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TECHNOLOGICAL INTERVENTIONS IN INDIAN AGRICULTURE FOR ENHANCEMENT OF CROP PRODUCTIVITY

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ACRONYMS

AP	Andhra Pradesh
ADB	Asian Development Bank
AER	Agro-Ecological Regions
ASTI	Agricultural Science and Technology Indicators
BGA	Blue Green Algae
BCM	Billion Cubic Meter
BCR	Benefit-Cost-Ratio
cm	Centimetre
CSS	Centrally Sponsored Schemes
CAGR	Compound Annual Growth Rate
CRISP	Centre for Research on Innovation and Science Policy
CIAE	Central Institute of Agricultural Engineering
CGIAR	Consultative Group on International Agricultural Research
dS/m	deciSeimens per metre
DAP	Diammonium Phosphate
FAO	Food and Agriculture Organisation
FTE	Full Time Equivalent
GW	Ground Water
GCF	Gross Capitl Fornation
GDP	Gross Domestic Product

GOI	Government of India
Ha	Hectare
HP	Horse Power
HYV	High Yielding Variety
IGP	Indo-Gangetic-Plain
IIM	Indian Institute of Management
IRR	Internal Rate of Return
IFA	International Fertiliser Association
INM	Integrated Nutrient Management
IPM	Integrated Pest Management
ICAR	Indian Council of Agriculture Research
IWMI	International Water Management Institute
IFPRI	International Food Policy Research Institute
kg	Kilo gram
kW	Kilo Watt
MI	Micro Irrigtion
MP	Madhya Pradesh
MOP	Murate of Potash
N	Nitrogen
NCF	National Commision on Farmers
NGO	Non-Government Organisation
NPK	Nitrogen, Phosphorous, Potassium
NATP	National Agricultural Technology Project
NRSC	National Remote Sensing Centre
NABARD	National Bank for Agriculture and Rural Development
NBSS & LUP	National Bureau of Soil Survey and Land Use Planning
ppm	Parts per million
q	Quintal

RCT	Resouce Conservation Technologies
R-W System	Rice-Wheat Cropping System
sq.m	Square metre
SAU	State Agriculture University
SRI	System of Rice Intensification
SRR	Seed Replacement Rate
t/Ha	Tonnes per Hectare
TE	Triennium Ending
TP	Treadle Pump
TFP	Total Factor Productivity
TFPG	Total Factor Productivity Growth
UP	Uttar Pradesh
UDP	Urea Deep Placement
USG	Urea Super Granules
US$	United States Dollar
USA	United States of America
(10^9 m3/yr)	Billion cubic meter per year
4WT	Four Wheeled Tractors
2 WT	Two Wheeled Tractors

Terminology

Cultivated Area	Total area under crop cultivation
Irrigated Area	Total area under irrigation
Irrigation equipped area	Total area where irrigation capacity has been created
Irrigation Potential	Total area that is and can be brought under irrigation
Irrigated Rice	Rice crop grown under irrigation
Rain-fed Rice	Rice crop grown under rain-fed condition

EXECUTIVE SUMMARY

INTRODUCTION

Agriculture provides employment to majority of Indian population and food security to the nation. India has made impressive strides on the agriculture front in the past three decades. Policy support, production strategies, public investment in infrastructure, research and development, extension services, among others, have helped in increasing agricultural production, yield per hectare, and per capita food availability. Growth in agricultural output over the past three decades has been strong; more importantly, crop production has been able to broadly keep pace with the demands from a growing population. Considerable changes have been experienced by the country in the crop mix, yield and production, since the inception of the Green Revolution.

Despite the growth in production in the Indian agricultural sector over the recent decades, crop yields remain low as compared to global averages, and growth in yields has only been marginally higher than the world average. While India with 158 million hectares of arable land produces only 249 million tonnes of cereals, China with 110 million hectares and USA with 163 million hectares of arable land produces 483 million tonnes, and 420 million tonnes of cereals, respectively. Dilemma also lies in resource instillation in Indian agriculture in relation to crop productivity. While India has the second largest consumption of fertilizer in the world, just next to China, its productivity in cereal is half of that of China, and USA with much lower fertilizer consumption than India, has productivity three times higher than India in foodgrains. Similar situation is also observed in case of agriculture water use. India's total agricultural water withdrawal is twice as much as China, and around four times higher than that of USA.

Within India, agriculture development varied in terms of intensity among the states. With relatively high productivity, the Indo-Gangetic Plain (IGP – mainly comprising of Punjab, Haryana, Uttar Pradesh, Bihar and West Bengal) has been the mainstay of India's agricultural economy, and a strong base for food security of the country, Punjab and Haryana have been the high productive regions of the country and the heartland of Green Revolution, much due to the favourable factors. Parts of other states such as Uttar Pradesh, Andhra Pradesh, Tamil Nadu have also benefitted during the Green Revolution phase. Following Green Revolution, early 1990s also witnessed equitable growth rate in agriculture. However, growth rates in agriculture NSDP decelerated in most of the states, post 2000, with no significant improvement in crop productivities. This may be attributed to structural weaknesses of the agricultural sector, reflected in the input implants in the sector, which is analysed in this Study. The objective of the Study is to determine the factors which might be responsible for such weaknesses and explore possible suggestions to overcome them. While the Study has reviewed trends in usage of all inputs, specific focus is attributed to irrigation and water management. Similarly, the Study specifically focuses on analysis of impact of technological intervention in productivity with respect to rice cultivation. It is endeavoured to bring out the impact of technological intervention in select other crops, as a series, subsequently.

INPUT USE TRENDS IN INDIAN AGRICULTURE

Input management plays a vital role in crop production and productivity. The key inputs to supplement crop production and productivity are: hybrid seed, fertilizer, pest-management, and irrigation. According to some research findings, the growth in per hectare input-use at constant prices decelerated from 3.66 percent per annum during 1980s to 0.94 percent per annum during the 1990s; the Mid-Term Appraisal of the Tenth Five Year Plan also attributes a part of the decline in agriculture growth to lower input-use.

Fertilizer

Consumption of fertilizer is largely dependent on growing conditions, such as weather and soil, and socio-economic status of the farmers. Analysis of fertilizer use since the Green Revolution shows that the average per hectare use of fertilizer doubled in absolute terms in every decade from 1971 to 1991. Subsequently, the average growth in per hectare use of fertilizer has slowed down.

With respect to type of fertilizers used, it has been generally noted that use of plant nutrients in many parts of the country is highly skewed towards nitrogenous fertilizers over the years resulting into an imbalance in the ratio of Nitrogen : Phosphorous : Potassium (NPK) use. While the recommended NPK ratio aggregated for the country as a whole is 4 : 2 : 1, the ratio was distorted to the extent of 9.5 : 3.2 : 1.0 following decontrol of prices of Phosphatic and Potassic fertilizers, which still continues to be at 5.0 : 2.4 : 1.0. Following decontrol, the prices of P and K increased sharply, making the fertilizer usage in favour of N, due to its favourable price. Analysis of fertilizer subsidy of the country as a whole also reveals that it is skewed towards Nitrogen fertilizers; on an average, subsidy on Nitrogen fertilizers amounted to over 60 percent of total fertilizer subsidy of the country. This has raised considerable concerns regarding soil fertility, productivity and efficiency of fertilizer use in the country.

Seed

Seed is the vehicle for delivering the benefits of technology, and is the most important input, influencing the growth and sustainability of agriculture. Use of quality seeds alone can improve the productivity of crops to the tune of 15 percent. Supply of certified/quality seeds and Seed Replacement Rate (SRR) are the two important factors in enhancing productivity in agriculture.

While the use of hybrid seeds in Indian agriculture has been growing, there has been low penetration of hybrid seeds in case of staples in the country. The levels of hybridization in food crops significantly vary – from 2 percent to 5 percent in paddy and wheat, to 20 percent to 50 percent in coarse grains, such as jowar, bajra and maize. There are also considerable interregional variations in SRR. The SRR is highest in the western and southern regions of India, with the state of Maharashtra having the highest SRR followed by Tamil Nadu, and Andhra Pradesh. SRR is the lowest in the Central, Eastern and North Eastern regions of the country.

Farm Mechanisation

Farm mechanization is an important component for increasing crop production and productivity, besides reducing the drudgery of farm labourers. Farm mechanization also enables efficient use of agricultural inputs and reduces the cost of production.

Analysis of average tractor use in agriculture per thousand hectares in the world reveals that tractor use has been highest in Europe, followed by America and Asia. Tractor use has remained particularly low in South Asian countries, such as Bangladesh, Nepal, Sri Lanka, Pakistan and India. However, given the magnitude of arable land, agricultural area, and population of farm labourers in India, tractor use in India has been considerably low.

Total farm power (combination of tractor, power tiller, diesel engines and electric motor and other animate and mechanical power) input per unit of cultivated land in India is still very low at 1.5 kW/Ha compared to Japan (14kW/Ha), South Korea (7kW/Ha), China (6.8kW/Ha), and USA (6kW/Ha). The contribution of different farm power sources to the total farm power changed with time in India. The share of agricultural workers continuously declined since 1981 and expected to be having a share of only 5.09 percent in 2011-12. The increase in share of farm power has been mainly through introduction of tractors, whose contribution has increased from 7.5 percent in 1971 to 51.08 percent in 2011-12. Thus, farm mechanization in India has been associated with the use of prime movers, tractors, and power tillers, rather than adoption of farm machinery that perform specific tasks.

Agriculture R&D and Extension Services

Agricultural R&D is a crucial determinant of agricultural productivity involved through the introduction of improved crops, cropping practices, labour-saving technologies, improved quality of food storage, processing, and marketing. According to a study by the World Bank, agriculture R&D as a percentage of GDP has been 2.36 percent for developed countries, and the same is lower at 0.53 percent for developing countries of the world, further lower at 0.41 percent for developing countries of Asia, and at 0.34 percent for India.

Extension services in India is also characterized by high ratio of farmers to a extension worker, at 914: 1, if all posts in the Department of Extension Services, Government of India (nearly 140,000) is filled up and all the extension services officials are involved; 1464: 1, if all those who are in place are involved in extension; and as high as 4880: 1 if at least 30 percent personnel are involved in extension. Across the country, only in 6 States, extension service is present at village level, and in 11 States, it is present up to Panchayat Level. The desired ratio of farmers to extension worker is 300 to 500: 1. This indicates inadequate agricultural extension services in India.

Capital Formation and Total Factor Productivity

Capital formation in agriculture is divided into two segments; one is that of additions to capital stock within agricultural sector which influences productivity, and the second is investment in capital stock that is made elsewhere, but is closely linked with productivity, efficiency and profitability in crop production. A review of capital formation in Indian agriculture reveals that gross capital formation in agriculture as a proportion of agriculture GDP has been steadily increasing since 2004-05, which in 2009-10 stood at 20 percent. In India, the share of private sector in capital formation has been dominant at around 80 percent.

Analysis of the effect of technological progress in total agricultural factor productivity is limited in this Study. However, recent research studies on the subject have been reviewed for making inferences. Various empirical studies reveal that the Total Factor Productivity Growth (TFPG) has declined over the years. A few studies have inferred that technological gains have not occurred in a number of crops, notably coarse cereals, pulses, oilseeds, fibres, sugarcane and vegetables. Further, the inferences from the studies reveal that crops and areas, where these TFP gains occurred during Green Revolution, have exhausted their potential.

IRRIGATION AND WATER MANAGEMENT

Water is the leading input in agriculture. Development of irrigation and water management are crucial for raising the levels of production and productivity. According to a joint study by International Water Management Institute and Asian Development Bank, in absolute numbers, South Asia has the largest land area under irrigation (82.4 million hectares). India has the largest area under irrigation within Asia constituting about 30 percent of total area under irrigation in Asia. India also has largest potential area under irrigation in Asia. Considering the size of arable land and agricultural R&D in India, the growth in area equipped under irrigation in the country has been considerably low. The share of area equipped with irrigation in potential area of irrigation in India is about 44 percent for India, which is higher for China (83 percent).

According to the Central Board of Irrigation and Power, Government of India, at the end of Tenth Five Year Plan, around 17 percent of available irrigation potential from the major and medium irrigation projects in the country still remains to be exploited. Around 15 percent of ground water blocks have been over exploited in India, leading to rapid depletion of ground water levels, which is particularly observed in the case of leading foodgrain producing states, such as Punjab (75 percent over exploited), Haryana (49 percent), Karnataka (38 percent), Tamil Nadu (37 percent), Andhra Pradesh (18 percent), and Gujarat (14 percent). In addition to the concerns over the availability of fresh ground water for potable use, this alarming over exploitation of ground water resources has been raising concerns over sustainability of irrigation in these states, and subsequent impact on crop production and productivity. The status of groundwater in the country calls for adoption of micro-irrigation system in the country.

Micro-irrigation technologies, such as drip and sprinkler irrigation systems ensure judicious use of water in agriculture, thereby improving water use efficiency and crop productivity. According to a study by International Water Management Institute, the percentage of actual area against estimated potential area under drip irrigation in different states varied significantly - between Nil in Nagaland to as much as 49.74 percent in Andhra Pradesh. Compared to the potential of 42.23 million hectares in the country, the area under micro-irrigation is 3.87 million hectares, which is just about 9.2 percent of the potential.

CASE STUDY : TECHNOLOGICAL INTERVENTION AND RICE PRODUCTIVITY

Crop productivity in India is one of the lowest in the world, especially in comparison to some of our neighbours in the region, such as China and Viet Nam, which shares a similar agricultural system. While crop-wise productivity comparison of India with its peer countries is not within the scope of this Study, analyses have been undertaken to compare select factors that may be responsible for a relatively high productivity of rice in India's peer countries.

India is second largest producer of rice in the world after China, with largest area under rice cultivation; however, India has one of the lowest productivity of rice among the leading rice producing countries in the world. Productivity of rice in all leading Indian rice producing states is below the global average. Eastern states, most of which falls under the Indo-Gangetic Plains, and are predominantly rice producing states having over 40 percent of land under rice cultivation, have some of the lowest productivities of rice in the country. Among the Indian states, Punjab, which also falls in the Indo-Gangetic Plains, has the highest productivity of rice, with almost all rice cultivated is under irrigation. Punjab also closely compares to the productivity level of Bangladesh, which is the fourth largest producer of rice in the world, where around 55 percent of rice is grown as irrigated rice.

China was having the highest level of rice productivity (6582 kg/ha in 2009) in the world, followed by Japan (6521 kg/ha), Viet Nam (5237 kg/ha), Indonesia (4999 kg/ha), Brazil (4405 kg/ha), Bangladesh (4203 kg/ha), Myanmar (4085 kg/ha), Philippines (3589 kg/ha), Pakistan (3581 kg/ha, Thailand (2883 kg/ha), as compared to India's 2178 kg/ha during the same period. Some of the factors that might have helped these countries in achieving higher crop productivity are discussed below:

Hybrid rice in leading rice producing regions

The spread of hybrid rice in select rice producing countries, especially in Asia, has been strong as compared to India. The share of hybrid in total rice acreage has been 52 percent in China, 10 percent in Viet Nam, 7 percent in Bangladesh, 5 percent in Indonesia, and 4.4 percent in Philippines, as compared to 3.9 percent in India, in 2009. Hybrid seed production has also been rising in these countries, especially in China and Viet Nam. The production of hybrid seeds in India has also been increasing; hybrid rice seeds are also being exported to countries such as Indonesia, Philippines, Viet Nam, Nepal, Myanmar and Bangladesh. High cost of hybrid rice is being cited as one of the reasons for low penetration in India. Besides, researchers find that the time-lag between availability of seeds between the seasons, quality of seeds, and low level of awareness regarding the benefits of hybrid seeds among farmers, as possible reasons for low penetration of hybrid rice cultivation in India.

Agricultural mechanization

Though India has made remarkable advances in the farm-machinery sector, mechanization of farm operations remains relatively low, in comparison to other rice producing countries such as China, Cambodia, Thailand and Viet Nam. A research Study by United Nations (Asia and Pacific Centre for Agricultural Engineering and Machinery) classifies countries based on select parameters, such as a) share of mechanised fields in total, b) the power of machines employed in a field (kW/Ha), c) the number of manufacturers of agricultural machinery, and d) the regional markets of agricultural machinery. Based on this classification, India is classified under high-level of mechanization, along with China, and Korea. An interesting feature is that FAO datasets include only 4-wheeler tractors as farm machinery and do not include 2-wheeler tractors, although they perform at the same level as that of 4-wheeler tractors.

In contrast, several studies have identified Bangladesh as one of the Asian countries having most mechanized agricultural operations, as a result of high spread of small-scale 2-wheeler tractors driven by single cylinder diesel engines. Bangladesh is reportedly depending on imports (mainly from China) for such small-scale machinery, and has established a market for services of 2-wheeler tractors, pumpsets, threshers etc. Bangladesh is reported to have over 1-million small horsepower diesel irrigation sets and nearly 400,000 2-wheeler tractors. In comparison, there are only 110,000 2-wheeler tractors in India, which is low as compared to the magnitude of agricultural operations.

Fertilizer usage

Fertlizer usage in rice cultivation depends on various factors such as agro-climatic (soil, terrain and climate) variations, and economic incentives. Relationship between crop productivity and fertilizer usage is also related to soil moisture level, and thus is associated with irrigation.

In general, in developed countries, there has been a marked improvement in efficiency of fertilizer usage; however, in developing countries fertilizer use is often inefficient, particularly in Asia, Consumption of nitrogen fertilizers is highest in Asia due to existence of intensive irrigated rice-based cropping system. Analysis of nutrient (NPK) uptake and productivity of rice by the major producing countries in Asia also reveals that nutrient management is relatively poor. Comparison of nutrient (NPK) intake per hectare of rice cultivation and productivity reveals that countries such as Bangladesh, Pakistan, Indonesia, Philippines and Thailand have higher rice productivity despite lower nutrient (NPK) intake. Another notable feature is fertilizer application technique, which is reported to be much efficient way of urea application in rice cultivation as compared to commonly practiced broadcasting a basal application.

Pest management

A research study points out Integrated Pest Management (IPM) system in Indonesia as one of the reasons for growing crop productivity. Beginning late 1960s, Indonesia witnessed a series of pest attack in rice during the initial years of intensive farming. With the policy for subsidizing pesticides by the Indonesian Government, rampant usage of pesticides was witnessed in Indonesian fields. This overuse of pesticides not only killed the predators of the original crop pest, giving rise to the pest population, but also resulted in considerable increase in pest related hazards. The Indonesian Government worked directly with the farmers, through the frontline agricultural extension workers, to educate them on pest management based on eco-system analysis. International organizations, in several review and analysis, have judged the programme a success.

The Rice-Wheat System

Though greatest yields of wheat have been obtained from the temperate areas of the world, Rice-Wheat cropping system in Asia has been important due to its significant contribution to total global wheat production. Practiced mostly in South and East Asia within sub-tropical to warm-temperate climates, the system extends across Indo-Gangetic Plains (IGP) into the Himalayan foothills, spanning a vast area from Pakistan's Swat valley in the North to Maharashtra in the South, and from the mountainous Hindu Kush of Afghanistan in the West to the Brahmaputra floodplains of Bangladesh in the East. Approximately 85 percent of Rice-Wheat cropping system is practiced in the IGP. In China, they are practiced widely in the provinces of Jiangsu, Zhejiang, Hubei, Yunnan, Sichuan, and Anhui, alongwith the Yangtse River Basin, and in the plains of Chengdu. The use of technology and level of management vary widely across Rice-Wheat cropping region, especially in China, Pakistan, and Bangladesh. Wheat production in these countries has largely benefitted from certain Resource Conservation Technologies (RCTs). Wheat yields from China's Rice-Wheat System have been one of the highest in the world.

DECLINING PRODUCTIVITY – CHALLENGE AREAS

Irrigation and Water Management

There are challenges associated with water-use efficiency in Indian agriculture. Currently, irrigation efficiency in India is around 35 percent in surface water system and 65 percent in ground water system. Growing entrepreneurship in Indian farming community, coupled with subsidized power for agriculture, is making ground water exploitation a more convenient option for irrigation. This has been adversely affecting water table in India. Incidences of drying of wells and tube-wells have become common in recent years, burdening the farm households with huge cost in deepening the wells to re-energize the water levels. Even after continued support and promotion of micro-irrigation by the Government of India, the percentage of area under micro-irrigation has not been remarkable. Even though the returns are higher, there has been reluctance among Indian farmers to adopt micro irrigation due to several factors including high initial capital cost, low level of technical knowledge for operations, and low level of awareness on the long term benefits.

Land degradation

Land degradation or deterioration in land quality for agricultural production has been a matter of concern for quite some time. The Netherlands based International Soil Reference Information Centre has estimated that around 80 percent of India's cultivated land is being slowly reduced to unproductive parched terrain due to wind and water erosion. According to a joint Study by Indian Council of Agricultural Research and National Academy of Agricultural Sciences, of the 141 million hectares of land under cultivation in India, 100 million hectares (70 percent) is heading down a path of having limited capability for supporting farming. Overuse of fertilizers and pesticides, and declining organic content due to intensive cultivation are also largely responsible for soil degradation. Apart from retarding growth in yields, this unbalanced use of fertilizers has also resulted in physical deterioration of the soil. For instance, over use of urea turns soil acidic; more energy is required to cultivate such degraded land, and a higher proportion of rain water is lost as run-off.

