizers.
3. What are the climatic factors affecting the growth and production of *Azolla*?
4. How does the production of organic acids by PSM help decrease phosphate fixation in soil?
5. What is the government's future planning for the promotion of bio-fertilizer production?
6. What precautions should be taken into account while using bio-fertilizers?
7. Define bio-fertilizers and specify from where to order the bio-fertilizers.
8. What are the different private companies engaged in bio-fertilizer production, marketing and promotion.
9. Explain in detail the various methods of use of different types of bio-fertilizers.
10. Write a short note on the following:

(a) Potential of bio-fertilizers in India
(b) Carrier
(c) Economics of bio-fertilizers
(d) Quality control constraints
(e) *Rhizobium*
(f) *Azospirillum*
(g) *Azotobacter*
(h) Pricing policy

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Chapter 6
Potential of Organic Resources as Plant Nutrients in India

Abstract The nutrient content of various organic resources having the total nutrient potential of 14.85 million tonnes was estimated in 2000, which would become around 16.34 and 32.41 million tonnes by 2010 and 2025, respectively. Out of these organic resources, considerable tapable potential of nutrients ($N + P_2O_5 + K_2O$) from human excreta, livestock dung and crop residues has been worked out to the order of 5.05 million tonnes in 2000, which would be about 6.24 and 7.75 million tonnes by 2010 and 2025, respectively, for the required food grain production of the increased human population. However, use of all tapable nutrients would not be sufficient to produce the required food grains for the burgeoning human population. Thus, integrated use of the chemical, organic and biological sources of plant nutrients and their different management practices have a tremendous potential not only in sustaining agricultural productivity and soil health but also in meeting a part of chemical fertilizer requirement for different crops and cropping systems.

Keywords Organic resources • nutrient potential • chemical sources • organic and biological sources • agricultural productivity • soil health

India is endowed with a vast potential of plant nutrients locked up in organic, biological and industrial by-products. However, their use in INM system is limited, because of their alternate utilities as animal feed, fuel and building material. Major crop improvement strategies for sustainable agricultural production mainly pursue the use of natural processes such as nutrient cycles, biological nitrogen fixation and pest–predator relationship in agricultural production. For sustainable agriculture, the main organic resources used for plant nutrients are FYM, compost, crop residues, green manure, bio-fertilizers, legumes, vermicompost, biogas slurry, etc. Apart from these organic sources utilized for plant nutrients, other sources include soil reserves, human wastes, urban and rural wastes, sewage sludge, tree and aquatic wastes, agro-industrial wastes like press mud, coir pith from coconut industry, distillery waste, fruit and vegetable wastes, marine wastes, sea wastes and fishmeal, etc. (Singh and Singh, 2003a). Tandon (1997) has made projections of nutrient supply through organics for the period 2000–2025 in Table 6.1.

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Table 6.1 Some projections on availability of organic resources for agriculture in India during 2000–2025 (Adapted from Tandon [1997])

Resources	2000	2010	2025
I. Generators			
Human population (millions)	1,000	1,120	1,300
Livestock population (millions)	498	537	596
Food grain production (million tonnes)	230	264	315
II. Nutrients (theoretical potential in million tonnes of N + P_2O_5 + K_2O)[a]			
Human excreta	2.00	2.24	2.60
Livestock dung	6.64	7.00	7.54
Crop residues	6.21	7.10	22.27
Total	14.85	16.34	32.41
III. Nutrients (considerable tapable potential in million tonnes of N + P_2O_5 + K_2O)[b]			
Human excreta	1.60	1.80	2.10
Livestock dung	2.00	2.10	2.26
Crop residues	2.05	2.34	3.39
Total	5.05	6.24	7.75

[a] All data pertaining to nutrients in dung and residues are counted as twice the amount fed to the animals.

[b] Tapable = 30% of dung, 80% of excreta, 30% of crop residues.

As per the projections on the availability of organic resources for agriculture in India, it is estimated that organic resources would have a total nutrient potential of 14.85 million tonnes by 2000, which would increase to around 32.41 million tonnes by 2025, of which the tapable potential of N + P_2O_5 + K_2O would be about 5.05 and 7.75 million tonnes by 2000 and 2025, respectively. The advantages in making these projections for the organic resources are mostly derived from plants and animals. Thus, the theoretical availability of crop residues and resources of animal and human origin can be worked out from agricultural production and population projections. What is more difficult to predict and project is the actual availability of these resources which will be decided by emerging trends in their competing uses and prices they fetch from sectors other than farming.

6.1 Animal Dung and Wastes

As the fertilizer use in most Indian farming is suboptimal, organic resources can supplement available fertilizer supply. Approximately 25% of nutrient need of Indian agriculture can be met by using various organic sources. In an estimate the annual production of dung and urine from bovines in India is nearly 1,528 and 800 million tonnes, respectively. If the total amount of dung and urine produced by bovines is conserved for manurial purposes, their potential for supplying N, P_2O_5 and K_2O has been estimated to be about 7 million tonnes, i.e. 3.44, 1.31 and 2.21 million tonnes respectively. The potential availability of cattle dung in India is about 2 billion tonnes, with a nutrient potential of about 6.96 million tonnes (approximately 7 million tonnes as stated above).

Acharya and Kapur (1993) reproached the cumbersome practice of carrying and spreading of bulky wastes from cattle sheds to fields situated at a distance. Direct spreading of widely growing wastes like wild sage (*Lantana camara*) and eupatorium (*Eupatorium adenophorum*) in the standing maize crop at the recession of the monsoon is a better option. This practice not only conserves moisture for timely sowing of wheat without any pre-sowing irrigation, but also produces the highest grain yield of wheat. In another study, Acharya et al. (1998) reported that soil structure beneath wild sage and eupatorium was mellow, and therefore sowing of wheat with conservation tillage and recommended P and K doubled the grain yield of wheat compared to usual farming practices.

6.2 Crop Residues

Crop residues, another important component of the ecosystem of any country, are good sources of plant nutrients. A large amount of crop residue is annually produced in India. In areas where mechanical harvesting has been adopted, a sizeable quantity of crop residues is left in the field which can be recycled for nutrient supply. The annual production of crop residues in the country has been estimated in the range of 270–300 million tonnes. About one third of the residues produced may be recycled on the land and these can add 2.47 million tonnes of $N + P_2O_5 + K_2O$ annually, two thirds of which is potash alone. As per current estimates, organic resources can supplement 3.9–5.7 million tonnes of nutrients (Subba Rao and Srivastava, 1998). In another estimate, an annual production of crop residues in India is about 313–356 million tonnes with nutrient potential of 6.7–7.5 million tonnes (Singh and Singh, 2003b). About one third of the crop residues are available for direct recycling, amounting to 136.4 million tonnes, and if used can add 3.54 million tonnes of N, P_2O_5 and K_2O annually. Crop residues can be recycled either by composting or by way of mulch or direct incorporation in the soil.

6.3 Green Manures and Legumes

As regards green manure, traditionally India has been using dhaincha, sunn hemp, cowpea, cluster bean (guar), black gram, green gram, etc. Dhaincha and sunn hemp are more popular. On the other hand, legumes are grown for fixing atmospheric N through *Rhizobium* symbiosis, and are planted before flowering, i.e. after 6–8 weeks of growth, into the soil to improve its fertility and for raising another crop (Katiyar, 2000). According to Katyal (1991) green manures and legumes have the potential to supply N up to 50–60 kg N ha^{-1} and P_2O_5 10–60 kg N ha^{-1}, respectively.

Planting of green manure crops into the soil increases the availability of N and other plant nutrients (Singh and Singh, 2003a). One of the most conspicuous green manuring crops is dhaincha (*Sesbania aculeata*). It can grow on most of the soils, fix a large amount of N and produce on an average about 5 t of dry matter per hectare and 100 kg N ha^{-1} in about 60 days. Effects of green manure and FYM on rice and wheat yield have been recently reported (Singh et al., 2004).

6.4 Bio-Fertilizers

Projections show that possible N gains through symbiotic bacteria, asymbiotic bacteria and blue-green algae (BGA) in Indian agriculture can be equivalent to 1.00, 0.15 and 0.75 million tonnes per year, respectively (Katyal, 1991). In N economy of rice, BGA, namely *Anabaena*, *Nostoc Tolypothrix*, etc., and *Azolla* have tremendous potential which still needs to be explored. *Azolla* has a potential to fix the atmospheric N amounting to 100–150 kg ha^{-1} $year^{-1}$ and thus can save about 50% mineral fertilizer N (Subba Rao et al., 1993).

Vesicular arbuscular mycorrhizal fungi, namely *Glomus etunicatum* and *G. acrocarpus*, have a potential to substitute 15 kg P_2O_5 ha^{-1} of chemical fertilizers besides mobilizing micronutrient cations like Zn and Mn (Gupta and Chhonkar, 1995). According to Katyal (1991) bio-fertilizers have the potential to supply up to 20–50 kg N ha^{-1}. Currently more than 10,000 t of bio-fertilizers is being used in the country.

Use of bacterial cultures of *Pseudomonas* and *Bacillus* spp. and fungal culture of *Aspergillus* spp. can assist in converting insoluble phosphate into soluble phosphate, which ultimately improves the availability of phosphorous to plants.

6.5 Compost and Vermicompost (Soil Conditioner)

Organic manure prepared from plant residues (leaves, stalks, twigs, bark, etc.) and animal waste products (especially cattle dung) is called compost, and the process of preparing it is known as composting. On an average, it contains 1.01% N, 0.5% P_2O_5 and 0.8–0.9% K_2O. The availability of rural compost and city refuse in India are 285 and 14 million tonnes, respectively, which provides 4 million tonnes of plant nutrients (NPK) per year.

Vermicomposting, i.e. the technology of rearing earthworms, is an effective tool of sustainable agriculture. In India, a large number of vermicompost units established by city corporations, municipalities, besides non-governmental organizations (NGOs) provide vermicompost to numerous private entrepreneurs, especially in the states of Madhya Pradesh, Rajasthan, Uttar Pradesh, Kerala, Karnataka, etc. In the Jammu region (Jammu & Kashmir), a number of vermicompost units have now been started by many of the farmers themselves. They are using vermicompost for augmenting the yield of strawberry and other crops.

Table 6.2 Organic source required to meet 25% of India's nutrient needs in 2000 and 2050 (Adapted from Tandon [1997])

Organic resource (million tonnes)	2000	2050
Farmyard manure	200	400
Crop residues	30	50
Urban/rural wastes	10	50
Green manure	25	50

6.6 Biogas Slurry

The residual slurry that comes out of the digestion tank is called biogas slurry. For biogas slurry, India has been a pioneering country in the world in developing biogas plants. These plants produce digestive slurry, which can be applied directly in cultivated fields. Such slurry is generally richer in N than FYM, which contains about 1.5–2.0% nitrogen, 1% phosphorous and 1% potash. There are more than 3.2 million biogas plants, whose slurry (around 28 million tonnes) may be utilized as a unique organic source of plant nutrients. Biogas plants serve the dual purpose of providing fuel as well as good-quality manure. Therefore, construction of biogas plants by the farmers should be encouraged in the country.

As estimated, about 25% of the nutrient needs of Indian agriculture can be met by utilizing various organic resources. The resources required to achieve this are suggested in Table 6.2. Thus, integrated use of the chemical, organic and biological sources of plant nutrients and their different management has a tremendous potential not only in sustaining productivity and soil health but also in meeting a part of chemical fertilizer requirement of different crops and cropping systems.

Impact Points to Remember

- The annual production of crop residues is estimated to be in the range of 270–300 million tonnes. About one third of the residues produced may be recycled on the land and these can add 2.47 million tonnes $N + P_2O_5 + K_2O$ annually, two thirds of which is potash alone.
- Potential availability of nutrients ($N + P_2O_5 + K_2O$) from animal dung and urine is 7.0 million tonnes with production of 3.2 billion tonnes.
- Cattle account for about 90% of the total animal dung and nutrients.
- The results of a long-term experiment in the rice–wheat cropping system revealed that the combined use of 12 t of FYM ha^{-1} and 80 kg N ha^{-1} gave rice yield comparable to 120 kg N ha^{-1}, which means a net saving of 40 kg N ha^{-1}.
- Farmyard manure also showed considerable residual effect on the succeeding wheat crop.
- Bio-fertilizers differ from chemical fertilizers in the sense that the farmers do not directly supply any nutrient to crop plants. They, in fact, are the cultures of

some specific bacteria (*Rhizobia*, *Azotobacter*, *Azospirillum*), algae (BGA) and fungi (*Asperigillus*).

- As per current estimates, organic resources can supplement 3.9–5.7 million tonnes of nutrients.
- *Azolla* has a potential to fix the atmospheric N amounting to 100–150 N ha^{-1} year^{-1} and thus can save about 50% mineral fertilizer N.
- Vesicular arbuscular mycorrhizal fungi, namely *G. etunicatum* and *G. acrocarpus*, have a potential to substitute 15 kg P_2O_5 ha^{-1} of chemical fertilizers besides mobilizing micronutrients cations like Zn and Mn.
- Green manures, bio-fertilizers and legumes have the potential to supply N up to 50–60, 20–50 and 10–60 kg N ha^{-1}, respectively.
- The availability of rural compost and city refuse in India are 285 and 14 million tonnes respectively, which provide 4 million tonnes of plant nutrients (NPK) per year.
- The earthworms in vermicompost consume nearly two to five times their body weight, and after utilizing 5–10% of the feedstock for their growth, excrete mucus coated with undigested matter as worm casts or vermicasts.
- Biogas plants serve the dual purpose of providing fuel as well as good-quality manure.
- There are more than 3.2 million biogas plants, whose slurry (around 28 million tonnes) may be utilized as a unique organic source of plant nutrients.
- As estimated, about 25% of the nutrient needs of Indian agriculture can be met by utilizing various organic resources.
- The use of organics not only helps to substitute partly for chemical fertilizers, but also improves the overall soil productivity through its beneficial effects on physical, chemical and biological properties of soils.

Study Questions

1. Explain briefly the potential of organic resources of plant nutrients in India.
2. Explain briefly the potential of bio-fertilizers in India.
3. Explain briefly the potential of compost, vermicompost and biogas slurry in India.
4. What are the different organic sources required to meet 25% of India's nutrient needs in 2050?

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Chapter 7
The Rice–Wheat Cropping System

Abstract The rice–wheat rotation is the principal cropping system in south Asian countries that occupies about 13.5 million hectares in the Indo-Gangetic Plains (IGP), of which 10 million hectares are in India, 2.2 million hectares in Pakistan, 0.8 million hectares in Bangladesh and 0.5 million hectares in Nepal. This system covers about 33% of the total rice area and 42% of the total wheat area in the four countries as stated above, and account for one quarter to one third of the total rice and wheat production. This cropping system is dominant in most Indian states, such as Punjab, Haryana, Bihar, Uttar Pradesh and Madhya Pradesh, and contributes to 75% of the national food grain production. This cropping system is also very prevalent in Himachal Pradesh and Jammu & Kashmir, especially the Jammu region. There was a time when the yield of paddy was the highest, i.e. more than 4.2 t ha^{-1} in the valley of Kashmir among the north-western Himalayan states, but now it has reduced considerably. Thus, the rice–wheat cropping system is the cornerstone of India's food self-sufficiency. The environmental requirements for the growth and development of both rice and wheat crops are contrastingly different. Rice grows best under stagnant water conditions, while wheat requires a well-pulverized soil with a proper balance of moisture, air and thermal regime. Therefore, a dominating feature of the rice–wheat cropping system is the annual conversion of soil from aerobic to anaerobic and then back to aerobic conditions.

Keywords Rice–wheat cropping system • south Asian countries • Indo-Gangetic Plains self-sufficiency • food grain production

The rice–wheat is the most dominant double-cropping system in Asian subtropical countries such as China, India, Nepal, Bangladesh and Pakistan, where it is practised on about 24 million hectares. Rice is cultivated in 111 countries of the world compared to wheat, which is grown in 92 countries. On an average, the world yields of 1 ha of rice could sustain 5.7 persons per year compared to 4.1 persons per year for wheat. Globally, rice ranks second to wheat in terms of area harvested, but first in terms of calories per hectare (18% of total kilocalories per person per day). China and India produce more than half of the world's rice, and the rice cultivation

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generates the highest employment for the rural Asian population. These two most important crops are rich sources of starch and fair to good sources of proteins, certain minerals and vitamin B.

7.1 Distribution of the Rice–Wheat Cropping System and Contribution to Food Security in South Asian Countries

In south Asian countries, the rice–wheat cropping system is prevalent in about 13.5 million hectares in the Indo-Gangetic Plains (IGP), 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 the four countries, namely India, Pakistan, Bangladesh and Nepal, and accounts for one quarter to one third of the total rice and wheat production (Ladha et al., 2000). It provides food, income and employment to millions of people. The annual system productivity in IGP is low (3–5 Mg ha^{-1}) compared to the climatic crop yield potential of the region, i.e. 12.0–19.3 Mg ha^{-1} (Ladha et al., 2003; Pathak et al., 2003). The rice–wheat system is pivotal to food security not only of the country, but also of the Indian subcontinent as a whole. The tenfold increase in rice–wheat sequence in India, Nepal, Bangladesh and Pakistan during the last 30 years is an ample proof of it (IRRI, 1992). Further, rice has been grown as a food crop for more than 6,000 years in Asia. Today, more than 90% of global rice supplies are produced and consumed in Asia (Blake, 1992), contributing 30–75% of dietary calories for populations in Asian countries (Dobermann and Cassman, 1996). About half of the irrigated wheat production in South Asia comes from rice–wheat rotation (Pillai, 1994).

In India, the rice–wheat is the most extensive and traditional cropping system which has become the mainstay of cereal production in the country. It occupies an area of 9.77 million hectares (Table 7.1) (Yadav, 1996), dominates agricultural systems in India, mostly in Punjab, Bihar, Haryana, Uttar Pradesh and Madhya Pradesh (Table 7.2) (Kanwar and Sekhon, 1998), and contributes to the tune of

Table 7.1 Area under major cereal-based cropping systems (Adapted from Yadav [1996])

Cropping system	Area (million hectares)
Rice–wheat	9.77
Rice–rice	2.12
Maize–wheat	1.29
Pearl millet–wheat	1.03
Pearl millet–sorghum	1.35
Sorghum–sorghum	0.74
Rice–wheat–gram	1.03

Table 7.2 Dominant cereal-based cropping systems in major food grain producer and fertilizer consumer states (Adapted from Kanwar and Sekhon [1998])

Cropping system	States
Rice–wheat	Punjab, Haryana, Uttar Pradesh and Madhya Pradesh
Rice–rice	Andhra Pradesh and Tamil Nadu
Rice–cotton	Andhra Pradesh and Tamil Nadu
Rice–sugarcane	Andhra Pradesh, Tamil Nadu and Maharashtra
Maize/millet–wheat	Haryana and Uttar Pradesh

Table 7.3 Area and production of rice and wheat in India over the years (Adapted from Anonymous [2005–06])

	Area (million hectares)		Production (million tonnes)	
Year	Rice	Wheat	Rice	Wheat
1950/51	30.81	9.75	20.58	6.46
1955/56	31.52	12.37	27.56	8.76
1960/61	34.13	12.93	34.57	10.99
1965/66	35.47	12.57	30.59	10.44
1970/71	37.76	19.14	42.23	23.83
1975/76	39.48	20.45	48.47	28.85
1980/81	40.15	22.28	53.63	36.31
1985/86	41.14	23.00	63.83	47.05
1990/91	42.69	24.17	74.29	55.14
1991/92	42.67	23.26	74.68	55.69
1992/93	41.78	24.59	72.87	57.21
1993/94	42.54	25.15	80.30	59.84
1994/95	42.81	25.70	81.81	65.77
1995/96	42.84	25.01	76.98	62.10
1996/97	43.50	25.96	81.74	69.35
1997/98	43.48	26.70	82.54	66.35
1998/99	44.80	27.52	86.08	71.29
1999/2000	45.16	27.49	89.68	76.37
2000/01	44.71	25.73	84.98	69.68
2001/02	44.90	26.35	93.34	72.77
2002/03	41.76	25.20	71.82	65.76
2003/04	42.59	26.60	88.53	72.16
2004/05	41.91	26.38	83.13	68.64
2005/06	–	–	91.04	69.48

75% of the national food grain production (Yadav and Subba Rao, 2001). Besides, it also occupies a sizeable area in the adjoining parts of Rajasthan, Himachal Pradesh and the Jammu region (Jammu & Kashmir). This cropping system has helped tremendously in the socio-economic development of the rural population in India. On an all-India basis, the total area under rice and wheat cultivation is 41.91 and 26.38 million hectares, with the production of 91.04 and 69.48 million tonnes (Table 7.3) (Anonymous, 2005–06), respectively. Thus, the rice–wheat cropping system is of considerable significance to India's food self-sufficiency and self-esteem.

7.2 Characteristics of the Rice–Wheat Cropping System

The rice–wheat cropping system in the Indian subcontinent is quite new and started only in the late 1960s with the introduction of dwarf wheat from CIMMYT, Mexico, which required a lower temperature (mean below 23°C) for good germination than that required for traditional tall Indian wheat. On the other hand, rice is cultivated in diverse growing conditions such as wet tropical, humid to subtropical and temperate climate with elevation below sea level to 2,000 m. The environmental requirements for the growth and development of both rice and wheat crops are quite different. Rice grows best under soft, puddled and water-saturated soil conditions, while wheat requires a well-pulverized soil having fine tilth with a proper balance of moisture, air and thermal regime. Thus, a dominating feature of the rice–wheat cropping system is the annual conversion of soil from aerobic to anaerobic and then back to aerobic conditions (Mahajan, 2006).

Rice in most parts of south and south-east Asia is traditionally cultivated in well-puddled soils. Puddling (wet tillage) is an intensive system, which brings about significant changes, especially in physical properties of soil, including structural, hydraulic and mechanical properties. Sometimes puddling induces pan formation in rice-growing soils besides reducing percolation (Greenland and De Datta, 1985). However, in rice soils of the north-west Himalayas, no pan formation was observed; instead massive structures were seen in lower horizons (Gupta and Tripathi, 1993; Mahajan, 2001; Mahajan et al., 2007c). Such changes, although favourable for rice, are not suitable for the following upland wheat crop (Sharma and De Datta, 1986; Sharma et. al., 2003). Consequently, the growth and the yield of wheat crop are poor in post-rice soils, probably constrained due to factors such as large turnaround time (Fujisaka et al., 1994), poor soil tilth of seedbed (Chenkual and Acharya, 1990), subsoil compaction (Bhushan and Sharma, 1997), poor drainage (Regmi et al., 2002), restricted aeration (Bhushan and Sharma, 1999), nutrient stress (Hobbs, 1994) and high mechanical impedance to roots (Bhagat and Verma, 1991). Apart from alteration of chemical and physical changes in flooded rice soil as mentioned above, its microbial activities are also changed (Gupta et al., 1992; Mahajan and Bhagat, 2006). Generally, ammonifying bacteria predominated over nitrite or nitrate formers. There was invariable presence of *Clostridium* and *Beijerinckia*. The atmospheric nitrogen fixed in these soils was mainly through *Clostridium* spp. Table 7.4 summarizes the relative advantages and disadvantages of puddling in the rice–wheat cropping system (Sharma et al., 2003).

The water requirement for rice cultivation is very high, and puddling reduces the permeability besides controlling weeds. It consumes around 5,000 l of water under irrigated conditions for each kilogram of grain produced (IRRI, 1995). On the other hand, a good crop of wheat requires about 1,000–1,200 l of water to produce 1 kg of wheat. Flooding of rice fields also causes several chemical changes in the soil, which regulates transformations and availability of nutrients (Ponnamperuma, 1972 and 1985). The flooded lowland soil is characterized by larger amounts of exchangeable K and Na compared to the upland soil, particularly in the cultivated layer. Submerged soils differ from others in the control of acidity and alkalinity because the partial pressure of CO_2 in floodwater buffers carbonate content and lower pH. The change

Table 7.4 Summary of advantages and disadvantages of puddling in rice–wheat cropping system (Adapted from Sharma et al. [2003])

Rice

Advantages

- Levelling land for proper water control.
- Making soil soft for ease of transplanting.
- Enhanced water and nutrient use efficiency; reduction in water permeability leads to decrease in total water requirement and leaching losses of nutrients.
- Enhanced plant availability of soil nutrients; reduced conditions in puddled soils increase solubility of various macronutrients and micronutrients.
- Weed control.
- Takes advantage of monsoon in land preparation.

Disadvantages

- Labour-, capital-, and energy-intensive process.
- Leaching losses of residual soil NO_3-N during puddling.

Wheat

Advantages

- Moderate subsoil compaction due to puddling in highly permeable coarse-textured soils may improve nutrient and water use efficiency as well as wheat yield.

Disadvantages

- Destruction of soil structure, leading to higher bulk density, higher soil penetration resistance and more surface cracking.
- Higher draft power requirement.
- Clod formation and difficulties in obtaining seedbed with fine tilth.
- Longer turnaround time, leading to delayed sowing.
- Development of subsurface hardpans, having high bulk density, low porosity, high soil penetration resistance, and low water permeability, which lead to problems of water logging, poor soil aeration and restricted root growth.
- Reduced subsoil conditions decrease the availability of soil nutrients to wheat.

of pH alters chemical equilibria and consequently the availability of different plant nutrients. However, most of the changes are reversible on drainage, which suggests important implications for nutrient management in rice–wheat systems.

7.3 Package of Practices and Methodologies for the Rice–Wheat Cropping System

The package of practices and methodologies pertaining to improve fertilizer use efficiency has been published for the rice–wheat cropping system as well as for other major cropping systems (Acharya et al., 2003). Some additional information is given below:

- Use of 40–50% of the recommended doses of NPK through chemical fertilizers and the rest (50–60%) through green manuring and FYM gave the yield of rice crop almost equivalent to that which was obtained through the use of 100% NPK recommended doses.

- Application of 20–25 kg of $ZnSO_4$ was found to increase the yield of both the rice and wheat crops under the soil conditions of Jammu & Kashmir and Himachal Pradesh.
- Application of 40 kg $ZnSO_4$ ha^{-1} was found to eliminate Zn deficiency in rice-growing sodic soils when treated with gypsum, FYM, pyrites and rice husk.
- Under saline soil conditions of Uttar Pradesh, application of one third of total N at the time of sowing and one third as top dressing indicated maximum yield of wheat.
- Application of *Azolla* along with 30 kg N ha^{-1} produced rice yield equivalent to use of 60 kg N ha^{-1}, thereby showing a net gain of 30 kg of N ha^{-1} in the soil conditions of eastern Indian states.
- Application of sulphur to an extent of 20–40 kg ha^{-1} in the form of gypsum has increased yield of rice in the eastern hill regions and in the north-west Himalayas.

7.4 Nutritional Value of Rice and Wheat

Cereals such as rice, wheat, maize and barley form the staple food of the population of the Indian subcontinent and differ widely in their content of various nutrients. They are rich sources of starch and fair to good sources of proteins, certain minerals and vitamin B. About 70–80% of our food requirement comes from cereals (Yadav et al., 1999). Rice alone accounts for 40% of the protein in Asian diet. In India, rice provides 25% of the protein requirement, besides being the principal source of vitamins (thiamine and riboflavin) and minerals (Fe and Ca). The protein content of husked rice varies from 6% to 8% with good vitamin B and P content, poor source of Ca and fair source of Fe. The quality of rice depends on milling. Among cereal proteins, rice protein is biologically the richest by virtue of its true digestibility (88%), high lysine content (4%) and relatively better net utilization.

The wholewheat flour contains germ and bran. It contains more proteins than other cereals, which varies between 11% and 15%. It is a good source of thiamine, nicotinic acid and vitamin B. It also contains a fair source of Ca and Fe and is a good source of P. Besides, their significance in nutrition principally concerns in providing the characteristic substance ‘gluten’ which is very essential for bakers. In bakeries, gluten provides the structural framework for the familiar spongy, cellular texture of bread and other baked products. Therefore, other cereals lacking gluten are not good for bread-making.

Impact Points to Remember

- The rice–wheat rotation is the principal cropping system in south Asian countries that occupies about 13.5 million hectares in the IGP, of which 10 million hectares are in India, 2.2 million hectares in Pakistan, 0.8 million hectares in Bangladesh and 0.5 million hectares in Nepal.

- Rice is cultivated in 111 countries of the world compared to wheat, which is grown in 92 countries.
- China and India produce more than half of the world's rice, and rice cultivation generates highest employment for the rural Asian population.
- This cropping system is dominant in India, mostly in Punjab, Haryana, Uttar Pradesh and Madhya Pradesh, and contributes 75% of the national food grain production.
- The total area under rice and wheat in India is 42.50 and 26.58 million hectares with the production of 85.31 and 72.00 million tonnes respectively.
- The environmental requirements for the growth and development of both rice and wheat crops are quite different. Rice grows best under stagnant water conditions, while wheat requires a well-pulverized soil with a proper balance of moisture, air and thermal regime.
- The dominating feature of the rice–wheat cropping system is the annual conversion of soil from aerobic to anaerobic and then back to aerobic conditions.
- Rice in most parts of south and south-east Asia is traditionally cultivated in well-puddled soils.
- Wheat growth and yield are poor in post-rice soils, probably constrained due to factors such as large turnaround time, poor soil tilth of seedbed, subsoil compaction, poor drainage, restricted aeration, nutrient stress and high mechanical impedance to roots.
- The water requirement of rice is very high compared to that of wheat. Rice consumes around 5,0001 of water under irrigated conditions for each kilogram of grain produced, while a good crop of wheat requires about 1,000–1,2001 of water to produce 1 kg.
- These two crops are rich sources of starch and fair to good source of proteins, certain minerals and vitamin B.
- Among cereal proteins, rice protein is biologically the richest by virtue of its true digestibility (88%), high lysine content (4%) and relatively better net utilization.

Study Questions

1. Define the following:
   (a) Puddling
   (b) pH
   (c) Protein
   (d) Milling
   (e) Minerals
   (f) Vitamins
   (g) Starch
   (h) Milled rice
2. Explain briefly the distribution of the rice–wheat cropping system in India and its contribution to food security.

3. Justify the statement ‘Environment requirements for growth and development of rice and wheat are contrastingly different’.
4. Why are wheat growth and yield poor in post-rice soils?
5. What are the advantages and disadvantages of puddling in rice–wheat cropping system?
6. Write a short note on the nutritional value of rice and wheat.
7. Differentiate the following:
   (a) Water-logging and submergence
   (b) Acidity and alkalinity
   (c) Lowland crops and upland crops
8. How much water is required to produce 1 kg of rice and wheat grains under irrigated conditions?
9. Explain the package of practices and methodologies for rice–wheat cropping system.

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Chapter 8
Balanced Use of Plant Nutrients

Abstract The concept of balanced fertilization is very simple and was in fact developed more than 150 years ago. Application of balanced fertilization is the key in enhancing nutrient use efficiency of the applied plant nutrients for maintaining soil productivity. It ensures the application of fertilizers in optimum quantities and in right proportion through appropriate methods, which in turn results in sustenance of soil fertility and crop productivity. Balanced fertilization leads to building up soil health, while imbalanced fertilization leads to soil mining and its sickness. Only soil building leads to a sustainable land use system where most food grain production continues to come from the existing agricultural land. It is well documented that unbalanced availability of nutrients not only produces low and poor-quality yield, but can also lead to mining of soil nutrient reserves which results in short supply. Thus, to obtain higher fertilizer use efficiency, a certain balance among the various nutrients is very essential.

Keywords Balanced fertilization • plant nutrients • soil fertility • crop productivity • soil building • soil mining • fertilizer use efficiency

Balanced application of fertilizers enhances the fertilizer use efficiency and leads to increase in the crop yields by improving physical, chemical and biological environment of the soil. It ensures application of fertilizers in optimum quantities and in right proportions through appropriate methods, which in turn results in sustenance of soil fertility and increase in crop productivity. It takes into account the removal of nutrients; the economics of fertilizers and profitability; farmers' investment ability; agro-techniques; soil moisture regime; soil physical environment and adverse soil conditions such as salinity, alkalinity and acidity. Balanced use of fertilizers also ensures that the plants become more tolerant to drought, cold, insects, pests and diseases.

8.1 Concept of Balanced Fertilization

The concept of balanced fertilization is very simple and was in fact developed more than 150 years ago. The idea is that a crop requires an adequate supply of all essential mineral nutrients for optimum growth. If more than one is in short

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supply, growth is affected by the nutrient which is in the lowest supply (Kumar and Shivay, 2007). Balanced fertilization or balanced use of fertilizer does not mean only an application to soil of a certain definite proportion of N, P and K (or other nutrients) in the form of fertilizers, but also the use of organic manures. According to the recent concept of balanced fertilization, as summed up by Goswami (1997), it evinces rational use of fertilizer and organic manures for supply of nutrients for agricultural production in such a manner that would ensure:

- Efficiency of fertilizer use
- Harvesting of best positive and synergistic interactions amongst the various other factors of production, namely seed, water, agrochemicals, etc.
- Least adverse effect on environment by minimizing nutrient losses
- Maintenance of soil productivity
- Sustaining high yield to commensurate with the biological potential of the crop variety under the unique combinations of soil-climate and agro-ecological set-up

8.2 Definition of Balanced Fertilization

Balanced fertilization refers to the application of plant nutrients in optimum quantities in the right proportion through appropriate methods at the time suited for a specific crop and agro-climatic situation (Dibb and Dev, 1996). Balanced fertilization leads to ‘soil health building’, while imbalanced fertilization leads to ‘soil mining’, causing soil sickness and an uneconomic waste of scarce resources. Only ‘soil health building’ leads to a sustainable land use system where most food grain production continues to come from existing agricultural land.