Quality of Seeds

Seed management is a very crucial element for growth in crop productivity. Seed production has not been showing significant improvement in India. About 85 percent of farmers are using farm-saved seeds that lose its vigour and thereby the productivity over a period. The genetic gains in seeds achieved during the Green Revolution period has also been decelerating. The Seed Replacement Rate has also not improved in the past decades. According to a Review Report of the Planning Commission, on Eleventh Five Year Plan period, for the past two decades, there has been little change in Seed Replacement Rate in some of the states in India.

Fertilizer usage

Declining factor productivity in Indian agriculture is also partly attributed to the soil degradation which in turn is a result of accumulating nutritional deficiency over the years. One of the main factors for distorted nutritional status of our soil is the imbalance in the use of NPK in fertilizers. Against the recommended proportion of 4:2:1 of NPK, the aggregate national averages has been at 5:2.4:1.

This tendency is more prevalent in the Indo-Gangetic belt devoted to high productivity of wheat and rice, and where the symptom of soil fatigue due to nutritional imbalance has been already evident. Nitrogen deficiency is high in western Punjab, Haryana, Uttar Pradesh, Rajasthan, Gujarat, Maharashtra, parts of Bihar, Jharkhand, Madhya Pradesh, Andhra Pradesh, and Tamil Nadu due to acidic soils. Phosphorous deficiency is high in parts of Himachal Pradesh, Haryana, Uttar Pradesh, Rajasthan, Gujarat, Maharashtra, parts of Bihar, Jharkhand, Madhya Pradesh, Andhra Pradesh, Tamil Nadu, West Bengal and Assam. Deficiency of micro nutrients, such as zinc, iron, boron, manganese and copper in soil are widely reported in the Indo-Gangetic Plains, particularly in Punjab and Haryana, raising questions about sustained benefits of canal irrigation in these areas.

Increased use of fertilizers has also led to pollution of water resources, both surface and ground water, resulting in poor quality of irrigation water, having negative impact on crop growth and productivity. The problem is acute in the intensive rice and wheat growing regions, particularly in the north western Indo-Gangetic Plains of India, e.g. Punjab, West Bengal, Bihar and Uttar Pradesh.

Farm Mechanisation

Farm mechanization is uneven in some parts of the country. While the mechanization has been relatively extensive in some states, like Punjab and Haryana, it is low in some of the states in east India. According to research reports, in these states, the rate of growth in animal operated machinery is high as compared to tractor or power operated machinery. Main reasons for low penetration of farm mechanization in India have been: fragmented holding of farms, low levels of usage as compared to cost, low level of awareness, and high initial investments.

Research and Extension

There are challenges associated with delivery mechanism of public research system in India. According to National Commission on Farmers (NCF), there exist large gaps between yields in research stations and farmer's fields. NCF also claims that there is technology fatigue in Indian agriculture. Close interaction among researchers and agriculture extension services has long been a challenge in India. According to a Working Group Report by International Food Policy Research Institute, and a study by the Centre for Research on Innovation and Science Policy, India, on agricultural extension services, the extension services machinery is weak in several parts of the country and there is a disconnect between the extension, research and development, and market needs. Further, the existing extension machinery has neither been able to keep itself updated with the evolving technology, nor has been able to orient to the diversified agricultural development.

STRATEGIES

Irrigation and Water Management Practices

Technological improvements in irrigation systems increase production opportunities and productivity. Water use efficiency in

India is presently estimated to be only around 38 percent for canal irrigation, and about 60 percent for ground water irrigation schemes. It is estimated that with 10 percent increase in the present level of water use efficiency in irrigation projects, an additional 14 million hectare area can be brought under irrigation. One of the foremost efforts to be made in this direction is to evolve irrigation management techniques that are diverse and location specific, rather than spending resources on large scale irrigation project which takes years to complete. Various types of on farm soil and water conservation technologies and engineering measures can reduce peak runoff rates and soil loss by 60 percent to 80 percent, and raise crop yields by 30 percent to 40 percent through a combination of mechanical and vegetative measures.

Modern irrigation technologies, such as treadle pumps and micro irrigation, increase water use efficiency. They have opened up opportunities to cultivate soils with low water-holding capacity and to cultivate low quality lands and steep slopes. These technologies have also enabled regions facing limited water supplies to shift from low-value crops with high water requirements (e.g. cereals) to high-value crops with low-water requirements (e.g. fruits, vegetables and oil seeds). Salient advantages of micro irrigation techniques include: enhanced water utility, better crop growth and yield, reduced salinity, high fertilizer use efficiency, reduced weed growth, and saving of labour cost. It has been assessed that there is potential of bringing around 42 million hectares under drip and sprinkler irrigation in India. Out of this about 30 million hectares are suitable for sprinkler irrigation for crops such as cereals, pulses, and oilseeds, in addition to fodder crops. This is followed by drip irrigation technique with a potential of around 12 million ha under cotton, sugarcane, fruits, vegetables, spices and condiments, and pulse crops such as red gram. Studies have estimated that the Benefit to Cost Ratio of micro-irrigation techniques (in Bt Cotton) ranges 2.0 to 2.5.

Adoption of System of Rice Intensification (SRI)

SRI involves the use of certain management practices which together provides better growing conditions for rice plants, particularly in the root zone, than those plants grown under traditional practices. Four components of SRI include: early planting, limited irrigation, weeding, and application of organic matter. SRI is currently practiced in over 40 countries, including China, Indonesia, Cambodia, Bangladesh, Cuba, Myanmar, Nepal, Sri Lanka, Viet Nam, and West Africa. In India, SRI is being practiced mainly in southern India, in the states of Tamil Nadu, Andhra Pradesh, and Karnataka, and sporadically in North Eastern States of Tripura and Assam. The benefits of SRI include: less seed rate, less nursery area, labour saving, water saving, better aeration, enhanced yield, and control of diseases. Simplification of SRI methodology and scaling up this innovative approach throughout the country alone may help sustain the irrigated rice cultivation in future.

Agri-Biotechnology:

Agricultural biotechnology has the potential for making huge impacts on many facets of agriculture – crop and animal productivity, yield stability, environmental sustainability, and consumer traits important to the resource poor population. Yield stability is important for all farmers, especially for farmers in subsistence agriculture, whose food and livelihood security are vulnerable to pest and disease outbreaks, droughts and other stress. Agri-biotech varieties that are disease and pest resistance provide yield stability; Agri-biotech varieties that are adaptable to climate change are drought, flood and heat tolerant, and thus the yield becomes stable. There is an urgent need to increase public investments in agri-biotech research to develop and introduce such varieties in Indian agricultural system.

Soil Health and Nutrient Management

Nutrient management and improving soil health enhances crop production and productivity. In many cases, imbalances can be corrected through the application of appropriate inorganic and organic fertilizers. Integrated Nutrient Management (INM) approach should be adopted not only to increase agricultural production, but also to safeguard the environment for the future. INM, through judicious use of chemical fertilizers, including secondary and micro nutrients, in conjunction with organic manures and bio-fertilizers, improves soil health and its productivity. Another input-saving and resource-conserving technology for improving soil fertility is introducing legumes in farming systems to provide multiple benefits, most notably biologically fixing nitrogen that reduces the need for chemical fertilizers.

Integrated Pest Management Approach

Like the use of water under flood irrigation, chemicals and pesticides are also used injudiciously. Use of un-prescribed pesticides in inappropriate doses has not only been disturbing the soil conditions but also destroying the healthy pool of bio-control agents that normally coexist in the vegetation. Integrated Pest Management propagates alternative methods for controlling pests, like cultural, mechanical and biological control in a compatible manner. The chemical-based pesticides are resorted to only when other methods fail to provide desired results. IPM strategies are different for different crops, or for a country, for a region, or even for a location, depending on local varieties used, and local agronomic practices. Designing and practicing effective IPM systems is about learning and continuously finding solutions to suit the changing field situations and problems.

Farm Mechanisation

The present day need of the country is to increase the productivity and profitability of production and post production agriculture. Besides, the exodus of rural labour has increased the need for farm mechanization. Technological intervention for land leveling and drainage minimize the water use and improve water use efficiency, besides providing better growing conditions. Technology intervention for irrigation or other input usage, especially with electronic monitoring, helps in appropriate distribution of inputs and thereby helps in protecting the soil health. Use of such equipments, though increases the capital cost of operations, contribute to enhanced productivity – ranging from 20 percent to 50 percent, neutralizing the capital cost in the long run.

Adoption of mechanization in farming is at various levels in different states in the country depending much on land holding status of farmers. To expand the spread of mechanization in the country and in order to have a tangible impact on crop and farm productivity, there is a need to establish an efficient technology transfer mechanism. Some of the suggested approaches are:

Encouraging custom-hire and service centres for machinery – this could be achieved through establishment of agri-implements bank which will provide custom-hire machinery, besides repair and maintenance services. The Centres may also impart training on operations of such machinery.

Developing and promoting low-powered tractors – such as 2-wheeler tractors that are largely used in small farms in other countries like Bangladesh.

Promoting Information Technology for information dissemination.

Conservation Tillage

Another approach for enhancing crop production and productivity is conservation tillage which minimizes or eliminates tillage and maintains crop residues as ground cover. According to FAO, conservation agriculture is based on enhancing natural biological processes above and below the soil surface. In contrast, conventional agriculture recommends extensive soil tillage and burning of crop residues, which leads to soil degradation through loss of organic matter, soil erosion and compaction.

In conservation tillage, the soil is disturbed the least, and thus, significant amount of residue remains on the surface, which helps in reducing run-off, sediment and nutrient loss. Energy is also saved due to less manipulation of soil, while mulch and cover crops also improve soil, water and nutrient conservation. However, community participation is very often necessary. In Latin America (particularly in Brazil and Argentina), conservation tillage is used in more than 40 million ha (about 43 percent of total arable land). Originally adopted by large and midsize farmers, the practice has spread to small farmers in southern Brazil. The Rice-Wheat Consortium, a network of scientists, extension agents, private machinery manufacturers and

NGOs in the Indo-Gangetic Plains of South Asia, has also been promoting conservation tillage farming.

Efficient Extension Services

The existing Training and Visit (T&V) system of extension services provided in India is top-down in its approach and there has been little participation by the farmers. This approach needs to be corrected so that the existing agriculture extension system could be reformed and revitalized. The approach to the reforms may include active involvement of farmers through user-group associations, extension methods including farmer-to-farmer extension, as has been practiced in many parts of the world. For example, the Programa Campesino a Campesino in Nicaragua, and Mviwata network in Tanzania provide national coverage of extension services through farmer-to-farmer approaches.

Mixing of public and private extension systems, including NGOs and farmer organizations would help improve extension delivery mechanism in India, especially to cater to farmers who are subsistence on agriculture. Besides, policies to improve ICT access in rural areas need to focus as much on content and education as on infrastructure.

IN SUM

Scientific and technological interventions are critical both for agricultural development and enhancing crop productivity. Technological interventions are important to meet the growing demand for food, rising resource constraints and energy costs. Innovation is also central for maintaining market competitiveness, both domestic and global.

Since Indian agriculture is heavily dependent on input usage – be it energy, water, fertilizers, or pesticides, strategies need to be adopted for sustainable management of resources to counter any negative impact on crop production and yield levels. For such sustainable productivity enhancement, with balanced use of water and fertilizers, policy support is required; especially, review of Government interventions in farm fertilizers, and farm power pricing may be needed.

1. INTRODUCTION

India has a large agricultural sector. The role of agriculture in economic development of India is well known. Agriculture not only contributes to the overall growth of the economy but also provides employment and food security to majority of Indian population. While the sector's share in GDP has halved in the past 30 years to around 15 percent, it still employs over half of India's workforce. India has made impressive strides on the agricultural front during the past three decades. Policy support, production strategies, public investment in rural infrastructure, research and extension for crop, livestock and fisheries have significantly helped in increasing the agricultural productivity, food production and availability. Growth in agricultural output over the past three decades has been strong, and importantly, crop production has been able to broadly keep pace with the demands from a growing population. Notwithstanding these achievements, producing additional food with limited land and providing economic access to food at the household level ensuring food security continues to be a major challenge for the nation.

India has experienced considerable changes in the crop mix, yield and production since the inception of the Green Revolution. The Green Revolution phase displayed a high yield growth per unit of input. Post Green Revolution, the first phase, (from late-1960s to mid-1980s), was marked by the continued growth in returns from land through the intensification in use of chemical inputs and machineries; and the second phase, (beginning mid-1980s), was characterized by high input-use and decelerating productivity growth.

Despite the growth in production in the Indian agricultural sector over the recent decades, crop-yields remain low when compared to world averages, and growth in yields has only been marginally higher than the world average. This calls for a focus on the issues related to the trends in agricultural productivity, and strategies to address it adequately.

India is among the largest producers of foodgrains in the world. It ranks third in the world in production of cereals, next to China and USA. India's arable area is 53 percent of its total land area, which is second largest in the world. In comparison, USA's arable land is 18 percent of its total land area, while it is 12 percent for China, the world's two leading food grain producers. While India with 158 million hectares of arable land produces only 249 million tonnes of cereals, China with 110 million hectares and USA with 163 million hectares of arable land produces 483 million tonnes and 420 million tonnes of cereals, respectively, which is almost double to that of India. This

Table 1.1 Land Area of India

Area (million ha)	India	World total	India's rank
Total area	329	13459	7
Land area	297	13003	7
Arable land	158	1381	2
Irrigated land	61	288	1

Source: FAOSTAT

Table 1.2 Land Availability and Crop Production by Major Producing Countries

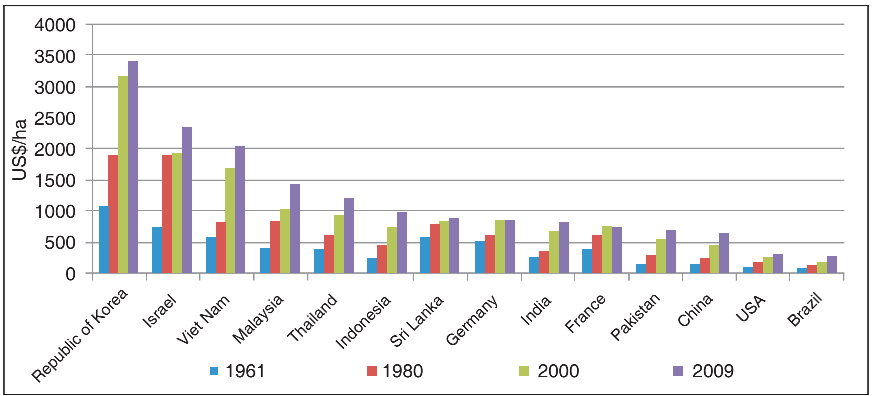
Countries	Land Area	Arable Land	% Arable to Total Land Area	Total Cereals million tonnes
	million ha	million ha		
China	933	110	12	483
USA	915	163	18	420
India	**297**	**158**	**53**	**249**
Russia	1,638	122	7	96
Brazil	846	61	7	71
France	55	18	33	70
Germany	35	12	34	50
World	**13,003**	**1,381**	**11**	**2,494**

Source: FAOSTAT

highlights the low productivity of Indian agriculture. Despite such large land resources being devoted to agriculture, India's overall production has been relatively low (Table 1.1 and 1.2).

According to a study undertaken by FAO on productivity in Asian agriculture, land productivity measured as the value of aggregate agricultural output per hectare of agricultural land, increased by an average of 2.26 percent per year and 2.34 percent per year from 1961 to 2009 in the World and Asia, respectively. Asia has the highest land productivity in the world compared to other regions (Exhibit 1.1). Though USA has been one of the leading grain producers, its land productivity has been considerably low compared to Asian grain producers. This may be largely attributed to the value of crop production in the USA, which mainly consists of corn and soybean used mostly for feed and seed production. In Asia, growth in land productivity was highest in Pakistan (3.25 percent) during the period 1961-2009; however, in absolute terms Republic of Korea had the highest land productivity during the period (Table 1.3). During the same period, land productivity in India was much lower compared to other Asian and neighbouring countries.

Exhibit 1.1 Land Productivity in Agriculture in Select Countries
(International 2004-06 US$/hectare)



Note: Net agricultural production is gross production minus feed and seed. Growth rates are 3-year centered moving averages

Source: FAOSTAT 2011

Table 1.3 Land Productivity in Agriculture
(International 2004-06 US$/hectare)

Country/ Year	1961	1980	2000	2009	1961-2009 % per year
	US$ / ha				
Republic of Korea	1090	1904	3173	3408	2.66
Israel	753	1900	1933	2351	2.73
Viet Nam	599	835	1705	2013	2.66
Malaysia	409	854	1028	1451	2.86
Thailand	405	612	956	1215	2.53
Indonesia	238	453	735	977	3.09
Sri Lanka	592	802	860	898	1.15
Germany	520	624	865	867	1.03
India	**269**	**377**	**679**	**843**	**2.70**
France	411	633	771	764	1.31
Pakistan	156	299	563	703	3.25
China	160	245	469	651	3.02
USA	120	198	282	323	2.61
Brazil	100	131	191	287	2.47
Asia	***159***	***252***	***351***	***472***	***2.34***
World	***99***	***150***	***227***	***287***	***2.26***

Note: Net agricultural production is gross production minus feed and seed. Growth rates are 3-year centered moving averages

Source: FAOSTAT 2011

Agriculture in India is categorized in two broad sectors, namely, farm sector and non-farm sector. The later comprise mainly of allied activities, such as livestock and fisheries, and the former comprise of crops. The crop sector in India is dominated by foodgrains production, which accounts for about 65 percent of the total cropped area. A comparison of productivity of Indian foodgrains and oilseeds with the world also highlights the low productivity aspect in foodgrain and oilseed sectors in India (Table 1. 4) Annexure-I.

Table 1.4 Comparisons of Area, Production and Productivity of Select Crops in India and World

Select Crops	World			India*				
	Production (Million Tonnes)	Area Harvested (Million Ha)	Yield (kg/ha)	Production (Million Tonnes)	Share in world production	Area Harvested (Million Ha)	Share in world area %	Yield (kg/ha)
Paddy	684.8	158.4	4324	99.0	14.5	41.9	26.4	2178
Wheat	687.0	224.8	3055	80.7	11.7	27.8	12.3	2839
Maize	820.0	158.8	5160	17.0	2.1	8.3	5.2	2024
Pulses	63.1	68.7	919	14.2	22.4	20.9	30.5	630
Sugarcane	1668.0	23.7	70274	285.0	17.1	4.4	18.6	64486

*Source: FAOSTAT 2011; * Ministry of Agriculture, Govt. of India*

Box - I
Productivity of Fruits & Vegetables in India

India is the second largest producer of fruits and vegetables in the world, next only to China, with a production of 71.5 million tonnes and 133.7 milllion tonnes, respectively, during 2009. However, India's productivity in fruits and vegetables is significantly low compared to some of the leading producers in the world. India's productivity in vegetables is below world average, and in fruits it is marginally above the world average.

Fruits

Countries	Production (million tonnes)	Area (million Ha)	Yield (ton/Ha)
USA	27.8	1.2	23.9
Indonesia	16.0	0.7	22.2
Brazil	38.7	2.4	15.8
Italy	17.6	1.3	13.9
Philippines	15.6	1.1	13.9
Mexico	16.1	1.2	13.4
Turkey	12.8	1.0	12.4
India	71.5	6.3	11.3
Iran	13.2	1.3	10.4
China	109.6	11.1	9.9
Spain	16.3	1.7	9.3
Others	228.9	26.2	8.7
World	579.9	55.0	10.5

Vegetables

Countries	Production (million tonnes)	Area (million Ha)	Yield (ton/Ha)
Rep of Korea	11.3	0.3	36.7
Spain	12.6	0.4	35.8
USA	37.3	1.2	32.1
Egypt	19.2	0.7	26.5
Italy	13.7	0.5	26.1
Iran	15.0	0.6	25.3
Turkey	27.2	1.1	24.6
China	457.8	24.1	19.0
Russia	14.3	0.8	18.7
Mexico	12.1	0.7	18.1
India	133.7	8.0	16.7
Others	221.3	16.9	13.1
World	931.9	53.7	17.3

Source: FAOSTAT and National Horticulture Board (NHB), India

Foodgrains production has been an area of concern for India since many years. India was dependent on foodgrain imports for almost two decades after independence. End of 1960s marked the beginning of a turning point in Indian agriculture with the advent of the Green Revolution. Production of foodgrains in India, which mainly consists of rice and wheat, grew by 25 percent and 45 percent, respectively, in the year 1967-68 over the previous year. During the same year, the yield in paddy and wheat recorded an increase of 20 percent and 24 percent, respectively. The levels of growth continued to show upward trend during 1970s, 1980s and upto 1990s. However, the highest growth in production and productivity was recorded during the 1980s and 1990s, which was mainly due to the realization of the reforms brought about in the Indian agricultural research system, government policies, and capacity building of farmers during the beginning of the Green Revolution in the 1960s. The development of high-yielding variety (HYV) of seeds in mid 1960s and the subsequent use of the fertiliser-pesticides-irrigation package and education of farmers led to quantum jumps in the productivity in the Indian foodgrain sectors. Consequently, productivity of rice, wheat and foodgrains grew at an average rate of 4.9 percent, 4.5 percent, and 4.4 percent, respectively during 1980s as compared to the growth level of 2.9 percent, 3.0 percent and 2.6 percent, respectively during 1970s. Production of foodgrains also recorded similar growth trends. Upward trend in average growth rates were also recorded in productivities and productions of pulses and oilseeds during 1980s when compared to 1970s (Table 1.5).

The productivity of Indian agriculture, however, witnessed a fatigue with the average growth rate of production of rice, wheat and foodgrains during 1990-2010 slowing down to 0.85 percent, 2.6 percent and 1.6 percent, respectively. This was mainly due to stagnancy in yields of rice, wheat and foodgrains, which grew at an average rate of 1.3 percent, 1.5 percent and 1.6 percent, respectively. Moreover, the average growth rate of foodgrains production at 1.6 percent during 1990-2010 trailed the average

Table 1.5 Growth Rate of Yields and Production of Foodgrains and Oilseeds in India

Periods	Production Growth					
	Rice	Wheat	Coarse Cereals	Pulses	Total Foodgrains	Oilseeds
1960-1970	3.25	9.10	3.20	1.57	3.77	4.82
1970-1980	3.81	6.10	1.33	0.38	3.08	3.16
1980-1990	6.05	5.43	2.43	5.44	4.79	8.56
1990-2010	0.85	2.64	1.22	-1.38	1.56	3.60
2005-2010	- 0.27	3.34	0.82	- 8.00	2.04	1.46
Periods	**Yield Growth**					
	Rice	**Wheat**	**Coarse Cereals**	**Pulses**	**Total Foodgrains**	**Oilseeds**
1970-1980	2.88	3.07	2.13	(-) 0.25	2.60	0.98
1980-1990	4.93	4.48	3.43	4.13	4.40	4.64
1990-2010	1.28	1.55	2.26	0.33	1.60	2.49
2005-2010	1.47	1.72	1.85	1.69	1.79	2.31

Source: Data-Ministry of Agriculture, Govt. of India; Exim Bank Research

population growth of 1.9 percent (Table 1.5) indicating decrease in per capita availability of foodgrains.

Regional Disparities

Agricultural development pathways followed in different states of India varied in the intensity and extensity of the agricultural growth. Wide disparities exist in the agricultural productivities in the states (Table 1.6).

With relatively high productivity, the Indo-Gangetic-Plain (IGP) has been the mainstay of India's agricultural economy and a strong base for food security of the country. The IGP mainly comprises five contiguous states – Punjab, Haryana, Uttar Pradesh, Bihar and West Bengal. Parts of Northeastern states, Rajasthan, Madhya Pradesh, Orissa, and Jharkhand also falls under the IGP. Large spatial variations exist in the physiographic, climatic, edaphic, and socio-economic production features of the IGP, which is noticeably

Table 1.6 Productivity of Foodgrains in Select Indian States

State/UT	2000-01	2004-05	2005-06	2006-07	2007-08	2008-09	2009-10
Punjab	4032	4040	3986	4255	4231	4144	4180
Haryana	3060	3092	3045	3420	3388	3383	3401
West Bengal	2231	2479	2423	2525	2493	2522	2570
Tamil Nadu	2461	1874	1847	2125	2225	2477	2364
Kerala	2094	2278	2219	2221	2440	2470	2519
Andhra Pradesh	2089	2138	2365	2613	2744	2294	2514
Uttar Pradesh	2105	1961	2057	2206	2365	2236	2387
Uttarakhand	1712	1697	1548	1785	1715	1780	1840
Assam	1457	1405	1416	1378	1551	1662	1951
Gujarat	827	1412	1551	1831	1595	1560	1845
Bihar	1694	1192	1311	1546	1766	1530	1516
Jammu & Kashmir	1224	1686	1680	1711	1851	1405	1452
Orissa	950	1300	1349	1484	1363	1397	1442
Karnataka	1412	1388	1776	1548	1511	1377	1645
Himachal Pradesh	1366	1923	1731	1918	1757	1297	1936
Madhya Pradesh	945	1131	1130	1069	1168	1285	1161
Maharashtra	757	836	948	1150	1001	1039	1189
Chhattisgarh	589	979	1111	1238	1041	1008	1457
Rajasthan	883	1008	919	1180	1263	931	1244
All India	1626	1652	1715	1860	1909	1798	1921

States ranked according to productivity

Source: Department of Agriculture and Cooperation, Govt. of India

reflected in the agricultural productivities and growth. Punjab and Haryana has been the high productive regions of the country and the heartland of Green Revolution much due to the favourable factors. The Northwest region of IGP comprising these two states, besides other northern states, are mainly semi-arid with an annual rainfall of 500 mm to 800 mm, with a well developed irrigation infrastructure. Summer and winter temperatures are in extremes. Wheat has traditionally been and continues to be the main crop in the region, and in the recent decades, rice production has expanded rapidly. In contrast, eastern plains comprising Bihar and West Bengal, besides others, face challenges, such as flooding, and its average rainfall ranges from 1,000 mm to 2,000 mm. Summer and winter temperatures in the region is moderate. Rainfed lowland rice is the main crop, and only lately, wheat production has been introduced, which has picked up substantially. Further, the population pressure on the natural resources in the eastern region is also high. Bihar and West Bengal have double the population density as compared to Punjab and Haryana, which in relative terms, make eastern region land scarce and labour abundant. Farm size is negatively correlated to population density. Hence, in Punjab and Haryana individual holdings are larger than the holdings in the states of eastern region. The aggregate asset base is, thus, more favourable in the north-western states i.e., Punjab, Haryana and parts of Uttar Pradesh, having more access to irrigation and mechanization.

Besides, there are wide regional disparities in output across regions in India (Table 1.7). Certain regions such as Punjab, Haryana, western Uttar Pradesh, parts of Andhra Pradesh and Tamil Nadu had benefited more during the initial phase of the Green Revolution than others could. This had accentuated regional disparities in the immediate post- Green Revolution period. An important feature of the 1980s and the early-1990s, however, was a more equitable spread of agricultural growth. Assam, Bihar, Orissa, Madhya Pradesh and West Bengal, have shown significant growth during the 1980s. Oilseeds productions has gained in the dry belts of Rajasthan, Madhya Pradesh, Karnataka and Maharashtra during the same period. Table 1.7 shows that growth rate in agriculture Net State Domestic Product (NSDP) was high for many states during the period 1980-90 and 1990-2000. However, growth rates in agriculture NSDP decelerated in all the states post 2000 except in Gujarat and Madhya Pradesh. There also has been no significant change in crop productivities in the states.

With area under the foodgrains productions growing marginally for the past three decades at average annual growth rate of 0.42 percent, low yield per unit area across major crops has become a regular feature of Indian agriculture in the recent years. Further, agricultural growth declining in almost all the major states in India, the major concern during the post-reform period has been the

Table 1.7 Growth Rates of Agriculture NSDP in Different States

	CAGR (%p.a.)		
States	**1980-1990**	**1990-2000**	**2000-2010**
Andhra Pradesh	11.0	12.3	9.6
Punjab	12.2	12.5	7.5
Haryana (SDP)	10.2	10.4	8.9
Uttar Pradesh	9.1	10.5	8.1
Tamil Nadu	10.7	13.9	9.1
West Bengal	12.3	14.4	8.1
Bihar	9.7	4.1	5.3
Gujarat	9.5	8.6	15.1
Rajasthan	11.2	10.5	8.1
Orissa	9.0	13.0	11.2
Madhya Pradesh	9.7	7.8	11.0
Karnataka	9.7	14.9	4.9
Maharashtra	11.8	11.4	6.9
Kerala	9.1	11.5	8.8
Assam	11.0	12.2	7.1

Source: CMIE

decline in yield growth for both foodgrain and non-foodgrain crops. However, the reduction has been much higher for foodgrains than non-foodgrains. This can be attributed to structural weaknesses of the agriculture sector reflected in the input implants in the sector, which is further analysed in the subsequent chapters of the study. The objective of the analysis and thereby the study is to determine the factors, which might be responsible for such weaknesses and explore possible solutions to address them adequately.

2. INPUT USE TRENDS IN INDIAN AGRICULTURE AND IMPACT ON PRODUCTION

One of the reasons for the decline in output growth and farm income in India has been low yield growth in the post-reform period. According to some research findings, the reduction in yield growth, in turn, was largely as a result of reduction in input growth in agriculture. The growth in per hectare input-use at constant prices decelerated from 3.66 percent per annum during 1980s to 0.94 percent per annum during the 1990s (Sen and Bhatia; 2004). Mid-term Appraisal of the Tenth Plan also attributes a part of the decline in agricultural growth to lower input-use, which in turn, has been due to lower returns in the post-reform period.

The key inputs to supplement crop production and productivity are hybrid seed, fertilizer, pest management, and irrigation. Considering the above aspects, input management plays a vital role for crop production and productivity. Detailed analysis on impact of all inputs on productivity in Indian agriculture is limited in this study. However, impact of some key inputs on productivity has been analysed in this chapter.

Fertilizer

Consumption of fertilizer is largely dependent on growing conditions, such as weather and soil, and socio-economic status of the farmers. Table 2.1 illustrates uptake of fertilizer during the green revolution period and post reform period in India. Average per hectare use of fertilizer doubled in absolute terms in every decade from 1971 to 1991. Subsequently, the rate of increase slowed down, which however, increased at an annual average rate of 4.02 percent per

Table 2.1 Fertilizer Use in India (1971-2009)

	1971	1981	1991	2000 -01	2001 -02	2002 -03	2003 -04	2004 -05	2005 -06	2006 -07	2007 -08	2008 -09-	2009 -10	Growth (CAGR) in Fertiliser Use (1991-2009) (%)
Fertilizer use (kg/ha)	16.5	34.2	69.8	89.6	91.1	91.5	88.1	94.5	105.5	111.8	116.5	128.6	144.1	4.02

Source: Department of Agriculture and Cooperation, Govt. of India

year until 2009-10. In 2009-10, the average rate of fertilizer application was 144 kg per hectare (Table 2.1).

Fertiliser use has varied vastly throughout the regions in the world. Asia has been leading in terms of total fertilizer consumption as well as average per hectare consumption of fertilizer. The top five fertilizer consumers, namely, China, India, USA, Brazil and Indonesia, accounts for nearly 70 percent of fertilizer consumption while top five producers (China, Canada, Russia, USA and India) controls about 60 percent of world fertilizer production (Table 2.2).

Currently, India is the second largest producer of fertilizer-nitrogen in the world, and holds the third position for phosphate fertilizers. However, potash is totally imported. India is second only to China in nitrogen and phosphorus consumption. The consumption of chemical fertilizers (in terms of nutrients) during 2010-11 has been 282 lakh tonnes comprising of 166 lakh tonnes of Nitrogen, 81 lakh tonnes of phosphatic and 35 lakh tones of potassic fertilizer. Nonetheless, average consumption of fertilizers in the country is low and, currently at 144 kg per hectare of arable land (2010-11). This is below the average consumption of fertlisers in countries such as China (395.1 kg per hectare), Egypt (388.1 kg per hectare), Chile (269 kg per hectare), Vietnam (195.5 kg per hectare), Pakistan (174.1 kg per hectare) and Bangladesh (149.8 kg per hectare in 2008). However, it is higher than USA (116 kg per hectare).

The total fertilizer consumption in India, in 2010-11, is estimated at 28.3 million tonnes (Table 2.3). There has not been any significant

Table 2.2 Fertilizer Consumption in Select Countries 1961-2009

Countries	Total NPK consumption in thousand tonnes							CAGR (%)					
	1961	1971	1981	1991	2001	2005	2009	1961-71	1971-81	1981-91	1991-01	2001-05	2005-09
China	1012	4311	15271	29125	35556	46668	49100	15.6	13.5	6.7	2.0	5.6	1.0
India	418	2383	5724	12728	17359	20364	26493	19.0	9.2	8.3	3.2	3.2	5.4
USA	7879	15579	19427	18785	19614	19273	18908	7.1	2.2	-0.3	0.4	-0.4	-0.4
Brazil	228	1165	2747	3386	7090	8720	9045	17.7	9.0	2.1	7.7	4.2	0.7
Indonesia	144	253	1454	2400	2529	3710	4466	5.8	19.1	5.1	0.5	8.0	3.8
Pakistan	73	382	1080	1884	2924	3936	4361	18.0	11.0	5.7	4.5	6.1	2.1
Viet Nam	67	216	219	782	2028	2071	2090	12.5	0.2	13.6	10.0	0.4	0.2
Turkey	53	494	1304	1769	1671	2068	2054	25.1	10.2	3.1	-0.6	4.4	-0.1
Thailand	20	101	329	962	1710	1747	1633	17.8	12.6	11.3	5.9	0.4	-1.3
Bangladesh	22	116	396	1005	1467	1605	1610	18.3	13.1	9.8	3.9	1.8	0.1
Malaysia	67	216	420	941	1141	1606	1532	12.4	6.9	8.4	1.9	7.1	-0.9
Iran	15	141	697	1149	1320	1502	1449	25.5	17.3	5.1	1.4	2.6	-0.7
Japan	1640	1913	1882	1752	1354	1294	921	1.6	-0.2	-0.7	-2.5	-0.9	-6.6
Philippines	81	205	322	448	786	704	646	9.7	4.6	3.4	5.8	-2.2	-1.7
Korea Republic	329	628	829	928	675	722	485	6.7	2.8	1.1	-3.1	1.4	-7.7
Israel	37	62	90	94	89	105	91	5.3	3.8	0.4	-0.5	3.3	-2.7

Source: International Fertiliser Association 2012

increase in indigenous capacities of finished fertilizers in the past decade, except improvement in capacity through revamping in some of the urea plants. Consequently, import of finished fertilizers has also increased significantly. Currently about 38 percent of the total fertilizer consumption is fulfilled through imports. The imports of total finished fertilizers have gone up to 21.7 million tonnes in 2010-11 from 3.6 million tonnes in 2000-01. Out of 21.7 million tonnes, the import of urea was 6.6 million tonnes, DAP 7.4 million tonnes, and MOP 6.4 million tonnes (Exhibit 2.1).

Another notable feature of fertilizer use in India has been the considerable interregional variation, especially in the irrigated areas. For instance, in Andhra Pradesh and Punjab, average fertilizer use is as high as 252.8 kg/Ha and 237.3 kg/Ha, respectively. Fertiliser application is the lowest in the Eastern and North Eastern regions of the country with wide variations. During 2010-11, it varied from 3 kg/Ha in Arunachal Pradesh to 173.5 kg/Ha in Bihar (Annexure-II).

Table 2.3 Production, Consumption and Imports of Fertilizer Nutrients in India

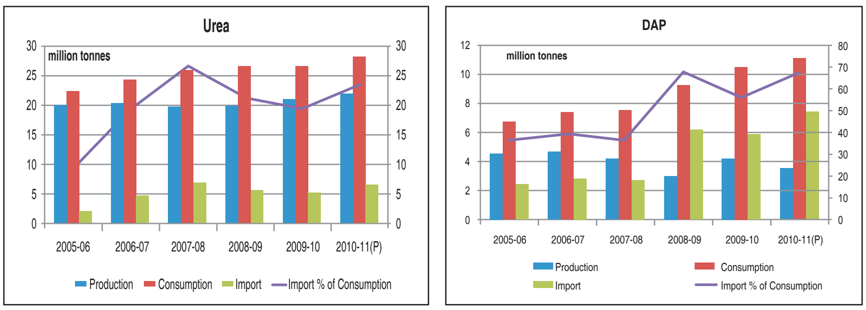
(million tonnes)

Year	Nitrogen (N)	Phosphate (P_2O_5)	Potash (K_2O)	Total	% increase over the previous year	Kg/ hectare (N+P+K)
2007-08	14.4	5.5	2.6	22.6	4.2	115.7
2008-09	15.1	6.5	3.3	24.9	10.4	127.7
2009-10	15.6	7.3	3.6	26.5	6.3	135.8
2010-11*	16.9	8.0	3.4	28.3	6.8	145.0

**(Provisional)*

Source: Working Group on Fertilizer for 12th Five Year Plan, Govt. of India

Exhibit 2.1 Trends in Production, Consumption and Import of Urea and Di-Ammonium Phosphate (DAP) in India



Source: Working Group on Fertilizer for 12th Five Year Plan, Govt. of India

With respect to type of fertilizers used, nitrogen fertilizer is most commonly used by the farmers in India (Table 2.4). It has been generally noted that use of plant nutrients in many parts of the country is highly concentrated towards nitrogenous fertiliser and over the years, a large imbalance has emerged between ratio of Nitrogen (N), Phosphorous (P) and Potassium (K) as applied by farmers and the ratio that is considered optimum. The ideal N : P : K ratio, aggregated for the country as a whole, is 4:2:1; however, during 1992-93, following decontrol of phosphatic and potassic fertilizers, the NPK consumption ratio distorted to 9.5:3.2:1 and still continues to be quite wide at 5:2.4:1. This has raised considerable concerns regarding soil fertility, productivity and efficiency of fertiliser use in the country. Analyses reveal that the growth in fertilizer application has not been able to create a significant positive impact on crop production (Table 2.5). Nitrogen use efficiency in rice crop is only 30-35 percent, with an overall efficiency level at 50 percent. Phosphatic fertilizers are the costliest on (Rs./kg) of nutrient basis but their use efficiency is 20-25 percent only. Efficiency of potash is around 70-80 percent[1].

Table 2.4 Consumption of NPK Fertilizer in India

(Lakh tonnes)

Fertilisers	1991-92	1995-96	2000-01	2005-06	2009-10	2010-11
Nitrogenous (N)	80.46	98.23	109.2	127.23	155.8	165.58
Phospatic (P)	33.21	28.98	42.15	52.04	72.74	80.5
Potassic (K)	13.61	11.56	15.67	24.13	36.32	35.14
Total (NPK)	127.28	138.77	167.02	203.4	264.86	281.22
Consumption of Fertiliser (kg/Ha)	69.84	74.02	89.63	105.5	135.76	144.14

Source: Department of Agriculture and Cooperation, Govt. of India

Table 2.5 Growth Rate in Fertiliser Use and Crop Output

Period	Annual Average Growth Rate (%)		NPK/Ha
	Fertilizer	Crop Output	Range
1950-51 to 1966-67	17.7	2.4	0.5 to 7.0
1966-67 to 1991-92	9.2	2.8	7 to 70
1991-92 to 2006-07	3.4	1.3	70 to 113
1994-95 to 2008-09	4.6	1.7	72 to 129
1998-99 to 2006-07	2.6	1.1	87 to 113

Growth rates except in 1998-99 to 2006-07 and 1994-95 to 2008-09 were significant at 0.1 to 5% level; Growth rate in fertilizer refers to quantity of NPK and growth rate in crop output refer to index number of production of principal crops.

Source: Department of Agriculture and Cooperation, Govt. of India

[1] US Awasthi (1999)

With the economic reforms introduced in India, prices of P and K were decontrolled and subsidy on these fertilisers was severely reduced. This led to a very sharp increase in prices of P and K, making a distinct change in fertiliser prices in favour of N, which was almost halved. This has been an important factor in shifting balance of fertiliser use in favour of N and against P and K (Table 2.6).

Table 2.6 Fertilizer Subsidy in India

Year	Fertilisers			Total Fert. Subisdy (Rs. Crore)	N Subsidy to Total Fert. Subsidy (%)
	Indigenous Urea	Imported Urea	Decontrolled (P & K)		
1990-91	3730	659	-	4389	100
1991-92	3500	1300	-	4800	100
1992-93	4800	996	-	5796	100
1993-94	3800	762	-	4562	100
1994-95	4075	1166	528	5769	90.8
1995-96	4300	1935	500	6735	92.6
1996-97	4743	1163	1672	7578	77.9
1997-98	6600	722	2596	9918	73.8
1998-99	7473	333	3790	11596	67.3
1999-2000	8670	74	4500	13244	66.0
2000-01	9480	1	4319	13800	68.7
2001-02	8044	47	4504	12595	64.2
2002-03	7790	-	3225	11015	70.7
2003-04	8521	-	3326	11847	71.9
2004-05	10243	494	5142	15879	67.6
2005-06	10653	1211	6596	18460	64.3
2006-07	12650	3274	10298	26222	60.7
2007-08	12950	6606	12934	32490	60.2
2008-09	16517	10981	48351	75849	36.3

Source: IIM Ahmedabad; Exim Bank Research

Box - II: Fertilizer Subsidy in Indian States

Amount of fertiliser subsidies going to different states depend upon size of the state i.e. area under cultivation, amount of fertiliser used per hectare and composition of fertiliser used. Out of total subsidy on fertiliser in the country, largest chunk (18 percent) goes to Uttar Pradesh followed by Andhra Pradesh (11.4 percent). Around 9 percent of total subsidies go to Maharashtra and Punjab each. Assam, Himachal Pradesh, Jammu and Kashmir, and Uttaranchal received below 1 percent. This distribution does not indicate which states have benefited more from subsidies.