On the other hand, unbalanced use of fertilizers has resulted in poor crop yields and also in deterioration in the physical condition of the soil. Moreover, an imbalanced use of chemical fertilizers alone leads to the deficiency of secondary and micronutrients in the soil in many parts of the country. N alone fails to respond in the absence of P in certain cases. Long-term use of N alone reduced soil productivity even below the control. The use of N alone probably promoted an imbalanced removal of soil nutrients, while in the control nutrient depletion was in natural proportion.

8.3 Aim of Balanced Fertilization

Balanced and judicious use of fertilizers is the key to efficient nutrient use and for maintaining soil productivity. A plant nutrient added to the soil would be efficiently used by the crop only if the other essential nutrients are present in adequate amounts. According to Von Uexkull and Mutert (1992), balanced use of fertilizers should be aimed at the following considerations.

- Increasing crop yields
- Improving the quality of the produce

- Profitable crop production
- Correction of inherent soil-nutrient deficiencies
- Maintaining or improving long-term soil fertility and productivity
- Environmental safety
- Restoring fertility and productivity of the land that has been degraded by wrong and exploitative activities in the past

8.4 NPK Use Ratios

Nutrient balance is a key component in enhancing crop productivity. It ensures an efficient use of all the nutrients, since the deficiency of any one essential nutrient limits the efficient use of all other nutrients even when they are available in adequate quantities. The fertilizer promoters in India advocate use of N/P_2O_5/K_2O fertilizers in the ratio of 4:2:1. This ratio is generally considered to be an ideal one for achieving the maximum use efficiency of each nutrient. If one nutrient is present in large amounts, it may depress the uptake of some other nutrient(s) and reduce crop yield. Thus, there must be a proper balance among the essential plant nutrients. Here the lesson is:

> If you wish to secure N efficiency, make sure there is no P deficiency as functions of P cannot be done by N and those of K by P.
>
> Gupta and Kanwar

The balanced use of fertilizers in the country has received a serious setback due to the decontrol and price escalation of chemical fertilizers, a non-renewable source of energy as well as subsidy on urea. Balanced fertilizer use should consider two important points: rate of application and the ratio in which the nutrients are applied. If the recommended fertilizer rate for wheat is 120 N, 60 P_2O_5 and 30 K_2O kg ha^{-1} (total of 210 kg ha^{-1}), the ratio in which they are applied is 4:2:1. If one applies 60 N, 30 P_2O_5 and 15 K_2O kg ha^{-1} (total of 105 kg ha^{-1}), the use ratio is still 4:2:1, which is not the appropriate amount of plant nutrients for optimum crop yield. An ideal ratio of balanced use of nutrients on a national scale is practically not possible as it differs from one agro-ecological region to another, and from one soil to another. However, there is wide variation in the consumption ratios of fertilizers from region to region and from year to year. The fertilizer consumption ratios computed for the last few years are given in Table 8.1.

8.5 Balanced NPK Fertilization in the Rice–Wheat Cropping System

Because of continuous cultivation of various crops over centuries and intensification of agriculture in recent years, there has been progressive and substantial depletion not only of N and P but also of K (Acharya et al., 2003) and other nutrients. Hence, a balanced use of NPK is a must to obtain good productivity of rice and wheat.

Table 8.1 NPK use ratios in India over years (Adapted from Anonymous [2005–06])

Year	NPK ratio	NP ratio
1950/51	7.9:0.9:1	8.5:1
1955/56	10.0:1.3:1	8.3:1
1960/61	7.3:1.8:1	4.0:1
1965/66	7.4:1.7:1	4.3:1
1970/71	6.3:2.3:1	2.7:1
1975/76	7.7:1.7:1	4.6:1
1980/81	5.9:1.9:1	3.0:1
1985/86	7.0:2.5:1	2.8:1
1990/91	6.0:2.4:1	2.5:1
1991/92	5.9:2.4:1	2.4:1
1992/93	9.5:3.2:1	3.0:1
1993/94	9.7:2.9:1	3.3:1
1994/95	8.5:2.6:1	3.2:1
1995/96	8.5:2.5:1	3.4:1
1996/97	10.0:2.9:1	3.5:1
1997/98	7.9:2.9:1	2.8:1
1998/99	8.5:3.1:1	2.8:1
1999/2000	6.9:2.9:1	2.4:1
2000/01	7.0:2.7:1	2.6:1
2001/02	6.8:2.6:1	2.6:1
2002/03	6.5:2.5:1	2.6:1
2003/04	6.9:2.6:1	2.7:1
2004/05	5.7:2.2:1	2.5:1
2005/06	5.3:2.2:1	2.5:1

Balanced fertilization in the rice–wheat cropping system is very important (Dev, 1997; Lian, 1989; Mohanty and Mandal, 1989; Prasad, 2000; Prasad and Power, 1991; Rattan and Singh, 1997; Tandon, 1980). The rice–wheat system being highly exhaustive results in a greater nutrient removal from soil not only of major nutrients but also of secondary and micronutrients. Therefore, regular replenishment of nutrients from extraneous sources judiciously based on soil tests becomes imperative, resulting in a balanced nutrition. However, the direct and residual effects of nutrients applied through fertilizers to different crops of the system should not be taken into consideration. Application of nutrients should not only match their uptake, but also make allowances for unavoidable losses to maintain and improve soil fertility for sustaining high crop productivity of the system. Data from some research centres under PDCSR are presented in Table 8.2 and these bring out the importance of balanced NPK fertilization in the rice–wheat cropping system. The following major points can be derived from these data:

- Yields of both rice and wheat without fertilizer declined over time.
- Response of both rice and wheat to N alone declined over time, showing the need for P and K and other nutrients.
- Response to P in the presence of N increased over time, showing a decline in the available native soil P.
- Response of K in the presence of N and P increased over time, showing a decline in the available native soil K.

Table 8.2 Change in response to NPK over a period of 10–12 years in the rice–wheat cropping system at some centres under AICRPCS (Adapted from Hedge and Sarkar [1992]. All India Coordinated Research Project on Cropping Systems, Modipuram)

			Control[a] ($t\ ha^{-1}$)		Response kg grain kg^{-1} nutrients[b]					
					N		P		K	
Centre	Soil	Crop	A[c]	B[d]	A[c]	B[d]	A[c]	B[d]	A[c]	B[d]
R.S. Pura, Jammu	Inceptisol	Rice	1.49	1.55	20.8	7.3	18.7	28.2	−7.5	20.2
		wheat	2.08	0.98	7.3	3.5	12.2	13.0	2.0	68.2
Pantnagar	Mollisol	Rice	3.49	1.33	3.4	7.9	4.1	7.3	8.2	6.6
		wheat	1.07	1.19	19.3	14.3	5.1	−15.4	0.7	3.7
Faizabad	Entisol	Rice	1.01	0.82	24.2	22.0	14.2	26.4	1.5	7.0
		wheat	0.83	0.60	21.9	17.8	17.6	33.4	12.1	3.0
Varanasi	Alfisol	Rice	3.42	1.88	7.9	15.6	10.7	10.0	6.4	14.7
		wheat	1.35	1.00	19.6	16.5	−0.4	8.3	3.8	18.5
Rudrpur	Vertisol	Rice	2.34	1.12	20.5	23.6	5.4	36.3	4.9	12.0
		wheat	1.22	0.85	20.4	13.3	4.8	13.5	6.2	8.5

[a] Control–no fertilizer check plot. Response to P in presence of N and to K in presence of NP.

[b] N at 120 kg N ha^{-1}, P at 35 kg ha^{-1} and K at 33 kg ha^{-1}.

[c] Start of experiment 1977/78 to 1980/81.

[d] Final year for which data were collected: 1986/87 to 1989/90.

'On Farm Research' conducted on rice (IET-1410 variety) under Krishi Vigyan Kendra (KVK) Jammu (Jammu & Kashmir) showed that recommended use of NPK fertilizers gave (38.69 q ha^{-1}) followed by treatment where 40% of the recommended NPK was applied through fertilizers and the rest (60%) through green manuring (31 q ha^{-1}). With 50% through FYM and 50% through NPK fertilizer, the yield was 29.8 q ha^{-1} (Gupta and Sharma, 2004).

Thus, the main objective of balanced use of fertilizer is to correct any nutrient deficiency through the correct and appropriate methods that may be applied at any time during the growth of a crop which is grown at a specific location. Moreover, when balanced fertilization is practised, one nutrient increases the efficiency of the other(s) through a synergistic effect. Here the lesson is that the response of N fertilizer increases when use of N is balanced with the application of P and K. Similarly in balanced application of fertilizers K increases the availability of P.

Impact Points to Remember

- Balanced fertilization refers to application of plant nutrients in optimum quantities and in right proportion through appropriate methods and at suitable time for a specific crop and agro-climatic situation.
- Balanced fertilization takes into account removal of nutrients, the economics of fertilizers and profitability, farmers' investment ability, agro-techniques, soil moisture regime, soil physical environment and adverse soil conditions such as salinity, alkalinity and acidity.

- Balanced fertilization leads to soil health building while imbalanced fertilization leads to soil mining and its sickness.
- Only soil health building leads to a sustainable land use system where most food grain production continues to come from existing agricultural land.
- The aim of balanced use of fertilizer is to increase crop yields, improve quality of the produce, correct soil nutrient deficiencies, maintain or improve soil fertility, and eventually restore fertility and productivity of the land that has been degraded by wrong and exploitative activities in the past and profitable crop production.
- The ideal balance ratio of $N/P_2O_5/K_2O$ in India for use is 4:2:1.
- Balanced fertilization in the rice–wheat cropping system is very important. This system being highly exhaustive results in greater nutrient removal from soil not only of major nutrients but also of secondary and micronutrients. Therefore, regular replenishment of nutrients from extraneous sources judiciously based on soil tests becomes imperative, resulting in balanced nutrition.

Study Questions

1. Define the following:
   (a) Balanced fertilization
   (b) Soil mining
   (c) Crop production
   (d) Salinity
   (e) Low recommendation and optimum or average recommendation
   (f) Crop
   (g) Yield
   (h) Deficiency
   (i) Soil moisture regime
   (j) Interaction
   (k) Soil testing
   (l) Soil physical environment
2. What is the aim of balanced fertilization?
3. Explain the concept of balanced fertilization.
4. Differentiate between primary and secondary nutrients.
5. Explain balanced NPK fertilization in rice–wheat cropping system.
6. Write a short note on NPK use ratios.
7. Justify the statement ‘Balanced fertilization leads to soil building while imbalanced fertilization leads to soil mining’.

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Chapter 9
Effective Use of Fertilizers and Water Management for Rice–Wheat Cropping System

Abstract In this chapter of the book, effective use of fertilizers and water management for the rice–wheat cropping sequence has been detailed. It is related to the selection of the right kind of fertilizers, including the use of modified urea compounds, their timely application and balanced use, application of macro- and micronutrients and use of organic manures and bio-fertilizers. Methods and practices of fertilizer use efficiency in irrigated and rainfed areas have also been elucidated in terms of water and nutrient availability; movement of nutrients, soil moisture and root distribution; optimization of water and fertilizer use; and water use efficiency.

Keywords Effective fertilizer use • water management • rice–wheat cropping pattern

With the advent of the Green Revolution followed by the Golden and Yellow Revolutions, consumption of chemical fertilizers and pesticides increased. This was due to the introduction of high-yielding varieties of crops, responding to high rates of N, P and K use and water, especially rice and wheat. In many of the Indian states, however, indiscriminate use of fertilizers and pesticides not only rendered the ‘soil ecosystem sick’ but also created ‘health hazards’ in human beings and animals (Gupta and Singh, 2006). Moreover, the production of chemical fertilizers demands sufficient amount of energy and fossil fuels, both of which are very limited in the country. Hence, it becomes imperative to make an efficient use of fertilizers and other related inputs for increasing soil fertility and crop productivity without harming the soil and human beings/animals as well as the environment.

9.1 Efficient Use of Fertilizers

To get a successful/bumper crop, particularly of rice and wheat, it becomes essential to make effective use of fertilizers along with other important soil and water management practices. Some of these methods or ways are described below.

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9.1.1 Selection of the Right Kind of Fertilizers

As efficiency of nitrogenous fertilizers is very low, especially in rice crop, seldom exceeding 40%, unnecessary soil N is lost in the atmosphere through denitrification in the form of NO, N_2O, NO_2, N_2, etc. Excess amounts of these gases cause air pollution and greenhouse gas effect.

The nitrate form of N is susceptible to losses through leaching besides denitrification. Excess NO_3 in groundwater creates the ‘blue baby’ disease. Hence, use of nitrogenous fertilizers having NO_3-N is less effective than those having NH_4-N, and accordingly their use should be avoided. Although application of NH_4-containing fertilizers like $(NH_4)_2SO_4$ and NH_4Cl have proved useful for rice crop production, their availability in the market is a big problem. Urea is generally considered as effective as NH_4 sources in most of the soils. This is because after application of urea its N, which is in amide form, is immediately converted into NH_4^+ and NO_3 form and becomes available to plants, depending upon the crop grown. The fate of NH_4^+ is threefold, as has been shown in Fig 9.1.

9.1.2 Application of Modified Urea Materials

As urea has now become the only principal nitrogenous fertilizer and its importance has increased manifold, concerted efforts for improving its efficiency, particularly for rice crop, have been made. As a consequence, a number of modified urea compounds have been developed. Sulphur-coated urea, lac-coated urea, neem-coated

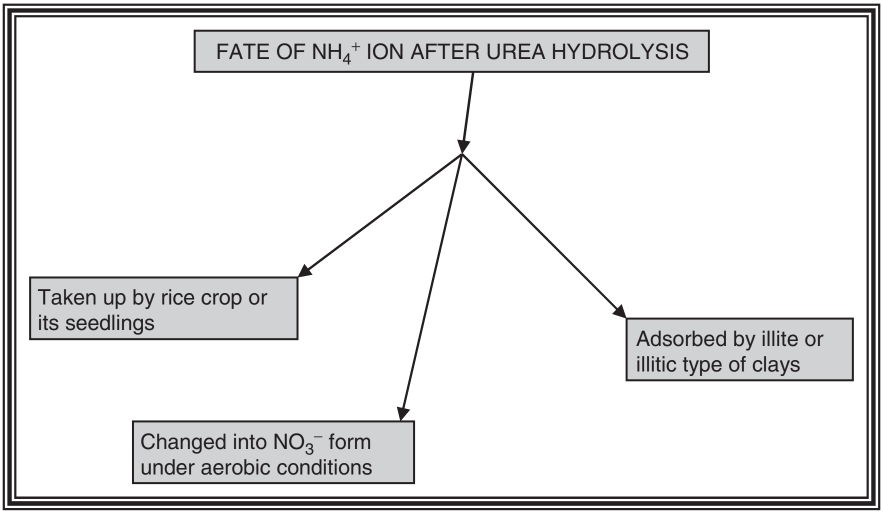

Fig. 9.1 Fate of NH_4^+ ion after urea hydrolysis

urea and urea super granule are some of the examples of modified urea compounds. The results of field experiments conducted by various scientists at the University of Agricultural Sciences and Technology, Pantnagar, and CSK Himachal Pradesh Krishi Vishvavidyalaya at Palampur have shown increase in rice yield with use of neem-coated, lac-coated and sulphur-coated urea compared to when urea prills were used.

Urea super granule should be used as a deep placement fertilizer in rice fields. When it is placed at 5–8 cm below soil surface about a week after rice transplanting, it has shown higher grain yield than split application. In light-textured soils, due to high percolation rate, its application is found to be less effective.

9.1.3 Timely Application of Fertilizers

In the case of rice crop, the whole amount of the phosphatic and potassic fertilizers and one third of nitrogenous fertilizers should be applied at the last puddling operation, but not more than 1–3 days prior to transplanting. Fertilizers should be applied well in the top 10–15 cm of puddled soil (Gupta and Kanwar, 1984). The remaining N will be applied in two equal splits, i.e. one 3 weeks after transplanting and the other 4–5 weeks later when the plants attain panicle-initiation stage. As already mentioned, application of urea or ammonium sulphate is preferred. However, if these are not available, calcium ammonium nitrate can be used for split application. But through this source of N application, considerable loss is likely to occur. As regarding phosphatic fertilizer application, superphosphate has proved more effective. The efficiency of two major K sources as potassium chloride (muriate of potash) is recommended because of its being cheaper than that of sulphate of potash.

In the case of wheat also, one third of the nitrogenous fertilizers and the whole amount of phosphatic and potassic fertilizers is applied at the time of sowing. The rest of the nitrogenous fertilizers should be added in two splits, i.e. one after first irrigation (25–30 days after sowing) and the other at the boot stage or before ear formation. While broadcasting the fertilizers, care should be taken for uniform distribution.

In light-textured soils, the number of splits should be increased from three to four. By doing so, the leaching losses due to heavy rains or irrigational water of nitrogenous fertilizers can be reduced.

9.1.4 Balanced Use of Fertilizers

Full benefit of nitrogenous fertilizers can be obtained only when the recommended doses of phosphatic and potassic fertilizers are applied (Gupta and Kanwar, 1984). In this connection, it is stressed that while adding the nitrogenous, phosphatic and potassic fertilizers their proper ratio should be maintained, i.e. 4:2:1.

9.1.5 Application of Fertilizers on the Basis of Soil Test

The best way to apply fertilizers both to rice and wheat is on the basis of soil test. Soil test is a chemical test which indicates the availability of plant nutrients in the soil vis-à-vis the texture and pH of the soils. It is worthwhile to mention that neither excess nor deficiency of nutrients in the soil is desirable for good crop yield. So it must be advocated to the farmers to make use of fertilizers based on the soil test. They must get the soil of their fields tested twice a year – once prior to transplanting the rice crop and again before sowing the wheat crop.

9.1.6 Saving Phosphatic and Potassic Fertilizers

In the fields where rice and wheat have been followed for 3 successive years with an application of recommended doses of nitrogenous and phosphatic fertilizers every year, the quantity of N should be reduced to about half for rice crop of the recommended dose for at least a year. Similarly, application of phosphatic and potassic fertilizers may be reduced or completely avoided in acidic soils if these have been applied to the preceding Rabi crops, i.e. wheat or linseed.

9.1.7 Application of Secondary and Micronutrients

There is no doubt that the rice and wheat cultivation is an optimal cropping pattern for the agriculture of Punjab, Haryana, Himachal Pradesh, Jammu region (Jammu & Kashmir) and other Indian states, but this scenario may not remain for two possible reasons. Firstly, due to continuous use of high analysis fertilizers during the Green Revolution, widespread deficiency of secondary nutrients like S, Ca and Mg and micronutrients like Zn, Fe, Cu and Mn has been seen, which limits the crop growth (Takkar and Nayar, 1986). Secondly, due to rice cultivation over a long period, there will be lowering of the water table, as this requires a large amount of water. Hence, the productivity of rice will decline. The soils of Jammu region, where rice and wheat or maize/pearl millet are grown, have also been found deficient in available Zn and S (Gupta et al., 1997a, b; Jalali et al., 2001).

To overcome the deficiency of Zn, an application of $ZnSO_4$ at the rate of 25 kg ha^{-1} has been found to be beneficial in increasing the yields of crops like wheat, rice and maize. However, in soils where *Khaira* disease of rice due to deficiency of Zn is a serious problem, basal application of $ZnSO_4$ may not prove beneficial. In such cases Zn sprays with the following schedules have given excellent results:

- First spray of 5 kg $ZnSO_4$ + 2.5 kg lime in 750–1,0001 of water in the nursery about 10 days after sowing has proved effective in controlling the *Khaira* disease.

- Second spray as stated above should be done 20 days after sowing.
- Another spray as above is required about 15–30 days after transplanting the rice.

9.1.8 Practice of Green Manuring

Wherever it is possible, green manuring should be done. It has been found that on an average, the green manure of dhaincha (*Sesbania aculeata*), guara (*Cyamopsis* spp.) and sunn hemp (*Crotolaria juncea*) add about 82, 65 and 75 kg N ha^{-1} respectively. Green manuring in the soil is therefore a valuable means of enriching soils with N and saving nitrogenous fertilizers. Use of green manure of dhaincha prior to transplanting of rice has shown a saving of one third of the recommended dose of nitrogenous fertilizer under Ranbir Singh Pura, Jammu region (Jammu & Kashmir) soil condition (Gupta and Sharma, 2004). For proper decomposition of the green manure, it is essential to use it in a succulent condition and sufficient moisture should be present in the soils. As plants before the flowering stage contain the largest quantity of organic matter with low C/N ratio, green manuring crop should be buried into the soil prior to the flowering stage.

9.1.9 Right Conservation of Farmyard Manure

FYM generally refers to the refuse from the farm animals which contains two original components, the solid and liquid, in the ratio of 3:1. On an average, a tonne of FYM contains approximately 5–10 kg of N and 2.5–5.0 kg each of P_2O_5 and K_2O. It also possesses about 200 kg of organic matter and other plant nutrients (secondary Ca, Mg, S and micronutrients Fe, Mn, Cu, Zn, Mo, B and Cl). In addition to supplying macro- and micronutrients, FYM increases the water-holding and cation-exchange capacities of the soils, improves the structure and texture and soil porosity, and maintains the magnitude of bulk density.

Keeping in view the great importance of FYM as stated above, it must be prepared in pits to conserve the nutrient present in it and to protect it from the weather to avoid loss of nutrients.

9.1.10 Use of Azolla in Rice Fields

The use of *Azolla* as an organic fertilizer in rice cultivation was first made in North Vietnam in 1957 (Pareek and Maurya, 1984–85). Generally, one or two *Azolla* crops are taken which are then incorporated into the soil prior to transplanting paddy. For this purpose, the fields are prepared for rice cultivation, i.e. flooded with water followed by seedlings of *Azolla*. After 5–10 days, the water of the fields is drained off and the *Azolla* mat is ploughed into the soil. The process may be repeated for two crops of *Azolla*. It has been found that successive layers of *Azolla* incorporated into the soil can supply 50% of N requirement of rice.

Results have shown that generally green manuring of *Azolla* (*Azolla–Anabaena* association) has been found to fix more N=N and play an important role in increasing rice yield (Pareek and Maurya, 1984–85).

9.1.11 Use of Other Bio-Fertilizers

Use of *Azotobacter* culture in the dryland rice and wheat crops has been reported to save 25–50 kg N ha^{-1}. Bacteria like *Caulobacter* spp. and *Bacillus megatherium* living in association with blue-green algae (BGA) either double the vigour of N assimilation by *Nostoc* or stimulate N fixation. In a large number of Indian trials, BGA complemented with recommended doses of N has been found to increase the yield of rice by about 10%.

9.1.12 Timely Control of Weeds

An unwanted plant growing at an unwanted place is called a weed. Weeds rob soil fertility by competing with crops for plant nutrients, water, light, space, etc., and thus reduce the crop yields (Gupta and Kanwar, 1984). Thus, the control of weeds at a proper time in crops must be one of the important operations for the farming community. Stem F-34 (Propanil) should be sprayed at the rate of 8.5 l in 750–800 l of water with a high-volume spray pump at two- to three-leaf stage of paddy (20–25 days after transplanting) for controlling the grassy weeds which are the main problem.

9.1.13 Management of Micronutrients for Rice Soils

With the introduction of new rice varieties, the application of micronutrients for submerged rice soils has become essential due to their excess uptake by these varieties. Zn deficiency has since been observed in one or more Asian countries, both in lowland and upland soil conditions. Besides, the deficiency of Fe has also been noticed in rice-growing soils, especially in Latosols due to increased uptake of Mn (Fe–Mn antagonistic effect). Management of Zn and Fe deficiency in terms of their sources and methods of application have been detailed elsewhere (Gupta et al., 1997). They are briefly described below.

9.1.13.1 Sources of Zn and Fe

Among several inorganic compounds, zinc sulphate ($ZnSO_4$) and ferrous sulphate ($FeSO_4$) are most commonly used for combating Zn and Fe deficiencies, respectively. Though application of Zn through $ZnSO_4$ (20–25 kg ha^{-1}) has been found suitable to prevent Zn deficiency, this can also be cured by foliar spray with $ZnSO_4$ (0.5% $ZnSO_4$ + 0.25% lime) two or three times (after every 2 weeks) depending upon the persistence and severity of symptoms.

Ferrous sulphate ($FeSO_4.5H_2O$) and ferric sulphate [$Fe(SO_4)_3$] are most commonly used for combating Fe deficiency. If ferrous sulphate has to be applied, it must be broadcast followed by light harrowing. The dose may vary from 100 to 300 kg ha^{-1} or even more depending upon the extent of Fe deficiency.

Foliar spray of soluble salts is an alternative to soil application. Three per cent ferrous sulphate solution is generally found most suitable to relieve chlorosis.

9.1.14 Water and Fertilizer Interaction

Water and fertilizer are both high-cost inputs in crop production. However, they are also the highest-return input. When water is readily available to plants, nutrients may move towards roots easily for their absorption or uptake. This is the reason why under dryland conditions, the applied fertilizers have a very limited response to the growing crops. Therefore it is recommended that very little or no use of fertilizers is done in dryland agriculture due to the uncertainty of the monsoon rains. This calls for the rationalized use of fertilizers, depending upon the availability of water to crops. The fertilizer use efficiency in irrigated and rainfed areas can be enhanced through better water management and conservation practices. Some broad aspects of soil water and fertilizer interaction are described below.

9.1.14.1 Water and Nutrient Availability

The availability of soil water and mineral nutrients are related in a complex way to their effect on growth and yield of crops. Soil water, in fact, serves as a solvent for the nutrients and its amount present in the soil has both short- and long-term effects on the distribution and balance of mineral nutrients.

The short-term effect of water is on the balance of nutrient ions in the soil solution or solid phase. All nitrate in the soil remains mostly in the solution phase at any soil water potential range which supports the plant growth. P and K form the adsorbed or the solid phase but can maintain the concentration of the solution phase only in highly buffered soils. The long-term effect of water on nutrients is on the balance among the soluble, adsorbed and solid forms, and is related to the effect of water and oxygen on the chemical and microbial activity in the soil.

All nitrate, chloride, most of the sulphate and part of the boron and their associated cations move readily in the soil system and they are liable to be leached in excess of irrigation or rain water.

Mineralization of N increases with available water content of soil. The increase in soil water to an optimum level also increases P and K availability. There is a higher uptake of N, P, K Fe and Mn in rice under submerged soil conditions. Favourable soil moisture affects the response of fertilizers in two ways:

- By increasing availability or intake of nutrients contained in the fertilizers
- By utilization of adsorbed nutrients

In rainfed conditions, thus, there is a need to limit fertilizer application to rates that will not promote more growth than what available soil water can sustain until harvest.

9.1.14.2 Movement of Nutrients, Soil Moisture and Root Distribution

The movement of nutrients in the soil is primarily related to the soil moisture and secondarily by the extent of root distribution. In fact, the root distribution affects the availability of both the soil water and the nutrients from the soil profile. A deeper and extensive ramification of the root system assists in exploration of moisture and nutrients from deeper layers of soil. This together with improved top growth due to balanced fertilizers improves the water use efficiency as the effective depth of the reservoir increases according to which plants can absorb water. The available moisture capacity of the soil and its rate of use at different growth stages of the crop are important and must be understood well. The fertilizer application may stimulate early vegetative growth and exhaust the available moisture in the root zone faster. As a result, the fertilizers may have no effect on grain yield. The latter occurs more significantly when soil moisture becomes deficient to a grain crop like wheat or maize at a critical growth phase, namely flowering and grain formation. This can be, however, managed by selecting the proper crop varieties and improved water-conservation and other agro-economic practices.

9.1.15 Management of Soil Water and Fertilizer Use

A general belief of the farmers that more fertilizer application requires more irrigation is not true although more consumption of fertilizers has been reported in irrigated areas. Fertilizers and irrigation act independently as well as jointly, and application of economic doses of fertilizers is justified over a wide range of combinations. In irrigated conditions, the response to application of 120 kg N + 60 kg P_2O_5 has been reported in the case of wheat in many states. There is also response of K_2O application up to a certain extent (Tomar and Singh, 1984–85). It was attributed to a higher content of K in most of the soils due to the presence of

K-bearing minerals. But now, in many Indian soils very good response of added potassic fertilizers has been noticed in the rice–wheat cropping sequences. It is due to exhaustion of K reserves in the soils.

The effect of each unit of application of nitrogen fertilizer has enabled the production of more grain of wheat, and response was found to increase with the number of irrigations. The fertilizer use efficiency seems to be the highest with an application of 120 kg N ha^{-1}.

9.1.16 Optimizing Water and Fertilizer Use

For optimizing soil moisture and fertilizer use, application of fertilizers should be made according to the amount of available soil moisture. As nitrogenous fertilizer stimulates early vegetative growth and may exhaust the soil water supply before the critical crop growth stage like the reproductive stage. Therefore, in the areas where the entire water requirement of the crop has to be met from the stored soil water, the N doses should be just enough to stimulate the deeper and extensive root growth. Once the plants are well established, water can be extracted from deeper soil depth. This is observed more in high water-table areas. Application of P is known to improve the yields under low rainfall conditions by improving early growth plus root vigour development and maturity of crops. As discussed earlier, when fertilizers were applied at the rate of N (120 kg ha^{-1}), N + P_2O_5 (120 + 60 kg ha^{-1}) and N + P_2O_5 + K_2O (120 + 60 + 60 kg ha^{-1}), the wheat grain yield increased by 57%, 38% and 13%, respectively, over the control. Total increase in wheat yield was 108% over the control, when N, P_2O_5 and K_2O were applied in proper amounts.

Thus, the balanced use of fertilizers is beneficial to increase the yield of the crops both in limited and irrigated conditions.

9.2 Water Use Efficiency

Water use efficiency refers to the yield of marketable crop produced per unit of water used for consumption. Among others, the primary soil management practices affect water use efficiency in the use of fertilizers. If fertilizer use results in high yield, this may also increase the water use efficiency. Under irrigated conditions it becomes imperative to make use of applied water more efficiently. This can be done by making the irrigation schedule according to the need of the rice and wheat crops. The level of nutrient supply should be maintained to ensure the efficient use of soil water supply. In rainfed conditions, however, every effort should be made to increase the amount of water available to the crop for production. Loss of water that occurs due to evaporation and transpiration must be reduced.

9.3 Suggestions and Priorities for the Future

- Where water is scarce, high-value but low-water-requiring crops should be grown.
- All pulses and oilseeds are important income-earning and soil-enriching crops, so they should be included in rice-farming systems wherever they can be grown.
- Hidden hunger of soils due to the deficiency of S, Zn and B leads to hidden hunger in human diet.
- As crop management systems totally based on the use of chemical fertilizers have already lost, and will further lose, their production potential in the long term, farmers must take steps to restore soil organic matter and control measures of secondary nutrients and micronutrient deficiencies.
- The farming families should be provided with Soil Health Cards, which will help them to maintain soil productivity at a high level without resorting to soil mining. Factor productivity with reference to nutrients will go up only if integrated attention is given to the physics, chemistry and microbiology of the soils.
- There is an urgent need to develop and disseminate eco-technologies for rainfed and semi-arid, hill and island areas, which have so far been bypassed by modern yield-enhancement technologies.
- For defending the gains already obtained, in the rice–wheat cropping sequence, an important requirement is the development and adoption of technologies that will lead to economic gain without ecological loss.
- As intensive cropping involving rice and wheat removes N, P_2O_5 and K_2O from the soil to the extent of 500–700 kg ha^{-1} per year, this amount of nutrients is required to be added.
- Many of the farmers are, however, not able to apply such amounts of nutrients as the fertilizers are very costly. Hence, an alternative is to apply nutrients through other sources (FYM, compost, green manure).
- So far, infrastructure, technology and skill have been built on such lines so as to carry on the rice–wheat enterprises successfully. It took decades to build the system. Similarly, it should be restructured slowly and steadily.
- Since these days sustainability is the major concern, alternatives have to be found by stressing on research activities. For example, maize can be an alternative food grain for rice during *Kharif* season.
- Increase the area under irrigation. This is the most practical and technically feasible solution. By increasing the area under irrigation, the productivity of crops, especially of rice and wheat, can definitely be increased.
- In soils where faulty irrigation has caused salinity and alkalinity, suitable measures should be taken. This can be done by introducing modern irrigation systems such as drip or sprinkle irrigation.
- A variant drip irrigation system, with features such as drip emitters, drip laterals, filters and fertigation equipment to better suit India's small-sized farms, should be used.

Impact Points to Remember

- Excess of NO_3 in groundwater may lead to ‘blue baby’ disease.
- Urea super granule should be used as a deep placement fertilizer in rice fields.
- The use of *Azolla* as an organic fertilizer in rice cultivation was first made in North Vietnam in the year 1957.
- Weeds rob soil fertility by competing with the crops for plant nutrients, water, light, space, etc., and thus reduce the crop yields.
- The fertilizer use efficiency in irrigated and rainfed areas can be enhanced through better water management and conservation practices.
- There is higher uptake of N, P, K, Fe and Mn in rice under submerged soil conditions.
- Application of P is known to improve the yields under low rainfall conditions by improving early growth plus root vigour development and maturity of crops.
- Water use efficiency refers to the yield of marketable crop produced per unit of water used for consumption.

Study Questions

1. Define the following:
   (a) Leaching loss of NO_3^-
   (b) Soil testing
   (c) Balanced use of fertilizers
   (d) Modified urea compounds
2. Write down the fate of NH_4^+ ion after hydrolysis of urea.
3. What is meant by selection of right kind of fertilizers?
4. Differentiate between effective use of fertilizers and water management for rice and wheat cropping pattern.
5. What are the various modified forms of urea? How do they help in checking the nitrate losses in rice soils?

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Chapter 10
Role of INM in Sustainable Rice–Wheat Cropping System

Abstract To meet the ever-increasing demand for food of the huge population of the Indian subcontinent and to exploit the high yield potential of cereals, it requires higher fertilizer doses, which are a non-renewable source of energy. However, long-term fertilizer experiments have revealed that continuous application of sub-optimal doses of chemical fertilizers to soil has resulted in the deterioration of soil health, environmental pollution and stagnation or decrease in crop productivity. Thus, integrated use of organic manures with optimal levels of NPK fertilizers is the need of the day that will not only improve the nutrient status and soil health but has also shown greater potential in stabilizing crop yields over a period of time. The integrated use of organics and chemical fertilizers at optimum levels as determined by soil tests in long-term fertilizer experiments indicate the build-up of micronutrient and secondary nutrient reserves such as Zn, Cu, Mn, Ca, Mg and S. Therefore, INM in sustainable rice–wheat cropping system is of paramount importance. It will also ensure increased crop productivity in an efficient and environmentally benign manner, without diminishing the capacity of the soil to produce for present and future generations. In other words, INM system is an ecologically, socially and economically viable approach, which on the whole is non-hazardous. In this chapter, the importance and beneficial role of various organic sources (organic manures like FYM, compost, green manures, crop residues, vermicompost, bio-fertilizers, leguminous crops and locally available nutrient sources) in conjunction with chemical fertilizers are discussed.

Keywords Chemical fertilizers • soil health • environmental pollution • rice–wheat cropping system • INM system • organic manures • crop residues • green manures • compost • vermicompost • bio-fertilizers • leguminous crops

Recent studies have revealed that continuous use of sub-optimal doses of nutrients in the intensive rice–wheat cropping system has led to severe depletion of nutrient reserves of soil, causing multiple nutrient deficiencies. The use of high analysis fertilizers devoid of micronutrients has aggravated micronutrient deficiencies, causing significant decline in crop productivity (Singh and Swarup, 2000).

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No single dose of plant nutrient through chemical fertilizers, organic manures, crop residues or bio-fertilizers can meet the entire nutrient need of a crop in modern intensive agriculture. Rather, these need to be used in an integrated manner following a management technology which is practicable, economically viable, socially acceptable and ecologically sound (Swarup, 1998).

> *Without new technology, we would not be able to provide food for 7 billion people (Worldwide).*
>
> Norman E. Borlaug

Past research has shown that the use of mineral fertilizers has helped in boosting rice–wheat yield in the Indo-Gangetic Plains, but their rising cost and diminishing resources have led to the exploitation of potential alternative sources of plant nutrients (Ladha et al., 2000, 2003; Pathak et al., 2003). Complementary use of available renewable sources of plant nutrients (organic/biological) along with mineral fertilizers has resulted in the development of the new technology – INM system. The role and contribution of each of the components of INM system to rice–wheat cropping system are discussed in the following sections.

10.1 Chemical Fertilizers

Chemical fertilizers are and will remain the major and most important component of INM system under intensive cropping system as these contribute about 50% to the increase in food grain production for the increased population of our country. About three fourths of fertilizer is consumed in rice and wheat. In the rice–wheat system, the recommended dose of N should be applied to both crops as there is almost no residual effect on succeeding crops. Due to increased availability of native soil P under submergence, rice generally responds to applied P than wheat. Therefore, P application to wheat should be preferred over rice. However, in P-deficient soils, it is very essential to apply P in both the crops. Rice is more responsive to K than wheat and it should be added as per soil test-based recommendation. Increased use of sulphur-free fertilizers like urea, diammonium phosphate (DAP) and muriate of potash (MOP) has accentuated the need of sulphur application (Plate 10.1). Due to intensive cropping with high nutrient-responsive varieties of rice and wheat widespread deficiencies of micronutrients, particularly that of Zn, are emerging as yield-limiting factors. Hence, the deficient micronutrients should be applied through their respective carriers in soil as per the crops' needs. In rice–wheat rotation, if soil is Zn-deficient, it can be applied as soil application as well as foliar spray in both the crops (Ram, 2000).

10.2 Organic Manures

Organic manures are the most important component of the INM system (Choudhary et al., 2002; Ram, 2000). Use of organic manures to replenish soil nutrients is the oldest and most widely acceptable practice, especially in hilly states like Himachal

Plate 10.1 Chemical fertilizers supplying NPK nutrients

Pradesh where farmers invariably apply 10–15 t FYM ha^{-1} (Acharya et al., 2001). The rice–wheat cropping system of the Indo-Gangetic Plains was traditionally dependent on organic manurial sources. The share of organic manures in total nutrient supply was drastically curtailed after the introduction of intensive farming, which demands quick nutrient availability. Energy crisis, high price index of chemical fertilizers coupled with their limited production, soil health problems, yield non-sustainability and pollution have led to a renewed interest in the use of organic manures. It has been observed that inclusion of FYM regulates nutrient uptake, improves crop yields and the physical status of soils and thus has a synergistic effect (Yadav and Kumar, 2002).

Use of organic manures in India was 99.86% of the total nutrient use in 1949 but by 1993 it had decreased to 32.5% (Subba Rao and Srivastava, 1998). At present, it is expected to have further decreased to 20–25% of the total, however, saving 25% of fertilizers. Research results of INM studies have established that besides serving as a source of plant nutrients to crop, the bulky organic manures improve soil aeration, permeability and aggregation, water-holding capacity, nutrient-holding capacity and biological properties of soils, thereby enhancing the fertilizer use efficiency when applied in conjunction with mineral fertilizers. This also provides essential secondary and micronutrients like S, Mg, Cu, Mn and Fe (Roy and Dudal, 1993). The use of organic sources with fertilizer application increased the NPK uptake in rice and wheat, decreased the soil pH and electrical conductivity at a faster rate and depleted nutrients at a slower rate than inorganic fertilizers. Higher reduction in pH, electrical conductivity and exchangeable sodium percentage of soil was observed by using organic manures along with chemical fertilizers compared to fertilizers alone (Table 10.1). The combination of chemical fertilizers with FYM registered higher increase in available N and P content of the soil against the chemical fertilizers alone. The higher build-up in available N and P is attributed to solubilization of nutrients from their native sources during decomposition and mineralization of organic manures (Yadav and Kumar, 2002).

The INM system also supplies micronutrients like Zn, Cu, Mn and Fe in soils of rice–wheat cropping system (Roy and Dudal, 1993; Yadav and Kumar, 2000). The depletion rate of DTPA-extractable micronutrient cations, namely Zn, Cu, Mn and Fe, was found to be higher when inorganic fertilizers were added compared to organic fertilizers (Table 10.2). Moreover, chelating action of the applied organic compounds increased the availability of micronutrients by preventing their fixation, oxidation, precipitation and leaching (Yadav and Kumar, 2000).

The INM apart from improving physical properties like soil aeration, perme ability, aggregation, water-holding capacity and nutrient-holding capacity (Acharya et al., 1988) also had significant influence on soil bulk density and total soil porosity (Table 10.3) after harvesting of rice under rice–wheat system in silty loam calcareous

Table 10.1 Effect of organic nutrient management on soil fertility changes after 12 cycles of rice and wheat sequence (Adapted from Yadav and Kumar [2002])

Treatments						Available nutrients (kg ha^{-1})		
Rice	Wheat	pH	EC (dS m^{-1})	ESP (%)	O.C. (%)	N	P	K
Control	Control	8.5	0.41	23	0.19	64	6.4	214
50% NPK	100% NPK	8.3	0.31	19	0.45	117	23.9	248
50% NPK + 50% (FYM)	100% NPK	7.9	0.32	16	0.56	132	26.7	269
Initial value		8.80	0.50	27	0.37	102	13.8	355

Table 10.2 Effect of nutrient management on micronutrient cations after 12 cycles of rice and wheat sequence (Adapted from Yadav and Kumar [2000])

Treatments		DTPA-extractable micronutrient cations (ppm)			
Rice	Wheat	Zn	Cu	Mn	Fe
Control	Control	0.86	1.06	7.8	10.8
50% NPK	100% NPK	0.71	0.95	7.9	12.0
50% NPK + 50% (FYM)	100% NPK	1.07	1.10	9.2	14.0
Initial status		2.02	2.40	12.6	17.0

Table 10.3 Effect of INM on bulk density and total soil porosity after harvesting of rice–wheat system (Adapted from Amgain and Singh [2001])

	Bulk density (Mg m^{-3})		Total soil porosity (%)	
Treatments	Surface layer	Sub-surface layer	Surface layer	Sub-surface layer
Due to organics				
No organics	1.45	1.49	45.18	43.87
FYM	1.32	1.36	50.19	48.68
GM	1.40	1.38	47.36	48.02
LSD (0.05)	0.10	0.065	3.83	2.49
Due to inorganic fertilizers				
No NPK	1.47	1.47	44.53	44.65
50 NPK	1.42	1.43	46.54	45.91
75 NPK	1.35	1.38	48.93	47.80
100 NPK	1.32	1.35	50.31	49.06
LSD (0.05)	NS	0.075	NS	2.88

soil at Rajendra Agricultural University Farm (Pusa), Bihar (Amgain and Singh, 2001). In the surface soil layer (0.0–0.075 m), application of FYM significantly reduced the bulk density (1.32 Mg m^{-3}) in comparison to the control (1.45 Mg m^{-3}). But in the sub-surface soil layer (0.075–0.15 m), FYM and NPK fertilizer treatments showed significant reduction in bulk density over the control. The inverse relationship between soil bulk density and total porosity was observed in all the plots. The increment in soil bulk density and reduction in total porosity in the surface layer of the rice field was attributed to soil particle dispersion and soil submergence (Sadanandan and Mahapatra, 1973). The lower values of bulk density in the plots under recommended levels of fertilizers was due to the presence of more crop residues (roots) being left after crop harvest (Bhatnagar et al., 1992; Mishra and Sharma, 1997; Patnaik et al., 1989). The significantly higher pore space in plots receiving FYM and higher levels of fertilizer treatments was credited to better soil profile aggregation and reduction in bulk density (Gupta and O'Toole, 1986; Prasad et al., 1995).

The application of organic manure enhanced the water retention capacity of the soils (Amgain and Singh, 2001). The data in Table 10.4 representing water retention capacity of soil at field capacity (0.33 bar suction), permanent wilting point (15 bar suction) and available soil moisture (%) in Bihar revealed that the control plot recorded the minimum values for all these characteristics. Increasing levels of fertilizers markedly increased the water retention capacity. Similarly, the application of organic manure enhanced the water retention capacity. The maximum moisture content values (25.47%) recorded in FYM + 100% NPK may be due to the improvement in soil aggregates by more root residues production which were left after crop harvest. The variation in moisture content at permanent wilting point among the treatments was not as apparent as it was at field capacity. This might be explained by the native capacity of the soil to hold water under stress conditions (Srivastava, 1992; Yadav and Kumar, 1993).

Table 10.4 Effect of INM on water retention capacity (W/W) of soil after harvesting of rice–wheat system (Adapted from Amgain and Singh [2001])

	Soil layer (0.0–0.15 m)		
Treatments	Field capacity (0.33 bar)	Permanent wilting point (15 bar)	Available water (%)
No organics and no NPK	25.86	6.00	19.86
50% NPK	27.00	6.47	20.53
75% NPK	27.18	6.10	21.08
100% NPK	28.36	6.00	22.36
FYM	28.31	6.73	21.58
FYM + 50% NPK	30.80	6.78	24.02
FYM + 75% NPK	32.00	6.80	25.20
FYM + 100% NPK	32.33	6.86	25.47
C.V. (%)	6.73	5.11	7.72

Table 10.5 Effect of organic nutrient management on the grain yield (t ha^{-1}) of rice and wheat grown in a sequence (average of 3 consecutive years) (Adapted from Yadav and Kumar [2002])

Treatments		Rice			Wheat		
Rice	Wheat	1984–87	1990–93	1995–98	1984–87	1990–93	1995–98
Control	Control	2.00	1.59	1.12	1.30	0.74	0.67
50% NPK	100% NPK	3.94	4.37	4.19	3.42	3.25	3.86
50% NPK + 50% (FYM)	100% NPK	2.99	4.47	4.57	3.41	3.45	4.22
50% NPK + 50% (GM)	100% NPK	3.23	4.34	4.21	3.16	3.02	3.83

The grain yield, total productivity and net returns in rice–wheat cropping system increased with the application of organics in combination with inorganic fertilizers (Tiwari et al., 2002; Yadav and Kumar, 2002). The results of a 16-year-old permanent long manorial trail on rice–wheat system at Faizabad, Uttar Pradesh, revealed that substitution of 25–50% N through FYM along with 50–75% recommended NPK through chemical fertilizers to rice resulted in higher yield compared to 100% chemical fertilizer application alone. The results indicated that FYM application at the rate of 12–15 t ha^{-1} to rice could substitute nearly 60 kg N ha^{-1} (Table 10.5).

In another field experiment the effect of INM on productivity and economics of rice–wheat sequence at Jabalpur, Madhya Pradesh, from 1985/86 to 2000/01 (Table 10.6) indicated that mean grain yield, total productivity and net returns of rice and wheat crops increased with the application of 50% recommended dose of fertilizers (RDF) integrated with 50% fertilizers through FYM at the rate of 12 t ha^{-1} in rice crop followed by 100% RDF to wheat crop compared to farmers' practice. This was comparable to 100% NPK and thus there was a saving of 25–50% costly fertilizers through FYM application and also less ill-effects of chemical fertilizers on soil properties in the long run.

Table 10.6 Effect of INM on productivity and economics of rice–wheat sequence at Jabalpur (1985–86 and 2000–01) (Adapted from Tiwari et al. [2002])

Treatments		Mean yield (t ha^{-1})		Total productivity (t ha^{-1})	Net returns (Rs ha^{-1})
Kharif	*Rabi*	Rice	Wheat		
No fertilizer, no organic manure	No fertilizer, no organic manure	2.2	0.9	3.11	3,995
50% NPK	50% NPK	3.7	2.4	6.1	16,119
75% NPK	75% NPK	4.4	2.2	6.6	18,701
100% NPK	100% NPK	4.7	2.7	7.4	22,664
50% NPK + 50% through FYM (12 t ha^{-1})	100% NPK	4.6	2.6	7.2	21,536
75% NPK + 25% through FYM	75% NPK	4.7	2.4	7.1	21,424
LSD (0.05)		0.6	0.5	1.4	937

10.3 Enriched Compost

The process of decomposition of organic wastes, especially of plant residues along with small amounts of dung and urine, is termed composting and the material after full decomposition is called compost. On an average, it contains 1.01% N, 0.5% P_2O_5 and 0.8–0.9% K_2O. Compared to FYM, compost has high percentage of humus and is free from pathogenic disease and weed seeds. The enrichment of organic manures is of practical interest because the demerits of bulky organic manures can be overcome by their enrichment and they offer a low-cost alternative to chemical fertilizers. It increases the nutrient content of manures, reduces the bulk to be handled per unit of nutrients, decreases the period of composting, making it more acceptable to the farmers, and offers a potential for the effective utilization of insoluble materials such as low-grade phosphate rocks. Phosphorous-enriched compost called phosphocompost has been developed by incorporating rock phosphate in organic wastes during composting (Mishra et al., 1982). The phosphocompost is prepared by incorporation of rock phosphate during decomposition of organic wastes consisting mainly of plant residues, cattle dung and well-decomposed compost. Studies on the mechanism of transformation of rock phosphate during composting reveal that microbial activity and humic substances are responsible for conversion of insoluble forms of P to soluble forms. In an effort to increase N content of phosphocompost, the incorporation of 2% urea and 10% pyrite has been found useful to increase N content of phosphocompost (Banger et al., 1989; Singh et al., 1992).

By using N-fixing bacteria and P-solubilizing bacteria and fungi, the nutrient content of compost can be further improved (Mishra, 1992). The use of efficient microbial inoculates, e.g. *Azotobacter chroococcum* (N-fixer), *Bacillus polymyxa, Aspergillus awamorii, A. nigra* and *A. lipoferum* (P-solubilizing fungi), along with mineral N and rock phosphate produces nutrient-rich compost with low C/N ratio, which produces higher crop yields than ordinary compost and FYM. Enrichment

Table 10.7 Effect of enriched[a] rice straw compost on the grain and straw yields of the wheat crop (Adapted from Gaur and Singh [1993])

Treatments	Grain yield ($q\ ha^{-1}$)	Increase in yield over control (%)	Straw yield ($q\ ha^{-1}$)
Control	17.5	–	30.7
100% NPK (120–60–60)	45.2	157.8	75.3
50% NPK (60–30–30)	30.8	75.9	57.8
Chopped straw compost	24.9	41.8	44.4
Chopped straw compost + 50% NPK	40.0	127.9	75.3
Unchopped straw compost	24.0	36.9	37.1
Unchopped straw compost + 50% NPK	38.9	121.8	68.4
LSD (0.05)	6.2	–	–

[a] Enriched with rock phosphate and microbial inoculation

of the compost can also be done using urea, DAP and rock phosphate. Field trials conducted at Kanpur, Uttar Pradesh (Table 10.7), on the effects of enriched straw compost prepared from chopped and unchopped material on the yield of wheat crop showed that the grain yield increased by 41.8% and 36.9%, respectively. Similarly, chopped straw compost + 50% NPK produced statistically similar grain yields to 100% NPK dose (Gaur and Singh, 1993). The inoculation of composts with microbes like N-fixers and P-solubilizers hastened the composting and enriched these composts with plant nutrients which play a vital role in crop production.

10.4 Vermicompost

Vermicomposting is one of the best processes of recycling of different types of wastes available on farm, rural areas and urban settlements and may become most important components of INM system. It has attracted the attention not only of scientists but also of farmers worldwide. Since it is a natural organic product which is eco-friendly, it does not leave any adverse effects either in the soil or in the environment. Thus, much interest in vermicomposting has been noticed due to the fact that earthworms play an important role in soil improvement, organic matter decomposition and enhancing plant growth (Gupta and Bhagat, 2004). On an average, vermicompost contains 1.6% N, 5.04% P_2O_5 and 0.8% K_2O. Apart from this, it also contains hormones like auxins and cytokynins, enzymes, vitamins and useful micro-organisms like bacteria, actinomycetes, protozoa, fungi and others. The C/N ratio of vermicompost is much lower (1:16) than that of FYM (1:30). Field experiment conducted at IARI, New Delhi (Table 10.8), concluded that the integrated use of half the dose of 120 kg N ha^{-1} Prilled Urea (PU) along with 60 kg N ha^{-1} through vermicompost gave comparable grain yield of rice and wheat crop with application of 120 kg N ha^{-1} PU (Adhikari and Mishra, 2002).

Briefly, it is summarized that earthworms feed on any organic waste. They consume nearly two to five times their body weight and after utilizing 5–10% of

Table 10.8 Effect of integrated sources of nitrogen on the grain yield of rice and their effect on succeeding wheat (Adapted from Adhikari and Mishra [2002])

	Yield (q ha^{-1})			
	Rice		Wheat	
Treatments	Basmati 370	Pusa Sugandh-3	After Basmati 370	After Pusa Sugandh-3
0 kg N ha^{-1}	24.9	38.2	30.0	30.7
60 kg N ha^{-1} PU	29.1	52.7	30.9	30.6
120 kg N ha^{-1} PU	38.4	64.6	32.2	32.8
80 kg N ha^{-1} PU + 40 kg N ha^{-1} vermicompost	36.2	62.7	36.5	39.8
60 kg N ha^{-1} PU + 60 kg N ha^{-1} vermicompost	38.8	63.5	36.6	37.8
LSD (0.05)	5.1		4.2	

the feed stock for their growth, excrete the mucus coated with undigested matter as wormcasts or vermicasts. Wormcasts consists of organic matter which has undergone physical and chemical breakdown through the activity of the muscular gizzard, which grinds the material to a particle size of 1–2 µ. Vermicasts are rich in calcium and other available nutrients. They are readily soluble in water for the uptake of plants. Vermicompost is organic manure produced from earthworms.

10.5 Micronutrients

With the adoption of exhaustive rice–wheat systems involving HYVs and changed fertilizer use pattern in favour of high analysis NPK fertilizers (practically devoid of secondary and micronutrients), widespread deficiencies of S and Zn and sporadic deficiencies of Fe, Mn and B have been noticed and remain unattended. Among micronutrients, Zn deficiency is the most common soil disorder as nearly 50% soils of intensively cultivated areas suffer from Zn deficiency, especially lowland rice soils with low organic matter which are alkaline in reaction (Prasad, 2000). In India, Zn deficiency was discovered first at Pantnagar, in erstwhile Uttar Pradesh, now Uttranchal (Nene, 1966), in *tarai* (forest hill) soils and was then observed almost everywhere in rice–wheat cropping systems (Takkar and Randhawa, 1978). In rice–wheat areas of north-west India, deficiencies of Zn, Fe, Cu and Mn have been found to the extent of 52–75%, 8–32%, 2–4% and 1–8%, respectively (Yadav et al., 1998). It has also been found that 3.25 kg Fe, 2.60 kg Mn and 0.80 kg Zn ha^{-1} are removed from soil by these crops. Hence, nutrient deficiencies/imbalances are inevitable unless steps are taken to restore the soil fertility level (Swarup, 1998).

In the light of the above, INM system appears to be the sole alternative in bridging the gap between nutrient requirement and supply in intensive cropping systems. Integrated use of fertilizers with organic manures, crop residues including green manure can serve as a source of micronutrients and complexing agents.

Singh et al. (1998) conducted experiments on medium black soils on integrated use of organics and micronutrients at Rajendra Agricultural University Farm, Pusa (Bihar), and indicated that integrated use of 2.5 kg Zn ha^{-1} and 2.5–5 t ha^{-1} biogas slurry was quite effective in improving fertilizer use efficiency and grain yield of rice–wheat cropping systems (Table 10.9).

The plant height, grain weight and grain yield of wheat in rice–wheat cropping systems increased significantly with the adoption of INM system. Yield and yield attributes of wheat studied in rice–wheat sequence (average of 3 years) in sandy loam soils at Bulandshar, Uttar Pradesh, indicated that when Zn was added to 100% NPK and FYM, it increased plant height, grain weight and grain yield rather than 150% NPK and Zn (Table 10.10). This was due to the gradual and uniform availability of Zn to crops by chelation with FYM (Vivek and Dhyani, 2002).

Table 10.9 Effect of Zn and biogas slurry (dry weight) on grain yield of rice–wheat sequence (Adapted from Singh et al. [1998])

	Grain yield (q ha^{-1})			
	1993–94		1994–95	
Treatments	Rice	Wheat	Rice	wheat
Control	19.0	21.3	9.0	25.7
BGS @ 6.25 q ha^{-1}	23.0	23.0	13.5	26.7
BGS @ 6.25 q ha^{-1} + Zn @ 2.5 kg ha^{-1}	42.5	26.2	26.7	30.3
BGS @ 12.5 q ha^{-1}	24.8	22.7	16.0	27.0
BGS @ 12.5 q ha^{-1} + Zn @ 2.5 kg ha^{-1}	44.0	27.0	26.3	30.7
BGS @ 12.5 q ha^{-1} + Zn @ 5 kg ha^{-1}	45.5	28.0	24.3	30.3
BGS @ 25 q ha^{-1}	25.8	23.4	18.5	28.0
BGS @ 25 q ha^{-1} + Zn @ 2.5 kg ha^{-1}	47.3	28.3	22.0	31.0
BGS @ 25 q ha^{-1} + Zn @ 5 kg ha^{-1}	48.3	29.0	28.0	31.3
LSD (0.05)	3.9	2.8	4.5	3.8

Table 10.10 Effect of fertilizer treatments on yield and yield attributes of wheat in rice–wheat sequence (average of 3 years) (Adapted from Vivek and Dhyani [2002])

Treatments	Plant height (cm)	1,000 grain weight (g)	Grain yield (q ha^{-1})
100% NPK	84.3	39.6	46.7
100% NPK + Zn	84.6	39.9	49.2
100% NPK + FYM	84.7	40.2	52.3
100% NPK + Zn + FYM	84.9	40.4	54.7
125% NPK	85.3	40.5	49.8
125% NPK + Zn	85.7	40.6	56.1
125% NPK + Zn + FYM	85.9	41.1	61.1
150% NPK	86.6	41.2	54.0
150% NPK + Zn	86.8	41.5	58.1
150% NPK + FYM	87.2	41.9	61.9
150% NPK + Zn + FYM	87.4	42.1	63.6
LSD (0.05)	1.3	0.5	2.1

Thus, continuous application of organic manures like FYM, poultry manure, decomposed pressmud, biogas slurry and sewage-sludge prevented Zn deficiency even in intensive cropping systems, except in soils severely deficient in Zn where organic manures alone failed to meet the Zn demands of the crops. Nevertheless, improvement in the use efficiency of fertilizer Zn in cropping systems consequent to application of organic manures has been reported under normal, calcareous as well as salt-affected soils (Prasad et al., 1989; Swarup, 1984).

10.6 Plant Growth Regulators

Plant growth regulators or substances are natural bio-chemicals produced by plants (endogenous) or are synthetic substances applied to plants externally (exogenous) which modify plant growth and development. Plant growth regulators produced by plants are referred to as phytohormones. Growth substances initiate biochemical processes, which help increase production of roots, shoots, flowers, etc., and ultimately crop yields. Growth substances also play an important role in translocation of accumulated carbohydrates and other nutrients to the crop (Chuilakhyan and Khrianin, 1978; Mc Carty, 1995; Mok et al., 1987). Thus, growth substances in combination with fertilizers can play a key role in INM system with the following objectives: (i) to economize the use of fertilizers in field crops, (ii) to increase the fertilizer use efficiency, and (iii) to maximize crop yields and economic returns. In a field experiment conducted at Waraseoni, Madhya Pradesh, on clay loam soil during 1991/92, it was concluded that foliar application of cytokinin (Anand Vishal) at the rate of 500 ml ha^{-1} or its soil application at the rate of 500 ml ha^{-1} at 25 and 50 DAT in combination with foliar application of triacontanol (Anand Kiran) at a rate of 500 ml ha^{-1} at fertility level $N_{100}P_{26.4}K_{33.6}$ significantly increased the grain yield of rice (Paraye et al., 1995). Another field experiment conducted at Tikamgarh, Madhya Pradesh, during 1991/92 and 1992/93 on integrated use of chemical fertilizers and growth regulators revealed that *Azotobacter* and growth regulators along with chemical fertilizers produced significantly higher wheat yield as compared to NPK fertilizers application alone (Tomer et al., 1995).

10.7 Crop Residues

Residues left out after the harvest of the economic portion of the crops in the field are called crop residues. India has a vast potential of crop residues such as rice, wheat and sugarcane, which are a substantially rich source of plant nutrients (Plates 10.2 and 10.3). On an average, they contain 0.5% N, 0.6% P_2O_5 and 1.5% K_2O. They mostly constitute the staple food of, and/or are mostly used as dry fodder for, animals, but in certain regions where mechanical harvesting is done, the crop residues are left behind in the field which can act as a source

Plate 10.2 Crop residues of rice placed in the field

Plate 10.3 Wheat residues incorporated in the field

of nutrient supply. Application of well-decomposed crop residues improves soil properties and the nutrient status of the soil; they also meet a part of the micronutrient supply and thus help in sustaining rice–wheat crop productivity (Sharma and Bali, 1998).

Table 10.11 Effect of crop residue management on soil fertility of a loamy sand soil over 11 years of the rice–wheat cropping system (Adapted from Beri et al. [1995])

	Crop residue management		
Soil property	Burned	Removed	Incorporated
Total P (mg kg^{-1})	390	420	612
Total K (mg kg^{-1})	17.1	15.4	18.1
Olsen P (mg kg^{-1})	14.4	17.2	20.5
Available K (mg kg^{-1})	58	45	52
Available S (mg kg^{-1})	34	55	61

Judicious use of crop residues has another important consideration in reducing nutrient loss through leaching, volatilization or fixation, especially under adverse soil conditions. Direct application of crop residues with wide C/N ratio many a times immobilizes all the available nutrients, particularly N and P, leading to adverse effects on crop growth during initial periods of decomposition. However, the composting upgrades their quality. Introduction of certain microbial strains capable of accelerating carbon mineralization can cut short the time necessary for complete residue composting. The major advantage of incorporation of rice–wheat residue increases the soil organic carbon (Dhiman et al., 2000). In a study at Pantnagar, Uttranchal (Sharma et al., 2000a), after five cycles of rice–wheat cropping system, organic C, total N, total K and available K were significantly higher in plots receiving crop residue compared to plots where residue was burnt or removed. In an 11-year field experiment on a loamy sand soil in Ludhiana, Punjab, the incorporation of residues of both crops in the rice–wheat cropping system increased the total P, available P and K contents in the soil over the removal of residues (Beri et al., 1995). Total P, available P and available S were on the order of residue incorporation > residue removal > residue burning (Table 10.11).

In another study over a 5-year period on a silty loam soil at Palampur, Himachal Pradesh, which has a relatively cooler climate than Punjab, the incorporation of rice straw in wheat caused a slight increase in the availability of P, Mn and Zn and a marked increase in the availability of K (Verma and Bhagat, 1992). The incorporation of crop residues on a long-term basis increased the DTPA-extractable Zn, Cu, Fe and Mn content in the soil (Singh et al., 2000). In a long-term study carried out in the eastern part of the Indo-Gangetic Plains (Bihar), Misra et al. (1996) observed increases in available N, P and K in the soil with the incorporation of crop residues in the rice–wheat rotation.

Crop residues also play an important role in improving soil physical properties like soil aggregation, compaction and structure, but the degree of improvement depends upon particle size distribution. Sharma et al. (2000b) from Delhi reported that an incorporation of crop residue also reduced the bulk density of soil. Similar results were reported by Prasad and Power (1991). In a loamy sand soil under the rice–wheat cropping system, the incorporation of wheat straw into the soil before transplanting of rice over a 5-year period promoted the formation of soil aggregates, particularly 1–2 mm in size, and increased the mean diameter of the aggregates. The mixed application of green manure and crop residues was more effective than their separate applications. The incorporation of residues alone or in conjunction with green manures also lowered the bulk density of surface soil (Meelu et al., 1994). In a long-term experiment in the rice–wheat cropping system in sandy loam soil, the incorporation of both rice and wheat straw vis-à-vis their burning or removal increased both the infiltration rate and cumulative infiltration (Walia et al., 1995; Singh et al., 1996). Rice straw was more effective in increasing porosity of soils than *Sesbania* green manure or pig manure (Li et al., 1986). Bhagat et al. (2003) noted a significant increase in the porosity of fine-textured soils after the application of rice straw and lantana residue. In general, the incorporation of crop residues into paddy soils reduced bulk density, penetration resistance and compaction in soils under rice–wheat cropping systems (Bellakki et al., 1998; Meelu et al., 1994; Singh et al., 1996; Walia et al., 1995).

10.7.1 Effect of Paddy Straw on Wheat

The effect of compost prepared from paddy straw on the yield of wheat crop was studied at KVK Farm, Jammu (Jammu & Kashmir), during 1999/2000 and 2000/01. The data indicated that the use of compost prepared from paddy straw treated with DAP (at the time of composting) along with one third recommended doses of N, P_2O_5 and K_2O fertilizers has given almost similar increase in wheat yield as obtained with urea-treated compost (Table 10.12). Increase in yield of wheat in both of these treatments was in the range of 95.4–98.5% compared to the control (Gupta et al., 2004).

10.7.2 Effect of Rice Stubbles on Wheat

A field experiment was conducted on Inceptisol at Ranbir Singh Pura Research Farm under SKUAST-Jammu (Jammu & Kashmir) to see the effect of rice residue management in wheat yield and soil properties (Sharma and Bali, 1998). The results

Table 10.12 Effect of paddy straw compost on the yield of wheat (Adapted from Gupta et al. [2004])

	Yield (q ha^{-1})			
Treatments	1999–2000	2000–2001	Average	Increase in yield over control (%)
1/3 N, P_2O_5 and K_2O + Urea treated compost	26.8	25.9	26.4	98.5
1/3 N, P_2O_5 and K_2O + DAP treated compost	27.2	26.5	26.9	99.2
Recommended N, P_2O_5 and K_2O	26.0	25.4	25.7	95.4
Control	14.3	12.3	13.3	–

Table 10.13 Growth and yield attributes and yield of wheat as influenced by rice residue management (pooled data of 2 years) (Adapted from Sharma and Bali [1998])

Treatments[a]	No. of plants m^{-2}	Tillers m^{-2}	Effective tillers m^{-2}	Grains $spike^{-1}$	Test weight (g)	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})
T_1	41.10	105.80	92.00	37.16	38.88	2.80	3.91
T_2	38.70	92.16	81.24	36.00	38.65	2.50	3.60
T_3	45.26	113.00	98.05	40.20	39.70	3.12	4.21
T_4	49.25	125.12	104.16	41.38	40.10	3.17	4.51
LSD (0.05)	NS	6.80	5.16	1.15	NS	0.25	0.28

[a] T_1-Removal of rice stubbles + 120 kg N ha^{-1}; T_2-No urea application to decompose rice stubbles + 120 kg N ha^{-1}; T_3-Urea @ 30 kg N ha^{-1} to decompose rice stubbles + 90 kg N ha^{-1} and T_4-Urea @ 30 kg N ha^{-1} to decompose rice stubbles + 120 kg N ha^{-1}

Table 10.14 Nutrient uptake by wheat and soil properties as influenced by rice residue management (pooled data of 2 years) (Adapted from Sharma and Bali [1998])

	Nutrient uptake (kg ha^{-1})			Soil properties				Available nutrients (kg ha^{-1})		
Treatments	N	P	K	pH	EC (dS m^{-1})	O.C. (%)	CEC (cmol $[p^+]$ kg^{-1})	N	P_2O_5	K_2O
T_1	82.10	17.43	85.05	6.5	0.43	0.39	12.30	170.0	14.20	227.28
T_2	78.35	16.10	80.16	6.7	0.40	0.40	13.29	190.2	15.40	228.60
T_3	86.25	19.75	92.21	6.5	0.42	0.43	14.28	205.3	15.80	229.32
T_4	89.50	21.05	95.49	6.6	0.42	0.42	14.31	205.1	16.15	231.45
LSD (0.05)	3.26	1.31	3.38	NS	NS	0.03	1.28	3.58	1.35	2.48

showed a significant effect of urea application with rice stubbles at the time of field preparation on growth and yield attributes (Table 10.13). This was attributed to proper decomposition of rice stubbles. The uptake of N, P_2O_5 and K_2O by the crop was also significantly higher with T_3 treatment (30 kg N ha^{-1} through urea to decompose rice stubbles + 90 kg N ha^{-1}) over T_2 (no N application through urea to decompose rice stubbles + 120 kg N ha^{-1}) and T_1 (removal of rice stubbles + 120 kg N ha^{-1}) treatments (Table 10.14). However, these values were statistically at par with T_4 (30 kg N ha^{-1} through urea to decompose rice stubbles + 120 kg N ha^{-1}).