Fertilizer subsidy on per hectare basis varies in the range of Rs. 393 in Rajasthan to Rs. 3167 in Punjab. After Punjab, the second most benefited state is Haryana with subsidy of Rs. 2516 per hectare of net sown area. Farmers in West Bengal, Uttar Pradesh and Andhra Pradesh are estimated to have received subsidy between Rs. 1626 per Ha and Rs. 1730 per Ha. Among other states, per hectare subsidy was above Rs. 1000 in Uttaranchal, Bihar and Tamil Nadu. States with less than Rs. 600 subsidy are Assam, Chattisgarh, Jharkhand, Madhya Pradesh, Orissa and Rajasthan.

One limitation of this measure, as an indicator of disparity in subsidies, is that it ignores variation in productivity resulting from variation in use of fertiliser. For instance, Punjab and Haryana, which rank at the top in per hectare subsidy, also rank among the top states in productivity. When productivity too is considered in reference to subsidy as percent of value of crop output in a state, also shows that Punjab and Haryana receives highest benefit from fertilizer subsidy closely followed by Andhra Pradesh.

Statewise Subsidies on Fertilizers, TE 2005-06

States	State's share in all India subsidies (%)	Subsidy/ha (Rs.)	Subsidy as % of value of crop output
Punjab	8.83	3167	4.92
Haryana	5.89	2516	4.75
Andhra Pradesh	11.41	1655	4.73
Uttar Pradesh	18.13	1626	3.93
Tamil Nadu	4.85	1460	3.9
Bihar	4.22	1115	3.63
Karnataka	6.55	971	3.57
Chhattisgarh	1.77	559	3.25
Gujarat	6.23	975	3.12
Madhya Pradesh	5.38	543	2.71
Uttarakhand	0.66	1286	2.57
Rajasthan	4.42	393	2.45
Maharashtra	9.11	788	2.44
West Bengal	6.34	1730	2.39
Orissa	1.93	518	1.77
Jharkhand	0.67	572	1.66
Jammu & Kashmir	0.45	905	1.43
Assam	0.74	517	1.43
Kerala	1.03	719	1.05
Himachal Pradesh	0.25	704	0.91
All India	100	1067	3.16

Source: Ramesh Chand and L.M. Pandey (2008)

Seed

Seed, is the vehicle for delivering the benefits of technology, and is the most important input, influencing the growth and sustainability of agriculture. Use of quality seeds alone can improve the productivity of crops to the tune of 15 percent[2]. Supply of certified/quality seeds and the Seed Replacement Rate (SRR) are the two most important factors in enhancing productivity in agriculture.

Seeds have been in the forefront of technological advances in Indian agriculture. The two levels of developments in seed technology have been: a) hybridization and b) genetic modification. Hybridization requires cross-breeding of seeds to get the desired characteristics, such as drought resistant, pest resistant and increased yield or quality. In Genetically Modified (GM) seeds, the desired changes are brought about by altering the genetic configuration of the crop species. Use of quality seeds has been increasing in Indian agriculture (Exhibit 2.2). Use of hybrid seeds in Indian agriculture is mostly in case of cash crops, such as cotton and sunflower. There has been a low penetration of hybrid seeds in case of staples in the country. The levels of hybridization in food crops vary significantly from 2 percent to 5 percent in paddy and wheat, to 20 percent to 90 percent for coarse grains, such as jowar, bajra and maize (Table 2.7).

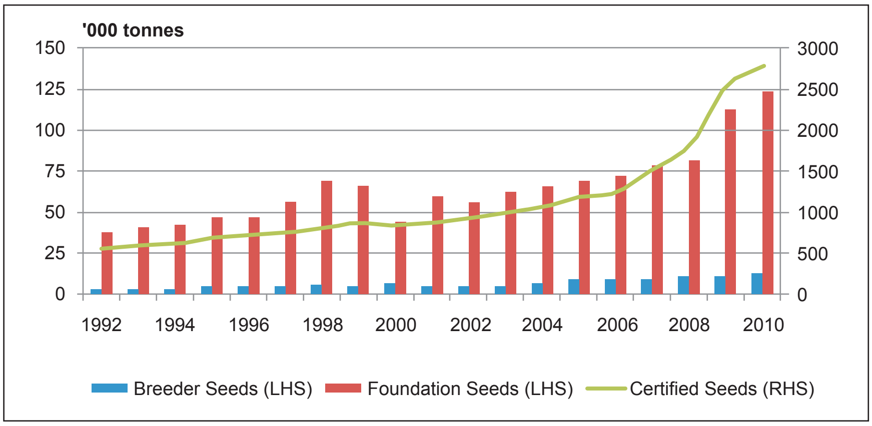
Table 2.7 Use of Hybrid Seeds in Food Crops in India

Crop	Total Cropped Area (Million Ha)	% Hybrid Coverage
Sunflower	1.2	95
Bajra	6.5	90
Cotton	8.5	80
Sorghum	6.5	Kharif-80 Rabi< 5
Castor	0.5	70
Maize	6.5	60
Jowar	7.9	20
Wheat	70.2	5
Rice	44.5	2
Total	144.3	60

Source: National Seed Association of India, 2009

[2] ICAR

Exhibit 2.2 Production of Various Types of Seeds in India, 1992-2010 ('000 tonnes)



Source: Department of Agriculture and Cooperation, Govt. of India; Planning Commission

Though SRR for principal food crops in India has almost doubled from 16 percent during 2001 to 31 percent during 2008-09 (Table 2.8); however, it has been considerably low. There are also considerable interregional variations in SRR. The SRR is highest in the Western and Southern regions of the country, with the state of Maharashtra having the highest SRR, followed by Tamil Nadu and Andhra Pradesh. SRR is the lowest in the Central, Eastern and North Eastern regions of the country.

Farm Mechanization

Farm mechanization is an important component for increasing crop production and productivity besides reducing drudgery of farm labourers. It also enables efficient utilization of agricultural inputs and reduces the cost of production. In the current study, extent of farm mechanization in relation to crop productivity is assessed in terms of tractor use only. An analysis of average tractor use in agriculture per thousand hectares in the world reveals that tractor use has been highest in Europe, followed by America and Asia (Table 2.9).

Table 2.8 Seed Replacement Rate (SRR) in India in Principal Food and Oilseed Crops

Percentage

Crops	2001	2002	2003	2004	2005	2006	2007	2008
Wheat	13.0	13.0	13.0	16.5	17.6	21.8	25.2	26.8
Paddy	19.2	19.3	19.2	16.3	21.3	22.4	25.9	30.1
Maize	21.0	21.4	24.4	31.5	35.4	43.8	44.2	48.5
Jowar	18.4	18.8	26.7	19.3	19.0	19.4	19.9	26.2
Bajra	45.9	48.5	51.0	44.9	55.4	55.1	48.5	62.9
Gram	4.2	4.2	7.1	9.9	9.4	9.0	11.9	14.4
Urad	16.6	17.1	20.5	17.2	15.7	13.7	23.9	26.3
Moong	13.5	13.8	19.5	12.3	12.5	20.0	21.8	21.9
Pigeon Pea	8.7	8.8	13.6	9.8	10.5	11.6	16.1	16.0
Groundnut	5.2	5.5	11.0	7.1	6.9	9.8	14.3	17.0
Soybean	12.4	12.5	15.6	27.0	28.9	28.4	33.3	35.1
Sunflower	13.7	15.7	19.6	60.2	67.7	66.9	62.9	43.6
Principal food crops	16.0	16.5	20.1	22.7	25.0	26.8	29.0	30.7

Source: Department of Agriculture and Cooperation, Govt. of India

Table 2.9 Use of Tractors in the World

	1961	1971	1981	1991	2001	2003*
	(tractors per 000 Ha)					
World	2.5	3.6	4.8	5.3	5.5	5.6
Africa	0.2	0.3	0.4	0.5	0.5	0.5
Americas	5.2	5.8	5.7	5.8	6.1	6.1
Asia	0.2	0.8	3.0	4.2	4.7	5.2
Europe	6.3	10.7	14.5	16.3	22.7	22.8
Oceania	0.7	0.9	0.9	0.8	0.8	0.9

*Latest available data for comparison
Source: FAOSTAT 2011

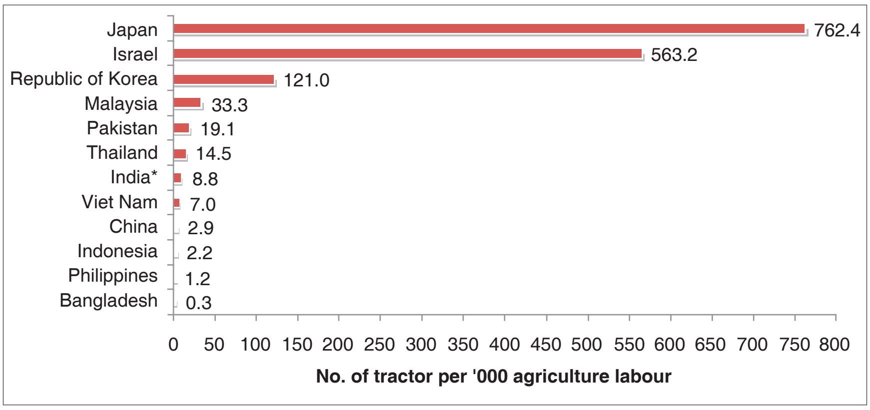
At the beginning of the green revolution in Asia, few tractors were in use in Asian agriculture. The number of tractors per thousand hectares of agricultural area as well as per thousand agricultural labourers rapidly increased in developing economies of Asian region. Growth in tractor use per thousand hectares of agricultural area was highest between 1961 to 1981, with the most rapid growth, 17.2 percent, witnessed during the Asian green revolution. Japan and the Republic of Korea experienced the most thorough growth. Tractor use has remained particularly low in the South Asian countries, such as Bangladesh, Nepal, Sri Lanka, Pakistan and India (Table 2.10) (Exibit 2.3). However, given the magnitude of arable land, agricultural area and population of farm labourers in India, tractor use in India has been considerably low.

Table 2.10 Tractors per Thousand Hectares of Agricultural Land and Growth in use

Year / Period	1961	1971	1981	1991	2003*	1961-71	1971 81	1981 91	1991-2003
	(tractors per 000 Ha)					Growth in use per 000 Ha (percent per year)			
China (CAGR)	0.5	1.3	7.7	6.6	8.2	9.47	19.84	-1.5	2.2
India	0.2	0.8	2.3	5.9	14.0	15.2	11.4	11.5	7.2
Indonesia	0.0	0.2	0.2	0.8	1.9	19.4	0.4	13.0	8.0
Republic of Korea	0.0	0.1	1.7	24.5	111.2	27.2	37.2	29.1	13.8
Japan	1.0	42.5	233.8	347.7	428.2	55.3	22.5	4.8	1.8
Israel	14.6	30.4	49.3	44.8	44.5	8.1	5.7	-0.5	-0.2
Malaysia	0.4	1.1	1.6	3.9	5.5	10.7	5.1	11.1	3.2
Pakistan	0.3	1.0	4.4	10.5	11.8	16.3	16.9	9.6	0.9
Philippines	0.5	0.9	1.0	1.0	1.0	5.4	1.3	0.6	0.1
Thailand	0.4	0.5	1.1	3.0	11.3	1.2	10.7	11.4	12.2
Viet Nam	0.4	0.4	3.7	5.2	17.1	1.1	36.6	1.2	14.2
Bangladesh	0.1	0.2	0.5	0.5	0.6	11.6	6.7	1.0	0.9
Sri Lanka	2.7	6.3	5.0	2.7	4.4	8.4	-2.1	-6.3	5.7
Nepal	0.1	0.2	0.6	1.3	1.3	18.6	12.5	9.1	-0.1
Asia	*0.2*	*0.8*	*3.0*	*4.2*	*5.2*	*17.2*	*15.9*	*3.4*	*2.2*
World	*2.5*	*3.6*	*4.8*	*5.3*	*5.6*	*3.7*	*3.0*	*1.3*	*0.5*

*Latest data available for comparison; Growth rates are 3-year centered moving averages
Source: FAOSTAT 2011

Exhibit 2.3 Tractor per Thousand Agricultural Labour in Asia in 2003



*Data pertaining to 2001
Source: FAOSTAT

Over the past three decades there has been considerable progress in agriculture mechanization in India. However, total farm power (combination of tractor, power tiller, diesel engines and electric motor, animate, and mechanical power) input per unit cultivated land in India is still very low at 1.5 kW/Ha compared to Japan (14 kW/Ha), South Korea (7 kW/Ha), China (6.8 kW/Ha) and USA (6 kW/Ha). Main reason being, small farmers in India have been still adopting and utilising select farm equipments through custom hiring for efficient farm management.

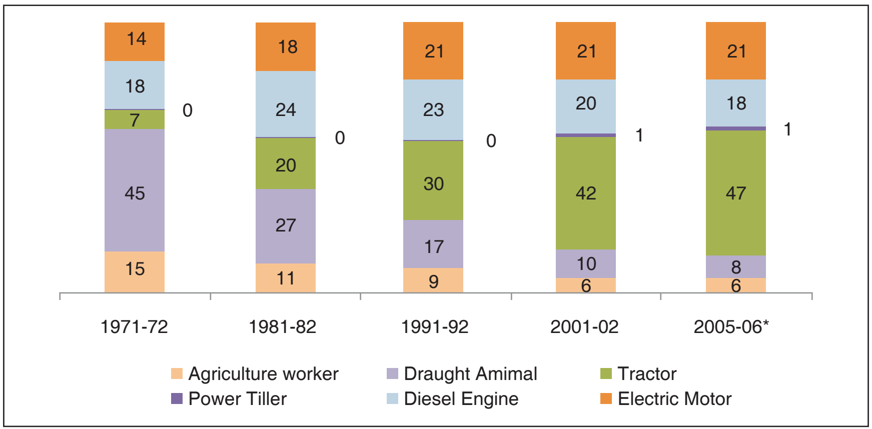
The contribution of different farm power sources to the total farm power changed with time (Table 2.11) (Exhibit 2.4). The share of agricultural workers continuously declined since 1981 and expected to be having a share of only 5.09 percent in 2011-12 and that of draught animal power expected to have come down from 27.23 percent to 6.37 percent in same period. The increase in power has been mainly through introduction of tractors, whose contribution has increased from 7.5 percent in 1971 to 51.08 percent in 2011-12.

Table 2.11 Contribution of Different Power Sources in India

Year	Agricultural workers	Draught Animals	Tractors	Power Tillers	Diesel Engines	Electric Motors	Power kW/ha
1971-72	10.64	52.86	8.45	0.11	17.16	10.79	0.424
1981-82	9.2	33.55	18.46	0.11	22.85	15.82	0.592
1991-92	7.22	20.50	26.14	0.16	21.14	24.84	0.907
2001-02	5.7	11.76	36.77	0.36	19.10	26.31	1.352
2005-06	5.39	9.97	38.45	0.44	20.09	25.66	1.498
2009-10	5.12	8.55	41.67	0.52	19.01	25.13	1.658

Source: Central Institute of Agricultural Engineering (CIAE), India

Exhibit 2.4 Percentage Share of Power Usage in Indian Agriculture Sector



*Latest available data

Source: Indiastat

Often, in India, farm mechanization has been coupled with the use of prime movers, tractors and power tillers, rather than adoption and availability of farm machinery, which perform the specific tasks. Extent of adaption of farm mechanization in India is driven by many factors, such as levels of monsoon, levels of irrigation, size of land holding, government declared support prices for crops, commodity prices, cost of crop production (including fuel, fertilizer, and pesticides), and the credit policies announced by the financial institutions.

Even though farm mechanisation shows an increasing trend in the country, there are wide ranging disparities in the levels of mechanisation across states. The Northern States such as Punjab, Haryana, Uttar Pradesh (particularly Western and Tarai belt) have achieved a faster growth in mechanization over the past three decades. Adaptation of other implements, such as combine harvesters, threshers and other power-operated equipments has increased almost throughout the country. During the period 1992-2003, six Indian states, namely Madhya Pradesh, Orissa, Andhra Pradesh, Karnataka and Tamil Nadu had more than 5 different farm automation equipment having an installed base growing at a CAGR of over 10 percent. Mechanization in Western and Southern states of the country viz., Gujarat, Maharashtra, Rajasthan and certain areas of Tamil Nadu, and Andhra Pradesh has increased with the increase in area under irrigation and also with the growing awareness among farmers. The pace of mechanization in Eastern States and North-Eastern States has not been satisfactory.

At present in India, tractors are being used for tillage for around 16 percent of total cultivated area and for sowing in 8 percent of total cultivated area (Table 2.12). Although, utility of manually and bullock-operated equipments has been established but the response of the farmers has been selective. Due to limited use in a year and economic advantages of the local alternatives, some improved versions of implements have not been able to replace successfully the local alternatives. The land levelers, seed-cum-fertilizer drills have been adopted by the farmers but on limited scale. Major adoption of agricultural machinery in addition to irrigation equipments and tractors, has been though introduction of threshers for wheat crop. Due to various usage of paddy straw, there has been limited preference for paddy threshers. Self propelled / tractor operated combines, reaper harvester, potato and groundnut mechanization machinery are also commercially available and adopted by the farmers in states where tractors have been introduced. Combine harvesters are commonly used in different parts of the country, on custom hire basis, for wheat, soybean and paddy harvesting.

Table 2.12 Level of Mechanization in Indian Agriculture

Operation	Percentage of Land Area
Tillage	**40.2**
Tractors	*15.6*
Animals	*24.7*
Sowing with drills and planters	**28.9**
Tractors	*8.3*
Animals	*20.6*
Irrigation	**37**
Thresher	
Wheat	47.8
Paddy and others	4.4
Harvesting	
Reapers	0.56
Combines	0.37
Plant protection	**34.2**

Source: Proceedings of 20th National Convention of Agricultural Engineers, Punjab Agricultural University (PAU)

Status of agricultural machinery industry in India is also a suggestive indicator of the status of farm mechanization in the country. India is the largest producer of tractors in the world. During 1986-87 to 2011-12, the compound annual growth (CAGR) in the production and sale of tractors was around 7.83 percent and 7.68 percent, respectively (Table 2.13).

Table 2.13 Sales of Tractor and Power Tillers in India

Year	Tractor Sales (Nos.)	Power Tillers Sales (Nos.)
2004-05	2,47,531	17,481
2005-06	2,96,080	22,303
2006-07	3,52,835	24,791
2007-08	3,46,501	26,135
2008-09	3,42,836	35,294
2009-10	3,93,836	38,794
2010-11	5,45,109	55,000
2011-12 (upto December 2011)	4,19,270	39,900

Source: Department of Agriculture and Cooperation

Currently, on an average over 400,000 tractors, 39,000 power tillers and 1.6 million irrigation pumps are introduced every year in the country.

Table 2.14 Status of Farm Machinery Industries in India

Equipment	Number of manufactures
Agricultural tractors	13
Power tillers	2
Earth movers	3
Pumps	600
Sprinkler set	35
Drip Irrigation system	35
Plant protection equipment	300
Combines	48
Reapers	60
Threshers	6000
Seed drills	2500
Ploughs, cultivators and harrows	5000
Tractors parts and accessories	546
Earth moving machinery and parts	188
Diesel oil engines	200
Rice processing machinery	300
Sugarcane crusher	50
Chaff cutter	50
Dairy and food industries	500
Village crafstmen	1 million

Source: Central Institute of Agricultural Engineering (CIAE), India

Increase in farm mechanization (tractor use) in the country has also not been able to create significant impact on farm productivity and production. Table 2.15 provides an analysis of impact of growth in tractor use on growth in productivity and crop production in the country.

Table 2.15 Growth in Tractor Use, Crop Productivity and Crop Output

Annual Average Growth Rate (%)			
Period	**Tractor use per 000 Ha**	**Yield* (kg/Ha)**	**Production* (million tonnes)**
1961-71	15.2	2.53	3.38
1971-81	11.4	1.90	2.50
1981-91	11.5	3.89	4.15
1991-2003	7.2	1.85	1.42
1961-2003a	11.4	2.46	2.69

a – Latest data available for analysis; * Data pertaining to foodgrains; Except in 1981-91 and 1991-2003, growth rates in 1961-71, 1971-81, and 1961-2003 were insignificant at 0.1 to 5% level implying impact of growth in tractor use on yield and production was positive only for the period 1991-2003.

Source: Department of Agriculture and Cooperation, Govt. of India

Agriculture R&D and Extension Services

Agricultural research and development (R&D) investments are a crucial determinant of agricultural productivity involved through the introduction of improved crops and cropping practices, labor-saving technologies, improved quality of food storage, processing, and marketing. In addition to newly developed technologies, existing technologies need to be better disseminated. Considerable empirical evidence indicates high rates of return from agricultural R&D investments in the range of 40-50 percent (Alston et al., 2000), making agricultural research a cost-effective way for governments to accelerate agricultural development. R&D spending on agriculture has been critically high in the developed and high-income countries. According to International Food Policy Research Institute (IFPRI), for every US$100 of agricultural output, developed countries spend US$ 2.16 on public agricultural R&D, whereas developing countries spend only US$ 0.55. According to a study by the World Bank, agriculture R&D as a percentage of GDP has been 2.36 percent for developed countries; the same is lower at 0.53 percent for developing countries of the world; further lower at 0.41 percent for developing countries of Asia, and at 0.34 percent for India (Table 2.16). According to a large number of studies conducted by the Agricultural Science and Technology Indicators (ASTI), the average internal rate of return (IRR) on agriculture R&D in the developing countries is just above 40 percent with a large variance. These results are generally considered to be evidence of under-investment in agricultural R&D.