10.7.3 Effect of Wheat Straw on Rice

The INM system using crop residues aims to maintain adequate nutrient cycling on a long-term basis while supplying sufficient quantities of nutrients to crops in the short term. The results of a field study conducted at Faizabad, Uttar Pradesh, indicated that wheat straw in combination with N application increased rice yield and net returns as mentioned in Table 10.15. The residual effect of the wheat straw was more pronounced and statistically higher than 100% N dose (Rajput and Warsi, 1992). This indicated that crop residues can substitute 50% N doses in rice–wheat cropping systems.

Table 10.15 Direct and residual effect of crop residues applied to rice on yield and economics of rice–wheat cropping system (Adapted from Rajput and Warsi [1992])

	Grain yield (q ha^{-1})		
Treatments	Rice	Wheat	Net returns of the cropping system (Rs ha^{-1})
Control	20.0	16.8	3,709
50 kg N ha^{-1}	27.3	17.4	5,012
100 kg N ha^{-1}	32.8	17.9	5,827
Wheat straw @ 10 t ha^{-1}	28.9	22.7	6,318
Wheat straw @ 10 t ha^{-1} + 50 kg N	31.2	23.0	6,623
Wheat straw @ 10 t ha^{-1} + 100 kg N	34.3	23.8	7,105
LSD (0.05)	4.5	0.3	–

10.8 Green Manures

Green manuring is also a very old and effective practice of nutrient recycling. Presently, it needs adequate attention as it is the cheapest locally available resource for building up soil fertility and supplementing plant nutrients, especially N. This practice is more appropriate for irrigated agriculture, due to easy mineralization of nutrients from the buried-over plants in the soil. Green manures may be grown *in situ* by raising a legume such as *Sesbania aculeata* or *Crotalaria juncea* for a period of 45–60 days, i.e. prior to flowering (Gupta et al., 2001). Green manuring may also be done by incorporating the foliage of green trees or shrubs such as *Glyricidia maculata*, *Leucaena leucocephala* and *Cassia tora*. It is one of the most effective and environmentally sound methods of organic manuring that offers an opportunity to cut down the use of chemical fertilizers. The green manuring practice also improves the physical and chemical properties of the soil (Singh and Proda, 1994; Mahapatra, 1995).

Green manuring with legumes in a rice–wheat cropping system is a time-honoured practice which enriches soil N due to fixation of atmospheric N. The green manuring practice not only improves N economy but also has many beneficial effects on soil health/quality on long-term basis. Decomposing green manures have a solubilizing effect on N, P, K and micronutrients in the soil. They also reduce leaching and gaseous losses of N to increase the nutrient use efficiency. Besides, these also improve the physical, chemical and biological properties of soil. *S. aculeata*, *C. juncea* and *Vigna unguiculata* are capable of accumulating 4–5 t ha^{-1} of dry mass and about 100 kg N ha^{-1} in 50–60 days. Apparent green manure recoveries are more or less similar to chemical fertilizers and range from 32% to 50%. Field experiments conducted on integrated use of green manures with recommended inorganic fertilizers at Pantnagar and Kanpur, India, during 1983–87 indicated that increase in rice and wheat yields was larger in the case of *S. aculeata* along with 100% NPK doses in both the crops than *C. juncea* and *V. unguiculata* green manure crops. However, the crop yields were significantly higher over 100% NPK alone at Kanpur (Dahama, 1997). Another field experiment carried out for 10 years (1983/84 to 1992/93) at Ludhiana, Punjab, under irrigated conditions in a rice–wheat cropping system on loamy sand soil having 0.33% organic carbon with available N, P and K as 143, 11.2 and 101 kg ha^{-1} indicated significantly higher yield of rice when 25% N substitution was done with prickly sesban green manure. Contrary to this, 50% N substitution through green manures and 100% NPK through fertilizers gave statistically similar yields of the rice–wheat cropping system as have been given in Table 10.16 (Hedge, 1998).

A field experiment carried out for 3 years during 1989–92 to evaluate the effectiveness of *S. aculeata* and *Phaseolus vulgaris* green manures grown in rice–wheat rotation at Palampur, Himachal Pradesh, indicated that fertilizer dose to rice could be saved up to 50% of the recommended dose in Table 10.17 (Thakur et al., 1995).

In another study, *V. radiata* straw incorporation could easily substitute 50% NPK needs of rice amounting to 60 kg N, 30 kg P_2O_5 and 15 kg K_2O ha^{-1} in rice–wheat system without any adverse effect on total productivity and also help in mobilizing the availability of N and micronutrients like Zn, Fe, Mn and Cu (Hedge and Dwivedi, 1993). Fresh loppings of some perennial leguminous trees like *G. maculata* grown in hedgerows and field bunds may also be used for incorporation into soil as green

Table 10.16 Effect of INM on the productivity of rice–wheat cropping system (average of 10 years) (Adapted from Hegde [1998])

Treatments		Grain yield (q ha^{-1})		
Rice	Wheat	Rice	Wheat	Total
Control	Control	21.4	12.4	31.6
50% NPK	50% NPK	43.9	32.0	77.4
100% NPK (120–30–45)	100% NPK (120–60–45)	63.6	45.2	102.3
50% NPK + 50% N through GM	100% NPK	63.7	43.9	101.3
75% NPK + 25% N through GM	75% NPK	65.7	40.4	99.5
Farmers' practice	Farmers' practice	30.0	15.3	41.6
LSD (0.05)		1.50	1.20	1.47

Table 10.17 Effect of green manuring and fertilizer application on grain yield (1991/92) and soil fertility (after 3 years of cropping) in rice–wheat system (Adapted from Thakur et al. [1995])

	Yield (q ha^{-1})		Available nutrients (kg ha^{-1})		
Treatments	Rice	Wheat	N	P	K
DGM[a]-rice (0 + 100)	37.4	30.3	741	31.9	265
DGM-rice (100 + 50)	36.0	29.8	743	31.1	263
DGM-rice (100 + 75)	23.5	27.8	740	32.8	260
DGM-rice (100 + 100)	23.2	25.3	749	33.7	264
FBGM[b]-rice (0 + 100)	44.7	27.4	737	29.9	260
FBGM-rice (100 + 50)	44.3	27.9	742	29.0	258
FBGM-rice (100 + 75)	43.0	31.3	735	29.6	258
FBGM-rice (100 + 100)	39.7	29.3	740	31.2	263
LSD (0.05)	2.2	NS			
	Initial value		677.3	27.3	238.1

[a] DGM: Dhaincha Green Manuring

[b] FBGM: French Bean Green Manuring

manure as a source of N (Kundu et al., 1991). The introduction of summer green manuring in north India under rice–wheat cropping system has shown ample promises to raise the crop productivity (Hedge, 1992).

10.9 Leguminous Crops

Legumes act as soil fertility restorers due to their ability to obtain N from the atmosphere in symbiosis with *Rhizobium*. Legumes can form an important component of INM system when grown for grain or fodder in rice–wheat cropping system, intercropped with other non-legumes or when introduced as green manure crops. The continuous practice of rice–wheat rotation has an adverse effect on physico-chemical properties and fertility status of the soil. Hence, inclusion of legumes in rice–wheat sequences may restore the soil fertility. It has been reported that carry-over of soil N for the succeeding cereal crop may be 60–120 kg in *Trifolium alexandrium* (berseem), 75 kg in *T. ripens* (Indian clover), 35–60 kg in *V. unguiculata* (fodder cowpea), 55 kg in *V. mungo* (blackgram), 60 kg in *Arachis hypogoea* (groundnut), 68 kg in *Cicer arietinum* (gram) and 50 kg in lathyrus, the legume intercrops. It also plays a vital role in atmospheric N fixation and economizing resource use, especially N. It has been estimated that with the inclusion of legume intercrops, the extent of N addition in cereal-based cropping systems would be on the order of 0.746 million tonnes (Saraf et al., 1990). A study at Pantnagar, Uttranchal, on summer legumes in relation to rice grain yield and N uptake in rice–wheat rotation has shown that *Sesbania* + 60 kg N ha^{-1} gave significantly higher grain yield compared to other treatments. This is because *Sesbania* is a deep-rooted and fast-growing crop and fixes more N than *V. unguiculata* and *V. radiata* and thus more N uptake by the rice crop as shown in Table 10.18 (Mahapatra et al., 2002).

Table 10.18 Summer legumes in relation to rice grain yield and nitrogen uptake in rice–wheat cropping system (Adapted from Mahapatra et al. [2002])

	Grain yield (kg ha^{-1})			Nitrogen uptake (kg ha^{-1})		
Treatments[a]	1997	1998	1999	1997	1998	1999
Control	2,361	2,415	2,685	52.0	46.7	45.7
60 kg N ha^{-1}	4,321	4,989	4,764	71.3	71.3	75.7
120 kg N ha^{-1}	5,953	6,321	6,300	124.3	111.3	109.7
Sesbania	4,870	5,269	5,310	71.3	76.3	72.7
Sesbania + 60 kg N ha^{-1}	6,429	6,721	6,925	136.7	123.7	128.3
Cowpea	4,010	4,658	4,324	56.0	87.7	54.0
Cowpea + 60 kg N ha^{-1}	5,067	5,369	5,290	76.7	79.3	82.3
Greengram	3,925	4,582	4,329	63.3	54.7	82.3
Greengram + 60 kg N ha^{-1}	5,721	5,712	5,351	87.3	80.0	83.7
LSD (0.05)	1,123	1,048	1,048	16.1	36.4	15.3

[a] Urea was applied in splits (50:25:25), *Sesbania* and greengram straw was incorporated at the time of puddling

10.10 Bio-Fertilizers

Some beneficial organisms used as bio-fertilizers have been recognized as important inputs in INM system and their use is of recent origin. They are apparently eco-friendly, low-cost and non-bulky agricultural inputs, renewable and pollution-free. They also play a significant role in plant nutrition acting as supplementary and complementary sources of plant nutrients and have no deleterious effect on the environment. Various bio-fertilizers can be used according to the needs of crops. Some of the organisms which can be used as bio-fertilizers (Mahajan et al., 2003b; Subbian et al., 2000) are listed in Table 10.19.

Out of the bio-fertilizers described in Table 10.19, BGA and *Azolla* are of great significance in the N economy of rice cultivation under water-logged conditions (Mahajan et al., 2003a). Their use may contribute 25–50 kg N ha^{-1} to rice crop (Singh, 1989; Singh and Singh, 1992; Adil and Karte, 1992; Venkataraman and Shanmugasundaram, 1992). Phosphorous solubilization also possesses the ability to bring the insoluble phosphates in soil into soluble forms by secreting organic acids (formic, acetic, propionic, lactic, and succinic acids, etc.) which help in better growth and development of plants. These acids lower down the pH and bring about dissolution and immobilized forms of phosphates and its application has shown 15–30% higher increase in the yield of cereals such as rice and wheat.

10.10.1 Blue-Green Algae (BGA)

BGA or cyanobacteria are predominant in submerged rice soils, which provide an ideal condition for their growth with respect to their requirement for light, water,

Table 10.19 Some beneficial organisms used as bio-fertilizers in sustainable agriculture (Adapted from Mahajan et al. [2003b])

Name of organism	Mode of action	Crops for which used	Method of treatment	Quantity of inoculum required (g ha^{-1})
Rhizobium	Symbiotic N fixation	Leguminous pulses, fodder crops and groundnut	Seed treatment	600
Azotobacter	Asymbiotic N fixation	Vegetables, Cotton, Cereals and millets	Seed treatment	3,400
Azospirillum	Asymbiotic N fixation	Cereals and millets Vegetable crops	Seed treatment Soil application	1,000 2,000
Blue-green algae	Asymbiotic N fixation	Paddy	Soil application	10,000
Azolla	Asymbiotic N fixation	Paddy	Soil application	1 t (dried algae)
Phospho-bacterium	Phosphorous solubilization	Millets, wheat and paddy	Seed treatment	600

temperature, humidity and availability and atmospheric N fixation. Inoculation of rice fields with BGA was first initiated in Japan in the early 1950s (Watanabe et al., 1951). They are often referred to as Paddy Organisms because of their abundance in the paddy fields and play a significant role in rice culture. These are distributed worldwide and are believed to contribute to soil fertility in many agricultural ecosystems. Common genera found in Indian rice soils include Anabaena, Nostoc, Aulosria, Calothrix and Tolypothrix. The best pH range for fixation of N by them is between 7.0 and 8.5. When the water dries up, algal material adds organic matter to the soil (Gupta and Khajuria, 1996). In N fixation by N-fixing bacteria and BGA, nitrogenase enzyme is essential. Utilization of BGA as a bio-fertilizer for rice is very promising. Judicious use of the culture of BGA could provide the country's entire rice acreage as much N as obtained from 15–17 lakh tonnes of urea. It is estimated that at farm level, it can contribute about 25–30 kg N ha^{-1} (Hedge and Dwivedi, 1993). Recent researches have shown that BGA also help to reduce the soil alkalinity and thus help in bio-reclamation of the alkali soils. A field experiment conducted on loamy soil at Bilaspur, Madhya Pradesh, in rice–wheat sequence (Table 10.20) revealed that rice yields under treatments of BGA at the rate of 5 kg culture per hectare and FYM at the rate of 5 t ha^{-1} were statistically at par with each other. Organic manures and BGA combined with 60 kg N + 37.5 kg P_2O_5 + 22.5 kg K_2O ha^{-1} as chemical fertilizers proved superior to other treatments for rice yields and their residual effect on wheat yields (Rathore et al., 1995).

In another experiment conducted at Rajendra Agricultural University Farm, Pusa (Bihar), on INM system, the highest soil macro-aggregation (>1 mm) was observed in the treatments of NPK + FYM + BGA or NPK + FYM in rice–wheat cropping systems (Table 10.21). Similarly, integrated use of fertilizers with FYM, BGA and FYM + BGA increased the hydraulic conductivity of this cropping

Table 10.20 Effect of integrated use of BGA, FYM and chemical fertilizers on grain yield of rice–wheat cropping system (Adapted from Rathore et al. [1995])

	Rice yield (q ha^{-1})		Wheat yield (residual effect)	
Treatments	1987	1988	1987–88	1988–89
Control	28.2	33.4	7.7	7.9
BGA + F_0	33.3	39.3	8.6	9.3
FYM + F_0	33.2	38.8	8.5	9.1
BGA + F_1	42.5	51.8	9.7	10.9
FYM + F_1	45.8	51.9	9.4	10.7
BGA + F_2	42.5	55.7	9.7	10.5
FYM + F_2	46.1	55.9	9.7	10.9
BGA + F_3	46.3	56.8	9.7	10.4
FYM + F_3	47.1	56.9	9.8	10.4
LSD (0.05)	2.5	3.3	NS	1.4

F_0 = No fertilizer; F_1 = 40 kg N + 25 kg P_2O_5 + 15 kg K_2O ha^{-1}; F_2 = 60 kg N + 37.5 kg P_2O_5 + 22.5 kg K_2O ha^{-1}; F_3 = 80 kg N + 50 kg P_2O_5 + 30 kg K_2O ha^{-1}; BGA @10 kg ha^{-1} 7 DAT and FYM @ 5 t ha^{-1} (dry weight)

Table 10.21 Effect of INM on percentage of macro-aggregates and hydraulic conductivity in rice–wheat cropping system in calcareous soil (Adapted from Rokima [1985])

Fertilizer levels	Control	BGA (13 kg ha^{-1})	FYM (10 t ha^{-1})	FYM + BGA
Percentage of macro-aggregates (>1 mm)				
0% NPK	4.1	6.6	7.9	9.3
50% NPK	5.2	7.1	8.0	10.2
100% NPK	5.6	9.6	10.6	10.6
Mean	5.0	7.8	8.8	10.0
Hydraulic conductivity (cm hr^{-1})				
0% NPK	0.144	0.321	0.159	0.361
50% NPK	0.238	0.268	0.289	0.405
100% NPK	0.281	0.416	0.313	0.466
Mean	0.221	0.368	0.254	0.411

system as shown in Table 10.21 (Rokima, 1985). These results suggest that organic manures and bio-fertilizers play an important role in augmenting physical properties of soils apart from fixing atmospheric N.

10.10.2 Azolla

Azolla is another bio-fertilizer which can be used in rice crop. Azolla–Anabaena association (the symbiotic association of *Azolla pinnata* and *Anabaena azolle* is termed as Azolla–Anabaena complex) is a live, floating N factory using energy from photosynthesis to fix atmospheric N, amounting to 100–150 kg ha^{-1} annually from about 40–60 t of biomass and requiring temperatures around 250°C and high relative humidity. It helps increase crop yields by 15–25% in rice crop. It also enriches the soil with organic matter and improves soil structure and aggregation. Experiments conducted at Pantnagar, Uttranchal, on integrated use of bio, organic and chemical N sources in rice–wheat systems (Table 10.22) revealed that Azolla + chemical N (45 kg N each) produced highest rice and wheat yields over chemical N alone or in combination with FYM (Mahapatra et al., 1987).

10.10.3 Phosphate Solubilizing Micro-organisms (PSMs)

PSM, a bio-fertilizer, has the capacity to solubilize and mineralize the residual or fixed phosphorous, increase the availability in the soil, produce growth substances like indole acetic acid (IAA) and Gibberellins (GA) and thus increase the overall P use efficiency. Phosphate-solubilizing bacteria and fungi are also helpful for biological N fixation. There has been considerable research in India on phosphate-solubilizing micro-organisms and some of them concern rice and wheat (Chhonkar and Tilak, 1997). The introduction of PSM (*Pseudomonas striata*, *B. polymyxa*,

Table 10.22 Effect of bio, organic and chemical fertilizers on grain yield of rice and their residual effect on wheat in rice–wheat system (Adapted from Mahapatra et al. [1987])

	Grain yield (q ha^{-1})	
Treatments	Rice	Wheat
Control	25.2	14.5
60 kg N (Urea)	29.5	16.9
30 kg N + 30 kg N (Azolla)	35.7	22.1
30 kg N + 30 kg N (FYM)	29.2	16.3
90 kg N	36.4	18.2
45 kg N + 45 kg N (Azolla)	36.9	25.1
45 kg N + 45 kg N (FYM)	29.2	15.5
LSD (0.05)	6.1	2.5

A. awamorii, *Penicillium digitatum*, etc.) in the rhizosphere of rice and wheat increases the availability of phosphate from insoluble phosphates such as rock phosphate, i.e. tricalcium phosphate, and increases the utilization efficiency of ordinary super phosphate (Chhonkar, 1994). Inoculation of seeds or seedlings with PSM can provide 13 kg P ha^{-1} equivalent of ordinary super phosphate (Gaur, 1990).

In the light of the above facts and figures, the INM system involving chemical fertilizers, organic manures, bio-fertilizers and nutrient solubilizers with organic residues has shown great potential in stabilizing rice and wheat crop yields, and holds great promise in sustaining agricultural production at higher levels and long-term soil health on the one hand and meeting the existing nutrient demand on the other hand.

Impact Points to Remember

- Chemical fertilizers may still contribute about 50% to the increase in food grain production for the increased population of our country. About three fourths of the fertilizer is consumed in rice and wheat cultivation.
- Use of organic manures in India was 99.86% of the total nutrient use in 1949 but by 1993 it decreased to 32.5%. At present, it is expected that it has further decreased to 20–25% of the total, which is still a saving of 25% of fertilizer.
- Use of organic sources with fertilizers increased the NPK uptake in rice and wheat, decreased the soil pH, electrical conductivity at a faster rate and depleted nutrients at a slower rate than an application of inorganic fertilizers alone. They also provide essential secondary and micronutrients like S, Ca, Mg, Cu, Mn and Fe.
- The INM studies have also improved soil physical properties, for example use of bulky organic manures improved soil aeration, permeability, aggregation, water-holding capacity and nutrient-holding capacity in rice–wheat cropping system.
- The grain yield, total productivity and net returns in rice–wheat cropping system increased with the application of organics in combination with inorganic fertilizers.

- The process of decomposition of organic wastes, especially of plant residues, is termed as composting and the decomposed material is called compost. On an average, it contains 1.01% N, 0.5% P_2O_5 and 0.8–0.9% K_2O.
- Compared to FYM, compost has a high percentage of humus and is free from pathogenic disease and weed seeds.
- The enrichment of organic manures is of practical interest because the demerits of bulky organic manures can be overcome by their enrichment and they offer a low-cost alternative to chemical fertilizers.
- The effect of enriched straw compost prepared from chopped and unchopped material in rice–wheat cropping system at Kanpur showed that wheat grain yield increased by 41.8% and 36.9%, respectively.
- Vermicomposting is a method of making compost with the use of earthworms and their C/N ratio is much lower (1:16) than that of FYM (1:30).
- The integrated use of half the dose of 120 kg N ha^{-1} PU along with 60 kg N ha^{-1} through vermicompost gave comparable grain yield of rice and wheat crop with an application of 120 kg N ha^{-1} PU.
- Among micronutrients, Zn deficiency is the most common soil disorder as nearly 50% soils of intensively cultivated areas suffer from Zn deficiency, especially lowland rice soils with low organic matter and alkaline in reaction.
- In India, Zn deficiency was discovered first at Pantnagar, erstwhile Uttar Pradesh, now Uttranchal, in *tarai* (forest hill) soils and then almost everywhere in rice–wheat cropping systems.
- Integrated use of micronutrient fertilizers with organic manures, crop residues including green manure can serve as a source of micronutrients and complexing agents in rice–wheat system.
- Residues left out after the harvest of the economic portion in the field are called crop residues and contain 0.5% N, 0.6% P_2O_5 and 1.5% K_2O.
- The major advantage of the incorporation of rice–wheat residues increases the soil organic carbon.
- The incorporation of rice straw in wheat caused a slight increase in the availability of P, Mn and Zn and a marked increase in the availability of K.
- The incorporation of both rice and wheat straw vis-à-vis their burning or removal increased both the infiltration rate and cumulative infiltration, and increased porosity compared to green manure crops.
- Any green crop that is buried directly in the soil to increase its fertility and to improve its physical condition and chemical properties is called green manure.
- Green manuring with legumes in a rice–wheat cropping system is a time-honoured practice which enriches soil N due to fixation of atmospheric N.
- The green manuring practice not only improves N economy but also has many beneficial effects on soil health on long-term basis.
- Decomposing green manures have a solubilizing effect on N, P, K and micronutrients in the soil.
- Green manure reduces the leaching and gaseous losses of N to increase the nutrient use efficiency.

- BGA and *Azolla* are of great significance in the N economy of rice cultivation under water-logged conditions and their use may contribute 25–50 kg N ha^{-1} to rice crop or even up to 100 kg N ha^{-1}.
- Inoculation of rice fields with BGA was first initiated in Japan in the early 1950s and is often referred to as Paddy Organisms because of their abundance in the paddy fields and the significant role they play in rice culture.
- Common genera of BGA found in Indian rice soils include *Anabaena*, *Nostoc*, *Aulosria*, *Calothrix* and *Tolypothrix*.
- The best pH range for this fixation of N by them is between 7.0 and 8.5.
- Recent researches have shown that BGA also help to reduce the soil alkalinity and thus help in the bio-reclamation of alkaline soils.
- The Azolla–Anabaena association is a live, floating N factory using energy from photosynthesis to fix atmospheric N, amounting to 100–150 kg ha^{-1} annually from about 40–60 t of biomass requiring temperature around 25°C and high relative humidity.
- Phosphorous solubilization through phosphate-solubilizing micro-organisms also possesses the ability to change the insoluble phosphates in soil into soluble forms by secreting organic acids (formic, acetic, propionic, lactic and succinic acids.) which help in better growth and development of plants. These acids lower the pH and bring about dissolution and immobilized forms of phosphates and have shown 15–30% higher yield increase in cereals such as rice and wheat.

Study Questions

1. Define the following:
    - (a) Urea and prilled urea
    - (b) Diammonium phosphate (DAP)
    - (c) Muriate of potash (MOP)
    - (d) Fertilizer use efficiency
    - (e) Permeability
    - (f) Aggregation
    - (g) Electrical conductivity
    - (h) Exchangeable sodium percentage (ESP)
    - (i) Chelate
    - (j) Field capacity
    - (k) Permanent wilting point
    - (l) Fixation of atmospheric N
    - (m) Phytohormones
2. Differentiate the following:
    - (a) Compost and vermistabilization
    - (b) Oxidation and reduction
    - (c) Soil structure and soil texture

   (d) Solubilization and volatilization
   (e) Fine-textured soil and coarse-textured soil
   (f) Village compost and town compost
   (g) Mixed farming and intercropping
   (h) Infiltration rate and cumulative rate
   (i) Clod and ped
   (j) Immobilization and mineralization
   (k) Symbiotic fixation and asymbiotic fixation of N
   (l) Leaching and precipitation
   (m) Peat and muck

3. Explain the role and contribution of each of the components of INM system to rice–wheat cropping systems.

4. Define green manuring and explain its role in rice–wheat cropping systems.

5. List the contributions of beneficial organisms used as bio-fertilizers in sustainable agriculture.

6. Explain plant growth substances in detail and their objectives in combination with chemical fertilizers.

7. What is the role of vermicompost in sustainable rice–wheat cropping systems?

8. Write a short note on each of the following:
   (a) Paddy organism
   (b) Leguminous crops
   (c) Micronutrients
   (d) Azolla
   (e) Green manures and crop residues
   (f) Phosphocompost
   (g) PSMs
   (h) Chemical fertilizers and their advantages

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Chapter 11
Soil-Related Constraints in the Rice and Wheat Production

Abstract Rice and wheat are the two main crops of India that provide food, income and employment to millions of people. The environmental requirements for the growth and development of both rice and wheat crops are contrastingly different. Rice grows best under soft, puddled and water-saturated soil conditions, while wheat requires a well-pulverized soil having fine tilth with a proper balance of moisture, air and thermal regime. In this chapter, the major constraints encountered in rice production, namely rainfed uplands and lowlands, acid red laterite, lateritic and salt-affected soils, including those in coastal areas, and their management practices such as varieties, sowing method, application of lime and zinc, water management, application of green manuring coupled with water management and puddling have been detailed. Soil fertility (deficiency of N, P, K, S and micronutrients), soil water and other soil physical constraints, and their management through use of nitrogenous, phosphatic and potassic fertilizers, production technology coupled with optimum use of NPK, time and method of fertilizer application and deep or conventional tillage in wheat production have also been elucidated.

Keywords Lowland and upland rice • acid red laterite and lateritic soils • green manuring • water management • puddling • wheat production • soil fertility constraints • soil water constraints • fertilizer application • deep or conventional tillage.

As already stated, the yield of the rice and wheat cropping system in many countries of the world has either become constant or has decreased for the last so many years. Large variations in average rice and wheat yields in the fields and those obtained in National Demonstration Trails in different states of India and abroad suggested a considerable scope of increasing the crop yields. Use of organics and inorganics is the key factor in rice and wheat production.

The majority of soils in tropical countries, including India, Pakistan, Bangladesh, etc., are deficient in organic matter, N and P. Deficiency of secondary nutrients and micronutrients is also becoming a problem with the intensive cropping and the use of high analysis fertilizers.

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The main soil-related constraints in rainfed uplands rice cultivation may be due to the presence of Al and Mn toxicity, low availability of P and high P fixation capacity particularly in latosol soils and Fe deficiency in soils having neutral to slightly alkaline reaction. Moreover, soils being coarse-textured have low water retention capacity. Apart from this, the red and laterite soils have a large amount of free iron oxide, which often leads to crust formation, resulting in poor emergence of rice seedlings after sowing and eventually producing poor crop stand. Above all, the dominant presence of Kaolinite in these coarse-textured soils possesses low cation exchange capacity (CEC). There is also low nutrient retention capacity, leading to loss of plant nutrients, especially N through percolation, resulting in poor N use efficiency.

In lowland rice-growing areas there is a deficiency of N and Zn. Some lowland rice-growing areas have been identified and demarcated. In these areas, even use of balanced doses of N, P and K fertilizers have not resulted in good yields. It is attributed to Zn deficiency. In the light of the above, it becomes very important to know detailed accounts of the various soil-related constraints which have been given in this chapter.

11.1 Rice Crop

The eastern, north-eastern and peninsular India experience high rainfall, which is received mostly from the south-west monsoon during the months of June to October. Some parts of Tamil Nadu also obtain rains from the north-east monsoon during October to December. An average annual rainfall of these areas lies in the range of 1,000–2,000 mm or even more. Because of high rainfall, the land remains saturated or submerged with water to depths ranging from 20 to 50 cm or more during the monsoon season. Accordingly, under such situations no other crop can be grown except rice. Rice is therefore the traditional and main crop grown in these parts of India. Some of the areas are irrigated, and a second crop of dry-season-irrigated rice is grown with adequate water control.

11.1.1 Indian Rice Ecosystem

Rice is a principal source of food for more than half of the world population, especially in South and South-east Asia and Latin America. Elsewhere, it represents a high-value commodity crop. India is the largest rice-growing country, while China is the largest producer of rice in the world. The areas both under irrigated and rainfed rice ecosystem have been shown in Table 11.1. It is observed from the data that out of the 27 million hectares of rice lands in the eastern zone, nearly 20 million hectares are rainfed and the rest (7 million hectares) are irrigated. In the North-eastern Hill Region of India, out of 0.78 million hectares land, 0.55 million hectares

Table 11.1 Zonewise rice area (million hectares) of India (Adapted from Patnaik et al., [1991])

Zone	Irrigated	Rainfed upland	Rainfed lowland	Total
East zone	7.59	5.23	14.61	27.43
North-east hill states	0.23	0.28	0.27	0.78
North zone	2.51	0.07	–	2.58
West zone	0.71	0.79	0.75	2.25
South zone	6.58	0.64	0.73	7.95
Others	–	0.08	0.09	0.17

are rainfed. Contrary to this, in the peninsular India, of the 8 million hectares of rice lands, about 6.6 million hectares are irrigated and the remaining 1.4 million hectares are rainfed (Patnaik et al., 1991).

The rainfed-rice-growing areas of the country have been divided into two main categories, namely upland and lowland rice ecosystem, with varying depths of water on the soil surface. In the lowland rainfed rice ecosystem of eastern India, water begins to accumulate in the rice fields with the starting of monsoon rains from July. Rivers in spate are also responsible for causing stagnation of water in these rice fields. Based on the topography and rainfall intensity, the water depth in the fields of lowland rice-growing ecosystem varies from 20 to 70 cm from July to October, which then starts receding slowly from the fields with the withdrawal of monsoon by October end.

Since most of the rice-growing areas of India lie in the alluvial plains, many of the soils belong to Entisols and Inceptisols orders and Haplaquents, Ustifluvent, Udifluvents, Ustochrepts of Great Soil groups. In the eastern, north-eastern and peninsular India besides alluvial soils, coastal and deltaic alluvial (Haplaquepts), red soils (Alfisols – Haplustalfs, Paleustalfs and Rhodustalfs), red and yellow soils (Ultisols – Haplustults, Ochraqults and Rhodustults) and laterite soils (Ultisols – Plinthaqults, Plinthustults) occupy considerable area under rice.

11.1.2 Soil-Related Constraints in Rice Production

The data regarding trends in area, production and productivity of rice in India have shown that despite poor rice productivity, about 56% of the total rice production in the country comes from about 69% of rice lands in Assam, West Bengal, Bihar, eastern Uttar Pradesh and eastern Madhya Pradesh (Patnaik et al., 1991). Contrary to this, rice production and productivity in peninsular India is relatively high and about 16–18% rice lands located in this region contribute about 25% of the total production. The highest productivity of rice has been seen in the north zone (2,940 kg ha^{-1}) followed by the southern zone (2,158 kg ha^{-1}), North-east Hill Region (1,196 kg ha^{-1}) and western zone (1,064 kg ha^{-1}). Thus, taking into account the rice-growing environment and productivity, the soil-related constraints in rice production in the eastern, north-eastern and peninsular India have been narrated in the following situations.