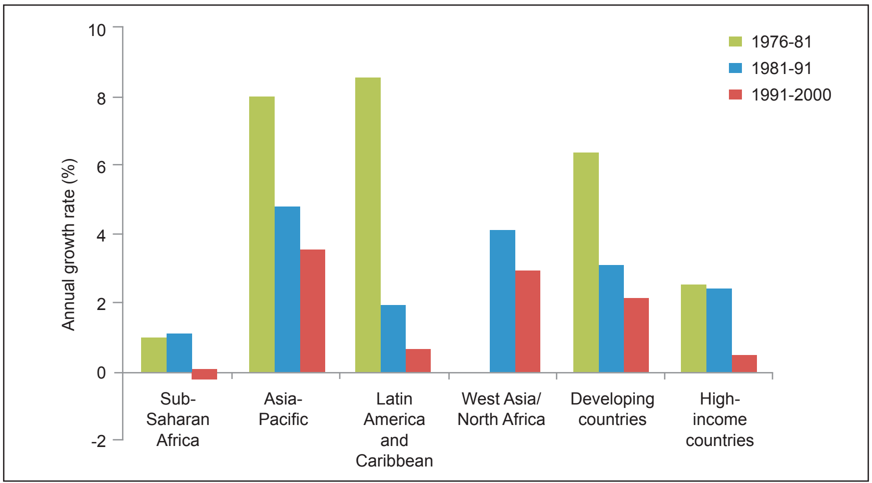
Table 2.16 Total Public Agricultural R&D Expenditures by Region and Select Countries, 1981 and 2000

	Public agricultural R&D spending		R&D spending as a % of agricultural GDP	
	1981	2000	1981	2000
	2000 int'l $ millions			
Developed Countries	**8,293**	**10,191**	**1.41**	**2.36**
Japan	1,832	1,658	1.45	3.62
USA	2,533	3,828	1.31	2.65
Developing Countries	6,904	12,819	0.52	0.53
Asia and Pacific	3,047	7,523	0.36	0.41
China	1,049	3,150	0.41	0.40
India	*533*	*1,858*	*0.18*	*0.34*
Latin America & Caribbean	**1,897**	**2,454**	**0.88**	**1.15**
Brazil	690	1,020	1.15	1.81

Source: World Development Report 2008, The World Bank

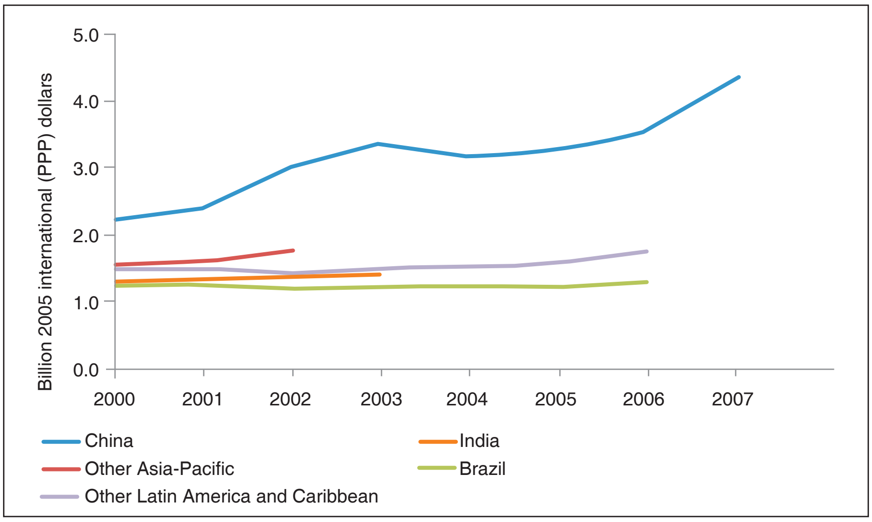
Globally, agriculture R&D spending has been in the public sector domain, more so is in the case of developing countries (Exhibit 2.5)

Exhibit 2.5 Growth Rates in Public Agricultural R&D Expenditures, 1976–2000*



Note: Growth rates exclude Eastern Europe and Former Soviet States *Latest data available for comparison
Source: International Food Policy Research Institute (IFPRI)

Exhibit 2.6 Evidence on Agricultural R&D Investment Trends Since 2000



Data for Brazil, India, other Asia–Pacific, and other Latin America and Caribbean are from ASTI datasets (various years); data for China are from Chen and Zhang (2010)

Source: International Food Policy Research Institute (IFPRI)

The Asia–Pacific region is highly diverse in its economic and agricultural development, and consequently to its agricultural R&D systems (Exhibit 2.6). In 2002, the Asia–Pacific region as a whole (excluding its high-income countries, such as Japan and South Korea) spent US$6.2 billion on agricultural R&D in 2005 purchasing power parity (PPP) prices. China and India accounted for nearly 70 percent of this total US$3.0 and US$1.4 billion, respectively. Regional investments in agricultural R&D grew considerably after the early 1990s, largely because of intensification of agricultural spending by China and India. Other Asian countries, such as Malaysia and Vietnam, also realized impressive agricultural R&D spending growth from 1990 to 2002, whereas spending in Pakistan, Indonesia, and Laos was low and also at times negative.

The Asia-Pacific region has also made considerable progress in building research staff capacity, both in terms of total researcher numbers and qualification levels (in terms of postgraduate levels). With more than 80,000 Full Time Equivalent (FTE) scientists and engineers in agriculture in 2008[3], China has the world's largest agricultural R&D system in terms of research staff numbers.

Dominance of public sector agriculture R&D is also evident in case of India, where government agencies account for over 78 percent of total agricultural R&D spending, whereas private sector accounts for only 22 percent (Table 2.17). An analysis of R&D expenses as percentage of sales for around 228 food processing companies in India, and over 180 agriculture based Indian companies shows that R&D intensity in both the categories are low: 0.57 percent for firms engaged in agriculture activities, and 0.17 percent for firms engaged in processed foods.

Table 2.17 R&D Expenses as Percentage of Sales for Indian Agri & Food Processing Companies[4]

Products	2008-09	2009-10
Companies in Processed Food products	**Rs. Crore**	**Rs. Crore**
R&D EXPENSES	206.14	197.04
Sales	98347.06	118260
R&D AS % OF SALES	0.21	0.17
Companies in Agriculture		
R&D EXPENSES	83.36	119.29
Sales	18168.3	20971.86
R&D AS % OF SALES	0.46	0.57

Source: Prowess

Considerable investments have taken place in public agricultural research in India during the past three decades. As a result India now ranks fourth in terms of total investments in public agricultural R&D in the world, following United States, Japan, and China. The agriculture research in public domain includes the Indian Council of Agricultural Research (ICAR), the State Agricultural Universities (SAUs), and various other government and higher-education

[3]Chen and Zhang 2010
[4]Private sector

agencies. In 2003[5], investment of more than Rs. 20 billion in public agricultural research (in 2005 prices) took place in India in agriculture R&D— equivalent to about 1.4 billion in 2005 international dollars using PPP indices. Public spending in agricultural R&D in India, in inflation adjusted terms, grew substantially during 1991–2003 at an average rate of 6.4 percent per year. Most of the growth took place in the late 1990s, indicating steady growth in agricultural R&D in the post reform period. According to ASTI, from 1961 to 2001, public investments, by central and state governments in agriculture R&D in the country, increased tenfold; the annual growth rate of agriculture R&D expenditure during 2000-03 however, slowed down considerably to 2.9 percent per year, this process of growth has been continuing in the next decade.

Table 2.18 Composition of Public Agricultural Research Expenditures and Professional Research Staff in India, 2003

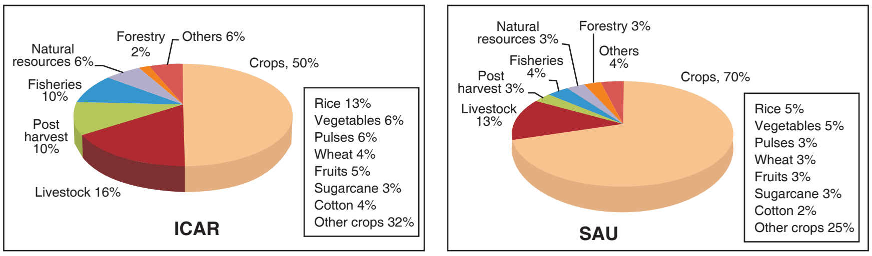
Period	Total spending[a]		Professional research staff		
	2005[b] rupees	2005 international (PPP) dollars	Researchers	Technicians with university degrees	Total
	(millions)		(full-time equivalents)		
ICAR (93)	9,051	617	4,034	2,228	6,262
SAUs (35)	10,381	708	7,677	1,387	9,064
Other government(16)	1,080	74	1,019	na	1,019
Other higher education (16)a	410	28	358	na	358
Public-sector total (160)	20,923	1,426	13,089	3,615	16,704

Figures in parentheses indicate the number of agencies in each category;
a. Expenditures for the other higher education agencies are estimates based on average expenditures per researcher at the SAUs.
b. Expenditure data corresponds to the year 2003.However expressed in 2005 prices
Source: ASTI, IFPRI

In 2003, the public agricultural research system in India had about 16,700 full-time equivalent (FTE) professional research staff comprising 13,089 researchers and 3,615 technicians with university degrees (Table 2.18). Most public agricultural R&D agencies in India do not have a full research mandate, with considerable time and

[5]Latest available collated data

Exhibit 2.7 Commodity Focus of Professional Research in ICAR and SAUs, 2003*



* Latest available collated data

Source: ASTI (2008), IFPRI

resources (about 70 percent) devoted to teaching/education, except in case of ICAR institutes where teaching activities accounted for 3 percent of its time and resources in 2003. However, in 2003, considerable time and resources in the SAUs were devoted to crop research (70 percent), and more than one half of ICAR research resources were engaged in crop research. In general, in agriculture R&D system in India, foodgrains ranks first, followed by horticulture and livestock. Across crops, rice received a greater focus during 2003, followed by vegetables, pulses, wheat, fruits, sugarcane, and cotton (Exhibit 2.7).

When moving from absolute to relative levels, the intensity of investments in agricultural research could be measured with the ratio of total public agricultural R&D spending as a to agricultural output (AgGDP). Agricultural output grew much faster in the developing countries as group than in the developed countries; as a result, intensity ratios remained fairly stable for the developing countries as group, with main drivers being Brazil, China and India. Despite a negative growth in agricultural R&D spending in Brazil during 1990s (-1 percent) compared to growth levels of 4 percent and 6 percent per year in China and India, respectively, Brazil's intensity ratio was 1.9 percent, which was five times greater than the corresponding ratios for China and India. Intensity ratio of India has been especially low compared to many other developing countries, indicating an underinvestment in agricultural R&D. More recent data of China and India (to 2003-05) show that the intensity ratio remained stable. This

Exhibit 2.8 Differences in Annual Growth Rates in Agriculture R&D Spending, 1981-2000*

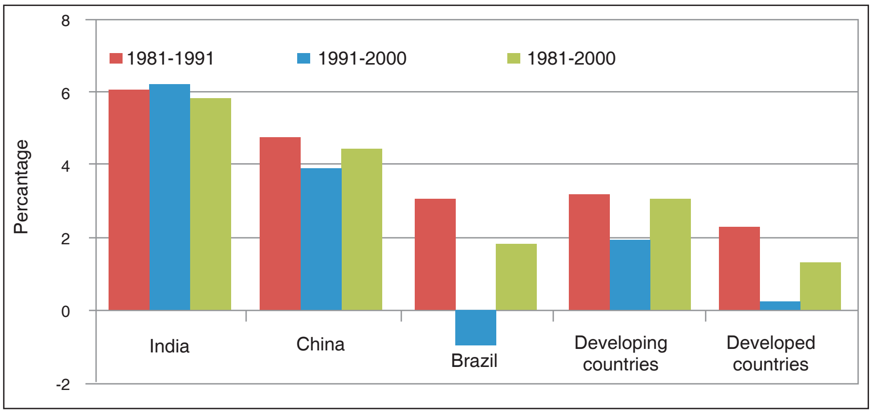
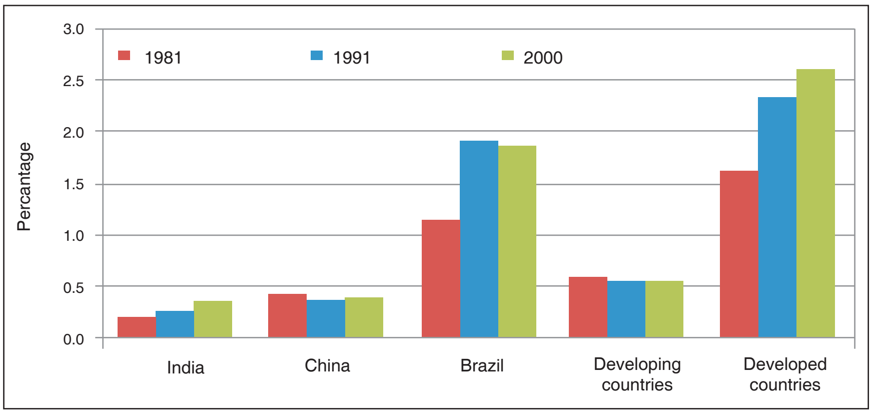


Exhibit 2.9 Differences in Intensity Ratios (Agriculture R&D Spending to Agricultural Output), 1981-2000*



*Latest data available for comparison

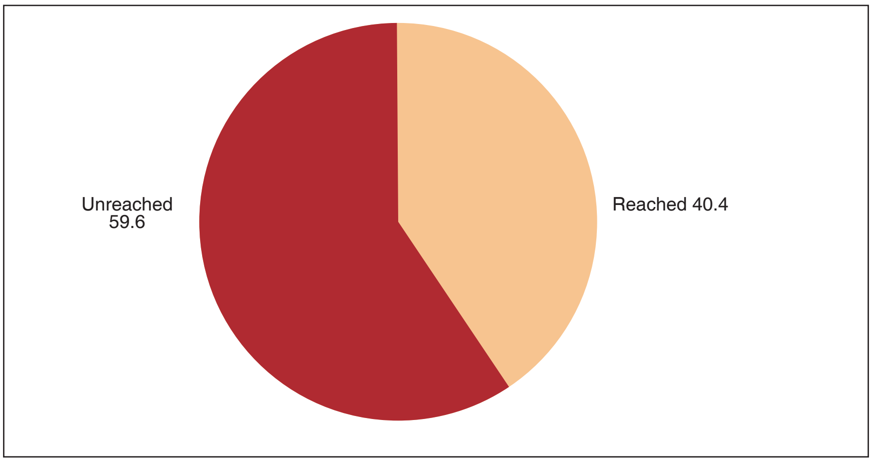
Source: ASTI, IFPRI

has been mainly because the large increase in total agricultural R&D spending has been offset by a similar growth spurt in the value of agricultural output in the recent years (Exhibit 2.8 and Exhibit 2.9).

In the past two decades, much of the improvement in plant materials in India has been the work of the public sector, while mechanical innovations have been mostly attributable to private R&D. The diffusion of both biological and mechanical innovations takes many years; so there is a lag between the R&D expenditures and the productivity gains at the farm level, which can even range from 25 to 40 years. Agriculture R&D produces yield gains at the trial plot level, which then require expenditures on extension to take them to the farmers' fields. Since more educated farmers are generally better at screening and adapting new technologies, farmer education plays an important role in productivity enhancement.

The extension services in India are characterized by huge farmer to extension worker ratio (desired ratio being 300 to 500:1). According to the latest data from the Extension Services Department, Ministry of Agriculture (MoA), Government of India (GoI), the ratio of farmer to extension worker in the country stands at 914:1 if all posts in the department (139,158 posts) is filled up and all the extension officials are involved in extension; 1464:1 if all those who are in place involve in extension (86,957 personnel); and as high as 4880:1 if at least 30 percent personnel are involved in extension. The data further reveals that, currently, around 40 percent of posts in the Department are vacant at the ground level and around 25 percent at the top level. Across the country, only in 6 States, extension is present at the

Exhibit 2.10 Percentage of Farmers Accessing Information Sources on Modern Technologies in India



Source: Chandragowda, 2011

village level, and in 11 States it is present upto Panchayat level. This indicates a large deficit in agriculture extension services in India, which is also reflected in degree of farmers' adaption of modern technologies on field (Exhibit 2.10).

Capital Formation in Agriculture and Institutional Credit

Capital formation in agriculture has been a subject of interest in the development perspective of Indian Agriculture. In agriculture, this is divided into two segments; one is that of capital formation in agriculture that comprises of additions to capital stock within the sector, which influence production directly; the other is capital formation for agriculture that comprises investments in capital stock made elsewhere but influences agriculture. Howsoever, capital formation in agriculture is closely linked with productivity, efficiency and profitability in crop production.

Table 2.19 Capital Formation as Proportion of GDP in Indian Agriculture

Year	GCF/GDP Agri (%)
2004-5	13.46
2005-6	14.57
2006-7	14.65
2007-8	16.03
2008-9	19.67
2009-10	20.03

Source: CSO

A review of capital formation in Indian agriculture reveals that gross capital formation in agriculture (GCFA) as a proportion of GDP in agriculture has been steadily increasing since 2004-05 and in 2009-10 it is estimated to have reached a level of 20 percent (Table 2.19).

Table 2.20 Gross Capital Formation (GCF) in Indian Agriculture

Year	Public	Private	Total	Share (%)	
	Rs. crores (at current prices)			*Public*	*Private*
2004-05	16182	62666	78848	20.5	79.5
2005-06	20739	76818	97557	21.3	78.7
2006-07	25606	78883	104489	24.5	75.5
2007-08	27379	101287	128666	21.3	78.7
2008-09	31755	143559	175314	18.1	81.9

Source: CSO

Another feature of the trends in capital formation trends in Indian agriculture has been that private sector investments have been dominant. The share of private sector in capital formation has been around 80 percent. The share of public sector in capital formation, which was around 20.6 percent in 2004-05 increased to around 25 percent in 2006-07, however, decreased to 18.2 percent in 2008-09 (Table 2.20).

While it is encouraging to note that Indian agriculture has been attracting more investments of capital nature, it has been also raising concerns whether the investment intensity in Indian agriculture is increasing. Increasing investment intensity generally leads to increase in the overall cost of production if productivity does not rise significantly. An in-depth analysis of GCF on productivity in Indian agriculture is limited in the study.

Table 2.21 Credit Flow to Indian Agriculture

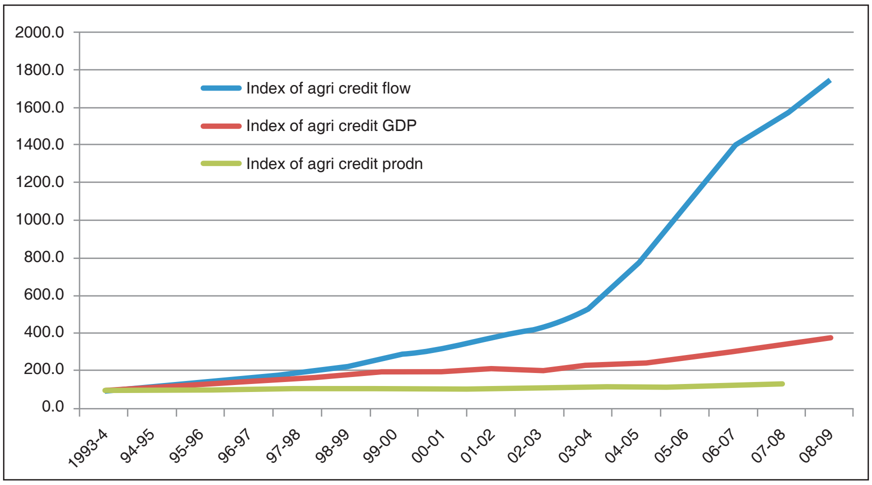
Year	Credit Flow	
	Rs. crore	Annual Growth Rate (%)
2001-02	62045	
2002-03	70810	14.13
2003-04	86981	22.84
2004-05	1,25,309	44.06
2005-06	1,80,486	44.03
2006-07	2,29,401	27.10
2007-08	2,54,658	11.01
2008-09	3,01,908	18.55
2009-10	3,84,514	27.36
2010-11	4,46,779	16.19

Source: Annual Report of NABARD and Economic Survey (various issues).

While it is encouraging to note that Indian agriculture has been attracting more investments of capital nature, it has been also raising concerns whether the investment intensity in Indian agriculture is increasing. Increasing investment intensity generally leads to increase in the overall cost of production if productivity does not rise significantly. An in-depth analysis of GCF on productivity in Indian agriculture is limited in the study.

In the recent years, with the introduction of policy measures to double the credit to agriculture initiated by the Government of India, particularly since late 1990s, there had been a considerable growth in flow of funds to agriculture (Table 2.21). An analysis of institutional credit flow in Indian agriculture reveals that total credit flow has increased at an annual average growth rate of 21.5 percent from 2004-05 to 2010-11.

Exhibit 2.11 Impact of Institutional Credit Flow on Agriculture Production in India



** At Constant Prices*
Source: CSO

While credit flow to agriculture has increased, the impact of credit flow on agriculture production and productivity does not seem to have undergone a significant change. A comparison of the indices of agricultural production, agricultural GDP and agricultural credit flow reveals that agricultural production has increased marginally over the 15 year period from 1993-94 to 2008-09, while agricultural GDP had increased by about two and a half times, and credit flow to agriculture has increased by about 18 times, indicating low level of correlation.

Besides the inputs discussed in this chapter, irrigation is a vital and critical input for agriculture, which is discussed separately in the next chapter of the study.

Total Factor Productivity

Technological progress in agriculture is invariably embodied in inputs like irrigation, HYV seeds, modern agriculture machinery and equipments, and fertilizers. The input growth is influenced by several factors, such as input-output prices, technological innovations, institutions, infrastructure and policy initiatives. Impact of improved technology is also influenced by several factors, such as research, extension, education, infrastructure and health of natural resources. The effects in productivity in agriculture are best measured by way of Total Factor Productivity Growth (TFPG). Analysis of TFP based on a real time data is not in the purview of the study due to limitations in

Table 2.22 Index of Total Factor Productivity

Average annual growth rate (%) by period	1970-1979	1980-1989	1.5	2000-2006
Sub-Saharan Africa	-0.4	0.9	1.5	0.6
Latin American & Caribbean	0.6	1.3	2.4	2.5
Brazil	-0.5	3.1	3.00	3.7
Meddle East & North Africa	0.4	1.7	1.6	1.6
Northeast Asia, developed	1.9	2.2	2.6	3.1
Northeast Asia, developing	0.5	2.6	4.00	3.4
China	-0.2	2.5	3.8	3.2
Southeast Asia	2.0	1.0	1.6	2.2
South Asia	0.7	2.0	1.7	1.4
India	0.8	2.1	1.7	1.4
North America	1.5	1.4	2.1	1.8
Oceania	1.1	1.0	1.9	-0.3
Western Europe	1.5	1.7	2.0	1.4
Eastern Europe	0.6	0.3	1.0	0.6
USSR. former	0.7	0.3	1.6	3.3
Developing countries	0.6	1.7	2.3	2.1
Developed countries	1.6	1.5	2.3	1.8
USSR & Eastern Europe	-0.5	0.3	1.6	2.1
World	0.6	0.9	1.6	1.6

Source: Fuglie, 2008

availability of reliable and comprehensive long run time series agricultural statistics. However, research studies[6] on the subject have been reviewed and referred in this study for making inferences. Various empirical studies reveal that the TFPG in Indian agriculture has declined over the years (Table 2.22).

Research studies examining the TFP growth of major crops grown in different states of India reveal two strong perception (a) technological gains have not occurred in a number of crops, notably coarse cereals, pulses, oilseeds, fibres, sugarcane, and vegetables, during 1990s; and (b) crops and areas, where these gains occurred during Green Revolution, have exhausted their potential. The studies further reveal that all crops have benefited from the technological change in some parts of the country, but there are some exceptions in pulses and oilseeds, where only a few states have performed well. Among the principal crops, paddy and wheat have performed well in productivity gains. However, TFP of paddy has started showing deceleration in Haryana and Punjab, but TFP of wheat has been still growing in these two premier Green Revolution states (Appendix Ia & b).

A recent[7] study on TFP reveals that the average TFP growth for both rice and wheat during 1975-2005 was the highest in Punjab. The TFP growth in other states (except Haryana in case of wheat) was not impressive. However, the contribution of TFP in overall output growth seemed to be substantial particularly in the less intensive agriculture. According to the Study, the contribution of TFP growth in rice output was the highest in Bihar (56 percent), followed by Punjab (31 percent) and West Bengal (19 percent). It was lowest in Haryana (7 percent). However, in wheat, TFP growth accounted for 36 percent of output growth in Punjab and 24 percent each in Haryana and West Bengal, and merely 2.6 percent in Bihar.

The studies on TFPG, thus, infer that wide gaps in adoption and performance of technology exist across states/regions owing to large variations in soil fertility, availability of ground water resources, climatic conditions, natural resource degradation, infrastructural

[6] 2006-2009
[7] Chand et al.,2010

development, generation and dissemination of technology, and implementation of policy measures.

TFPG also explains the concern of sustainability in production and productivity gains in Indian agriculture. As can be seen in Table 2.20, the area under rice with more than 1 percent TFP growth was 44 percent in 1971-86 and it increased to 52 percent in 1987-2000. However, the area under stagnant TFP for paddy declined from 31 percent in 1971-86 to 15 percent in 1987- 2000. Even for wheat, the stagnated TFP area declined from 10 percent in 1971-86 to 3 percent in 1987-2000. The coarse cereals experienced more than one percent TFP growth on 71 percent of the total crop area during the 1980s, which declined to 30 percent during the 1990s. About 60 percent of the area under coarse cereals is facing stagnated TFP. Similarly, the productivity gains, which occurred for pulses and sugarcane during the early years of Green Revolution, have now revealed to be exhausted their potential.

Table 2.23 Distribution of Crop Area According to TFP Growth in India: 1971-2000[8]

(percent share of crop area)

Crop	Period	Stagnation TFP < 0%	Annual TFP growth < 1%	Annual TFP growth > 1%
Paddy (Rice)	1971-86	30.5	25.9	43.6
	1987-00	15.0	32.8	52.2
Wheat	1971-86	10.3	17.3	72.4
	1987-00	2.8	74.7	22.5
Coarse cereals	1971-86	19.8	9.6	70.5
	1987-00	60.2	9.8	30.1
Pulses	1971-86	42.8	36.6	20.5
	1987-00	69.2	26.6	4.2
Oilseeds	1971-86	35.6	18.3	46.1
	1987-00	28.3	10.6	61.1
Sugarcane	1971-86	20.3	61.0	18.6
	1987-00	90.9	5.4	3.7
Fibres	1971-86	53.8	7.2	39.0
	1987-00	32.5	1.4	66.1
Vegetables	1971-86	0.0	27.5	72.5
	1987-00	27.5	0.0	72.5

Note: Non-positive trend in TFP is an indicator of lack of sustainability of the production system
Source: Agricultural Economics Research Review, 2006

[8] *Praduman Kumar and Surabhi Mittal; Agricultural Economics Research Review, 2006*

3. IRRIGATION AND WATER MANAGEMENT

Water is the leading input in agriculture. Development of irrigation and water management are crucial for raising the levels of production and productivity. Total area under irrigation in the world stands at around 288 million hectares, which is just over 20 percent of total global arable land (Table 3.1). With over 205 million hectares, Asia has the largest share (71 percent) in total global area under irrigation (Table 3.2). Irrigated area accounts for only 34 percent of total arable land in Asia. However, irrigation is vital to Asia as the region produces around 50 percent of world's foodgrains.

Table 3.1 Summary of Area Under Irrigation in the World

Region	Irrigated Area (million Ha)
Africa	13.687
Americas	42.189
Asia	205.236
Europe	23.706
Oceania	3.105
Total	287.923

Source: International Water Management Institute (IWMI)

Agriculture is the primary user of water resources across Asia. According to a joint study by IWMI and Asian Development Bank (ADB) on Asian irrigation, in absolute numbers, South Asia has the largest land area under irrigation (82.4 million hectares), followed by East Asia (59.5 million hectares), Southeast Asia (16.7 million hectares), and Central Asia (10.7 million hectares). However, in percentage terms, with 95 percent, Central Asia is the most intensively irrigated part of Asia.

India has the largest area under irrigation within Asia constituting about 30 percent of total area under irrigation in Asia. With 140 million hectares, India also has the largest potential area under irrigation in Asia.

Table 3.2 Top 15 Countries in Asia by Area Under Irrigation

Country	Irrigated Area (million Ha)	Reference Year
India	60.850	2007
China	57.780	2009
Pakistan	19.590	2007
Iran	8.700	2009
Turkey	5.340	2009
Thailand	4.986	2007
Bangladesh	4.730	2002
Indonesia	4.500	2007
Uzbekistan	4.281	2007
Iraq	3.525	2007
Afghanistan	3.199	2007
Viet Nam	3.000	2007
Japan	2.530	2009
Myanmar	2.250	2007
Kazakhstan	2.122	2007

Source: International Water Management Institute (IWMI)

An analysis of area equipped for irrigation in Asia shows that infrastructure installed for irrigation purposes has grown in all Asian countries for the past three decades. Most significant growth in area equipped under irrigation has been reported by Nepal, which has grown at a CAGR of 7.11 percent during the period 1961-2002, followed by Bangladesh, Viet Nam and Thailand (Table 3.3). Considering the size of arable land and resources input in agriculture research in India, the growth in area equipped under irrigation in the country has been considerably low.

Table 3.3 Growth in Area Equipped with Irrigation in Asia

Country	Growth in area equipped with irrigation CAGR (%)	Period*
Nepal	7.11	1961-2002
Bangladesh	5.40	1961-2008
Viet Nam	3.52	1961-2005
Thailand	2.59	1983-2007
India	2.03	1962-2008
Malaysia	1.42	1961-1994
Philippines	1.28	1978-2007
Indonesia	1.24	1961-2005
Israel	1.18	1961-2004
Pakistan	1.10	1973-2008
China	0.93	1975-2006
Republic of Korea	0.74	1961-2002
Japan	0.19	1961-1993

** Latest country data reported*

Source: AQUASTAT 2011, FAO

Although area equipped for irrigation has increased in almost all countries in Asia at various levels, the gap between the area of land with potential for irrigation and with infrastructure installed for irrigation purposes is also wide in almost all countries in the continent (Table 3.4 and Table 3.5). For example, India reports an irrigation potential of 140 million hectares against an actual irrigated area of 60.85 million hectares, which accounts for just about 44 percent of the potential area. This gap is narrower in China, where around 58 million hectares of the estimated 70 million hectares are deemed to be suitable for irrigation. In the Southeast Asia there is a large gap between the potential area of around 44 million hectares and the currently irrigated area of 17 million hectares

A comparison of percentage of cultivated area under irrigation also shows that India has been lagging behind many of its neighbouring countries (Table 3.6)

Table 3.4 Area Equipped for Irrigation and its Percentage in Cultivated Land

Region	Area Irrigated (million Ha)			Area irrigated as a percentage of cultivated land (%)		
Year	1980	1990	2003	1980	1990	2003
World	193.0	224.2	277.1	15.8	17.3	17.9
Africa	9.5	11.2	13.4	5.1	5.7	5.9
Asia	132.4	155.0	193.9	28.9	30.5	34.0
Latin America	12.7	15.5	17.3	9.4	10.9	11.1
Caribbean	1.1	1.3	1.3	16.4	17.9	18.2
North America	21.1	21.6	23.2	8.6	8.8	9.9
Oceania	1.7	2.1	2.8	3.4	4.0	5.4
Europe	14.5	17.4	25.2	10.3	12.6	8.4

Source: IWMI & ADB

Table 3.5 Area Irrigated as Percentage of Total Irrigation Potential in Select Countries in Asia

Country	Irrigation Potential (million Ha)	Land irrigated (million Ha)	Percentage of land actually irrigated against irrigation potential (%)
Bangladesh	6.9	4.7	68
China	70.0	57.8	83
India	139.5	60.9	44
Indonesia	10.9	4.5	41
Iran	15.0	8.7	58
Malaysia	0.4	0.4	93
Nepal	2.2	1.2	54
Pakistan	21.3	19.6	92
Republic of Korea	1.8	1.1	63
Sri Lanka	0.6	0.6	100
Thailand	12.2	5.0	41
Viet Nam	9.4	3.0	32

Source: IWMI & AQUASTAT 2011

Table 3.6 Percentage of the Cultivated Area Equipped for Irrigation in Asian Region

Country	Percentage of the cultivated area equipped for irrigation (%)
Pakistan	93.94
Japan	63.20
Bangladesh	59.07
Israel	59.04
China	51.35
Viet Nam	48.67
Republic of Korea	47.26
Nepal	47.19
Iran	43.84
India	39.11
Thailand	34.03
Sri Lanka	29.23
Philippines	18.51
Indonesia	16.80
Malaysia	4.77

Source: AQUASTAT 2011, FAO

Surface irrigation is by far the most widespread irrigation technique in the Asian region (Table 3.7). It includes all paddy rice cultivation and most of the other foodcrops. In most countries, sprinkler or drip irrigation systems are reported to exist on very small levels. Surface water is the major source of irrigation water in the region, except for Bangladesh and India where groundwater is widely used. Irrigation systems in Asia are generally grouped as:

systems supplied through surface reservoirs;

pumping from rivers;

pumping from groundwater.

Table 3.7 Origin of Irrigation Water In Asia

Country	Percentage of area equipped for full control irrigation	
	irrigated by surface water (%)	irrigated by groundwater (%)
Bangladesh	21.0	79.0
China	69.2	30.8
India	36.3	63.7
Indonesia	99.0	1.0
Iran	37.9	62.2
Japan	84.0	0.0
Malaysia	92.0	8.0
Nepal	79.6	19.2
Pakistan	35.9	21.4
Philippines	78.7	5.7
Republic of Korea	94.9	5.1
Sri Lanka	99.8	0.2
Thailand	90.9	9.1
Viet Nam	99.0	1.0

Source: AQUASTAT 2011, FAO

Around 40 percent of India's cultivated area is irrigated. The rain-fed area constitutes about 60 percent of the 142 million hectares net sown area in the country. The rain-fed agriculture is characterized by low levels of productivity and low input-usage. Of the total area with potential for irrigation in India, an assessed 58.46 million hectares is from major and medium irrigations and 81.42 million hectares from minor irrigation schemes.

According to various survey reports conducted to assess the irrigation development of the country, the overall performance of irrigation development has not been satisfactory. As per data given by the Union Ministry of Agriculture, from 1991-92 to 2006-07 (the latest year for which figures are available), there has been almost no addition to net irrigated areas by canals from major and medium irrigation projects. The net irrigated area by canals all over the country was 17.79 million hectares in 1991-92, which was lower in 2006-07, and has been more or less consistently falling (Table 3.8).

Table 3.8 Net Irrigated Area by Source, All India (1990-91 to 2006-07)

(Million Ha)

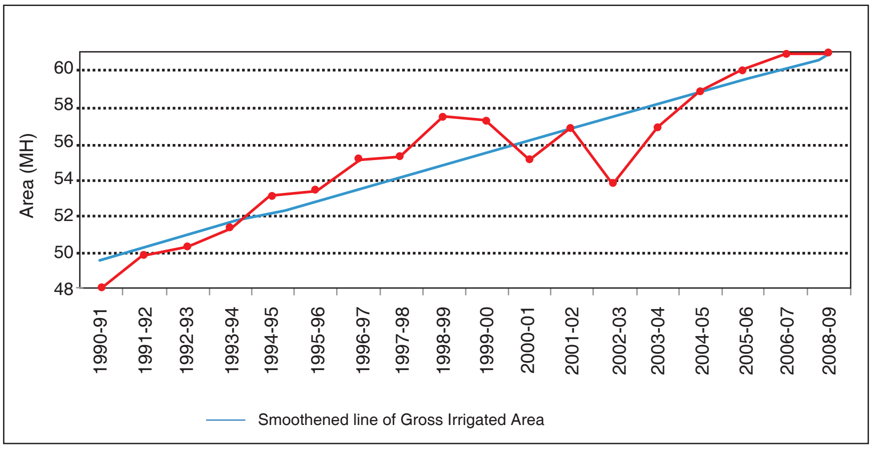
Year	Canals	Tube Wells	Other Wells	Total GW	Tanks	Other Sources	Total
1990-91	17.5	14.3	10.4	24.7	2.9	2.9	48.0
1991-92	17.8	15.2	10.9	26.0	3.0	3.0	49.9
1992-93	17.5	15.8	10.6	26.4	2.9	3.6	50.3
1993-94	17.6	16.4	10.7	27.1	2.8	3.8	51.3
1994-95	17.3	17.2	11.7	28.9	3.3	3.5	53.0
1995-96	17.1	17.9	11.8	29.7	3.1	3.5	53.4
1996-97	17.1	19.3	12.5	31.8	2.8	3.4	55.1
1997-98	17.4	19.7	12.4	32.1	2.6	3.1	55.2
1998-99	17.3	21.4	12.6	34.0	2.8	3.3	57.4
1999-00	17.0	22.1	12.6	34.6	2.5	2.9	57.1
2000-01	16.0	22.6	11.3	33.8	2.5	2.9	55.1
2001-02	15.3	23.2	11.7	35.0	2.2	4.4	56.8
2002-03 (p)	14.0	23.5	10.7	34.1	1.8	3.7	53.7
2003-04 (p)	14.4	24.5	11.6	36.1	1.9	4.3	56.7
2004-05 (p)	14.6	23.1	11.8	34.9	1.7	7.5	58.8
2005-06 (p)	15.3	23.4	11.6	35.1	2.1	7.4	59.9
2006-07 (p)	15.4	24.1	11.9	35.9	2.0	7.6	60.9

(p): Provisional

Source: Land Use Statistics at a Glance 1997-98 to 2006-07, Directorate of Economics & Statistics, Department of Agriculture and Cooperation, Ministry of Agriculture, Govt. of India

Table 3.8 reveals that the net irrigated area by all sources increased from 48.0 million hectares in 1990-91 to 60.9 million hectares by 2006-07. Similarly total gross irrigated area (if two irrigated crops are taken in a year on a given area, the area is counted twice in estimation of gross irrigated area, but not considered twice for estimation of net irrigated area) from all sources has been increasing during the analyzed period (Exhibit 3.1). This increase in all India net and gross irrigated areas have been mainly due to the increase in groundwater irrigated area from 24.69 million hectares in 1990-91 to 35.91 million hectares in 2006-07.

Exhibit 3.1 Gross Irrigated Area by All Sources in India (1990-91 to 2008-09)



Source: South Asia Network on Dams, Rivers & People (SANDRP)

According to the Databook for Planning Commission, Government of India, submitted by Central Board of Irrigation and Power (CBIP), Government of India, at the end of Xth Plan period, around 17 percent of the available irrigation potential from the major and medium irrigation projects in the country remained unexploited. Around 15 percent of groundwater blocks have been overexploited in India. Table 3.9 reveals the rapid depletion of groundwater due to overexploitation, which has now become the main source of irrigation in the country. This is particularly observed in case of the leading foodgrain producing states, such as Punjab (75 percent of groundwater blocks overexploited), followed by Rajasthan (59 percent), Haryana (49 percent), Karnataka (37 percent), Tamil Nadu (37 percent), Andhra Pradesh (17 percent), and Gujarat (14 percent).

Table 3.9 Status of Irrigation and Ground Water in India

	Total Irrigation Potential till end of X^{th} Plan (000 Ha)			Ground Water Status (Blocks)		
	Created (C)	Utilised (U)	% U of C	Total No.	Over exploited	% Over Exploited
Andhra Pradesh	6,693	6,089	91.0	1,231	219	17.8
Assam	935	719	76.9	23	0	0.0
Bihar	7,638	5,608	73.4	515	0	0.0
Chattisgarh	1,475	1,227	83.2	146	0	0.0
Gujarat	4,250	3,728	87.7	223	31	13.9
Haryana	3,831	3,477	90.8	113	55	48.7
Himachal Pradesh	186	153	82.3	5	0	0.0
Jammu & Kashmir	678	581	85.7	8	0	0.0
Karanataka	2,774	1,823	65.7	175	65	37.1
Kerala	3,750	2,766	73.8	151	5	3.3
Madhya Pradesh	2,040	1,564	76.7	312	24	7.7
Maharashtra	6,550	4,961	75.7	318	7	2.2
Orissa	3,623	3,321	91.7	314	0	0.0
Punjab	6,005	5,879	97.9	137	103	75.2
Rajasthan	5,329	4,900	91.9	237	140	59.1
Tamil Nadu	3,700	3,685	99.6	385	142	36.9
Uttar Pradesh	32,386	25,681	79.3	803	37	4.6
West Bengal	5,777	4,856	84.1	269	0	0.0
Uttaranchal	808	600	74.3	17	2	11.8
All India	101,737	85,222	83.8	5,723	839	14.7

Source: Central Board of Irrigation & Power, May 2011

The stage of ground water development for the country as a whole is 58 percent of the ground water levels required for sustained use. The status of ground water development is comparatively high in the states of Delhi, Haryana, Punjab and Rajasthan and Union Territory (UT) of Daman and Diu, and Pondicherry, where the stages of ground water development is more than 100 percent, which implies that in these states the average annual ground water consumption is more than average annual ground water recharge. In the states of Gujarat, Karnataka, Tamil Nadu and Uttar Pradesh the average stage of ground water development is 70 percent and above. In rest of the states / UTs the stage of ground water development is below

70 percent. According to the Central Ground Water Board (CGWB), out of 5723 assessed administrative units (Blocks/ Taluks/ Mandals/ Districts), 4078 units are 'Safe', 550 units are 'Semi-critical', 226 units are 'Critical', 839 units are 'Over-exploited' and 30 units are 'Saline' (Annexure-III). Number of 'Over-Exploited' and 'Critical' administrative units are significantly higher (more than 15 percent of the total assessed units) in Andhra Pradesh, Delhi, Gujarat, Haryana, Karnataka, Punjab, Rajasthan and Tamil Nadu and also the UTs of Daman and Diu and Pondicherry.