11.1.2.1 Rainfed Uplands and Lowlands

The average yield of rainfed rice crop grown on upland soils is very poor, being about 0.6 t ha^{-1} as against 1.3 and 1.7 t ha^{-1} in rainfed lowland and irrigated land, respectively. Soils of rainfed upland rice are generally coarse-textured (gravelly loamy sand, sandy loam) and belong to Alfisols or Ultisols or Oxisols. They are low in pH, CEC, base saturation, P and Fe and high in Al and Mn. The main soil-related constraints in rainfed uplands are:

- Toxicity of Al and Mn.
- Being coarse-textured, these soils are low in water retention capacity and hence the plants often suffer from water stress.
- The availability of P is very low, which is attributed to its high fixation capacity due to presence of Kaolinite types of clays.
- The presence of large amounts of free iron oxide often leads to crust formation, resulting in poor emergence of seedlings after sowing the seeds, eventually leading to poor yield.
- In neutral and alkaline soils there is deficiency of Fe.
- Nutrient retention capacity is low because of more leaching losses of nutrients, particularly of N.

As in the lowland rice soils, water depth lies in the range of 20–70 cm in the field during the crop growth period; hence, in peninsular India, no soil-related constraints are seen except deficiency of N and Zn.

The major constraints in the rice production of lowlands under rainfed conditions particularly in the eastern and north-eastern parts are:

- There is cultivation of indica varieties which respond poorly to application of fertilizers. Existing high-yielding varieties are not found suitable for growing in the wet season due to their short stature.
- The weather conditions in the monsoon season become conducive for build-up of pests and diseases, to which many of the present high-yielding rice varieties are susceptible.
- There is difficulty in transplanting if monsoons start with torrential rains by mid-July. If the rains occur after transplanting, there is mortality of seedling of the freshly transplanted crop due to submergence.
- In case the crop is directly sown after pre-monsoon showers in late May to June, there is a problem of weed infestation.
- Flash floods sometimes occur between mid-August to mid-September, which inundates the transplanted crop, resulting in partial or complete damage, necessitating retransplanting.
- Owing to the presence of a lot of water in the fields, application of N becomes difficult.

11.1.2.2 Acid Red Laterite and Lateritic Soils

These soils are dominant in the west coast from Malabar to Konkan, in the plateau of Bihar, Bengal, Orissa and Madhya Pradesh as well as in scattered areas of Tamil Nadu, Andhra Pradesh and Assam. The main problems encountered with these soils are:

- Moderate-to-high acidity when the soil is not submerged.
- Poor soil fertility because of low organic C, N, CEC and other available plant nutrients.
- There are large amounts of Fe, Al and sometimes that of Mn, which results in causing high fixation of P. This calls for a higher rate of application of the water-soluble P.
- There is toxicity of Fe and Mn in rice grown on flooded soil conditions.
- There are physiological disorders due to impeded drainage in some areas.

11.1.2.3 Salt-Affected Soils Including in Coastal Areas

Soils having pH near 8.5 or more in some pockets of peninsular India and also in some parts of West Bengal, where rice is grown under upland conditions either as rainfed or with tank irrigation, rice crops suffer from Fe deficiency, particularly in the event of inadequate supply of water.

The crops may also suffer from the deficiency of Zn because of low solubility of Zn at the high pH values of the soils. Soils which are high in Ca also cause deficiency in Zn as well as K. Soils high in salt content ($EC > 4\,dS\ m^{-1}$) and exchangeable Na percentage (>15) show Zn and Fe deficiency. Moreover, there is boron toxicity.

11.1.3 Management Practices for Increasing Rice Production

The management practices which have been found suitable in increasing productivity and production of rice crop are as follows.

11.1.3.1 Varieties

Varieties of rice having duration of 80–110 days which are considered suitable for rainfed uplands should be grown because such crop varieties will complete their life cycle in the short monsoon period of 2–3 months. Varieties of this duration with yield potential of 3.5–5.0 t ha^{-1} have been released by the Central/State Variety Release Committee.

11.1.3.2 Sowing Method

Another important crop management practice for establishing a good crop is line sowing, or at least sowing behind the plough, which helps in controlling weeds and managing fertilizers easily.

11.1.3.3 Application of Lime

- In acid red and laterite upland soils having pH lower than 5.5, an application of lime to meet one fourth to one third lime requirement of the soil has resulted in a marked increase in grain yield.
- Laterite soils on flooding record a considerable amount of extractable Fe and Mn, which in some cases, may be toxic for rice. Therefore, the application of small amounts of lime along with the balanced use of NPK fertilizers at puddling would suppress Fe concentration, thereby preventing its toxic effects.

11.1.3.4 Application of Zn

- In rainfed lowlands, Zn amendments like spray of Zn sulphate has brought improvements in plant growth and amelioration of Zn deficiency, significantly increased Zn content and grain yields. Experiments carried out for six cropping seasons in the Cauvery delta have revealed beneficial effects of $ZnSO_4$ and $CuSO_4$ in enhancing yield of rice (Patnaik et al., 1991). Zn deficiency has now been observed in all rice-growing soils of India (Prasad, 2005).
- In saline and alkali soils Zn deficiency also occurs which can be corrected by giving two to three foliar sprays of Zn. Normally 3% $ZnSO_4$ is used. A quantity of 7.5 kg of $ZnSO_4$ in 250 l of water is sufficient for spraying in a 1 ha rice-grown field. About 3.75 kg of unslaked lime must be added to make the above-said spray solution neutral.

11.1.3.5 Water Management

Land submergence is practised for lowland rice crop due to the associated advantages of a relatively weed-free environment, reduced N losses and increased availability of nutrients, particularly P, K, Ca and Fe.

11.1.3.6 Application of Green Manuring Coupled with Water Management

To overcome the deficiency of Fe in alkali and alkaline soils, green manuring, coupled with water management to keep the soil saturated or flooded all the time, is the most desirable practice. This is because a semi-anaerobic environment gets created which facilitates reduction of ferric to more soluble ferrous iron.

11.1.3.7 Puddling

The traditional method of preparing land for transplanting lowland rice is puddling (wet tillage or tillage in standing water). Puddling, in general, refers to an intensive tillage system in which soil is repeatedly ploughed and harrowed under submerged conditions to make the soil soft for transplanting and less permeable to water. It breaks the soil aggregates and peds into fine plastic mud, thereby practically eliminating the water transmission (macro) pores especially in water-intensive rice crop, resulting in a corresponding increase in water retention and residual pores. Dispersed clay particles settle in a horizontal orientation in the puddle layer, while fine clay particles move downwards with percolation water, and clog the remaining macro-pores. Puddling, therefore, increases bulk density from 1.4 to 1.8 Mg m^{-3}. Increase in bulk density and reduced porosity due to puddling largely decreased the deep percolation of water because of the reduction in hydraulic conductivity.

11.1.4 Suggestions for the Future

- By 2025, the world population is expected to increase to 8.35 billion, requiring 60% more than the current rice production. Therefore, increasing the yield potential of rice varieties beyond the present level is considered an important strategy to meet this challenge.
- Soil fertility in terms of macronutrients, including secondary and micronutrients, must be sustained for increasing productivity.
- Soil sickness, if any, like acidity, alkalinity or sodicity must be removed.
- Soil microbiological activities need to be ameliorated by encouraging use of organic manures and discouraging chemical fertilizers.
- Hybrid rice technology should be fully developed.

11.2 Wheat Crop

Wheat is the second most important food crop of the country after rice which contributes nearly one third of the total food grain production. It is consumed mostly in the form of unleavened griddle-cooked bread, called *chapatti*. India shares about 1.5% of the world's wheat-growing area and 11.4% of the world's production. In 2000 about 26.7 million hectares area was under wheat cultivation, and the production was about 74.2 million tonnes. Currently the area under wheat cultivation has decreased from 26.7 to 22.5 million hectares (Mann et al., 2005), so it is natural that the production has also reduced. Rising temperatures is the most crucial factor in the decline in production and productivity of wheat crop in major growing areas. Availability of irrigation water and plant nutrients use are the other factors contributing substantially to wheat production. However, the imbalanced use of

N, P and K fertilizers has not only declined the production, but also made the soil sick in terms of organic matter and micronutrient deficiency, and deterioration of the physical, chemical and biological properties. So use of organics is a must to improve the yield and soil properties.

11.2.1 Indian Wheat Ecosystem

About 10.5 million hectares area is under the rice–wheat cropping system. The management of rice ecosystem has a telling effect on the productivity of wheat crop. Under such situations instead of managing a single crop, both the crops must be taken into account in the overall management of plan. In the past there were four species, namely *Triticum aestivum*, *T. durum*, *T. dicoccum* and *T. sphaerococcum*, under cultivation in India. The common bread wheat, *T. aestivum*, is the most important species, occupying more than 90% of the total area and grown all over India from the sea level up to an elevation of 3,500 m in the Himalayas. The *T. durum* (macaroni wheat) is the second most important species occupying nearly 10% of the total wheat area, and its cultivation was primarily confined to central and southern India, with very small areas in Punjab and West Bengal. Its cultivation was most common under rainfed conditions only on account of the high susceptibility to rust.

The third variety, *T. dicoccum*, is grown on a very restricted scale in Gujarat, Maharashtra, Karnataka, Andhra Pradesh and Tamil Nadu, where it is known as *popatiya*, *khapli*, *ravva*, *godhumalu*, *samba*, etc. A large pocket of several thousands hectares of this species exists in Belgaum district of Karnataka along the river Krishna. The last one, *T. sphaerococcum*, is no more cultivated because of its low productivity and high susceptibility to diseases. Throughout the country only spring-type wheat varieties are grown, though these are raised in winter season.

11.2.2 Soil-Related Constraints in Wheat Production

Like rice, wheat is also an important crop of India, especially in the northern states. In the year 1985/86 the total area under wheat cultivation was 23.07 million hectares and grain production was 46.89 million tonnes (Meelu et al., 1991). At present the area under cultivation is 22.5 million hectares with an annual production of 70 million tonnes (Mann et al., 2005). However, the production and productivity of wheat varies from state to state in north India. A large variation obtained in the yield of wheat in ‘On Farm Trials’ and/or ‘National Demonstration Plots’ and those in various states tender a lot of scope in increasing the wheat yield (Meelu et al., 1991). Although the application of fertilizers is a key factor, yet its continuous use has produced a number of soil constraints like deterioration of its quality, deficiency of secondary and micronutrients, etc., which are detailed below.

11.2.2.1 Soil Fertility Constraints

Among soil-related constraints, soil fertility is a major one, i.e. soils are low in available plant nutrients.

Deficiency of N

Many of the Indian soils are deficient in available N, P and to some extent K. N is however the limiting factor in wheat crop production. A number of experiments carried out at various research stations of agricultural universities and central institutes have shown that wheat crop generally responded to 120 kg N ha^{-1}, though in some areas responses to lower and higher doses than 120 kg N ha^{-1} have been found. Comparative efficiency of N sources in wheat showed that both calcium ammonium nitrate (CAN) and urea were equally effective, as was evident from almost similar yields of wheat obtained with the use of CAN and urea in Delhi, Haryana and Punjab soil conditions (Meelu et al., 1991).

Deficiency of P

Application of P has also been found suitable to obtain a good yield of wheat crop along with an addition of N. It has been estimated that 20–25% of applied P is used by the crop, which suggested, thereby, that previous crops grown should be taken into consideration, while recommending fertilizers in the rice–wheat cropping sequence. In rice–wheat-growing soils, particularly under added N, good yield is not obtained unless P is added.

Deficiency of K

Although a lack of sufficient response of added K has been observed in north Indian soils, it was attributed to the dominance of illite/illitic nature of clay minerals in soils of Himachal Pradesh (Gupta et al., 1984, 1990b), Jammu & Kashmir (Gupta et al., 1986, 1990a) and Punjab (Sehgal, 1972), which on weathering supply K to the plant. However, long-term fertilizer studies in maize–wheat and rice–wheat cropping sequences have shown response to added K in wheat and maize crops significantly. This reveals that with intensive cultivation without K application, soils may soon become deficient in available K.

Continuous Use of N Leads to Deficiency of P and K

Long-term fertilizer experiments have shown that continuous use of N alone can never do the job well without adequate use of P and K fertilizers. This could be

Table 11.2 Response of N, P and K over years in the rice–wheat cropping sequence in alluvial soils at Faizabad (Uttar Pradesh, India) (Adapted from Anonymous [2000])

			Response (kg ha^{-1})		
Crop	Period	Control yield (kg ha^{-1})	N (120)	P_2O_5 (80)	K_2O (40)
Rice	1977/78	1,008	2,905	500	50
	1989/90	820	2,642	925	231
	Change	−188	−263	+425	+181
Wheat	1977/78	833	2,625	617	25
	1989/90	602	2,141	1,169	398
	Change	−231	−484	+552	+373

verified from the P and K fertilizer use efficiency during 1989/90 as compared to 1977/78 (Table 11.2). The results show time and again that intensive cropping with only N input is a short-lived phenomenon, and omission of nutrient (be it P or K) leads to its progressive deficiency as a result of their heavy removal, sites initially well supplied with P and K become deficient when continuously cropped using N alone.

Deficiency of S

Recently deficiency of S has also been noticed in wheat crop in many light-textured soils and considerable response to S has been obtained. The response of wheat to S in different Indian soils has been reported with an increase in wheat yield from 7% to 186% in comparison to control (Meelu et al., 1991).

Deficiency of Micronutrients

Apart from N, P and S, the deficiency of Zn and other micronutrients like B, Mn and Fe has been found (Meelu et al., 1991; Anonymous, 2000). Therefore, the application of NPK in rice and wheat for high yield is no longer sufficient, and care of secondary and micronutrients should also be considered.

11.2.2.2 Soil Water Constraints

Cultivation of wheat under rainfed conditions occupies nearly 40% of the total growing area in India. In these areas, limited availability of soil water is the major constraint in wheat production. The response of added fertilizer to wheat crop varies according to water retention capacity of the soil, which is very much related with its texture and amount of organic matter. Wheat crop responded up to 80 kg ha^{-1} in soils of medium-to-high water retention capacity but only to 30 kg N ha^{-1} in lower ones.

11.2.2.3 Other Soil Physical Constraints

Generally, there is a feeling that wheat yield becomes low when it is sown after rice cultivation. It is attributed to dispersion of soil during puddling and to affect adversely the physical, chemical and biological properties of soils due to its submergence during most of the growing period of the crop (Mahajan, 2006).

11.2.3 Management Practices for Increasing Wheat Production

The following management practices have been found suitable in increasing productivity and production of wheat.

11.2.3.1 Use of Nitrogenous Fertilizers

To increase N use efficiency in the case of wheat crop, nitrogenous fertilizer should be used at an appropriate growth stage. For example, in upland wheat crop, soils having light texture, nitrogenous fertilizer application in one, two and three equal splits at different stages of its growth has been found beneficial for increasing the yield. In wetland rice ecosystem this practice has also been found more efficient particularly in loamy sand/sandy loam soils.

11.2.3.2 Use of Phosphatic Fertilizers

The band placement of phosphatic fertilizers has been invariably found better than broadcast application. Use of single super phosphate, triple super phosphate and urea ammonium phosphate has proved superior to less-water-soluble/water-insoluble sources like nitrophosphate and rock phosphate (Meelu et al., 1991).

11.2.3.3 Use of Potassic Fertilizers

P and K are important nutrients for plant growth and its higher yield. Response of K at 60 kg ha^{-1} was about 370 kg ha^{-1} in wheat, 460 kg ha^{-1} in paddy and 550 kg ha^{-1} in maize (Anonymous, 1993). Response of P was higher than K for all the aforesaid crops under its various levels.

11.2.3.4 Production Technology Coupled with Optimum Use of NPK

Adoption of improved production technology and optimum use of N, P and K have given yield level a considerable rise both in the rice–rice (Tamil Nadu) and the rice–wheat systems (Punjab, Uttar Pradesh) of cropping.

11.2.3.5 Time and Method of Fertilizer Application

In rainfed areas, regarding the time and method of fertilizer application, drilling all its quantity at the sowing time was found to be significantly superior to broadcast or drilling half at sowing and spraying half on the foliage. Hence this practice needs to be followed.

11.2.3.6 Deep or Conventional Tillage

Soil tillage has been found important in alleviating soil-related constraints encountered in crop production. An important effect of soil tillage on crop productivity through its influence on soil processes, soil-related and crop growth has recently been detailed (Mahajan et al., 2008d). Deep tillage ameliorates puddling-induced traffic pan and improved wheat yield, as shown in Table 11.3. In both the study years, the grain yield of wheat was significantly higher in plots where deep tillage (T_4) treatment was adopted, which was followed by conventional tillage (T_2 and T_3). This could be associated with improvement in soil physical properties and plant growth parameters. During the second year of the crop study, the grain yield in T_7 (where deep tillage–no tillage sequence was followed with a puddled rice crop in between) was significantly higher than T_1, T_2 and T_5. Since the puddling effects are mostly confined to the upper layers and the lower layers are left as such, this may be the reason for more pronounced effects of deep tillage in lower layers. This has also clearly indicated the positive effect of deep tillage even after inclusion of

Table 11.3 Effect of deep tillage on yield of wheat after rice in Himachal Pradesh (Adapted from Mahajan and Bhagat [2006])

	Grain yield (Mg ha^{-1})	
Treatments	2002/03[a]	2003/04[b]
T_1	2.10	2.16
T_2	2.39	2.66
T_3	2.86	3.00
T_4	3.35	3.53
T_5	2.36	2.55
T_6	2.90	2.76
T_7	3.39	2.99
LSD (0.05)	0.18	0.15

[a] T_1 – no tillage, T_2 – tillage up to 10 cm depth, T_3 – tillage up to 20 cm depth, T_4 – tillage up to 40 cm depth, T_5 – tillage up to 10 cm depth, T_6 – tillage up to 20 cm depth, T_7 – tillage up to 40 cm depth during first wheat-growing season (2002/03).

[b] T_1 – no tillage, T_2 – tillage up to 10 cm depth, T_3 – tillage up to 20 cm depth, T_4 – tillage up to 40 cm depth, T_5 – no tillage, T_6 – no tillage, T_7 – no tillage during second wheat-growing season (2003/04).

a puddled lowland crop. However, significantly lower grain yields were recorded with no tillage during both the years of the study due to crop–weed competition. This practice is therefore required after every 2–4 years.

11.2.4 Suggestions for the Future

Some major suggestions on which studies need to be initiated in future are given below:

- Long-term studies on nutrient requirements of wheat-based cropping system are required in relation to the soil physical environment in well-defined soils.
- Research on the effects of preceding crops, fertilizers and manures, and their integrated use in wheat-based cropping systems is currently required.
- Almost 50% of over 200,000 soil samples analysed have shown deficiency in Zn for wheat crop; therefore, the application of $ZnSO_4$ is essential to increase its yield. Usually 20 kg $ZnSO_4$ is sufficient to apply per hectare.
- Soil S deficiency which at one time was considered to be confined to coarse-textured soils for oilseed crops is now estimated to occur in a wide variety of soils in 130 districts. Yield increase to addition of S under field conditions has been reported in over 40 crops. So its application is essential to wheat crop also to enhance its yield.

Impact Points to Remember

- Rice is the traditional and main crop grown in eastern, north-eastern and peninsular India.
- India is the largest rice-growing country, while China is the largest producer of rice in the world.
- The rainfed rice-growing area of the country has been divided into two main categories, namely upland and lowland rice, with varying depths of water on the soil surface.
- Since most of the rice-growing area of India lies in the alluvial plains, many of the soils belong to Entisols and Inceptisols orders and Haplaquents, Ustifluvent, Udifluvents, Ustochrepts of Great Soil groups.
- The highest productivity of rice has been seen in the north zone (2,940 kg ha^{-1}) followed by the south zone (2,158 kg ha^{-1}), North-east Hill Region (1,196 kg ha^{-1}) and the west zone (1,064 kg ha^{-1}).
- The average yield of rainfed rice crop grown on upland soils is very poor, at about 0.6 t ha^{-1} as against 1.3 and 1.7 t ha^{-1} in rainfed lowland and irrigated medium land, respectively.

- Soils of rainfed upland rice are generally coarse-textured (gravelly loamy sand, sandy loam) and belong to Alfisols, Ultisols or Oxisols.
- Varieties of rice having a duration of 80–110 days which are considered suitable for rainfed uplands should be grown.
- The traditional method of preparing land for transplanting lowland rice is puddling (wet tillage or tillage in standing water).
- Wheat is the second most important food crop of the country, which contributes nearly one third of the total food grains production.
- Wheat is an important crop of India, especially in the northern states.
- India shares about 1.5% the world's wheat area and 11.4% of the world's total production.
- The common bread wheat, *T. aestivum*, is the most important species, occupying more than 90% of the total area in the country and grown all over India from the sea level up to an elevation of 3,500 m in the Himalayas.
- Throughout the country only spring-type wheat varieties are grown, though these are raised in winter season.
- Cultivation of wheat under rainfed conditions occupies nearly 40% of the total growing area in India.
- Among soil-related constraints, soil fertility is a major one, i.e. soils are low in available plant nutrients.

Study Questions

1. Define the following:
   (a) Transplanting
   (b) CEC
   (c) Electrical conductivity
   (d) Toxicity
   (e) Puddling
   (f) Lime
   (g) Deep tillage
   (h) Conventional tillage

2. Differentiate the following:
   (a) Lowland rice and upland rice
   (b) Alkali soils and alkaline soils
   (c) Laterite soils and lateritic soils

3. Write a short note on Indian rice and wheat ecosystem.

4. Explain the soil-related constraints in rice and wheat production and how you can manage it.

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Chapter 12
Constraints in the Adoption of INM System

Abstract The adoption of INM system by farming communities is limited in rural India because of increasing compulsion to use cowdung as a source of fuel; increasing competitive value of crop residue as animal feed therefore affects the recycling of agricultural wastes. Handling bulky organic manures containing small amounts of plant nutrients as well as problems in timely preparation of fields due to incorporation and decomposition of agricultural wastes and green manures which require irrigation are the other constraints faced by farmers. Large amounts of insoluble constituents of organic matter like cellulose, hemicellulose and lignin which delay the process of composting due to high C/N ratio, and development of other worms due to lack of proper air circulation in the container during vermicomposting are also problems in the adoption of INM system. Moreover, poor-quality bio-fertilizers that reach the farmers are ineffective and their marketing becomes difficult because the products contain living or latent organisms.

Keywords INM system • cowdung • crop residue • agricultural wastes • bulky organic manures • green manures • composting • bio-fertilizers • vermicomposting.

Recent studies in cereal-based cropping systems, particularly in that of rice–wheat, have indicated the detrimental effects of continuous application of high doses of chemical fertilizers, especially N without P and K fertilizers, leading to decline in crop productivity and environmental degradation. This is attributed to nutrient imbalances and micronutrient deficiencies (Hedge, 1992; Nambair and Abrol, 1989). Because of the subsidy on urea, many farmers have used and are using relatively more amounts of nitrogenous fertilizers, which has resulted in nutrient imbalance in the soil as the use of P and K fertilizers by the farmers is not strictly made according to soil needs. So, to increase production balanced use of nutrients including INM system should be adopted and is the need of the hour (Ram, 2000;

A. Mahajan and R.D. Gupta, *Integrated Nutrient Management (INM) in a Sustainable Rice–Wheat Cropping Systems*,

Mahajan et al., 2002, 2003a, b, 2007a, b; Mahajan and Sharma, 2005). Farmers are generally aware of the benefits of INM system, but adoption of this system is limited in India because of the following constraints.

12.1 Chemical Fertilizers

Fertilizers are the kingpin of the Green Revolution and will continue to be the best hope for meeting the future challenge for food grain production in India and other developing countries. Even high yielding varieties or the so-called miracle seeds of rice and wheat could not have created wonders without the use of chemical fertilizers. Nobel Laureate Norman E. Borlaug even prophesied that without chemical fertilizers India would have required two- to threefold its area to meet the food grain requirement of its population. However, in recent years long-term sustainability of agricultural productivity and ecological safety of the continuous use of chemical fertilizers are being questioned.

Chemical fertilizers which are also called artificial manures or synthetic chemical fertilizers are today being utilized by the farming industry largely but injudiciously. Although they can increase the yield of the crop in a very short time, in the long run they will lead to land degradation, environmental degradation, soil erosion (loss of top soil) and nutrient imbalance together with lowering of food quality. If these chemicals via the food chain are absorbed into the body, health would be harmed. The constraints encountered during the faulty use of chemical fertilizers are as follow:

- Extensive use of chemical fertilizers leads to change in the soil pH, causing soil acidity or soil alkalinity depending on the kind of fertilizer used.
- Due to change in the soil pH, there results an imbalance in the availability of native macro- and micronutrients which leads to deficiency symptoms or toxicity syndromes of certain plant nutrients.
- Change in soil pH also causes impairment in the population of beneficial micro-organisms and their activity. This becomes more so when the pH of the soil becomes very acidic (less than 5.5) or sodic (greater than 8.5). This further causes imbalance in the availability of native as well as applied nutrients.
- When high-analysis fertilizers are used to supply macronutrients, plant uptake of native micronutrients becomes higher, which impairs the micronutrient supply of the soil.
- Hardly 30–40% of the applied fertilizer nutrient is utilized by the crop and the rest is lost through various pathways like leaching, surface run-off, volatilization, denitrification, soil erosion and its fixation in soil through the adsorption phenomenon.
- Most of the chemical fertilizers are costly and beyond the reach of the peasants. At the same time, they also leave their harmful residual effects on soil.

- Many Indian soils are low in organic matter content and water-holding capacity.
- There may be an adverse effect on animals.

12.2 Organic Manures

Organic manures are also called bulky manures or natural manures. They are prepared from animal and plant wastes. The constraints of organic manures are as given below:

- Organic manures like FYM, poultry manure and compost have small amounts of plant nutrients and, thus, large amounts are required to fulfil the nutrient needs of various high-yielding crops, which is not possible for a country like India with a population of more than one billion to feed.
- Handling of bulky organic manures involves high cost of transportation.
- Organic manure alone cannot meet the nutrient requirement of a crop.
- The crop yield is very low, especially during the initial stages of organic manure applications, which later on becomes stabilized.
- The rate of mineralization and the rate of the release of nutrients, particularly that of nitrogen, are slow in organic manures but are residual in effect.
- The increasing compulsion to use cowdung as a source of fuel in rural areas of India leaves very little of it for composting and use in agricultural fields.
- It increases the cost of nutrient application in comparison to chemical fertilizers.
- Improper decomposition and storage of FYM, particularly during rainy season, creates groundwater pollution and loss of nutrients, especially nitrogen in terms of gaseous loss – N_2O, NH_3, NO, NO_2.

12.3 Crop Residues

Rural wastes like paddy straw, wheat straw, and residues of sorghum, pearlmillet, maize, sugarcane and others have a lot of potential to contribute plant nutrients. The crop residues have the following constraints:

- Rice and wheat straw are mostly used as livestock beddings and thatching materials for huts and temporary dwellings in villages. Besides this, they are also used as cattle feed or as a source of fuel.
- Increasing competitive value of crop residue as animal feed, as it is rich in silica and oxalic acid, affects recycling of agricultural wastes.
- Although organic residues of rice and wheat straw can be used to make up the plant nutrient need they require complete decomposition due to their wide C/N ratio, which is sometimes more than 100:1. If they are not fully decomposed and added as such, they can cause immobilization of nutrients, especially of N. Thus, the crop yields will be affected very badly (Gupta et al., 2005).

12.4 Green Manures

In green manure practice legumes are generally preferred because they have an additional benefit of fixing atmospheric nitrogen. The following constraints are encountered during the use of green manures:

- Problems in timely preparation of fields due to incorporation and decomposition of agricultural wastes and green manures.
- Due to improper decomposition, problems of insect-pests and diseases may arise.
- Extra cost and time are required in raising green manure crops.
- Growing of green manure crops is not adopted widely because additional labour/inputs are needed. Inadequate availability of water during their growth, inadequate supply of high-quality green manure crop seeds locally in time along with cheap rates and other competing uses of resources for raising other crops are the other constraints in practising green manuring.

12.5 Compost

Compost is manure similar to FYM and is made by the decomposition of plant residues under the action of micro-organisms. Compost has the following constraints:

- High C/N ratio in the plant residues. Sometimes, it is more than 100:1.
- Decomposition problems especially in hilly areas where temperatures are low or very low. Decomposition is possible only by the use of certain micro-organisms or certain amendments like urea, super phosphate or rock phosphate.
- More contents of insoluble constituents of organic matter like cellulose, hemicellulose and lignin, which delay the process of composting due to high C/N ratio
- In the Bangalore method night soil is used as catalyst. So, most of the farmers do not want to use this manure.
- The disadvantage of the Indore method is that it is not suitable except in rural areas.

12.6 Vermicompost

Vermicompost is the natural or organic manure prepared by earthworms from biodegradable organic materials. The constraints mentioned below are encountered during the use of vermicompost:

- Stinking garbage due to overwatering
- Development of other worms due to lack of proper air circulation in the container

- Protection of the bed as well as of earthworms from predatory birds and ants in the heap method of vermicompost
- Protection from cats/dogs/rats due to collected waste in the container
- Influx of mango flies if the garbage is left uncovered

12.7 Bio-Fertilizers

Bio-fertilizers have great potential as supplementary, renewable and environmentally friendly sources of plant nutrients and are considered an important component of INM system (Mahajan et al., 2008a), but there are some constraints as mentioned below:

- Poor-quality bio-fertilizers reaching the farmers are ineffective, and thus there are questions as to their usefulness.
- Marketing of bio-fertilizers becomes difficult because the product contains living organisms.
- Faulty transport and storage system and rising temperatures destroy the microbial population in inoculants.
- There is a lack of suitable carrier material which is used for restoration and longevity in field conditions.
- There is poor and inconsistent crop response to bio-fertilizers.
- There is lack of awareness and unavailability of bio-fertilizers to a large number of farmers.
- Demand and production of bio-fertilizers is seasonal.
- There is non-availability of mycorrhizal inoculum in large scales because of difficulty in mass production.
- The mycorrhizal inoculum can be stored for a short time span and there is almost no information on methods for long-term storage of mycorrhizal inoculum.

If attention is devoted to the above-mentioned constraints and solutions are provided to overcome them, INM system will be widely adopted. In view of the escalating prices of chemical fertilizers, loss in soil productivity, deterioration in soil health, environmental degradation and reduction in crop productivity, INM system will perhaps be a widely adopted technology in the future.

Impact Points to Remember

- Most of the chemical fertilizers are costly and beyond the reach of the peasants. At the same time, they also leave their harmful effects in the soil.
- Organic manures have small amounts of nutrient content so large amounts are required to fulfil the nutrient needs of various crops, which is not possible for India with more than one billion population to feed.

- Handling of bulky organic manures involves high cost of transportation.
- Increasing competitive value of crop residue as animal feed affects recycling of agricultural wastes.
- Organic residues of rice and wheat straw have wide C/N ratio. If they are not fully decomposed and added as such, they can cause immobilization of nutrients, especially of N, and crop yields will decrease enormously.
- Extra cost and time are required in raising green manure crops.
- Large amounts of insoluble constituents of organic matter like cellulose, hemicellulose and lignin delay the process of composting due to high C/N ratio.
- The problem in the heap method of vermicompost lies in the protection of the bed as well as of earthworms from predatory birds and ants.
- Marketing of bio-fertilizers becomes difficult because the product contains living organisms.
- There is a lack of suitable carrier material such as peat having longer shelf life.

Study Questions

1. Define the following:
    (a) Mineralization
    (b) Immobilization
    (c) Decomposition
    (d) Agroforestry
    (e) Poultry manure
    (f) C/N ratio
2. Why is the adoption of INM system in rice–wheat cropping limited in India?
3. List the demerits of organic manures and bio-fertilizers.
4. Differentiate between FYM and compost.
5. Write a short note on C/N ratio.
6. What are the detrimental effects of continuous application of high doses of chemical fertilizers?
7. What are the disadvantages associated with the use of inorganic fertilizers?

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Chapter 13
Future Research Strategies/Priorities

Abstract Integrated use of legumes, green manures, organic manures, crop residues, urban waste and bio-fertilizers, alone or in combination with chemical fertilizers, bring 25–50% economy in fertilizer-N applied to rice–wheat sequence and have proved to be a potential tool for sustaining the productivity of soil and crops in rice–wheat cropping systems on a long-term basis. The most critical output in this regard will be the ability to accurately adjust the rate and timing of fertilizer addition in line with organic manure management for different crops, soil types and agro-climatic situations. In this chapter, decomposition of crop residues having wide C/N ratio, advantages of manures prepared in pits, addition of nitrogenous and phosphatic compounds during preparation of organic manures, use of chemical fertilizers to supplement the organic matter, balanced use of fertilizer and manure application, and activation of biological activities are detailed. Creation of awareness about INM system, ban on use of cowdung as fuel and crop residues as feed, setting of agroforestry, growing of legumes, use of neem cake and neem leaves in rice soils, harnessing of other micro-organisms for rice–wheat development, micronutrient management, use of leaves and twigs of various plants, quantification of nutrient losses, development of better technology, soil test crop response, refinement of bio-fertilizer technology and research on the role of earthworms have also been elucidated.

Keywords Rice–wheat sequence • legumes • green manures • organic manures • crop residues • bio-fertilizers • micronutrient management • crops • soil types • soil test crop response • agro-climatic situations

Integrated nutrient management (INM) system holds a great promise not only in securing high yields and maintaining soil fertility but also in combating against emergence of multi-nutrient deficiencies in the rice–wheat production system. It is ecologically, socially and economically viable and environmentally non-hazardous (Jaggi et al., 2001). Moreover, the integrated use of legumes, green manures, organic manures, crop residues, urban waste and bio-fertilizers, alone or

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in combination with chemical fertilizers, results in 25–50% economy in fertilizer-N applied to rice–wheat sequence and has proved a potential tool for sustaining the productivity of soil and crops in rice–wheat cropping systems on a long-term basis (Mahajan et al., 2002; Mahajan and Sharma, 2005; Ram, 2000).

The need to sustain productivity of rice–wheat cropping systems in India is greater today than ever before. INM system offers more opportunities to increase and sustain productivity as well as income in most rice–wheat cropping systems (Gupta et al., 2005). In view of the above-mentioned concerns research work on the following lines is suggested.

13.1 Decomposition of Crop Residues and Their C/N Ratio

More research is needed on nitrogen mineralization for decomposition of wheat and paddy straws, pearlmillet stover, mung bean and cluster bean straws at different soil water levels. Decomposition of these residues is very low due to high C/N ratio. It is worth mentioning that the C/N ratio of paddy straw or wheat straw is as high as 100:1 or even more. During the decomposition process, both mineralization and immobilization of nutrients take place simultaneously. If the latter exceeds the former, the micro-organisms will compete with higher plants for available N.

Immobilization exceeds nitrogen mineralization when the C/N ratio of the decomposing material is greater than 30:1. In the range of 15:30, the C/N ratios for both are almost equal. Mineralization exceeds immobilization when the ratio is less than 15:1. So, it becomes necessary that the C/N ratio of the crop residues prior to blending with chemical fertilizers must be brought down.

Several things may be done to bring down the C/N ratio of the organic residues and to prevent competition between microbes and higher plants for nitrogen. But mostly the C/N ratio of the crop residues, tree leaves and grass choppings and other agricultural wastes may be lowered by composting, i.e. decomposition of the organic crop residues.

13.2 Advantages of Manures Prepared in Pits

The decomposition of the crop residues/organic wastes must be done in the pits and not in aboveground open heaps. Preparation of manure in pits has several benefits over method of preparation in heaps. The decomposition is mainly anaerobic, except in the surface few centimetres and proceeds slowly. Losses of organic matter as well as nitrogen are reduced. The materials are protected against loss of moisture by evaporation and excess water during rains. The manure remains in the pit until required without much loss due to very restricted decomposition even after it is ready.

13.3 Addition of Nitrogenous and Phosphatic Compounds During Preparation of Organic Manures

Recent trends in the preparation of compost/manures from crop residues (Gupta et al., 1998) consist of the following:

- Chopping of organic wastes to 5–6 cm size and filling them in pits.
- Sprinkling of super phosphate at the rate of about 5% (Garg et al., 1971) or addition of rock phosphate at 1% to narrow down the C/P ratio (Gupta et al., 1998).
- Urea or DAP can also be used to hasten the process of decomposition. However, their addition should be avoided as this will accelerate the loss of nitrogen through leaching and emission of gases like NH_3, NO and NO_2.
- Homogenized fungal culture of *Trichurus spiralis*, *Paecilomyces fusisporus*, *Trichoderma viridi* and *Aspergillus* species is then added at the rate of 300 g t^{-1} material.
- Within 8–10 weeks good quality compost from paddy straw could be prepared.
- Mixed crop wastes, sugar trash can also be used instead of wheat straw.

In this process, use of inoculants such as cellulolytic and lignolytic micro-organisms is known to speed up the process.

13.4 Use of Chemical Fertilizers to Supplement the Organic Matter

An ideal agricultural soil is that which contains as much as 5% organic matter (about 3% organic carbon) by weight. However, continuous cropping and maximal tillage exposes organic matter to increased aeration and microbial activity, resulting in losses of organic matter. Due to this loss, unfavourable changes in soil structure, increased erosion and subsequent decrease in crop productivity will occur. Thus the addition of chemical fertilizers alone will not suffice to maintain crop productivity. Use of synthetic fertilizers, therefore, must be supplemented with a supply of organic matter. Organic manures, crop residues, crop rotations, cover crops and legumes, and locally available organic wastes can be used in this connection.

The forages from the crop rotations are used to directly feed livestock. Livestock in turn supply manure directly on farms. Pollution problems are also minimal because the nitrogen run-off becomes less. Thus, the future strategies must be concentrated on these lines, i.e. use of both organics and inorganics, which in other words refers to integrated nutrient management (INM) system.

13.5 Balanced Use of Fertilizer and Manure Application

Never apply nitrogenous fertilizers alone as their continuous use not only makes the soils acidic (Gupta et al., 1992; Gupta and Singh, 2006) but also depresses the crop yield. Remember that there are elements other than nitrogen which the plants require for their growth. There is no substitution of plant nutrient by any other nutrient. For instance, the functions of nitrogen cannot be performed by phosphorous or those of phosphorous by potash. The response of added nutrient to crops is conditioned by the level of other nutrients. Therefore, it is essential to try to maintain a balanced supply of different nutrients in the soil. For this purpose soil testing is a must.

If the fertilizers have to be added without soil testing, the farmers must be advocated to use balanced dose of fertilizers, i.e. nitrogenous, phosphatic and potassic as per the 'Production Recommendations' formulated and issued by the State Agricultural Universities/State Departments of Agriculture (Gupta and Kanwar, 1984; Gupta, 2005d) from time to time.

To prevent the emerging deficiency of micronutrients and secondary nutrients, it is suggested that the farmers must be advocated to make use of cowdung or farmyard manure and compost, whichever is available to them.

13.6 Activation of Biological Activities

The biological activities of the soil become better with the use of organic manures as they supply organic matter. Organic matter serves as a foster mother for microorganisms involved in the decomposition of organic matter through various processes like aminization, ammonification, nitrosification and nitrification. In fact, soil is a big laboratory and plants get their nourishment or feed after performing a series of processes in the soils.

The main agents that carry out these biological processes are micro-organisms, i.e. bacteria, actinomycetes and fungi. Therefore, the soil laboratory can function well only if sufficient amount of organic matter is present. In addition to micro-organisms various enzymes and macrofauna are also activated which are responsible for the decomposition of organic matter and the release of nutrients in the growing plants. So sufficient amount of organic matter must be added in soils to activate biological functions.

13.7 Creation of Awareness about INM System

As the population of the country is increasing rapidly and is expected to rise to the level of 1.45 billion by 2035 at the rate of an average growth of 2% per annum, if food production is not increased in the near future our food security will be badly affected. Increase in food grain production cannot be paced with an application of chemical fertilizers alone due to their ill effects on soil. This therefore calls for inclusion of various organics in the chemical fertilizers to various crops for enhancing the food grain production. However, the majority of farmers are unaware of the combined use and importance of organics and inorganics for crop production.

In the light of the above, it is emphasized that various INM techniques must be organized as field demonstrations with high inputs of inorganic and organic fertilizers. Similarly, we must organize farmers' field days and organize audio-visual aid campaigns. All these extension teaching methods will definitely create an impact on the farming community with regard to the "know-how" of INM system.

13.8 Ban on Using Cowdung as Fuel and Crop Residues as Feed

As already stated, the population of India is increasing day by day and the land has now become a limited resource for food production, so intensive crop production is to be followed to feed the burgeoning population. In intensive cultivation, growing of several varieties of rice and wheat would demand more consumption of plant nutrients. This cannot be fulfilled by using chemical fertilizers alone due to their increasing prices. So, one will have to depend on the use of various sources of organics.

To make use of various crop residues for preparing organic manures, and thereafter, their utilization in crop production has become the need of the day. Hence, it is suggested that the use of organic residues as cattle feed and burning of cowdung as fuel be totally banned.

13.9 Setting of Agroforestry

The need/requirement of peasants in respect of fuel wood and cattle feed can be solved by setting up agroforestry practice. The wood species suitable for fuel which can be grown in an agroforestry system are Sababul (*Leucaena leucocephala*), Kikar (*Acacia nilotica*) and Phulai (*A. modesta*) for the plains. They can even be grown on the field bunds. *Salix* and *Quercus* spp. are suitable for hilly areas. They also provide fodder and timber. Planting of *L. leucocephala* at a distance of 3 m apart in wheat fields during *Rabi* and pulse during *Kharif* produced 12 kg wood per tree 3 years after plantation when cutting was done during November. Besides fuel wood, the trees, when cut at the height of 45 cm from the ground, gave 10 kg green fodder per tree during the time of sowing of wheat. The lopped trees again grow owing to breaking of apical dominance and developing of side shoots, which can be cut subsequently after a year in the same month (Gupta, 2005a). This can make people self-reliant for their basic needs of fuel, fodder and timber. Substitution of fuel wood like kerosene oil, gobar gas, solar cooker and smokeless chullahs should be made available freely and cheaply.

13.10 Growing of Legumes

Growing of legume as green manure crop for soil improvement and amelioration of rice–wheat crops productivity is one of the oldest practices. It has proved more beneficial in case of light textured soils (loamy sand, sandy loam or sandy soils). The main effect of this practice prior to transplanting rice is to increase supply of nitrogen and other nutrients. A green manuring practice of 'dhaincha' (*Sesbania aculeata*) before transplanting of rice–wheat cropping sequence has not only shown reduction of nitrogen content by one third of the recommended dose in rice and wheat, but has also enhanced yield of rice and wheat (Sharma and Gupta, 2003). The other benefits are protection of soil from erosion and reduction of leaching losses of nutrients.

13.10.1 Burial Stage of Dhaincha

Dhaincha is also suitable for heavy soils (clay loam, clay, etc.). It can withstand severe drought and also does well in poorly drained soils which are slightly saline. In irrigated areas of Jammu, it can be sown in the fourth week of April using 60–70 kg seed ha^{-1}. It becomes ready for burying in the soil about 45–50 days after sowing, i.e. before the flowering stage. This is because the plants before or at the flowering stage contain the greatest bulk of succulent organic matter with low C/N ratio. The incorporation of this crop in the soil at this stage allows quick liberation of nitrogen in available form. With advancing stage, the percentage of carbonaceous matter of plants increases and that of nitrogen decreases.

It is therefore suggested that wherever possible dhaincha should be used as green manure in rice soils. As the seeds of dhaincha are very hard, before sowing they must be soaked in water for about 2–3 days. This improves germination.

13.10.2 Other Legumes Suitable for Rice and Wheat Crop

Mung (*Phaseolus mungo*) being most popular as pulse for *Zaid* crop can also be used for green manuring in June–July, after two to three pickings. Mung can be sown in the second half of April immediately after harvesting of wheat, using 20–25 kg seed ha^{-1}. Paddy can be transplanted in such fields after 5–10 days after incorporation or after 10–15 days (Pandey, 1985 and 1986). Where irrigation facilities are not available it can be sown during *Kharif* season.

Table 13.1 Quantity of green matter and nitrogen added in soil by green manure crops (Adapted from Pandey [1985 and 1986])

Crop	Growing season	Green matter (q ha^{-1})	N – added (kg ha^{-1})
Sunnhemp	*Kharif*	212	75
Dhiancha	*Kharif*	200	69
Mung	*Kharif*	80	34

Sunn hemp (*Crotalaria juncea*) grows very rapidly and decomposes in the soil quickly. Where irrigation facilities are not available it can be grown with the first shower of monsoon using 60–70 kg seed ha^{-1} and ploughed for green manuring in the month of August. In dryland or rainfed areas, *Kharif* crop has to be missed. Missing of *Kharif* crop, however, can be compensated by growing and obtaining a bumper crop of wheat as has been observed in Dryland Agriculture Sub-Station at Rakh Dhiansar, under Sher-e-Kashmir University of Agricultural Sciences and Technology Jammu, Jammu & Kashmir. The quantity of green manure and nitrogen added in soil by sunn hemp, dhaincha and mung are listed in Table 13.1.

13.11 Use of Neem Cake and Neem Leaves in Rice Soils

It is surprising to note that neem cake and neem leaves when added to puddled rice soils make it more fertile. This is due to the presence of an ingredient in the neem cake that inhibits or checks the growth of nitrifying bacteria. Actually these bacteria remain in the initial stage of their growth and never reach the exponential stage of growth. This results in conversion of native soil organic nitrogen or added nitrogen (urea, ammonium sulphate) into ammonical form and not into NO_3 form (Gupta, 2005c). As such there is almost no leaching loss of nitrogen from the soil. Leaching loss of nitrogen in rice soils occurs through NO_3 which never happens in such soils when neem cake is added. Thus fertility of the soil is enhanced. In addition, there is little conversion of nitrogenous compounds into N_2, NO, N_2O, NO_2, etc. Not only neem cake but also leaves and twigs of the neem tree and neem-coated urea, available in the market, can be used to check nitrogen losses in rice-growing soils to increase the nitrogen use efficiency and finally to enhance rice yield. In view of the above, it is suggested that more research be conducted along the said lines.

13.12 Harnessing of Other Micro-organisms for Rice–Wheat Development

Apart from the well-known agriculturally important bacteria, Cyanobacteria or BGA and mycorrhizal fungi, scientists of the Division of Microbiology, Indian Agriculture Research Institute, New Delhi, have isolated certain bacteria from sewage water and rhizosphere of crops like wheat and sunflower. Such bacteria are *Proteus vulgaris*, *Bacillus subtilis* and *Klebsiella planticola*. These bacteria have the potential to provide nutrients and these in combination with one fourth the recommended dose of FYM or alone have been found promising in enhancing the yield of wheat crop (Balasubramanium, 2000).

Technologies for sustainable rice–wheat crop production based on the identified soil bacterial species from North West Himalayan soils like *B. subtilis*, *B. cereus* var. *mycoides*, *B. megatherium* var *phosphaticum* (Gupta and Tripathi, 1988) need to be developed. Similarly, 63 species of fungi isolated from the soils of North West Himalayas in Kangra District, Himachal Pradesh (Gupta and Dogra, 2000), belonging to six main classes and different species of *Streptomyces*, need to be evaluated in respect of their role in decomposition of organic residues (Table 13.2) for rice–wheat cropping systems.

Table 13.2 Distribution of soil fungi of north-western Himalaya (Adapted from Gupta and Dogra [2000])

Sr. No.	Species	Arablelands		Forestlands		Grasslands	
		Soil horizons					
		A	B	A	B	A	B
A.	Zygomycetes						
1.	*Mucor hiemalis* Wehmeyer	+	+	−	−	−	−
2.	*Mucor* spp. Mich ex Fr.	+	−	+	−	+	+
3.	*Rhizopus stolonifer* Ehrenb	−	+	−	−	−	−
4.	*R.* spp. Ehrenb ex corda	+	−	−	−	−	−
5.	*R. nodosus* Namys	−	+	−	−	−	−
6.	*R. oryzae* Went & Prinqshen Gerlings	−	−	−	−	+	+
7.	*Circinella musicae* (Sorok) Berl & De Toni	+	−	−	−	−	−
8.	*Thamnidium* spp.	+	+	−	−	−	−
B.	Ascomycetes						
9.	*Chaetomium globosum* Rai & Tewari	+	−	−	−	+	−
10.	*C. spirale* Zopf	−	−	−	−	+	−
11	*Thielavia terriocal* (Gilaman & Abbott) Emmous	+	+	−	−	−	+
12.	*T. basicola* Zopf	−	+	−	−	−	−
13.	*T. minuta* Lodha	−	+	−	−	−	−
14.	*T. sepedonium* Emmous	−	+	−	−	−	−
15.	*T. minutissima*	−	+	−	−	−	−
16.	*T. minor* (Rayss and Borut) Malloch & Cain	−	−	−	−	−	+
17.	*T. coactilis* Nicot ex Nicot & Longis	−	−	−	+	−	−
C.	Hyphomycetes						
18.	*Aspergillus niger* Van Tieghem	+	−	+	+	+	−
19.	*A. flavus* link ex Fries	+	−	+	+	+	+
20.	*A. ustus* (Balinier) Thom & Church	+	−	−	−	+	+
21.	*A. sydowii* (Bainier & Sartory) Thom & Church	+	+	−	−	−	−
22.	*A. candidus* Link	+	−	−	−	−	−
23.	*A. terreus* Thom	+	+	+	−	−	−
24.	*A. nidulans* (Eldam) Wingate	−	−	−	−	−	+

(continued)

Table 13.2 (continued)

Sr. No.	Species	Arablelands		Forestlands		Grasslands	
		Soil horizons					
		A	B	A	B	A	B
25.	*A. sejunctus* Bain Church	–	–	+	–	–	–
26.	*A. ruber* Thom Church	–	–	–	–	+	–
27.	*A. giganteus* Wehmer	+	–	–	–	–	–
28.	*A. phoenicis* (Corda) Thom.	+	–	–	–	–	–
29.	*A. fumigatus* Fresenius	+	–	+	+	+	–
30.	*A. nigricans*	+	–	–	–	+	–
31.	*Penicillium notatum* Westling	–	+	+	–	+	–
32.	*P. funiculosum* Thom	+	+	–	–	–	–
33.	*P. restrictum* Gilman & Abbott	+	–	–	–	–	–
34.	*P. vinaceum* Gilman & Abbott	+	–	–	–	+	–
35.	*P. chrysogenum* Thom	+	–	+	+	+	–
36.	*P. stipitatum* Thom	+	–	–	–	–	–
37.	*P. nigricans* (Bain) Thom	+	+	+	+	+	+
38.	*P. janthinellum* Blourge	+	–	–	–	+	–
39.	*P. citrinum* Thom	+	+	–	–	–	–
40.	*P. canescens* Sopp	+	+	–	–	+	–
41.	*P. viridicatum* Westling	+	+	–	–	–	–
42.	*P. prupurogenum* Stoll	+	+	–	–	–	–
43.	*P. expansum* Link	+	+	–	–	–	–
44.	*P. brefeldianum* (Dodge) Stock & Scott	+	–	–	–	–	–
45.	*Fusarium spp*. Link ex Fr.	+	–	–	–	–	–
46.	*Curvularia geniculata* (Tracy & Earle) Boedijin	+	+	–	–	–	–
47.	*Paecilomyces varioti* Bain	+	–	–	–	–	–
48.	*Paecilomyces* spp. Bain	+	–	–	–	–	–
49.	*Cladosporium oxysporum* Burk & Curt	+	–	–	–	–	–
50.	*C. cladosporioides* (Fres) de Vries	+	+	–	–	–	–
51.	*C. spp*. Link ex Fr.	–	–	–	–	–	+
52.	*C. herbarum* (Pers.) Link	–	+	–	–	–	–
53.	*Trichoderma* spp.	+	+	–	–	–	–
54.	*Alternaria* spp. Nees & Waller	+	–	–	–	–	–
55.	*A. alternata* (Fries) Kiessler	–	+	–	–	–	–
56.	*Verticillium* spp. Nees ex Wallr	–	–	+	+	–	–
D.	Deuteromycetes						
57.	*Trichurus spiralis* Hasselbring	+	–	–	–	–	–
58.	*Acrophialospora fusispora* (Saksena) Samson	+	–	–	–	+	+
59.	*A. levis* Samson & Mahmood	–	–	–	–	+	+
60.	*Scolecobasidium terreum* Abbott	–	–	–	–	+	+
E.	Coelomycetes						
61.	Phom spp. Desm	–	–	+	+	+	+
62.	P. sorghina (Sacc) Boerma, Dorenbosch & Van Kest	–	–	+	+	+	+
F.	Plasmodiophoramycetes						
63.	Aphanocladium album (Preuss) W. Gams	–	–	–	–	+	–
	White sterile fungi/sterile fungi	–	–	+	+	+	+

13.13 Micronutrient Management

With the advent of new rice varieties, application of micronutrients both for submerged and upland rice soils has become necessary because of their higher uptakes by several varieties. Deficiency of Zn has been observed in many Asian countries including India. Deficiency of Fe has also been noticed in rice-growing soils, especially on Latosols and toxicity in acid soils (Gupta et al., 1997). Barring acid-leached soils from Otacamund hills, none of the rice-growing soils have exhibited deficiency of Mn. Deficiency or toxicity of the above-mentioned micronutrients results in low yield of rice crop. Though some methods have been developed to prevent their deficiency or toxicity, more work is required to check the deficiency/toxicity and enhance rice yield.

Moreover, research must be carried out to identify cheaper, efficient and economic sources of micronutrients and techniques to alleviate micronutrient deficiency in location-specific situations. More studies must be made for appropriate macro- and micronutrient supply system for specific agro-ecological zones for intensive rice–wheat cropping systems.

13.14 Use of Leaves and Twigs of Various Plants

There is a need to generate more efficient integrated nutrient supply and management systems using locally available resources like leaves of various plants and twigs like *L. leucocephala* (Sababul), *Albizzia* spp. as well as FYM, compost, farm wastes, green manures, sewage, sludge, etc. Measures should be developed to quantify the effect of these resources so as to make necessary adjustment in chemical fertilizers.

13.15 Quantification of Nutrient Losses

Quantification of nutrient losses especially from organic manures which are prepared during heap methods is required. Similarly, there is a need to devise methods to increase the efficiency of their use.

13.16 Development of Better Technology

The scientists of different agricultural universities should develop simple techniques to handle bulky organic manures so that their processing, use and application is made as simple as that of chemical fertilizers. Direct and indirect effects of crop residue incorporation on soil quality and crop productivity in rice–wheat cropping systems should also be investigated. Development of better technology for *in situ* incorporation and rapid decomposition of crop residues through appropriate tillage, irrigation, fertilizer management and inoculation of suitable micro-organisms, particularly for intensive rice–wheat cropping systems, is very much needed.

13.17 Soil Test Crop Response

Fertilizer recommendations on the basis of soil test–crop response correlations and economics of different fertilizers and manures should be formulated for rice–wheat cropping systems for specific local sites. Moreover, the soil-testing laboratories need to be computerized and equipped with the facility for analysis of all nutrients including secondary and micronutrients (Raina et al., 2005). These should be strictly managed by soil scientists to ensure precise analysis and proper interpretation of results.

Where soil testing is not possible, the fertilizer recommendations are made on the basis of "Soil Test Plant Correlation" worked out by the Scientists/Officers of State Agricultural Universities (SAUs) and/or Department of Agriculture. On lack of Soil Test Plant Correlation data, the fertilizer recommendation formulated by the SAUs based on experimentation for various locations is another alternative.

13.18 Refinement of Bio-Fertilizer Technology

Bio-fertilizer technology needs to be refined for its easy adoptability by the farmers. Microbial strains which can compete with indigenous ones and work over a wide range of soil climatic conditions need to be isolated and multiplied (Mahajan et al., 2003a,b, 2008a). Moreover, research should be done with regard to suitability of bio-fertilizers against adverse conditions. A suitable carrier for different microbes to ensure long shelf life and effectiveness is also an area for research.

13.19 Research on the Role of Earthworms

The key role of earthworms in improving soil fertility is well known. Therefore, there is need for some systematic research to establish the role of earthworms in composting of organic wastes and the impact of vermicomposts on improving rice–wheat crop yields.

This research will provide information regarding proper integration of organic manures, crop residues, green manures, legumes and bio-fertilizers with chemical fertilizers. The most critical output in this regard will be the ability to accurately adjust the rate and timing of fertilizer application in line with organic manure management for different crops, soil types and cropping systems in different agro-climatic situations.

Important Points to Remember

- The integrated use of legumes, green manures, organic manures, crop residues, urban waste and bio-fertilizers, alone or in combination with chemical fertilizers, will result in 25–50% economy in fertilizer-N.
- To reduce the use of cowdung as a source of fuel large-scale plantation of quick-growing leguminous trees on roadsides, wasteland and field bunds may be encouraged, and biogas plants should be installed to solve the problem of fuel and plant nutrients.
- To prevent the emerging deficiency of micronutrients and secondary nutrients, it is suggested that farmers be advocated to make use of cowdung or farmyard manure and compost, whichever is available to them.
- Simple techniques should be developed to handle bulky organic manures so that their processing, use and application are as simple as chemical fertilizers.
- The biological activities of the soil become better with the use of organic manures as they supply organic matter.
- Fertilizer recommendations on the basis of soil test–crop response correlations, local availability and economics of different fertilizers and manures are to be formulated for rice–wheat cropping systems.
- More studies must be made for appropriate macro- and micronutrient supply system for specific agro-ecological zones for intensive rice–wheat cropping systems.
- Estimation of the percentage contribution of organic sources to the soil nutrient budget will be available during the current growing season and residual nutrients from their applications.
- Technologies for sustainable rice–wheat crop production based on identified soil bacterial species like *B. subtilis*, *B. cereus* var. *mycoides*, *B. megatherium* or *megaterium* var *phosphaticum* need to be developed.
- Quantification of nutrient losses especially from organic manures which are prepared during heap methods is required. Similarly, there is need to devise methods to increase the efficiency of their use.
- Bio-fertilizer technology needs to be refined for easy adoptability by the farmers.
- A suitable carrier for different microbes to ensure long shelf life and effectiveness is also an area for research.
- Various combinations of nutrient sources for a particular cropping system need to be worked out.

Study Questions

1. Define the following:
    a. Sewage
    b. Irrigation
    c. Aminization
    d. Ammonification
    e. Nitrosification
    f. Nitrification
    g. Sludge
    h. Tillage
    i. Micro-organisms
2. What future strategies/priorities should be considered in the adoption of INM in rice–wheat cropping systems?
3. Enumerate the ill effects of indiscriminate use of fertilizers.
4. Explain whether the functions of nitrogen are performed by phosphorous and those of phosphorous by potash.
5. What do you mean by soil testing?

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Appendix A
List of Journals Related to This Book

Name of the journals	Periodicals	Publishers
Agricultural Research	Monthly	Agricultural Research Services, IARI, New Delhi
Agropedology	Quarterly	Indian Society of Soil Survey and Land Use Planning (NBSS & LUP), Nagpur
Annals of Agricultural Research	Quarterly	Indian Society of Agricultural Science, New Delhi
Clay Research	Quarterly	Division of Soil Studies, National Bureau of Soil Survey and Land Use Planning, Nagpur
Co-operative Perspective	Biannual	Vaikunta Mehta National Institute of Co-operative Management, Pune
Crop Improvement	Half yearly	The Crop Improvement Society of India, Ludhiana
Crop Research	Bimonthly	Agricultural Research Information Center, Hissar
Environment and Ecology	Quarterly	Kalyani 741235, P.O. 22, West Bengal
Haryana Journal of Agronomy	Half yearly	Haryana Agronomists Association, Dept. of Agronomy, HAU, Hissar
Himachal Journal of Agricultural Research	Biannual	Directorate of Research, CSK HPKV, Palampur
Indian Journal of Agricultural Research	Quarterly	Agricultural Research Communication Center, Karnal
Indian Journal of Agronomy	Quarterly	The Indian Society of Agronomy, New Delhi
Indian Journal of Dry land Agricultural Research and Development	Half yearly	CRIDA, Hyderabad
Indian Journal of Fertilization	Monthly	Fertilizer Association of India, New Delhi
JNKVV Research Journal	Biannual	JNKVV, Jabalpur, Madhya Pradesh
Journal of Maharashtra Agricultural University	Quarterly	College of Agriculture, Pune
Journal of Oil Seeds Research	Half yearly	Indian Society of Oil Seeds Research
Journal of Potassium Research	Quarterly	PRII, Haryana
Journal of Research	Quarterly	Communication Center, PAU, Ludhiana
Journal of Research	Half yearly	Orissa University of Agriculture and Technology, Bhubaneswar (Orissa)

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Name of the journals	Periodicals	Publishers
Journal of Research	Half yearly	Rajendra Agriculture University, Bihar
Journal of Research	Quarterly	Sher-e-Kashmir University of Agricultural Sciences and Technology, Jammu
Journal of Soil and Water Conservation	Quarterly	Soil Conservation Society of India, New Delhi
Journal of Soils and Crops	Biannual	Associations of Soils and Crops Research Scientists 202/1, Nagpur
Journal of the Agricultural Science Society of North East India	Biannual	AAU, Jorhat
Journal of the Indian Society of Soil Science	Quarterly	ISSS, New Delhi
Journal of Tree Sciences	Biannual	Indian Society of Tree Scientists, Dr. Y.S. Parmar University of Horticulture and Forestry, Nauni (Solan)
Madras Agricultural Journal	Monthly	MASU, TNAU, Coimbatore
Manage Extension Research Review	Quarterly	National Institute of Agricultural Extension Management, Rajendranagar (Hyderabad)
Oryza	Quarterly	Association of Rice Research Workers, Central Rice Research Institute, Cuttack (Orissa)
Research and Development Reporter	Biannual	Rajasthan Fertilizers Trading Co-operation, Jammu & Kashmir
The Indian Journal of Agricultural Sciences	Monthly	ICAR, New Delhi
The Mysore Journal of Agricultural Sciences	Quarterly	UAS, Bangalore

Appendix B
List of Indian Magazines Related to This Book

Name of the magazines	Periodicals	Publishers
Agriculture Today	Monthly	Centre for Agriculture and Rural Development, New Delhi
Agrobios Newsletter	Monthly	Agrobios (India), Behind Nasrani Cinema, Chopasani Road, Jodhpur
Down to Earth	Monthly	Centre for Science and Environment, New Delhi
Farmers' Forum	Monthly	Bharat Krishak Samaj, New Delhi
Gram Vikas Jyoti	Quarterly	Council for Development of Rural Areas, 2, Vigyan Lok, Vikas Marg Extension, Delhi
Indian Farmers' Digest	Monthly	Director, Communication Centre, G.B. Pant University of Agriculture & Technology, Pantnagar
Indian Farming	Monthly	Indian Council of Agricultural Research, Krishi Anusandhan Bhavan, New Delhi
Intensive Agriculture	Monthly	Krishi Vistar Bhavan, Directorate of Extension, Ministry of Agriculture, IASRI Campus, Pusa, New Delhi
Kurukshetra	Monthly	Nirman Bhavan, Ministry of Rural Development, New Delhi
Progressive Farming	Monthly	PAU, Ludhiana
Yojana	Monthly	Ministry of Information and Broadcasting, Yojana Bhava, Sansad Marg, New Delhi

Appendix C
Indian Acronyms Related with Agriculture

Acronyms		
AADF	:	Associated Agricultural Development Foundation, New Delhi
ABMP	:	Association of Basic Manufacturers of Pesticides, Mumbai
ACPC	:	Agricultural Costs and Prices Commission, New Delhi
AISLUS	:	All India Soil and Land-Use Survey (IARI), New Delhi
APEDA	:	Agricultural and Processed Food Products Export Development Authority, New Delhi
ASRB	:	Agricultural Scientist Recruitment Board, New Delhi
CARI (ANGI)	:	Central Agricultural Research Institute for Andaman and Nicobar Group of Islands, Port Blair
CAZRI	:	Central Arid Zone Research Institute, Jodhpur
CCI	:	Cotton Corporation of India Limited, New Delhi
CCRI	:	Central Coffee Research Institute, Chikmaglur
CGRT	:	Centre for Geo-informatics Research and Training, Palampur (Kangra), Himachal Pradesh
CIAF	:	Central Institute of Agricultural Engineering, Bhopal
CICR	:	Central institute for Cotton Research, Nagpur
CIRCOT	:	Central Institute of Research on Cotton Technology (ICAR), Mumbai
CMRS	:	Central Mango Research Station, Lucknow
CPCRI	:	Central Plantation Crops Research Institute, Kasaragad
CPRI	:	Central Potato Research Institute, Shimla
CRIDA	:	Central Rainfed Institute for Dryland Agriculture, Hyderabad
CRLRRS	:	Central Rainfed Lowland Rice Research Station, Cuttack
CRRI	:	Central Rice Research Institute, Cuttack
CRSARD	:	Centre for Research on Sustainable Agricultural and Rural Development, Madras
CRURRS	:	Central Rainfed Upland Rice Research Station, Hazaribag
CSMRS	:	Central Salt and Materials Research Station
CSSRI	:	Central Soil Salinity Research Institute, Karnal
CSWCRTI	:	Central Soil and Water Conservation Research and Training Institute, Dehradun
CTCRI	:	Central Tuber Crops Research Institute, Thiruvanathapuram
CTRI	:	Central Tobacco Research Institute, Rajamundry
DARE	:	Department of Agricultural Research and Education, New Delhi
DPPQ&S	:	Directorate of Plant Protection, Quarantine and Storage, New Delhi
FAI	:	Fertilizer Association of India, New Delhi