In addition to the concerns over availability of fresh groundwater for potable use, this alarming rate of overexploitation of groundwater sources in the leading food producing states has been raising concerns over sustainability of irrigation in these states, and subsequent impact on crop production and productivity.

Box – III

Water Requirement in IGP and Water-Table in Central Punjab

Projected Water Requirements (bcm*) in the Indo-Gangetic Plain (IGP)

States	2010	2025	2050
Punjab	51.1	48.8	47.5
Haryana	32.1	31.8	31.6
Bihar	47.7	64.3	106.6
West Bengal	37.3	44.5	66.4
India	708.0	843.0	1178.0

*Billion Cubic Metres

Source: Central Ground Water Board (CGWB), Ministry of Water Resources, Government of India

Percentage Area under Different Water-Table Depths in Central Punjab

Year	< 5m	5-10 m	> 10 m
1973	38	58	4
1990	10	65	25
2002	3	22	75

Source: Jain and Kumar, 2007

Box - IV

Agriculture Water Use in Select Countries

Agricultural water withdrawal in India is the highest when compared to other leading food grain producing countries. The most striking fact is USA being the second largest producer of foodgrain, and with largest arable land has much lower agricultural water withdrawal than India. India's agricultural water withdrawal is around four times higher than that of USA. A comparison of agricultural water withdrawal and productivity of foodgrain indicates towards poor water use efficiency in India.

	Total agricultural water withdrawal	Irrigation water withdrawal	Arable Land	Productivity in Cereals
	(10^9 m3/yr)	(10^9 m3/yr)	million Ha	kg/Ha
India	688.0	550.4	158.0	2572
China	358.0	286.4	108.6	5450
USA	192.4	153.9	163.7	7236
Pakistan	172.4	137.9	20.4	2790
Indonesia	92.8	74.2	22.7	4813
Viet Nam	77.8	62.2	6.3	5080
Japan	56.8	45.5	4.3	5919
Thailand	51.8	41.4	15.3	2961
Brazil	31.7	25.4	61.2	3532
Bangladesh	31.5	25.2	7.5	4141
Rep. of Korea	15.8	12.6	1.6	7265
Malaysia	4.5	3.6	1.8	3677

Source: AQUASTAT & FAOSTAT 2011

The status of groundwater in the country calls for an attention towards levels of adoption of micro-irrigation system in the country. Micro-irrigation technologies, such as drip and sprinkler irrigation systems ensure judicious use of water in agriculture, thereby improving water use efficiency and crop productivity

To assess the levels and spread of micro-irrigation system in the country, a recent research study by the scientists from International Water Management Institute (South Asia Regional Office), Hyderabad, and Water Management Scheme, Agricultural University, Gujarat, was referred and reviewed. According to the study, the percentage of actual area against the potential estimated under drip irrigation in different states varied between nil in Nagaland to as much as 49.74 percent in Andhra Pradesh, followed by Maharashtra (43.22 percent) and Tamil Nadu with 24.14 percent. In case of sprinkler irrigation, the percentage of actual area against the potential estimated was as low as 0.01 percent in Bihar and the highest being 51.93 percent in Andhra Pradesh. Compared to the potential of 42.23 million hectares in the country, the present area under micro-irrigation accounts for 3.87 million hectares (1.42 million ha under drip and 2.44 million ha under sprinkler), which is just about 9.16 percent (Table 3.10 and Exhibit 3.2).

Table 3.10 Potential and Actual Area under Micro-Irrigation in Different States of India

(Area in ‘000 ha)

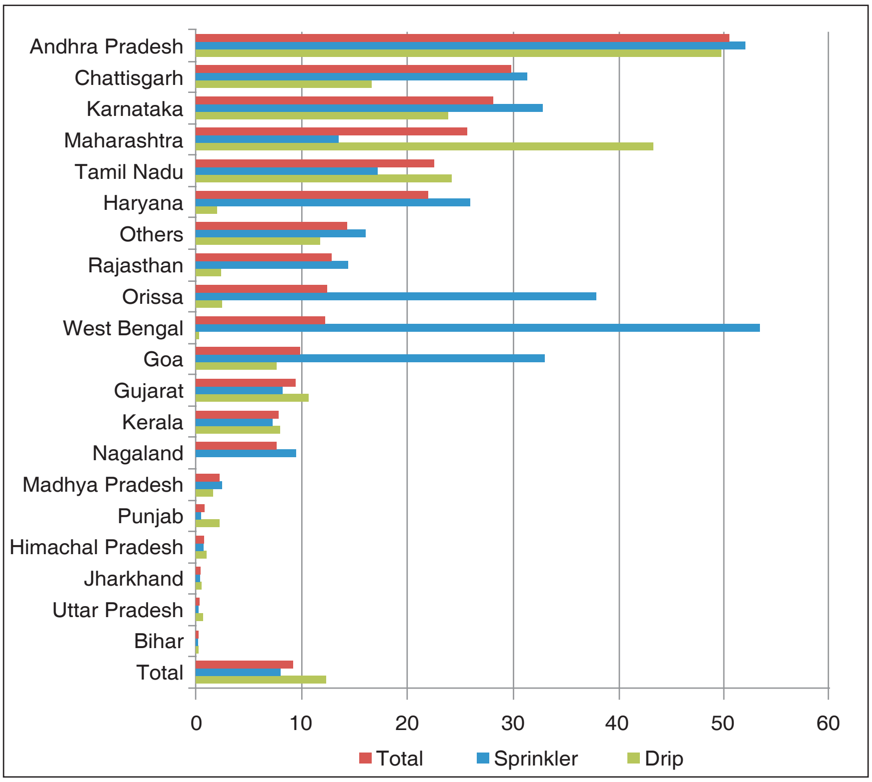
	Drip			Sprinkler			Total		
	P	A	%	P	A	%	P	A	%
Andhra Pradesh	730	363.07	49.74	387	200.95	51.93	1,117	564.02	50.49
Bihar	142	0.16	0.11	1,708	0.21	0.01	1,850	0.37	0.02
Chhattisgarh	22	3.65	16.59	189	59.27	31.36	211	62.92	29.82
Goa	10	0.76	7.60	1	0.33	33.00	11	1.09	9.91
Gujarat	1,599	169.69	10.61	1,679	136.28	8.12	3,278	305.97	9.33
Haryana	398	7.14	1.79	1,992	518.37	26.02	2,390	525.51	21.99
Himachal Pradesh	14	0.12	0.86	101	0.58	0.57	115	0.70	0.61
Jharkhand	43	0.13	0.30	114	0.37	0.32	157	0.50	0.32
Karnataka	745	177.33	23.80	697	228.62	32.80	1,442	405.95	28.15
Kerala	179	14.12	7.89	35	2.52	7.20	214	16.64	7.78
Madhya Pradesh	1,376	20.43	1.48	5,015	117.69	2.35	6,391	138.12	2.16
Maharashtra	1,116	482.34	43.22	1,598	214.67	13.43	2,714	697.01	25.68
Nagaland	11	0	0.00	42	3.96	9.43	53	3.96	7.47
Orissa	157	3.63	2.31	62	23.47	37.85	219	27.10	12.37
Punjab	559	11.73	2.10	2,819	10.51	0.37	3,378	22.24	0.66
Rajasthan	727	17	2.34	4,931	706.81	14.33	5,658	723.81	12.79
Tamil Nadu	544	131.24	24.13	158	27.19	17.21	702	158.43	22.57
Uttar Pradesh	2,207	10.68	0.48	8,582	10.59	0.12	10,789	21.27	0.20
West Bengal	952	0.15	0.02	280	150.03	53.58	1,232	150.18	12.19
Others	128	15	11.72	188	30.00	15.96	316	45.00	14.24
Total	11,659	1,428.46	12.25	30,578	2,442.42	7.99	42,237	3,870.88	9.16

P = Potential; A = Actual area

Source: Raman (2010) and Indiastat (2010)

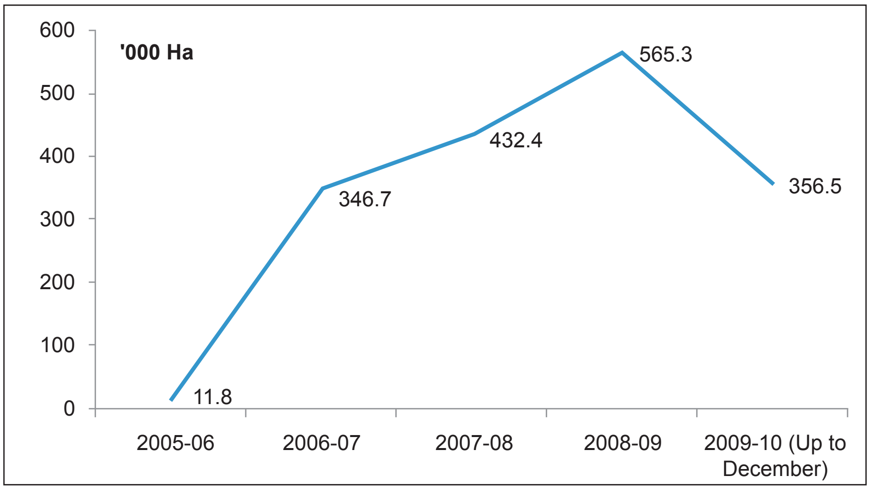
Micro-irrigation is being promoted under various government financial assistance schemes with the objective of increasing water use efficiency. Under the Centrally Sponsored Schemes (CSS) of Government of India, the implementation levels of micro-irrigation and the increase in physical performance of the system has been of the order of nearly 800 percent in Madhya Pradesh, 300 percent in Punjab and 150 percent in Orissa during 2006-08. The major crops vary from field crops (cotton, maize, groundnut, sugarcane) to vegetables, fruits (banana, papaya, mango, grapes), and plantation crops.

Exhibit 3.2 Potentiality and Actual Spread of Micro-irrigation in India (%)



Source: Raman (2010)

Exhibit 3.3 Micro-Irrigation Adoption in India (2005-06 to 2009-10)



Source: NCPAH 2009

The study also reveals that the majority of the farmers adopting micro-irrigation in the country varied amongst the States; in Kerala 52 percent of farmers adopting micro-irrigation are marginal farmers, whereas in Andhra Pradesh (70.67 percent), Karnataka (66 percent), Orissa (62.67 percent) and Punjab (55.34 percent) small farmers are adopting micro irrigation. Only in Maharashtra (63.33 percent) and Tamil Nadu (64.67 percent) the micro irrigation is adopted by large farmers (Table 3.12).

Table 3.11 Financial Assistance under CSS and Major Crops Grown under Micro-Irrigation in India

State	Financial Assistance under CSS (%)		Major crops under micro-irrigation
	Drip	Sprinkler	
Andhra Pradesh	70	70	Chilies, mango, sweet orange, groundnut
Bihar	90	90	Sugarcane, banana, coconut, maize, groundnut
Chhattisgarh	70	70	Sweet orange, vegetables
Goa	50	50	Vegetables
Gujarat	50	50	Cotton, vegetables, groundnut
Haryana	90	50	Orchard crops
Himachal Pradesh	80	80	Orchard crops, cole crops
Jharkhand	50	50	Vegetables
Karnataka	75	75	Grapes, vegetables, groundnut
Kerala	50	50	Coconut, areca nut, pepper
Madhya Pradesh	70	70	Sweet orange, banana, vegetables
Maharashtra	50	50	Grapes, banana, sugarcane, cotton
Orissa	70	70	Vegetables, mango, cashew, banana
Punjab	75	75	Vegetables, orchard crops
Rajasthan	70	60	Groundnut, maize
Tamil Nadu	65	50	Sugarcane, banana, coconut, maize, groundnut
Uttar Pradesh	50	100	Vegetables and mango, sugarcane
Uttarakhand	50	50	Potato, groundnut, orchard crops
West Bengal	50	50	Banana, maize, mango

Source: Raman (2010)

Table 3.12 Farm Size and Area Irrigated by Micro-Irrigation Systems in India

State	Farmer Category	% of Farmers	Average Farm Size (Ha)	Average Area under MI (Ha)	% of Area under MI
Andhra Pradesh	Marginal	6.00	0.82	0.76	92.68
	Small	70.67	1.70	0.90	52.94
	Large	23.33	14.08	2.96	21.02
Tamil Nadu	Marginal	13.33	0.62	0.48	77.42
	Small	22.00	1.72	1.31	76.16
	Large	64.67	4.67	2.41	51.61
Kerala	Marginal	52.00	0.54	0.15	94.44
	Small	28.00	1.44	1.25	86.80
	Large	20.00	2.38	2.22	93.27
Karnataka	Marginal	6.00	1.89	1.33	70.37
	Small	66.00	5.71	1.82	31.87
	Large	58.00	18.12	6.59	36.37
Maharashtra	Marginal	20.00	1.80	0.90	50.00
	Small	16.67	3.75	2.25	60.00
	Large	63.33	6.60	3.40	51.52
Orissa	Marginal	23.33	0.51	0.07	13.72
	Small	62.67	1.74	1.23	70.44
	Large	14.00	15.52	9.56	61.60
Punjab	Marginal	5.33	0.80	0.40	50.00
	Small	55.34	2.70	1.30	48.15
	Large	39.33	8.20	4.30	52.44
Rajasthan	Marginal	14.00	0.43	0.40	93.02
	Small	35.33	1.16	0.95	81.90
	Large	50.67	3.41	2.54	74.49
Gujarat	Marginal	2.00	0.80	0.58	72.50
	Small	20.67	1.75	1.13	64.57
	Large	77.33	3.65	3.00	82.19

MI = micro-irrigation

Source: Raman (2010)

The data given in Table 3.10 and 3.11 reflect the extent of micro-irrigation systems covered under different government programmes as well as own investments by the farmers. However, the actual area under micro-irrigation may vary according to the extent of use by the farmers.

4. CHALLENGES

The subdued performance of agriculture on productivity front in the recent decade in India has been raising concerns and the need for technology development in Indian agriculture. According to experts, the sharp erosion of total factor productivity in Indian agriculture has been on account of multiple factor relating to technology fatigue, soil fatigue, declining fertilizer response rate, and agro-climatic aberrations. This chapter, thus, deals briefly with the key challenges faced by the Indian agriculture with respect to productivity, and in the subsequent chapter, an attempt has been made to cite a few strategies for enhancing productivity, mainly through technological interventions.

Key Challenges

Water and Irrigation

Expansion of irrigation played a crucial role in fomenting green revolution in the decade of seventies and eighties. However, irrigation development in the country witnessed marginal improvement only. The net irrigated area crossed 50 million hectares mark in 1992-93 and it peaked at 57 million hectare in 1999-2000, and during 2006-07 it reached to 60.8 million hectares. The gross irrigated area in the corresponding period increased from 67 million hectares to 78 million hectares, and to 81 million hectares. Thus, the average annual increment in the net irrigated area during these 15 years was less than one million hectare per year and that of gross irrigated area was around 1.3 million hectares. The incremental gain in terms of cropping intensity in respect of irrigated area was also not much better than the overall cropping intensity of about 135 percent. This is not in consonance with the expectations that irrigation would enhance cropping intensity. There are also expert opinions that the existing infrastructure of irrigation is depreciating and the pace of new infrastructure has been slow.

Besides, there are challenges associated with water use efficiency in agriculture. Currently, irrigation efficiency in India is around 35 percent in surface water system and 65 percent in groundwater system. Water is becoming a scarce input. The greater entrepreneurship of Indian farmers, supported by subsidized electricity for agriculture makes ground water exploitation a more convenient option for irrigation. Excessive exploitation of ground water for the purpose of irrigation has been adversely affecting the water table in different parts of the country. The stressed water resources have been directly reflecting on the levels of ground water depletion. Incidences of wells and farm tube wells going dry have become common in the recent years, burdening the farm household with huge cost to reenergize the well by deepening (Table 4.1)

Table 4.1 Well Failures in Different Categories from Eight Major Indian States

State	Percentage of Wells which have failed/ (Not in Use)			Percentage of Wells in use facing discharge constraints
	Dug wells	Shallow Tube well	Deep Tube well	
Andhra Pradesh	17.3/20.2	2.4/2.9	1.6/2.2	40.0
Bihar	18.0/32.5	2.7/4.8	36.7/44.9	12.6
Gujarat	19.3/22.0	12.0/14.2	8.5/12.0	24.5
Madhya Pradesh	16.2/18.0	14.7/15.1	13.9/16.2	58.5
Maharashtra	9.30/10.9	4.3/7.9	10.7/13.6	59.9
Orissa	21.0/25.0	16.5/19.3	51.8/62.8	7.7
Punjab	0.0/0.0	0.0/0.0	1.2/1.6	0.1
Rajasthan	24.9/27.9	3.3/3.5	7.4/7.8	19.1
Tamil Nadu	20.0/22.1	7.5/8.1	19.7/20.4	34.1
Uttar Pradesh	4.4/9.50	0.80/1.2	3.7/5.0	9.3
West Bengal	6.30/10.3	3.5/4.4	9.8/12.2	0.3

* Analysis based in Minor Irrigation Census data 2001

Source: M. Dinesh Kumar, Institute of Resource Analysis and Policy (IRAP), India

A glance at the irrigation development in India also shows large disparity among states and regions; Irrigation development has been mostly concentrated in the northern region of the country. The eastern region states of Orissa, Bihar, Eastern Uttar Pradesh and West Bengal have large untapped potential for irrigation development[9]. The average level of groundwater exploitation in Bihar and West Bengal is around 39 percent and 42 percent, respectively, leaving a huge potential for development. All 589 blocks in Bihar are safe to be exploited.

Further, there has been increasing occurrences of flood and droughts in some parts of India mainly due to limited level of proper assessment of water system and water budgeting.

Box – V
Water Requirements in India

Water Requirements for Various Purposes in India
(In billion cubic metres)

Purpose	Demand in 2000	Demand in 2010*	Demand in 2025*
Domestic use	42	56	73
Irrigation	541	688	910
Energy	8	12	23
Industrial Use	2	5	15
Others	41	52	72
Total	634	813	1093

*etimates
Source: The Planning Commission, 2007, Government of India

Water requirement in India has been increasing and the demand for water by 2025 is projected at 1093 billion cubic metres. The annual replenishable ground water resource for the entire country is estimated at 433 billion cubic metre (bcm). The annual replinishable ground water resource is contributed by two major sources- rainfall, and other sources that include canal seepage, return flow from irrigation, seepage from water bodies and artificial recharge due to water-conservation structures. The overall contribution of rainfall to the country's annual replenishable ground water resource is 67 percent and the share of other sources taken together is 33 percent.

[9]State of Indian Agriculture: The Indo-Gangetic Plain, National Academy of Agricultural Sciences, 2010

With respect to micro-irrigation (MI), even after continuous support and promotion of MI by the Government of India, the percentage of area under MI has not grown remarkably. Even though the return is high under MI, there has been reluctance among the Indian farmers to expand the area due to other constraints, such as high initial capital cost, low awareness of the long term benefits, low level of technical knowledge in the operation and maintenance of the systems and types of crops grown.

Land Degradation

Land degradation or deterioration of land quality for agricultural production has been a matter of concern for quite some time. The Netherlands based International Soil Reference Information Centre has estimated that around 80 percent of India's cultivated land is being slowly reduced to unproductive parched terrain due to wind and water erosion. According to a report by the Indian Council of Agricultural Research (ICAR) and the National Academy of Agricultural Sciences, of the 141 million hectares of land under cultivation in India, 100 million hectares (70 percent) is heading down a path, having limited capability for supporting farming. Overuse of fertilisers and pesticides and declining organic matter content (0.2 percent - 0.5 percent) as a result of intensive agriculture (major and medium irrigation along with groundwater being principal inputs in that) are also largely responsible for soil degradation. According to the estimates of All India Network Project on Soil Biodiversity-Biofertilizers, Indian Institute of Soil Science, Bhopal, the humus (soil organic matter) depletion in the top soil (0-15 cms) in Indian soil is around 50 percent, and occasionally as high as 60 percent to 70 percent in some soil types. There is also a loss of 10 percent to 20 percent of humus content in the 15-100 cms below the top layer.

The loss of humus in surface soil has caused a significant chemical deterioration with the result that more inputs are required to sustain agricultural production. Apart from retarding growth in yields, this unbalanced use of fertilizers has also resulted in physical deterioration of the soil. For instance, over use of urea (nitrogenous fertilizer) turns soil acidic. Acidic soils have complex nutritional disorders due to their property of high leaching. According to the estimates of the ICAR, around 2 percent (6.98 million hectares) of total geographical area of India (328.2 million hectares), have acidic soils. More energy is required to cultivate such degraded land, and a higher proportion of rainwater is lost as runoff. Thus a vicious self - destructive cycle of natural resource base has been triggered off, which has been one of the key reasons of productivity loss in Indian agriculture.

Water logging has been one of the other major reasons for productivity loss in Indian agriculture arising mainly due to traditional irrigation practices, such as flood irrigation. Water logging leads to salinity (Table 4.2). When the water table rises up or if the plant roots happen to come within the capillary fringe, water is evaporated through capillarity. Thus, with the upward flow of water from the water table to the land surface during evaporation, the dissolved salts present in the water are carried to the surface resulting in deposition of salts in the root zone of crops, which eventually reduces the osmotic activity of the plants leaving the plants to salt stress.