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Acronyms		
FCI	:	Fertilizer Corporation of India, New Delhi
FCI	:	Food Corporation of India, New Delhi
FRI	:	Forest Research Institute, Dehradun
IARI	:	Indian Agricultural Research Institute, New Delhi
IASRI	:	Indian Agricultural Statistics Research Institute, New Delhi
ICAR	:	Indian Council of Agricultural Research, New Delhi
ICCC	:	Indian Central Coconut Committee, Kozhikode
ICCC	:	Indian Central Cotton Committee, Mumbai
ICJC	:	Indian Central Jute Committee, Calcutta
ICOC	:	Indian Central Oilseeds Committee, Hyderabad
ICRI	:	Indian Cardamom Research Institute, Myladumpara
ICSCC	:	Indian Central Spices and Cashewnut Committee
ICSC	:	Indian Central Sugarcane Committee, New Delhi
ICTC	:	Indian Central Tobacco Committee, Madras
IFFCO	:	Indian Farmers Fertilizer Co-operative Limited, New Delhi
IGFRI	:	Indian Grassland and Fodder Research institute, Jhansi
IIAER	:	Indian Institute of Agricultural Economics Research, New Delhi
IIHR	:	Indian Institute of Horticultural Research, Bangalore
IISR	:	Indian Institute of Sugarcane Research, Lucknow
IISS	:	Indian Institute of Soil Science, Bhopal
JARI	:	Jute Agricultural Research Institute, Barrackpore
JTRL	:	Jute Technical Research Laboratory, Calcutta
KRIBHCO	:	Krishak Bharati Co-operative Limited, Surat
MAIDC	:	Maharashtra Agro-Industries Development Corporation Limited, Mumbai
MARKFED	:	The Punjab State Co-operative Supply and Marketing Federation Limited, Chandigarh
MSSRF	:	M.S. Swaminathan Research Foundation, Madras
NAARM	:	National Academy of Agricultural Research and Management, Hyderabad
NAAS	:	National Academy of Agricultural Sciences, New Delhi
NABARD	:	National Bank of Agriculture and Rural Development, Mumbai
NAFED	:	National Agricultural Co-operative and Marketing Federation of India Limited, New Delhi
NAPL	:	National Agro Products Limited, Calcutta
NBPGR	:	National Bureau of Plant Genetic Resources, New Delhi
NBSS-LUP	:	National Bureau of Soil Survey and Land-Use Planning, Nagpur
NFL	:	National Fertilizers Limited, New Delhi
NRCA	:	National Research Centre for Agro-forestry, Jhansi
NRCC	:	National Research Centre for Cashew, Puttur
		National Research Centre for Citrus, Nagpur
NRCG	:	National Research Centre for Groundnut, Junagarh
NRCS	:	National Research Centre for Sorghum, Hyderabad
		National Research Centre for Soybean, Indore
		National Research Centre for Spices, Kozhikode
NRCWS	:	National Research Centre for Weed Science, Jabalpur
PNFC	:	Punjab National Fertilizers and Chemicals Limited, Naya Nangal, Chandigarh
RCNER	:	ICAR – Research Complex for North-Eastern Hills Region, Shillong

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Acronyms		
RRII	:	Rubber Research Institute of India (Rubber Board), Kottayam
SBI	:	Sugarcane Breeding Institute, Coimbatore
SFAC	:	Small Farmers agri-business consortium, New Delhi
SWCRDT	:	Soil and water Conservation Research, Demonstration and Training Centres in India
TFRI	:	Tropical Forest Research Institute, Jabalpur
WTC	:	Water Technology Centre (IARI), New Delhi

Appendix D

List of Indian State and Central Agricultural Universities

Sr. No.	Name of universities with address
A. STATE AGRICULTURAL UNIVERSITIES	
1.	Acharya N.G. Ranga Agricultural University (ANGRAU) Rajendranagar, Hyderabad (Andhra Pradesh) – 500 030 Email: angrau@ap.nic.in Web site: http://www.angrau.net Fax: 040-24015031
2.	Anand Agricultural University (AAU) Anand (Gujarat) – 388 110 Email: vc@aau.in Web site: http://www.aau.in Fax: 02692-261520
3.	Assam Agriculture University (AAU) Jorhat (Assam) – 785 013 Email: vc@aau.ren.nic.in Web site: http://www.aau.ac.in Fax: 0376-2340001
4.	Bidhan Chandra Krishi Vishva Vidyalaya (BCKVV) Haringhatta, P.O. Mohanpur, Nadia (West Bengal) – 741 246 Email: root@bckv.wb.nic.in Fax: 03473-222275
5.	Birsa Agricultural University (BAU) Kanke, Ranchi (Jharkhand) – 834 006 Email: root@bau.bih.nic.in Web site: www.bau.nic.in Fax: 0651-2455850
6.	Chandra Shekhar Azad University of Agriculrure and Technology (CSAUT) Kanpur (Uttar Pradesh) – 208 002 Email: csauknp@up.nic.in Web site: csauk.ac.in Fax: 0512-2210408
7.	Chaudhary Charan Singh Haryana Agricultural University (HAU) Hisar (Haryana) – 125 004 Email: root@hau.pnp.nic.in Web site: hau.nic.in Fax: 01662-234952

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Sr. No.	Name of universities with address
8.	Chaudhary Sarwan Kumar Himachal Pradesh Krishi Vishwavidyalaya (CSK HPKV) Palampur, Kangra (Himachal Pradesh) – 176 062 Email: vc@hillagric.org Web site: http://www.hillagric.org Fax: 01894-230465
9.	Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth (KKV) Dapoli, Distt. Ratnagiri (Maharashtra) – 415 712 Email: root@kkv.ren.nic.in Fax: 02358-282074
10.	Dr. Panjabrao Deshmukh Krishi Vishwa Vidyalaya (PKV) Krishinagar, Akola (Maharashtra) – 444 104 Email: vc@pdkv.mah.nic.in Web site: pdkv.mah.nic.in Fax: 0724-2258219
11.	Dr. Yashwant Singh Parmar University of Horticulture and Forestry (YSPUH & F) Nauni, Solan (Himachal Pradesh) – 173 230 Email: vc@yspuniversity.ac.in Web site: http://www.yspuniversity.ac.in Fax: 01792-252242, 52279
12.	Govind Ballabh Pant University of Agriculture and Technology (GBPAU & T) Pantnagar, Dist. Udham Singh Nagar (Uttranchal) – 263 145 Email: root@gbpuat.ernet.in Web site: http://www.gbpuat.ac.in Fax: 05944-233473, 233500
13.	Indira Gandhi Krishi Vishwa Vidyalaya (IGKVV) Krishak Nagar, Raipur (Chattisgarh) – 492 012 Email: adr@zrcmp01.mp.nic.in Fax: 0771-2442131, 2442302
14.	Jawaharlal Nehru Krishi Vishwa Vidyalaya (JNKVV) Adhartal, Jabalpur (Madhya Pradesh) – 482 004 Email: root@jnau.mp.nic.in Fax: 0761-2481389
15.	Junagadh Agricultural University (JAU) Junagadh (Gujarat) – 362 001 Fax: 0285-26702004
16.	Kerala Agricultural University (KAU) Vellanikkara, Trichur (Kerala) – 680 656 Email: kauhqr@hub.nic.in Web site: http://www.kau.org Fax: 0487-2370019
17.	Maharana Pratap University of Agriculture and Technology (MPUAT) University Campus, Udaipur (Rajasthan) – 313 001 Email: vc@mpuat.ac.in Web site: http://www.mpuat.ac.in Fax: 0294-2470682

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Sr. No.	Name of universities with address
18.	Maharashtra Animal Science and Fisheries Sciences University (MASFSU) Seminary Hills, Nagpur (Maharashtra) – 440 006 Fax: 0712-2511282, 251128
19.	Mahatma Phule Krishi Vidyapeeth (MPKV) Rahuri (Maharashtra) – 413 722 Email: kvmp@ren.nic.in Web site: mpkv.mah.nic.in Fax: 0246-243302
20.	Marathwada Agricultural University (MAU) Parbhani (Maharashtra) – 431 402 Email: mau@ren.nic.in Fax: 02452-223582
21.	Narendra Dev University of Agriculture and Technology (NDUAT) Kumarganj, Faizabad (Uttar Pradesh) – 224 229 Email: nduat@up.nic.in Fax: 5270-262097
22.	Navsari Agricultural University (NAU) Erucharrasta, Navsari (Gujarat) – 396 450 Fax: 02637-283794
23.	Orissa University of Agiculture and Technology (OUAT) Bhubaneswar (Orissa) – 751 003 Email: root@uat.ori.nic.in Web site: bhub.ori.nic.in/ouat Fax: 0674-2407780
24.	Punjab Agricultural University (PAU) Ludhiana (Punjab) – 141 004 Email: root@pau.chd.nic.in Fax: 0161-2402483
25.	Rajasthan Agricultural University (RAU) Bikaner (Rajasthan) – 334 002 Email: root@raub.raj.nic.in Fax: 0151-2202336
26.	Rajendra Agricultural University (RAU) Pusa, Samastipur (Bihar) – 848 125 Email: rau@bih.nic.in Fax: 06274-240266
27.	Sardar Krushi Nagar-Dantiwada Agricultural University (SDAU) Sardar Krishi Nagar, Banaskantha (Gujarat) – 385 506 Fax: 02748-278261
28.	Sardar Vallabhai Patel University of Agriculture and Technology (SVBPUAT) Modipuram, Meerut (Uttar Pradesh) – 250 110 Fax: 0121-2571941
29.	Sher-e-Kashmir University of Agricultural Sciences and Technology (SKUAST, Jammu) Camp Office, Railway Road, Jammu (Jammu & Kashmir) – 180 012 Email: vc_nsharma@rediffmail.com Web site: http://www.skuastjammu.org Fax: 0191-2473883

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Sr. No.	Name of universities with address
30.	Sher-e-Kashmir University of Agriculture Sciences and Technilogy (SKUAST, Kashmir) Post Box 262, GPO Srinagar, Shalimar Campus, Srinagar (Kashmir) – 191 121 Email: anwar_alam@jk.nic.in Web site: www.icar.org.in/sherk/welcome.htm Fax: 0194-2462160
31.	Tamil Nadu Agricultural University (TNAU) Coimbatore (Tamil Nadu) – 641 003 Email: root@tnau.tn.nic.in Web site: http://www.tnau.ac.in Fax: 0422-5511200
32.	Tamil Nadu Veterinary and Animal Sciences University (TNU & ASU) Chennai (Tamil Nadu) – 600 007 Email: root@tnvasu.tn.nic.in Fax: 044-25551576
33.	University of Agricultural Sciences (UAS) Bangalore (Karnataka) – 560 065 Web site: uasbng.kar.nic.in Fax: 080-3330277
34.	University of Agricultural Sciences (UAS) Krishi Nagar, Dharwad (Karnataka) – 580 005 Email: root@uasd.kar.nic.in; aris@uasd.net Web site: http://www.uasd.net Fax: 0836-2448349, 748377
35.	UP Pandit Deen Dayal Upadhyay Pashu Chikitsa Vigyan Vishwavidyalaya Evam Go Anusandhan Sansthan Mathura (Uttar Pradesh) – 281 001 Fax: 0565-2404819
36.	Uttar Banga Krishi Vishwavidyalaya (UBKV) P.O. Pundibari, District Cooch Behar (West Bengal) – 736 165 Fax: 03582-270249, 270726
37.	West Bengal University of Animal & Fishery Sciences (WBUA&FS) 68, Khudi Ram Bose Sarani, Belgachia, Kolkata (West Bengal) – 700 037 Fax: 033-25571986
B. CENTRAL AND DEEMED AGRICULTURAL UNIVERSITIES	
38.	Allahabad Agricultural Institute Deemed University Naini, Allahabad (Uttar Pradesh) – 211 007 Fax: 0532-2684394
39.	Central Agricultural University (CAU) Jroisemba, P.O. Box 23, Imphal (Manipur) – 795 004 Fax: 0385-2410450
40.	Faculty of Agriculture, Aligarh Muslim University Anoop Sahar Road, Aligarh (Uttar Pradesh) – 202 002 Fax: 0571-2700 528

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Sr. No.	Name of universities with address
41.	Institute of Agriculture, Banaras Hindu University Varanasi (Uttar Pradesh) – 221 005 Fax: 0542-2368174
42.	Nagaland University, School of Agricultural Sciences and Rural Development Medziphema (Nagaland) – 797 106 Fax: 03862-247113

Appendix E
Nutrient Composition in Various Fertilizer Materials

		Nutrient content (%)		
Sr. No.	Fertilizer	N	P_2O_5	K_2O
1.	Nitrate fertilizers			
	I. Sodium nitrate	16.0	–	–
	II. Calcium nitrate	15.5	–	–
2.	Ammonium fertilizers			
	I. Ammonium sulfate	20	–	–
	II. Ammonium phosphate	20 or 16	20	–
	III. Ammonium chloride	24–26	–	–
	IV. Anhydrous ammonia	82	–	–
	V. Ammonium solution	20–25	–	–
3.	Nitrate and ammonium fertilizers			
	I. Ammonium nitrate	33–34	–	–
	II. Calcium ammonium nitrate	26	–	–
	III. Ammonium sulfate nitrate	26	–	–
4.	Amide fertilizers			
	I. Urea	46	–	–
	II. Calcium cynamide	21	–	–
5.	Phosphatic fertilizers containing water-soluble phosphoric acid or monocalcium phosphate			
	I. Single superphosphate	–	16–18	–
	II. Double superphosphate	–	32	–
	III. Triple superphosphate	–	46–48	–
	IV. Ammonium phosphate	–	20	16
6.	Phosphatic fertilizers containing citric-soluble phosphoric acid or dicalcium phosphate			
	I. Basic slag	–	14–18	–
	II. Dicalcium phosphate	–	34–39	–
	III. Rhenania phosphate	–	23–26	–
7.	Phosphatic fertilizers containing substance which is not soluble in water, citric acid or tricalcium phosphate			
	I. Rock phosphate	–	20–40	–
	II. Raw bonemeal	3–4	20–25	–
	III. Steamed bonemeal	–	22	–

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Sr. No.	Fertilizer	Nutrient content (%) N	P_2O_5	K_2O
8.	Potassic fertilizers			
	I. Potassium chloride	–	–	60
	II. Potassium sulfate	–	–	48–52
	III. Potassium nitrate	13	–	44
	IV. Sulfate of potash-magnesia	–	–	25–30

Appendix F
Nutrients, Their Functions, Deficiency and Control of Deficiency

Plant nutrients	Function of nutrients	Deficiency symptoms	Control of deficiency
Nitrogen (N)	• N being building blocks of amino acids are essential in the formation of proteins. • N is also an integral part of chlorophyll which is the primary absorber of light energy needed for photosynthesis. • It imparts dark green colour to plants. • When N is used properly in conjunction with other needed soil-fertility inputs, especially P, it can speed up the maturity of various crops.	• N deficiency is characterized by yellowish and pale green colour of older leaves, but necrotic and chlorotic spots appear at an early stage. • N deficiency results in the collapse of chloroplasts and also in a disturbance of chloroplast development. • The plants remain small, stems have a spindly appearance, and leaves become small and premature which later on begin to fall.	• Use of nitrogenous fertilizers such as urea, CAN, ammonium phosphate, etc. as soil application. • Foliar spray of urea. It can be done in the morning and evening hours on the fully grown leaves of various crops. Urea can be used up to 3%. 7.5 kg of urea in 250 l of water is sufficient for an hectare of crop.
Phosphorous (P)	• The unique function of P in the metabolism is the function of adenosine mono, di and triphosphates (AMP, ADP and ATP) bond which allow energy transfer. • Since P is readily mobile in plants, it can be translocated both in upward and downward direction.	• Deficiency appears on the older leaves which are characterized by purple/violet or darkish green colour. • P deficiency accumulates low molecular weight of N compound. • There is reduction of RNA synthesis owing to deficiency of P in soils.	• Application of phosphatic fertilizer in the soil, e.g. super phosphate or diammonium phosphate (DAP).

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Plant nutrients	Function of nutrients	Deficiency symptoms	Control of deficiency
	• Phytin is an organic P compound which occurs in seed and regarded as P reserve. It is also an integral part of phospholipids. • In plants, P increased root growth and early maturity of crops. • It makes plants more tolerant to drought, cold, insects and diseases attack.	• Maturity of the crops gets delayed. • There is poor seed formation which eventually results in poor growth rate. • In cereals, tillering is affected and in fruit trees, growth of new shoots is reduced due to its deficiency.	
Potassium (K)	• K has high active uptake rate among all the essential mineral cation species. K is the only nutrient which can be transported against electrochemical gradients into plant cells. • K in plants is readily mobile, so its main transport action is towards the meristematic tissues. Often K from older plant organs is redistributed to younger tissues. • K enhances the translocation of assimilates. • It also promotes rate of CO_2 fixation. This fact is probably via ATP synthesis. • The main function of K is its activation of various enzyme system and over 80 plant enzymes require K for their activation. • Activator of enzymes involved in protein and carbohydrate metabolism, stomatal opening, membrane permeability, and pH control.	• K deficiency does not result immediately in visible symptoms. At first, there is only a reduction in growth rate which is called *Hidden Hunger* and later on necrosis and chlorosis occur. • Symptoms generally appear on the older leaves. • Its deficiency results in collapsing of chloroplast and mitochondria. • There is decrease in turgour pressure and plants become flaccid. • There is poor formation of xylem and phloem tissues due to its deficiency in soil. • Lignification of vesicular bundles is impaired. • K deficiency leads to synthesis of toxic amines such as Putrescine and Agnethine chemicals as well. • Due to deficiency of K, the plant becomes susceptible to lodging vis-à-vis insect and pest attack.	• Use of potassic fertilizer in the soil, e.g. muriate of potash (MOP).

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Plant nutrients	Function of nutrients	Deficiency symptoms	Control of deficiency
Calcium (Ca)	• The most important function of Ca in plants is the formation of middle lamella layer of their cell wall in the form of calcium pectate. • It is required for cell elongation and cell division. • It plays an essential role in biological membranes. • It is required for maintaining optimum membrane permeability. • Ca is required in plants to detoxify the divalent metal cations. • It plays an important role in abscission and delays leaf senescence. • Keeps the soil neutral in reaction.	• Its deficiency is characterized by the reduction in growth of meristematic tissues. • The deficiency can be first observed in the growing tips and youngest leaves. These became deformed and chlorotic and at a more advanced stage, necrosis occurs at the leaf margins. The affected tissues become soft due to the dissolution of the cell walls. • In apple, Ca deficiency causes a disease called bitter pit while in tomato and pepper, it causes blossom end rot. • A deficiency of Ca manifests itself in the failure of the terminal buds of plants and apical tips of roots to develop. • Inadequate supply of Ca to celery causes black heart disease.	• Use of calcium carbonate or hydroxide in the soil.
Magnesium (Mg)	• Mg acts as a cofactor in almost all enzymes activating phosphorylation processes. It forms a bridge between the pyrophosphate structure of ATP or ADP and the enzyme molecule. • Like N, Mg plays a key role as the centre and the only mineral of the chlorophyll molecule. So its deficiency in soils immediately affects the chlorophyll formation which ultimately will affect the photosynthesis phenomenon influencing, thereby, the crop growth.	• Since Mg is mobile in plants, deficiency always begins in the older leaves and then moves to the younger leaves. • Interveinal yellowing and chlorosis occurs and in extreme cases, the area becomes necrotic. • The plants give a withered appearance.	• Foliar application of Mg sulphate.

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Plant nutrients	Function of nutrients	Deficiency symptoms	Control of deficiency
	• Since the fundamental process of energy transfer occur in photosynthesis, glycolysis, tricarboxylic acic cycle and respiration, so Mg has importance throughout the plant metabolism. • Mg is required both in photophosphorylation as well as in phosphorylation reaction which otherwise limits the regeneration of ribulose diphosphate in the calvin cycle. • It is involved in N metabolism. • Mg with S increases oil content of many oilseed crops.	• Mg-deficient leaves often fall prematurely. Individual leaves suffering from its deficiency, however, are stiff and brittle and the intercoastal veins are twisted. • Inadequately supply of Mg often delays of reproductive phase in plants. • Its deficiency can inhibit CO_2 assimilation and protein synthesis.	
Sulphur (S)	• S helps in chlorophyll formation and encourages vegetation growth. • It promotes nodule formation on roots of legumes. • It is an essential constituent of proteins and enzymes. • S is one of the constituents of aminoacids. Cystine, cysteine and methionine are constituent of protein. Hence S promotes protein formation. • S is also needed in oil formation. It also constitutes allyle sulphide and vinyl sulphide found in onions and garlic. • Plant growth is stimulated and extra leaf yields of alfalfa, clover and tobacco is obtained. • Secures crops against deficiency diseases. • Promotes nodular growth of N-fixing bacteria.	• General deficiency symptoms are similar to N deficiency but persist even when N supply is adequate. • The whole leaf in plant has light green colour. • Chlorosis occurs in young leaves. • Stiffing of leaves is also common. • Flooding aggravates S deficiency by converting soluble sulphates to insoluble sulphides.	• S deficiency can be corrected by application of S-containing fertilizers such as ammonium sulphate, super phosphate, potassium sulphate, ammonium sulphate nitrate, S-containing complex fertilizers and gypsum.

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Plant nutrients	Function of nutrients	Deficiency symptoms	Control of deficiency
Iron (Fe)	• Fe plays an important role in synthesis of chlorophyll and carbohydrate synthesis. • It is essential for the synthesis of proteins present in the chloroplasts. • As a constituent of enzyme system, it regulates photosynthesis, respiration and reduction of nitrates and sulphates. • Fe is a constituent of leghaemoglobin (like haemoglobin of blood) found in the nodules of leguminous plants. • Fe is a constituent of porphyrin–protein complex such as cytochromes and catalase. It is present as a constituent of catalase and peroxidase enzyme. • It is involved in the biological nitrogen fixation mechanisms. • In fruit trees, chlorosis is cured by the supply of Fe. Chlorophyll does not fully develop without it.	• Young leaves become chlorotic but principal veins remain green. This has been noticed in groundnut in calcareous soils. • In severe deficiency, leaves became pale white due to loss of chlorophyll. • Death of young growing tissues can occur and rossetting appearance can be seen.	• Spraying of 0.5% ferrous sulphate on foliage.
Manganese (Mn)	• It is essential for the splitting of water molecule during photosynthesis, i.e. *Hill reaction*. • It helps in chlorophyll formation. It also helps a key role in nitrate assimilation, in the conversion of soluble nitrogen compounds to protein and in the splitting of peptide bonds. • It helps C assimilation and chlorophyll synthesis. • It acts as a catalyst in oxidation and reduction reactions within the plant tissues.	• Chlorotic patches between the veins are first visible on younger leaves where Mg deficiency is usually observed on older leaves. • Spots of death tissues scattered over young leaves are seen.	• Soil or foliar application of Mn sulphate.

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Plant nutrients	Function of nutrients	Deficiency symptoms	Control of deficiency
	• A good supply of Mn sometimes helps in counteracting the bad effect of poor aeration. • It prevents the disease known as grey speck on oats and sugarbeet.		
Boron (B)	• It helps in uptake and efficient utilization of Ca by plants. • It tends to keep calcium soluble and increases its mobility in plants. • It is necessary for the translocation of sugars in plants. • B can help to reduce the incidence of clubroot which is responsible for fungal diseases in brassica. • It promotes the growth of nodule bacteria in leguminous crops. • It saves the root crops from rot diseases. • Indirectly, it affects the intake of other elements from the soil by the plants.	• Its deficiency affects the growing points of roots, shoots and young leaves. • Its deficiency leads to cracking and cork formation in stocks, stems and fruits and shortened internodes. • Leaves become thicken and margins roll upward. • The leaf tip and margin of older leaves die prematurely.	• Foliar spray of boric acid or borax. • Use of boron in soil.
Zinc (Zn)	• As a constituent of enzyme systems, it regulates various metabolic reactions in the plant. • It is associated with water uptake and water relations in the plant.	• Development of light green and yellowish bleached spots in the leaves. • Chlorotic bands on either side of the midrib of the monocot leaves.	• Soil application of Zn sulphate at the rate of 25–50 kg ha^{-1}. • Foliar application of 5 kg Zn sulphate + 25 kg lime ha^{-1} in 1,0001 of water.
	• It helps in the formation of growth hormones like IAA in plants. Many of the enzymes active in hydrogen transfer are activated by Zn, and it is constituent of the protein which forms the enzyme carbonic anhydrase. This enzyme catalyses the reaction of carbonic acid with water vice-versa.	• Poor tillering. • Stunted growth. • In maize, leaves show white patches which turn to bluish red. • In wheat, white to yellow patches turn to brown. Ear formation and maturity are delayed.	

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Plant nutrients	Function of nutrients	Deficiency symptoms	Control of deficiency
	• It acts as a catalyst in chlorophyll formation. • Mottle leaf of citrus and little leaf of peaches are the peculiar deficiency diseases or disorders of Zn.	• In paddy, light yellow spots appear which turn to deep brown. Commonly known as '*Khaira*' disease of rice.	
Copper (Cu)	• Cu forms many compounds with amino acids and proteins in plants. • It acts as an electron carrier in enzymes which bring about oxidation–reduction reaction in plants. • It helps in utilization of Fe in chlorophyll synthesis. • It helps in preventing dieback disease in citrus. • Cu has been shown to facilitate the movement of Ca in barley and wheat.	• Young leaves are permanently wilted without spotting. Moreover, tip of the leaves may turn white. • Yellowing and chlorosis of normally green leaves. • At maturity, panicles and pods are poorly filled, sometimes even empty if deficiency is severe.	• Foliar and soil application of Cu.
Molybdenum (Mo)	• Mo helps in the function of atmospheric N – symbiotic as well as non-symbiotic. • It helps in protein synthesis. Actually it is essential in the reduction of NO_3 after its uptaken i.e., conversion of NO_3 into aminoacids, which are building blocks of proteins. Lack of Mo, growth of plants is limited by the inability to use NO_3; thus NO_3 may accumulate in the plant.	• Marginal scratching, rolling and cupping of young leaves are the main symptoms. • Mo deficiency is due to N deficiency and its active role in N fixation.	• Soil and foliar application of sodium molybdate or ammonium molybdate.
Chlorine (Cl)	• Cl is associated with the production of oxygen during photosynthesis for raising cell osmotic pressure and maintaining tissue hydration. • Encourages growth in crop plants.	• Chlorosis in younger leaves and overall wilting due to possible effects on transpiration.	• Potassium chloride application in the soil.

Appendix G
Sources of Plant Nutrients in Soil

Plant nutrients	Sources
C	Carbamate
N	Amino acids, amino sugars, proteins
P	Apatite, organic matter
K	Feldspar, micas
Ca	Apatite, augite, calcite, calcium carbonate, dolomite, gypsum
Mg	Augite, biotite, dolomite, hornblende, muscovite, olivine
S	Pyrite, gypsum, organic matter
Fe	Pyrite, magnetite
B	Tourmaline
Cu	Augite, biotite, chalcopyrite, hornblende, olivine
Mn	Augite, hornblende, muscovite, pyrolusite, olivine
Mo	Olivine
Zn	Augite, biotite, hornblende, olivine, sphalerite
Cl	Apatite

Appendix H

Forms of Mineral Elements Absorbed by Plants

Mineral element	Ionic form	Non-ionic form
N	NH_4^+, NO_3^-	$CO (NH_2)_2$
P	$H_2PO_4^-$, $H_2PO_4^{2-}$	Nucleic acid, Phytin
K	K^+	–
Ca	Ca^{2+}	–
Mg	Mg^{2+}	–
S	SO_4^{2-}	SO_2
Fe	Fe^{2+}, Fe^{3+}	$FeSO_4$ with EDTA
B	$H_2BO_3^-$, HBO_3^{2-}	–
Cu	Cu^{2+}	$CuSO_4$ with EDTA
Mn	Mn^{2+}	$MnSO_4$ with EDTA
Mo	MoO_4^{2-}	–
Zn	Zn^{2+}	$ZnSO_4$ with EDTA
Cl	Cl^-	–

Appendix I

Irrigation at the Critical Crop Growth Stages of Major Cereals

Sr. No.	Crops	Critical growth stages of cereals
1.	Rice (*Oryza sativa*)	I. Seedling stage II. Maximum tillering stage III. Panicle initiation stage IV. Flowering stage V. Soft dough or milky stage
2.	Wheat (*Triticum aestivum*)	I. Crown root initiation stage II. Tillering stage III. Jointing stage IV. Boot leaf stage V. Flowering stage VI. Milky and dough stage
3.	Maize (*Zea mays*)	I. Seedling stage (2 weeks after sowing) II. Tasseling stage (8 weeks after sowing) III. Silking stage (10 weeks after sowing) IV. Dough stage (12 weeks after sowing)
4.	Sorghum (*Sorghum bicolor*)	I. Seedling stage (2–4 weeks after sowing) II. Pre-flowering stage (12–14 weeks after sowing) III. Flowering stage (12–16 weeks after sowing) IV. Grain formation stage (17 weeks after sowing)
5.	Barley (*Hordeum vulgare*)	I. Tillering stage II. Flowering stage

Appendix J
Crop Yield Contributing Characters in Major Cereals

Sr. No.	Crops	Crop yield contributing characters
1.	Rice	I. Number of tillers per unit area
		II. Number of panicles per hill
		III. Number of grains per panicle
		IV. 1,000-grain weight (g)
		V. Grain weight per panicle
		VI. Panicle length (secondary character)
2.	Wheat and Barley	I. Number of productive plants per unit area
		II. Number of fertile spikelets per spike
		III. Number of grains per spikelet
		IV. 1,000-grain weight
		V. Number of grains per spike
		VI. Grain weight per spike
		VII. Spike length (secondary character)
3.	Maize	I. Number of productive plants per unit area
		II. Number of cobs per plant
		III. Number of rows per cob
		IV. Number of grains per row
		V. 1,000-grain weight
		VII. Grain weight per cob
		VIII. Cob length and cob diameter (secondary character)

Appendix K
Unit Conversion Factors

I. Land: Its Units and Conversion
1 bigha = 20 katha
1 acre = 3 or 2.5 bigha
1 acre = 4.3560 sq. ft or 0.40 ha
1 hectare = 2.471 acre or 10,000 m^2

II. Weight: Its Units and Conversion
1 ounce (oz) = 28.3495 g
1 gram = 0.0353 oz
1 pound (lb) = 0.454 kg
1 kilogram = 2.205 lb
1 metric ton = 1,000 kg
1 quintal = 100 kg

III. Length: Its Units and Conversion
1 foot = 12 in.
1 yard = 3 ft or 0.9 m
1 inch = 2.54 cm
1 feet = 30.48 cm
1 metre = 39.3701 in.
1 kilometre = 1093.61 yard or 0.62137 mile
1 square centimetre = 0.155 sq. in.
1 square feet = 92.9.3 cm^2
1 square yard = 0.48 m^2

IV. Liquid: Its Units and Conversion
1 gallon = 4.5431
1 litre = 0.22 gallon
1 kerosin tin = 181

Appendix L
Conversion of Nutrient Forms

1. $P \underset{\times 0.436}{\overset{\times 2.29}{=\!=\!=\!=\!=\!=}} P_2O_5$
2. $K \underset{\times 0.82}{\overset{\times 1.20}{=\!=\!=\!=\!=\!=}} K_2O$
3. $Ca \underset{\times 0.715}{\overset{\times 1.40}{=\!=\!=\!=\!=\!=}} CaO$
4. $Mg \underset{\times 0.60}{\overset{\times 1.66}{=\!=\!=\!=\!=\!=}} MgO$
5. $CaO \underset{\times 0.56}{\overset{\times 1.79}{=\!=\!=\!=\!=\!=}} CaCO_3$
6. $MgO \underset{\times 0.48}{\overset{\times 2.09}{=\!=\!=\!=\!=\!=}} MgCO_3$

Glossary

A

Absorption: The process by which a substance is taken into, or includes, another substance, like the intake of water by soil or the intake of nutrients by plants.

Acidity: The state of being acidic in reaction, i.e. pH less than 7.0, which would be evident to the taste as sourness.

Actinomycetes: A non-taxonomic term applied to a group of micro-organisms with characteristics intermediate between the simple bacteria and the true fungi. They are also called thread bacteria or ray fungi.

Adsorption: The physical process by which atoms, molecules or ions are taken up and retained on the surfaces of solids by chemical or physical binding (e.g. the adsorption of cations like Ca^{2+}, Mg^{2+}, NH_4^+, K^+, etc. by negatively charged clay minerals).

Aerobic: An organism that thrives best in the presence of oxygen or free oxygen for its respiration.

Aggregation: The cementing or binding together of several particles into secondary units formed by natural or artificial processes, such as clod, block or prism, crumbs and granules.

Agriculture: The art or practice of cultivating the land which is primarily aimed at the production of food, fibre, fuel, etc., by optimum use of terrestrial resources.

Agro-ecological zone: A land unit having a greater degree of commonality or homogeneity with respect to various conditions and resources such as climate, topography, soil type, geological information, water resources, mineral resources, cropping patterns.

Agroforestry: A sustainable land management system which combines production of agricultural crops with that of tree crops as also with that of livestock simultaneously on the same unit of land.

Agronomy: Derived from the Greek words *agros* meaning fields and *nomos* meaning management. It is a specialized branch of agriculture dealing with crop productivity and soil management or the application of scientific principles to the art of crop production.

Air pollution: Contamination of the air with undesirable solids, liquids and gases or addition of any foreign substance that disturbs the normal composition of the air. The substances that cause air pollution are called pollutants.

Amelioration: Addition of any chemical substance to the soil which can ameliorate or change the soil reaction.

Aminization: The process by which heterotrophs (bacteria, fungi and actinomycetes) break down complex organic molecules releasing amines and aminoacids is known as aminization.

Anaerobic: An organism that survives in the absence of air or molecular oxygen.

Asymbiotic nitrogen fixation: Fixation of molecular N by free-living organisms like *Clostridium* and *Azotobacter*.

Available moisture: Moisture range or limit available to plants which lies between field capacity and wilting point of a soil.

Available nitrogen: A small proportion of the relatively large amount of N present in the rooting zone of soil which is directly available to plants. It is mainly in the form of NO_3 present in soil solution and the dissolved and adsorbed NH_4.

Available nutrients: The proportion of any element or compound in the soil that can be readily absorbed and assimilated by growing plants.

Available phosphoric acid: The part which is soluble in water or in a weak dilute acid such as 2% citric acid.

Available water: The amount of water which lies between field capacity and permanent wilting point for plant use. The availability of water to plants is a function of soil–water–plant system rather than soil–water system alone.

***Azolla*:** A floating aquatic fern capable of fixing atmospheric N and is widely grown as a fertilizer crop, especially in lowland rice cultivation.

***Azospirillum*:** Non-symbiotic bacterial inoculants that grows around the roots of many cereals, grasses and other graminaceous crops and fixes atmospheric N freely.

***Azotobacter*:** An aerobic and non-symbiotic, N-fixing bacterium present in the soil, utilizing soluble carbohydrates and strongly susceptible to phosphorous deficiency or free-living bacteria which are capable of utilizing N under aerobic condition.

B

Bacteria: The smallest and most primitive unicellular micro-organisms, lacking of chlorophyll and multiply mostly by fission and are known as Procaryotes.

Basic slag: A by-product of steel industry obtained from phosphate iron ores which contains about 6–8% phosphoric acid.

Bio-fertilizers: A carrier-based preparation containing different micro-organisms, which have the ability to fix atmospheric N and/or solubilize the immobile soil phosphorous and make them available to the crop plants.

Biogas slurry: The residual slurry that comes out of the digestion tank of the biogas plant. On an average, it contains 1.8% N, 1.1% P_2O_5 and 1.5% K_2O.

Blood meal: A by-product of slaughter house which contains 10–12% highly available N, 1–1.5% P and 1.0% K. It is a very quick-acting manure and is effective on all crops and on all types of soil.

Blue-green algae: A heterogeneous group of prokaryotic photosynthetic organisms, which contain the chlorophyll ‘a’. They are non-symbiotic, free-living N fixers that grow very well in waterlogged soils like rice fields. Besides fixing atmospheric N, BGA secrete vitamins and growth-promoting substances, which contribute to better growth of the rice plants. They are also called cyanobacteria and belong to the class Cyanophyceae or Myxophyceae.

Bone meal: An inorganic phosphatic fertilizer made up of dried animal bones finely ground. It contains 20–24% P_2O_5 of which 16% are citrates soluble and small quantity of N (about 2%).

Bulk density: The ratio of the mass of the soil solid (oven-dried soil) to the bulk volume of the soil and determined by Core Sampler method. On an average, the value of the bulk density of general soil is 1.33 Mg m^{-3}. It is always smaller than its particle density, the average value of which is 2.65 Mg m^{-3}.

Bulky organic manures: Manures prepared artificially from plant residues and animal waste products. They contain very small quantities of plant nutrients and large quantities of organic matter.

C

C/N ratio: The ratio of the weight of organic C to the weight of total N in an organic material or soil. The representative organic soil possesses a high C/N ratio (20:1) as compared to 12:1 or 10:1 for a representative mineral soil.

Calcareous soil: Soil containing sufficient amount of free calcium carbonates (often with magnesium carbonate) and there is visible effervescence when treated with 0.1 N hydrochloric acid (cold).

Carbohydrates: A large group of compounds containing C, H and O only, of the general formula $C_x(H_2O)_y$. Carbohydrates contain C and H in the same ratio as is found in water. They are produced by plant photosynthesis and are essential to metabolism in all living organisms.

Carrier: A substance which has high organic matter, higher water-holding capacity and supports the growth of organism. Generally lignite, charcoal, peat, etc. are suitable carrier materials for bio-fertilizers.

Cation exchange capacity (CEC): The sum total of exchangeable cations that a soil can adsorb which is expressed in centi-moles per kilogram of soil.

Cereals: Crop plants belonging to the grass family graminaceae, which are grown for their edible starchy seed botanically known as caryopsis, e.g. wheat, rice, maize. Derived from *Ceres*, which is the name of the goddess of grain.

Chelates: Derived from the Greek word *Chela* meaning a crab's claw. They contain organo-metallic molecules of varying sizes and shapes in which the functional groups of organic matter bind the nutrients in a ring-like structure by the means of multiple chemical bonds.

Chlorophyll: A light-trapping green colouring matter or pigment which is essential for photosynthesis.

Climate: An aggregate of weather conditions over a long period of time.

Clod: A natural lump of soil that exists as an isolated entity in the field or formed artificially by soil disturbances like ploughing, digging, etc.

Compaction: The increase in bulk density of a soil due to mechanical forces which is caused by the use of heavy agricultural machines.

Compost: Organic manures prepared artificially from plant residues (leaves, stalks, twigs, bark, etc.) and animal waste products and the process of making compost is known as composting. On an average, it contains 1.01% N, 0.5% P_2O_5 and 0.8–0.9% K_2O.

Composting: The biological process in which micro-organisms of both types, namely aerobic and anaerobic, decompose the organic matter and lower the C/N ratio of the refuse.

Concentrated organic manures: Manure which is organic in nature and is made from raw materials of animal or plant origin. It contains higher percentages of primary nutrients as compared to bulky organic manures.

Conventional tillage: The traditional tillage system, which combines both primary and secondary tillage operations for growing a given crop in a given geographical area.

Crop: Plants sown and harvested by humans for economic purposes are known as crops.

Crop production: The exploitation of plant morphological (or structural) and plant physiological (or functional) responses within a soil and atmospheric environment to produce a high yield per unit area of land or it is basically conversion of environmental inputs like solar energy, CO_2, water and soil nutrients into economic products in the form of human or animal food or industrial raw materials.

Crop residues: The portion of the plant or crop left in the field after harvest, or that part of the crop that is not used domestically or sold commercially. On an average, it contains 0.5% N, 0.6% P_2O_5 and 1.5% K_2O.

Crop rotation: The process of growing different crops in succession on a piece of land in a specific period of time, with an object to get maximum profit from least investment without impairing the soil fertility.

Cropping intensity: The ratio of total cropped area to net cultivated area which is multiplied by 100 and represented in percentage:

Cropping intensity (%) = (Total cropped area/net area) × 100

Cropping pattern: A sequence in which various crops are grown in a locality or a zone which is influenced by agro-climatic and socio-economic factors prevailing in that zone.

Cropping scheme: A plan according to which crops are grown on individual plots of a farm during a given period of time with the object of obtaining maximum returns from each crop without impairing the soil fertility. Thus, it is related to the most profitable use of resources, land, labour, capital and management.

Cropping system: A system in which various crops are grown together on a piece of land like mixed, inter or relay cropping, etc.

Crust: A hard or brittle layer formed on the surface of many soils when become dry.

Cytokynins: Plant growth hormones that stimulate cell division, e.g. zeatin (naturally occurring) and 6-benzylamino-purine (synthetic).

D

Decomposition: The chemical breakdown of minerals and organic compounds into simpler compounds often accomplished with the aid of micro-organisms is known as decomposition.

Deep tillage: Tillage done at the depths of more than 20 cm with the purpose of conserving moisture during the monsoon season or to break hard pans and facilitate the plant roots into deeper layers for better crop performance.

Deficiency: The state of needing something that is absent or unavailable.

Denitrification: The biochemical reduction of nitrate or nitrite to gaseous N, either as molecular N or as an oxide of nitrogen, or it is the breakdown of nitrates by soil bacteria resulting in the release of free N.

Desertification: The degradation of dry lands caused by over-cultivation, over-grazing and deforestation that results in soil exhaustion and soil erosion. It decreases soil productivity, deprives the land of its vegetative cover and indirectly affects areas by causing floods, soil salinization, deterioration of water quality, and silting of rivers, streams and reservoirs.

Development: Series of changes which an organism goes through during its life cycle, but it may equally be applied to individual organs, to tissues or even to cells. Plant development involves both growth and differentiation.

Dispersion: The process of movement of fertilizers applied to the soil for short or long distances.

Drainage: The removal of excess surface water or groundwater from land by means of surface or subsurface drains.

E

Earthworms: Animals of the lumbricid family that burrow and live in the soil, which mix plant residues into the soil and improve soil aeration. They are long and cylindrical in shape and have a large number of grooves on their bodies. They are also called the tillers of the earth.

Ecosystem or ecological system: Any system of collection organisms that interact or have the potential to interact along with the physical environment in which they live. They are not static entities, but are dynamic systems with characteristic pattern of energy flow, nutrient cycling and structural change.

Ectomycorrhizae: A type of mycorrhizal relationship in which the fungi invade all cells of the root cortex. This relationship generally exists with evergreen trees and shrubs and some deciduous trees.

Electrical conductivity: The property of a substance to transfer an electric charge (reciprocal of resistance) used for the measurement of the salt content of an extract from a soil when saturated with water. It is measured in mmhos cm^{-1} or dSm^{-1} at 25°C.

Endomycorrhizae: An association between fungus and roots of a plant in which fungal hyphae infect the roots and remain up to the cortical region (parenchyma of roots) by secreting cellulotytic enzymes. They are particularly useful on deciduous shrubs and citrus plants.

Enriched compost: Compost fortified with the addition of fertilizers (urea, SSP, rock-P) during its production to raise its nutrient content and narrow down the C/N ratio.

Environment: The ambience or surroundings. The sum total of all the external forces or factors, both biotic and abiotic that affects the physiological behaviour or performance of an organism or a group of organisms or the region or circumstances in which anything exists.

Enzyme: A protein which catalyses or speeds up a specific chemical reaction usually in a living system.

Exchangeable sodium percentage: The degree of saturation of soil exchange complex with Na, and may be calculated as:

$$\mathbf{ESP = [Exchangeable\ Na\ (mequiv./100\,g\ soil)/CEC\ (mequiv./100\,g\ soil)] \times 100}$$

F

Farmyard manure (FYM): General manure which supplies all constituents of plant food although in low amount. It is a mixture of solid and liquid excreta of farm animals along with litter (bedding material) and leftover materials from roughages or fodder of the cattle. On an average, well-rotten FYM contains 0.5% N, 0.2% P_2O_5 and 0.5% K_2O. It is the oldest and most popular manure used in India.

Farming system: An appropriate combination of farm enterprises, namely cropping systems, livestock, fisheries, forestry, poultry and other means available to the farmer, which are raised for profitability. It interacts adequately with the environment without dislocating the ecological and socio-economic balance on one hand, and attempts to meet the national goals on the other.

Fertilizer use efficiency: The ratio of nutrient removed to nutrient applied and is expressed in percentage. Mathematically, it is computed as:

$$\mathbf{FUE = [(Nutrient\ uptake\ in\ treated\ plot - nutrient\ uptake\ in\ control)/nutrient\ dose\ applied] \times 100}$$

Agronomically, it is the grain yield per kilogram of fertilizer applied. In case of N, the FUE raises from 20–30% in lowland rice and as high as 60% in irrigated fields. However in case of P, FUE is 15–20% and that of K is 80%.

Fertilizers: Any natural or manufactured material, dry or liquid, added to the soil in order to supply one or more nutrients for plant's growth and free from toxic substances.

Field capacity: The percentage of water remaining in a soil 2 or 3 days after its saturation and after free drainage has practically ceased shows the field capacity.

Fixation: The process in soils by which certain chemical elements essential for plant growth are converted from a soluble or exchangeable form to a much-less-soluble or a non-exchangeable form, e.g. phosphate fixation.

Fungi: Any tiny aerobic, heterotrophic Protists containing no chlorophyll and are multicellular except yeast.

G

Global warming: The rise in the average atmospheric temperatures to a level which influences the life forms on the earth surface due to the phenomenon of greenhouse effect, which was first reported by the Swedish chemist Arrhenius in 1896:

The rise in the global temperature is due to greenhouse gases emitted by natural and anthropogenic factors, and this increase has been between 0.3°C and 0.8°C over the twentieth century. It will not only lead to loss of life and property but also cause a major reshuffle in flora, fauna, human population and cropping pattern of the world.

Grain: An indehiscent simple fruit of a grass in which the seed coat is united with the pericarp.

Green manures: Any green crop that is buried directly into the soil to increase its fertility and to improve physical condition and chemical properties.

Growth: An irreversible process in which there is an increase in size, shape and volume of an organism.

H

Harrowing: A secondary tillage operation which pulverizes, smoothens and packs the soil in seedbed preparation or control weeds.

Harvest index: The yield of the plant parts of economic interest (economic yield) as a percentage of the total biological yield in terms of dry matter is known as harvest index.

Harvesting: The operation of cutting, picking, plucking or digging, or combination of these for removing the useful part or economic part from the plants.

Hidden hunger: A situation in which a crop needs more of a given element, yet has not shown deficiency symptoms.

High analysis fertilizers: Fertilizers containing a higher percentage of the plant nutrients and have an advantage in the cost of bagging, handling and transportation per unit of plant nutrient. Such fertilizers are urea (46% N), triple super phosphate (45–47% P_2O_5) and muriate of potash (60% K_2O).

Humidity: The amount of water vapour present in the atmosphere (air) and measured by instrument known as hygrometers.

Humus: A complex organic component of the soil, resulting from the decomposition of plant and animal tissues, which is colloidal, amorphous, dark brown or black brown in colour and resistant to further decomposition.

Hydraulic conductivity: The ability of soil to conduct water and is expressed as length per unit time or an expression of the readiness with which a liquid such as water flows through a soil in response to a given potential gradient. It generally depends upon both the nature of the soil (the porous matrix) and the fluid (water) properties.

I

Immobilization: Conversion of an element from the inorganic to the organic form in microbial or plant tissues, thus rendering the element into unreadily available form to other organisms or to plants.

Infiltration: The process of downward entry or movement of water into the soil.

Inhibitors: Opposite of catalysts, as they retard or reduce the rate of a chemical reaction.

INM system: A system which aims at improving and maintaining soil fertility for sustaining increased productivity by optimizing the use of all possible organic, inorganic and biotic sources for plant nutrients required for crop growth and quality in an integrated manner. These sources are appropriate to each cropping system and farming situation in its ecological, social and economic possibilities.

Inorganic fertilizers: Fertilizers containing a mixture of chemical compounds which are added to the soil in order to improve its fertility, but can be harmful to the environment if used in large amounts and continuously.

Intensive farming: A farming system in which maximum number of crops per year is grown on the same piece of land with the objective of obtaining maximum income per unit area.

Intercropping: Growing two or more generally dissimilar crops simultaneously on the same piece of land which may or may not be sown or harvested at the same time. The main objective of this cropping is to utilize the wide space left between two subsequent rows of slow-growing main crops and to produce more grain per unit area.

Irrigation: The artificial supply of water to the soil for the purpose of providing moisture essential to plant growth.

L

Land: That part of the surface of lithosphere which is not usually covered with water and which forms the total natural and cultural environment where production takes place.

Leaching: The process of the removal of plant nutrients in soil by the passage of water through soil. This is one of the ways in which plant nutrients are lost from the soil and a primary step in the improvement of saline soils. Among the major nutrients, N is lost in large quantities by leaching through its NO_3 form.

Least significant difference (LSD): A value used to compare the differences between a set of averages as an aid to detect whether the differences are real or merely due to chance.

Legume: Derived from the Latin word *legre* meaning to gather. A type of dry, multi-seeded fruit formed from a single carpel and dehisces on both margins. It belongs to family leguminosae and forms N-fixing nodules on its roots.

Lichen: An association of blue-green algae or green algae with fungi.

Lodging: Falling of crop plants under the influence of heavy rains or wind.

Low analysis fertilizers: Fertilizers containing lower percentage of plant nutrients in them like Chilean nitrate (16% N) and single super phosphate (16–18% P_2O_5). They become very expensive because of higher unit cost and higher storage and handling costs.

Lowland rice: Rice grown on flooded flat land with controlled irrigation. This is also known as irrigated rice or waterlogged rice. Lowland rice is commonly flooded when seedlings are 25–30 days old.

M

Macronutrients: The nutrients which are required in large quantities such as N, P, K, Ca, Mg and S for the crop growth and development.

Manure: Any organic material, which is mainly prepared from the organic refuse from plants and animals, after its decomposition.

Mechanical impedance: Physical resistance offered by the soil matrix to the growing roots and measured by penetrometer is known as mechanical impedance.

Micronutrients: Trace elements which are required in very minute quantities but without their availability the growth and development functions of the plants are impaired. They include Fe, Zn, Cu, Mn, B, Mo and Cl.

Micro-organisms: A microscopic form of life, either plants (bacteria, actinomycetes, fungi) or animals (protozoa, nematodes).

Milled rice: Rice grain with husk, bran and germ removed.

Milling: The process of converting rough rice (paddy) into milled or brown rice. The purpose of milling is to remove the hulls and bran from harvested dried rough rice and to produce milled, polished white rice with minimum breakage and impurities in the final product.

Mineral: Naturally occurring, homogeneous elements or inorganic substances found in rocks which have a definite chemical composition and ordered geometric forms are known as minerals.

Mineralization: The conversion of an element from organic to inorganic state as a result of microbial decomposition.

Mixed cropping: Growing of two or more crops simultaneously on the same piece of land by using the mixed seeds of various crops without any definite row arrangement.

Muck: Highly decomposed organic material in which the original plant parts cannot be recognized or it refers to the soil which is well mixed with high percentage of organic matter.

Mulch: Any organic or inorganic materials such as straw, plant residues, leaves, loose soil, stone or plastic film placed on the soil surface to reduce evaporation and erosion, moderate diurnal soil temperature and control weeds is known as mulch.

Muriate of potash: A coarse or a fine salt resembling ordinary salt and having no bitter taste. It contains 60–90% potassium chloride and 60% potash. It is manufactured from potash-bearing minerals such as sylvite, carnallite, kainite, langbeinite, sylvinite, etc.

Mycorrhizae: A symbiotic association of fungi with roots of vesicular plants and is generally of two types – ectomycorrhizae and endomycorrhizae. It has beneficial effect on plant growth particularly in P-deficient soils, and is an effective tool in the solubilization of the unavailable P in the soil.

N

Naphtha: A petroleum product falling in the group of 5–10 C, which is used in the manufacture of fertilizers.

Night soil: Human excrement or excreta – solid and liquid – which is richer in nutrient content as compared to FYM or compost. On oven-dry basis, it contains 5.5% N, 4.0% P_2O_5 and 2.0% K_2O.

Nitrification: The process of biochemical oxidation of ammonium to nitrate ions by certain groups of bacteria like Nitrosomonas and Nitrobacter.

Nitrification or nitrifying inhibitors: The chemicals which decrease the activity of nitrifying bacteria, and thereby reduce N losses from wet soils, such as oxamide (31%), thiourea (36.8%), urea pyrolyzate (48%), dicyandiamide (42%). Thus, use of these chemicals is very beneficial especially in case of lowland rice fields. Neem cake or neem-coated urea and sulphur-coated urea also serve as nitrifying inhibitors.

Nitrosification: Conversion of ammonical nitrogen into nitrite form by the help of nitrite-forming bacteria.

Non-renewable energy sources: Energy sources that cannot be replaced or are replaced very slowly by natural processes. Primary examples are the fossil fuels such as oil, natural gas and coal. They are continually produced by the decay of plant and animal matter, but the rate of their production is extremely slow, very much slower than the rate at which we use them.

Nutrient cycling: The pathway of nutrient substances from their occurrence in the physical environment to their incorporation in the living organisms and their return to the physical environment through the metabolic activity, death and decay of organisms.

Nutrients: The chemical compounds needed for growth and metabolic activities of an organism (plant or animal).

O

Organic farming: An agricultural production system which favours the maximum use of organic materials and avoids or largely excludes the use of synthetically produced agro-products such as fertilizers, pesticides, growth regulators and livestock feed additives for maintaining soil productivity and fertility.

Organic fertilizers: Any fertilizer derived from animal products (bone meal, dried blood, etc.) or from plant residues (cotton seed-cake, groundnut cake etc.); even bulky manures like FYM.

Organic manures: Manures which are made up of dead plant and animal remains added to the soil specifically for the nutrition of plants, and are generally of two types – bulky manures and concentrated organic manures.

Organic matter: Partially decayed and partially synthesized plant residues and animal remains. It consists of humic substances (humic acid, fulvic acid and humin) and non-humic substances (polysaccharides and sugars, proteins and amino acids and fats). Generally, the term 'organic' refers to living materials, so organic matter is any material derived from living organisms. It improves physical condition of soils and also increases water-holding capacity. Organic manures including FYM and compost are the cheapest source of organic matter.

Oxidation: An energy-yielding process that usually results from the loss of hydrogen or addition of oxygen to a compound. The electron acceptor is called as oxidant.

P

Particle density: The weight per unit volume of the solid portion of soil. It is determined by Pycnometer method. Generally, the magnitude of particle density of normal soil is 2.65 Mg m^{-3}. Soils having higher inorganic constituents like iron oxides and various heavy minerals increase the value of particle density, whereas the presence of organic matter and light minerals decreases the value of particle density.

Peat: Unconsolidated soil material consisting of mostly undecomposed or only slightly decomposed organic matter under excessive moisture content.

Ped: A unit of soil structure such as an aggregate granule formed by natural forces.

Percolation: The downward movement of water through soil layers due to gravitational pull.

Permanent wilting point: The moisture content of a soil on an oven-dry basis at which plants begin to wilt and fail to recover their turgidity when placed in dark humid atmosphere.

Permeability: The ease with which gases, liquids, or plant roots penetrate or pass through a soil or soil layer.

pF: The logarithm of height, in centimetres, of water column that represents total stress with which water is held by the soil.

pH: The negative logarithm of the hydrogen ion activity or concentration of a soil solution. It is a measure of the acidity or alkalinity of soil and expressed in terms of a pH scale from 0 to 14. A pH of 7 indicates neutrality; higher values indicate alkalinity, and lower values acidity.

Phosphate-solubilizing micro-organisms: Micro-organisms which bring about solubilization of insoluble phosphates (tricalcium phosphate, rock phosphate etc.) into soluble ones by secreting organic acids such as formic, acetic, propionic, lactic and succinic acids.

Phytohormones: Plant growth substances produced by the plants.

Plant available water capacity: The difference between field capacity (moisture retained at 33.3 kPa suction) and permanent wilting point (moisture retained at 1,500 kPa suction).

Plant growth regulators: Organic compounds occurring naturally in plants as well as synthetic materials other than nutrients, which in small amounts promote, inhibit or modify any physiological process in plants.

Plant nutrient: An element that is essential for growth of the plant.

Pollution: Contamination of the environment with objectionable or offensive matter or accumulation of any elemental, ionic or molecule species at a concentration which has been accidentally raised as a consequence of human activity. It may pose a problem to human, animal and plant health.

Pore space: The volume of soil mass that is not occupied by soil particles. It is usually occupied by air and water.

Precipitation: The total amount of water falling from the atmosphere in the form of rain, snow, mist, etc. on the earth is termed precipitation. It is useful for human beings.

Pressmud: A by-product of sugar industry, which is used as manure in the field. It contains about 1.25% N, 2% P_2O_5 and 20–25% organic matter. Since it is very high in lime (up to 45%), its application has proved useful in acidic soils.

Primary nutrients: Nutrients required by plants in large quantities such as C, H, O, N, P and K. N, P and K are not usually available in large amounts in soils and are therefore added through fertilizers.

Puddling: The process in which soil aggregates are broken down into primary particles by repeated ploughings and harrowing near the saturation moisture content. The consequences of puddling are (i) destruction of soil structure; (ii) decrease in bulk density, soil penetration resistance, total porosity, permeability and gaseous exchange; and (iii) increase in moisture retention and soil redox potential.

R

Reduction: An energy-yielding process that usually results from the gain of hydrogen or the loss of oxygen to a compound. The electron donator is called as reductant.

Relative humidity: Amount of water vapour actually present in air compared with the maximum amount the air can hold at a given temperature. It is always expressed in percentage and hence it has no unit. It is simply the relative content and indicates the degree of saturation of air at a given temperature with water vapor. Relative humidity of saturated air is 100%.

Renewable energy sources: Energy captured from existing flows of energy and from ongoing natural processes such as sunshine, wind, flowing water, biological processes and geothermal heat flows or a form of energy that is replaced rapidly by a natural process such as power generated from the sun or from the wind. It is subset of sustainable energy.

Rhizobium**:** Bacteria which have the ability to fix atmospheric N in association with legumes and are site-specific.

Root: The growth of radicle in embryo of a seed.

Root growth: The lengthening of a root due to elongation of new cells that are formed in the apical region.

Rotational intensity: The ratio of the number of crops grown in a rotation to duration of the rotation which is multiplied by 100 and represented in percentage.

Run-off: The portion of precipitation which is lost through surface flow from an area without entering the soil.

Rural or village compost: Compost which is prepared from farm waste products, e.g. straw; crop stubbles; crop residues such as sugarcane trash, groundnut husks and leaves, cotton stalks, etc.; weeds; waste fodder; urine-soaked earth; litter from cowshed and hedge clippings. It contains 0.4–0.8% N, 0.3–0.6% P_2O_5 and 0.7–1.0% K_2O.

S

Secondary nutrients: Ca, Mg and S are next in importance to major nutrients, i.e. N, P and K, which are required for optimum crop growth. These nutrients are called secondary because they are not applied straight as commercial fertilizers, but are applied to the soil indirectly while adding N, P_2O_5 and K_2O in the form of commercial fertilizers. Thus, for manufactures of fertilizers containing major plant nutrients, Ca, Mg and S are of secondary importance.

Seed: A fertilized ovule consisting of an intact embryo, stored food and seed coat which is viable and has the capacity to germinate.

Seedbed: The soil which is prepared to promote germination of seed and the growth of seedlings.

Seedling: The young sprout which primarily depends upon stored food in the seed.

Sewage: Liquid portion of sewage system of sanitation.

Shoot: A collective term for that part of vascular plant which is above the ground, consisting of the stem and its leaves.

Shrub: Woody perennial plants or trees, low in stature, and which branch from the base, and have a bushy appearance.

Slow release fertilizers: Fertilizers whose nutrients are present as a chemical compound or in a physical state such that their availability to plants is slow and uniform over a period of time such as sulphur-coated urea, neem-coated urea, urea super granules, prilled urea, thiourea, etc.

Sludge: The solid portion of sewage system of sanitation. On an average, it contains 1.5–3.5% N, 0.75–4.0% P_2O_5 and 0.3–0.6% K_2O.

Soil: Derived from the Latin word *solumn* meaning floor. It is defined as an unconsolidated, three-dimensional, natural dynamic body on the surface of the earth, composed of complex system made up of organic matter, mineral matter, soil air, soil water and living forms in which plants can grow.

Soil alkalinity: The degree or intensity of alkalinity of a soil, expressed by a value greater than 7.0 on the pH scale is known as soil alkalinity. It is due to an excess of hydroxyl ions or having high exchangeable sodium content, or both.

Soil erosion: The process of detachment and transportation of soil by natural agencies such as water or wind.

Soil fertility: The inherent capacity of soil to supply adequate amount of nutrients in balanced form to plants necessary for their growth.

Soil health: The capacity of a soil to function within the ecosystem boundaries to sustain biological productivity, maintain environmental quality and promote plant and animal health is termed as soil health.

Soil management: The manner in which soil is used to produce food, fibre and forage.

Soil mining: The amount of nutrients mined from the soil. Balanced fertilization leads to soil building, while imbalanced fertilization use leads to soil mining. Only soil building leads to a sustainable land use system where most food grain production continues to come from existing agricultural land, while unbalanced use of fertilizers has resulted in the poor crop yields and also deteriorates the physical condition of soil.

Soil moisture regimes: The presence or absence of water in a soil at different times of the year is the soil moisture regime. It is a partial function of climate, soil and landform.

Soil pollution: The build-up in the soils of persistent toxic compounds, chemicals, salts, radioactive materials or disease-causing agents, which has adverse effects on plant growth and chemical health.

Soil porosity: The volume percentage of the total soil bulk not occupied by solid particles or percentage of pore space. It can be calculated by the formula:

$$\textbf{Porosity (\%) = (1 − bulk density/particle density) × 100}$$

Soil productivity: The capacity of soil to produce crop yield per unit area under a specified system of management practice is known as soil productivity.

Soil Profile: The examination of a vertical section of soil which reveals the presence of more or less distinct horizons or layers.

Soil structure: The arrangement of soil particles and their aggregate into certain defined patterns. It has main four forms – prism-like, plate like, block-like and spheroidal structure.

Soil testing: A chemical test of the soil that can be made rapidly and with low cost, as compared to conventional methods of soil chemical analysis which are more accurate but more time-consuming and expensive. It covers both rapid analysis in the field and laboratory.

Soil texture: The relative percentage of sand, silt and clay in a soil refers to soil texture. A soil is described as a coarse, medium or fine textured depending on the predominant particle size.

Soil tilth: Physical conditions of the soil vis-à-vis its fitness for crop production indicates soil tilth.

Sole cropping: A phenomenon in which one crop or variety is grown alone in pure stands at normal density.

Starch: A polymer of glucose. It consists of D-glucose linked in a linear fraction by 1–4 linkages (amylase) and branched chain fraction by 1–6 linkages (amylopectin).

Straw: The dried remnants of crop plants from which the seed has been removed, also called stover.

Stubble mulching: Stirring the soil with implements that leaves considerable part of the vegetative material or crop residues or vegetative litter on the surface as a protection against erosion and for conserving moisture by favouring infiltration and reducing evaporation.

Submergence: The process by which plants grow partially or completely under water.

Subsistence farming: A farming enterprise which provides food and commodities just sufficient for the farming family, and there is no surplus to sell.

Subsoil: The layer or horizon below the soil which is generally compact, light in colour and less fertile.

Sustainable agriculture: Successful management of resources for agricultural production to satisfy changing human needs, while maintaining or enhancing the quality of the environment and conserving the natural resources. It can also be defined as agriculture that is productive for the foreseeable future, competitive and profitable, conserves natural resources, protects the environment, and enhances public health, food quality, and safety. An agriculture system can be considered sustainable if it ensures that today's development is not at the cost of tomorrow's development prospects.

Symbiotic N fixation: Fixation of atmospheric N by the leguminous plants with the help of root nodule bacteria i.e. *Rhizobium* species is known by the symbiotic N fixation.

T

Temperature: The degree or intensity of hotness and coldness usually measured by a thermometer and expressed in degrees (Celsius or Fahrenheit or Kelvin).

Tillage: Derived from the Anglo-Saxon words *tilian* and *teolin*, meaning to plough and prepare the soil to sow seeds, to cultivate and raise crops. It is a mechanical manipulation of the soil to obtain a seedbed of optimum soil tilth for plant growth. It alters the soil environment by reducing the strength of the soil matrix and increasing its porosity, thereby improving the permeability of the soil for the flow of both water and gas.

Tilth: A physical condition of soil as related to its ease of tillage, fitness as a seedbed and its impedance to seedling emergence and root penetration constitutes tilth.

Translocation: Transfer of food or other materials such as herbicides, etc. from one plant to another.

Transplanting: The process of moving the seedlings from seedbeds to the field. For rice crop, 25–30-days-old seedlings are transplanted by maintaining 15 cm plant-to-plant distance. Two seedlings per hill are sufficient for transplanting.

Trap crops: Plant stands that are grown to attract insects or other organisms so that the target crop escapes from pest attack. For instance, okra can be used as trap crop around cotton for cotton jassid, amercian bollworm and spotted bollworms. The major benefit of trap crop is that insecticides are seldom required to be used on the main crop and this enhances the natural control of pests. Moreover, it may also attract natural enemies, thus enhancing natural control.

U

Upland rice: Rice grown on both flat and sloping fields that are prepared and seeded in dryland conditions and depend on rainfall for moisture. This is also known as rainfed rice. Brazil is the largest producer of upland rice.

Urban or town compost: Prepared from night soil, street and dustbin refuse. It is rich in nutrients (1.0–2.0% N, 1.0% P_2O_5 and 1.5% K_2O) as compared to FYM and rural compost.

Urea: A white, crystalline, non-protein N material, made synthetically from synthetic ammonia and CO_2 and contains 44–46% N.

V

Vermicompost: Compost produced from the digestion and discharge of refuse and other organic wastes by earthworms such as *Eisenia foetida*, *Eudrillus eugeniae* and *Pheritima elongate*.

Vermicomposting: Bio-processing of organic solid waste by using surface (epigeic) and sub-surface (anecic) earthworms. Vermicomposting is an appropriate technique for the disposal of non-toxic and liquid organic wastes.

Vesicular arbuscular mycorrhizae (VAM): A symbiotic association of fungi with the roots of vesicular plants and has beneficial effect on plant growth particularly in P-deficient soils.

Vitamins: Organic substances present in minute quantity for human beings and other organisms especially belonging to heterotrophic group to maintain growth and development for normal metabolism. Vitamin A, D, E and K are fat-soluble and are stored in the fat compounds of the body, whereas vitamins of B and C groups are water-soluble and as such cannot be stored.

Volatilization: The process where a condensed phase such as liquid or solid is transformed into vapour by elevation of temperature or reduction of external pressure.

W

Water-holding capacity: The moisture-saturated stage of the soil when all pores (micro and macro) and capillaries are filled with water. The maximum water-holding capacity of a given soil is determined by the amount of total pore space available in the soil.

Waterlogging: A condition of land where the groundwater and soil water content reaches a level that is detrimental to plants and other useful soil microflora, or addition of excessive water to a soil resulting in loss of soil structure and soggy conditions. It occurs occasionally due to heavy and continuous rains, lack of drainage and faculty irrigation practices.

Water pollution: The loss of any of the actual or potential beneficial uses of water caused by any change in its composition due to human activity or substances like bacteria or viruses or other pollutants which impair the quality of water, rendering it less suitable for use.

Water stable aggregates: A soil aggregate stable to the action of water such as falling drops, or agitation as in wet-sieving analysis.

Weather: The physical condition of atmosphere with respect to wind, temperature, cloudiness, relative humidity, pressure, etc. at a given time. It is dynamic and changes with time.

Weed: A plant growing where it is not desirable and which interferes with agricultural operations. It increase labour cost and reduces the crop yields. They compete with crop plants for soil moisture, nutrients and sunlight.

Y

Yield: The harvested produce obtained from a crop grown in a unit area of land, usually expressed as kilogram, quintals or tonnes per hectare.

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