Table 4.2 Salt Affected Areas in Select States of India

State	Excess salt concentration area ('000 ha)		
	Saline	Alkali	Total
Andhra Pradesh	5.0	22.8	27.8
Bihar	224.3	-	224.3
Gujarat	911.0	-	911.0
Haryana	125.2	72.0	197.2
Karnataka	34.2	17.1	51.4
Madhya Pradesh	-	35.8	35.8
Maharashtra	5.4	-	5.4
Punjab	490.0	-	490.0
Rajasthan	70.0	-	70.0
Tamil Nadu	48.0	92.3	140.3
Uttar Pradesh	1150.8	-	1150.8
Total	**3063.9**	**240.0**	**3303.9**
In million hectares	3.06	0.24	3.3

Source: Ministry of Water Resources, Government of India

Box – VI
Land Degradation in IGP

Extent of Land Degradation in the Indo-Gangetic Plains (IGP)

(area in % of geographical area)

	Water erosion	Wind erosion	Water logging	Salinity/ alkalinity	Soil acidity	Complex problem
Punjab	7.4	5.6	6.7	5.7	0	0
Haryana	7.1	12.1	3.3	5.8	0	5.5
Bihar	17.4	0	11.5	1.3	5.9	0
West Bengal	13.5	0	8	1.9	6.3	1.3
India	28.5	2.9	4.4	1.8	4.9	2.2

Source: NRSC, 2008 and NBSS & LUP, 2008

Area Affected (in %) by Potential Soil Erosion in the IGP

State	Moderate	Severe	Extremely severe
Punjab	3.42	1.79	1.48
Haryana	3.82	1.83	0.95
Bihar	9.64	2.73	0.58
West Bengal	16.13	3.67	0.39
India	17.84	10.01	11.23

Source: NRSC, 2008 and NBSS & LUP, 2008

Seeds

Seed management is a very crucial element for growth in crop productivity. Seed management in the recent past has been posing serious challenges in India. The seed production has not been showing significant improvement. About 85 percent of Indian farmers use farm-saved seeds that lose its vigor and thereby the productivity over a period. Low seed replacement rate, uncertified seeds of uncertain quality sourced from diverse seed supply chain, and poor quality of seeds saved from farm are the important reasons for low productivity. The genetic gains obtained during the green revolution period in the seeds have decelerated. Varietal breakthrough and its dissemination have not been able to keep pace with country's varied requirements. There are yield gaps among the varieties available in different regions of the country. Significant breakthrough has not been achieved in development of seed varieties for pulses and oilseeds. The varieties, such as PBW 343, evolved out of the process of pure line breeding ten years back and contributed the wheat productivity in Northern States, covering about 80 percent of wheat area, has been showing signs of fatigue. New varieties have made little inroads in the intervening period.

Seed production chain from breeder seed to certified seed is also facing challenges. According to the Review Committee Report on Agriculture by the Planning Commission, Government of India, for the review of Eleventh Plan Period, there is a mismatch between the seed multiplication ratio from breeder seed to foundation seed, and from foundation seed to certified seed, particularly in case of the public seed producing agencies, such as State Seeds Corporation and States' Department of Agriculture (Table 4.3). According to the Report, out of 15 odd State Seeds Corporations, only a few Corporations are active and performing well. The unorganized sector comprising a source mainly of farm-saved seed accounts for nearly 80 percent of seed supply in the country.

Table 4.3 Mismatch in Seed Production System

Quantity in quintals

	Seed Multiplication Ratio	Breeder Seed Allotted / Lifted	Foundation Seed Produced	Certified/ Quality Seed Produced
Wheat	1:40	5561.35*	1,76,900 (1:32)	40,01,000 (1:23)
Paddy	1:80	932.84**	2,00,000 (1:21)	36,70,000 (1:18)
Urad	1:40	215.38**	7,500 (1:35)	207,000 (1:28)
Moong	1:40	178.46**	4,500 (1:25)	1,90,000 (1:42)
Soybean	1:16	7549.43**	91,522 (1:12)	14,77,581 (1:16)

* Rabi; **Kharif

Source: Planning commission, Government of India

The Seed Replacement Rate (SRR) has also not improved in the past decades. According to the Review Report by the Planning Commission, in the past two decades there has been practically no change in the SRRs in the States of Orissa, Bihar, Uttar Pradesh, Jharkhand, Assam, Madhya Pradesh and Chhattisgarh. There is also little focus on hybrid seed production in the public sector, particularly for foodcrops. The existing technological gap and weakness in the delivery of technology in seeds to the farmers has provided opportunity to private seed trade in the country (Table 4.4). The private seed industry in India has been growing appreciably and has made significant contributions in cultivation of Bt. cotton, hybrids of maize, and sunflower. At present, the number of companies engaged in seed production or seed trade is of the order of 400 to 500. However, the main focus of private seed companies has been on the high value-low volume seeds with commercial value, with little focus on low value-high volume seeds for foodcrops. Thus, for seeds of cereals, pulses and oilseeds, the farmers are largely dependent on the public sector. The private seed research has also been cost intensive, which is reflected in the pricing of the seeds. The Seed Bill (2011) need to have adequate redressal mechanism for farmers investing in such high valued seeds claiming very high productivity.

Table 4.4 Share of Private Sector in Seed Production

Year of Production	Total Seed Production (Lakh qtls.)	Share of Private sector
2003-04	132.27	47.48%
2004-05	140.51	45.02%
2005-06	148.18	46.80%
2006-07	194.31	41.00%

Source: Seeds Division, Department of Agriculture & Cooperation, Government of Inida

Fertilizers

The declining factor productivity in Indian agriculture is also partly attributed to the soil de-gradation, which may be a result of accumulating nutritional deficiency over the years. One of the main factors for disturbed nutritional status of soil is the imbalance in the use of NPK in fertilizers. Against the generalized recommended proportion of 4:2:1 of NPK, the aggregate national averages has been 7:2:1. There is a tendency of higher use of nitrogen (urea) by the

Indian farmers and in several instances, the phosphate and potash has limited use. This tendency is more prevalent in the Indo-Gangetic belt devoted to high productivity of wheat and rice and where the symptom of soil fatigue due to nutritional imbalance has been already evident. Rice and wheat are reported to remove more than 800 kg/ha/annum of N, P2, O5 and K2O, and micronutrients to the extent of 1 kg to 1.2 kg Zinc (Zn)/ha, 6 kg to 8 kg Ferrous (Fe)/ha, 1.2 kg to 1.4 kg/Manganese (Mn)/ha, and 0.6 kg to 0.8 kg Copper (Cu) /ha. Loss in nutrients, such as nitrogen is high in the Indo-Gangetic Plains due to acidic soils. Nitrogen deficiency is high in western Punjab, Haryana, UP, Rajasthan, Gujarat, Maharashtra, parts of Bihar, Jharkhand, MP, AP and Tamil Nadu. Phosphorous deficiency is high in parts of Himachal Pradesh, Haryana, UP, Rajasthan, Gujarat, Maharashtra, parts of Bihar, Jharkhand, MP, AP, Tamil Nadu, Bengal and Assam.

The loss of micronutrients is another major concern with Indian soils and productivity. Deficiency in soil of micro nutrients, such as zinc, iron, boron, manganese and copper are widely reported in the Indo-Gangetic Plains, particularly in Punjab and Haryana, raising questions about sustained benefits of canal irrigation in these areas. Lack of micronutrients in the soil is also inhibiting ability of soils to absorb conventional fertilisers, besides contributing to decline in yields. In the saline, sodic and alkaline soils, boron and molybdenum toxicity in crops has also been reported. The depletion of soil micronutrients is largely due to inappropriate cropping pattern, usage of HYV, no or low use of organic manure (Indian farmers' use 0-5 tonnes/ha of organic manure against recommended 5-10 tonnes/ha), and use of fertilisers rich in Nitrogen, Phosphorous and Potassium.

Increased use of fertilizers has also led to pollution of water sources, both surface and groundwater sources, resulting in poor quality of irrigation water impacting negatively on crop growth and productivity. It is known that a large part of the nitrogenous fertilisers leach out to the water resources causing deterioration of the water resources. The problem is acute in the intensive rice and wheat growing regions, particularly in the north-western Indo-Gangetic Plains of India e.g. Punjab, West Bengal, Bihar and Uttar Pradesh.

The imbalanced use of fertilizers by the farmers may not be solely attributed to the little awareness on the aspect of soil health and its nutrition balance. It is also largely due to distorting role of policy and management of fertilizers. The price and availability of Nitrogenous, Phosphates and Potash has also been playing a key role in imbalanced use of fertilizers by the farmers. The pricing policy of Nitrogenous fertilizers and reported deficit in the production capability of Phosphatic and Potash fertilisers are reportedly causing the nutritional imbalance of the soil over the decades.

Farm Mechanization

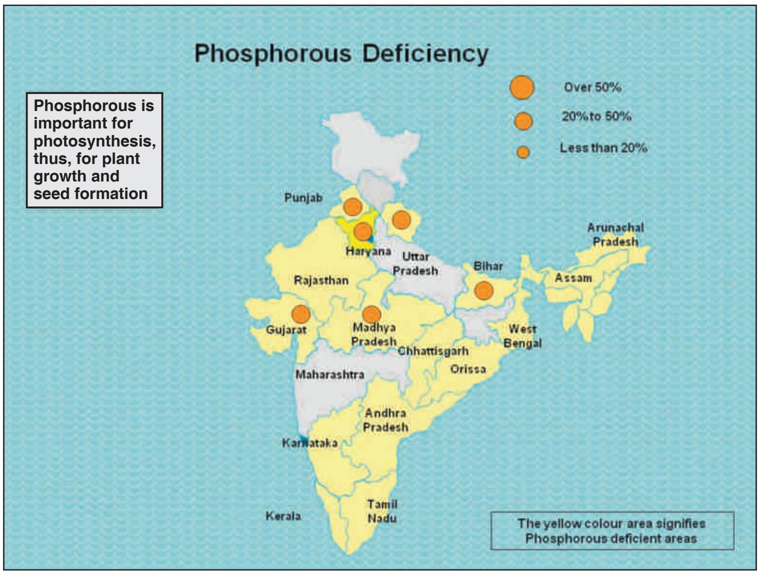
The agricultural development in the leading green revolution states, such as Punjab and Haryana is attributed to extensive farm mechanization. However, in eastern India, the progress of farm mechanization is very low. The rate of growth, in animal operated machinery, has remained high as compared to tractor or power operated machinery. State-wise analysis of the farm machinery utilization revealed that few states were using mechanical power source while others have been still using the animate sources and implements operated by them. Main reasons have been: low purchasing power and fragmented land holding of farmers, low levels of usage as compared to the cost of machinery, little awareness among farmers about the benefits of mechanization especially in hilly, backward and tribal areas, and limited availability of sale outlets and maintenance facility in nearby areas. Often buyers have to travel long distances for procurement, repair and maintenance. Quality and reliability of farm machinery being manufactured and supplied by various agencies and scale of manufacturers are yet to gain the confidence of common farmers.

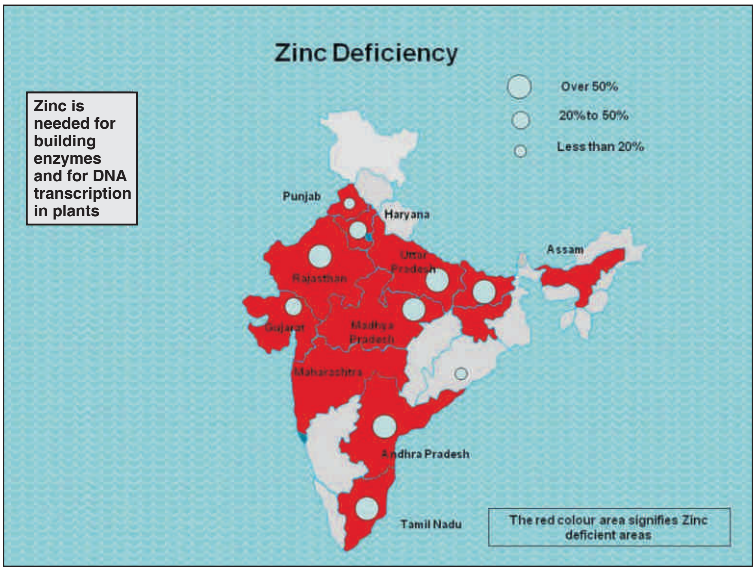
Research and Extension

Constraints have been highlighted with regard to delivery mechanism of public research system in India. The decline in yield growth for many crops during the 1990s has been attributed to the low impact level of the Indian public research system in keeping pace with the changing research requirements of the country. According to the National Commission on Farmers (NCF), there exist large yield gaps

Box - VII

Soil Micronutrient Deficiency Mapping of Select Micronutrients in India



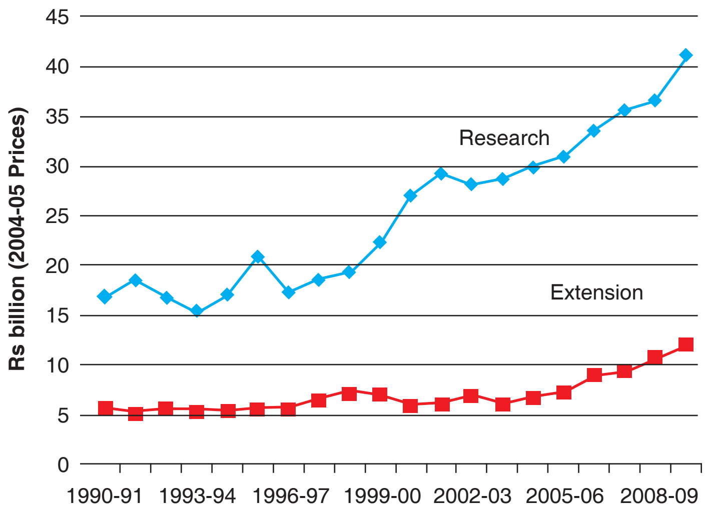


Source: Indian Institute of Soil Science Bhopal between yields in research stations and farmers' fields. The NCF also claims that there is a technology fatigue in Indian Agriculture. A review[10] of the research and development activities of the public research system of India reveals several weaknesses. Some of these are: (i) decline in role in seed development and its management; (ii) inadequate emphasis on the needs of rainfed areas, which account for over 60 percent of cultivated area; (iii) crop bias with major focus on rice and wheat; (vi) proliferation of programmes, resulting in resources being spread thinly, and inadequate focus in areas of relevance and opportunity; (v) inadequate priority to the emerging challenges, particularly productivity enhancement and management, post-harvest management, environmental conservation, and marketing; (vi) multiplicity of institutes with overlapping mandates leading to duplication of research work; (vii) less emphasis on multidisciplinary research; (viii) weak interaction among researchers extension workers, farmers and the private sector; and (ix) excessive centralization of planning and monitoring.

The relationship between R&D and agriculture extension has long been an issue. The deceleration in productivity growth is often linked to the slackness in the delivery of technology to the farmers (Table 4.5). According to a Working Group Report by the IFPRI and a study by the Centre for Research on Innovation and Science Policy (CRISP), India, on Indian agriculture extension, the extension machinery is weak in several parts of the country and there is a disconnect between the extension, research and development, and market needs. Further, the existing extension machinery has neither been able to keep itself updated with the evolving technology nor has been able to orient to the diversified agricultural development. Though information and communication technology is increasingly used for the purpose of extension, its reach is still very limited, since a large segment of farmers in the country are resource poor and do not have access to modern media system. For them the front line demonstration system by extension workers is the preferred source of knowledge dissemination.

[10] S. Mahendra Dev, Agricultural Economics Research Review Vol. 22 January-June 2009.

Box - VIII
Public Expenditure in Agriculture Research and Extension in India



Public Expenditure			
CAGR (%)	1980s	1990s	2000s
Research	6.09	4.40	4.82
Extension	5.94	2.76	6.23

Public Expenditure as		
% of Ag GDP	TE 1991	TE 2010
Research	6.09	4.40
Extension	5.94	2.76

TE - Triennum Ending

Source: Indira Gandhi Institute of Development Research, Planning Commission, India; FAO; The World Bank

Table 4.5 Agricultural Research Intensity in India

Agricultural research intensity	
> 1 % Ag GDP*	Uttarakhand (1.19) , Jammu & Kashmir (1.0)
0.6% to 1% Ag GDP	Himachal Pradesh (0.78), Jharkhand (0.63), Karnataka (0.58)
0.25% to 0.6 % of Ag GDP	Haryana (0.37), Punjab (0.28), Andhra Pradesh (0.27), Kerala (0.37), Tamil Nadu (0.50), Bihar (0.28),Gujarat (0.35), Maharashtra (0.42), Assam (0.40),
Less than 0.25 % of Ag GDP	Uttar Pradesh (0.15), Orissa (0.12), West Bengal (0.10), Madhya Pradesh (0.17), Rajasthan (0.14), Chhattisgarh (0.14),

*Agricultural GDP

Source: Indira Gandhi Institute of Development Research, Planning Commission, India; FAO; The World Bank

Other related issues

The small and marginal farmers account for around 80 percent of all operational holdings in India. Resultant to unabated demographic pressure and limited existence of alternative occupational options, the average size of operational holdings has steadily fallen to 1.34 hectare (2000-01 Agricultural Census). This has been impinging on agrarian economy in multiple dimensions, from dwindling farm household income to their propensity to invest, and is also exerting pressure on already stressed delivery mechanism for input distribution, particularly on technologies/options that are cost effective and efficient.

The agriculture sector of late has been witnessing dynamics of economic and market orientation, such as diversification to high value crops as well as value addition. These emerging changes are both supply driven, due to available cropping options and corresponding support systems, and demand driven, due to changing consumption habits and post harvest processing linkages. These changes, has been reflecting on overall agricultural growth. This has been necessitating assessment of investment and supporting infrastructure as well as commitments to allocate productive resources for sustenance of domestic supply to meet food security requirements of the country, without considerably disrupting trade.

Migration of farm labour from agricultural activities to other high-paid casual-labour employment through Government schemes has also been one of the hindering factors in agricultural growth. Rural wages have risen steadily in the past decade, such that a skilled labour is often, paid at rates higher than the minimum wage rate[11]. The wages increase significantly during the peak periods of cropping cycle, especially in high yield regions. Though employment guarantee schemes have assisted in renovation of ponds and canals, water conservation and water harvesting structures, drought proofing and tree plantation, flood control, micro and minor irrigation works and land development which will have a positive impact on agricultural productivity, they have also contributed to a substantial increase in the wage rates of agricultural and non-agricultural laborers, reduced

[11]Game Changer-Indian Agriculture, Kotak Institutional Equities Research (KIE)

the availability of labour for agricultural operations and increased the cost of cultivation. These increased wage rates have made farm labour expensive and also at times unavailable during the critical operational stages in farm management, which is reflected in farm production and productivity fall.

There has been a steady increase of agricultural wages in all major states of India in recent years. The annual average wage in Andhra Pradesh for unskilled agricultural labour has increased by 28.6 percent in 2009 compared to 2008, and further increased by 22.5 percent in 2010. Similarly in Orissa the wage increase has been 20 percent in 2009 over 2008, and 30.7 percent in 2010 over 2009. In Punjab the increase has been 22.2 percent in 2009 and 20.3 percent in 2010. In Tamil Nadu the increase has been 20.4 percent and 27.6 percent, respectively, in 2009 and 2010 in comparison to the respective previous years. Similar trend has prevailed in all the other States with double digit growth in wages even exceeding the rate of inflation that prevailed during this period. Rural wages in Kerala were the highest in the country in the range of Rs.216 to Rs.305 during 2008-10, followed by Tamil Nadu, Andhra Pradesh and Karnataka in that order in the Southern Region. In the Northern region, Haryana recorded the highest agricultural wages in the range of Rs.121 to Rs.182 during 2008-10 period followed by Punjab in the range of Rs 110 to Rs.162, and Rajasthan in the range of Rs.105 to Rs.139. West Bengal and Uttar Pradesh followed in that order.

Declining rate of investment in agriculture has also attributed to be an important factor for slow growth in productivity in recent decade. Farmers are unable to provide higher collateral and are unable to manage shorter maturities, and thus, are not in a position to invest in agriculture especially for capital assets. Flow of credit to the small and marginal farmers has been relatively less. According to the data from Reserve Bank of India (RBI), during 2008-09, the share of small and marginal farmers (farmers with less than 2.5 ha of land), who make up 83 percent of all farmers and cultivates on 43.5 percent of total agricultural land in India, in total agriculture credit is only 24 percent even as agricultural credit growth has been on the rise. There has been also considerable regional imbalance in credit flow to agriculture in India. According to a research paper ‘Agriculture Credit:

The Truth Behind the Aggregate Numbers' published in Economic and Political Weekly (EPW) October 15, 2011 Vol XLVI No. 42, Southern India, which accounted for 18.7 percent of the cropping area, accounted for 37.5 percent of agricultural credit during the 11th Five-Year Plan (2007-2012). Conversely, central and eastern India, which accounted for 28 percent and 15 percent of gross cropped area, respectively, received only around 13.2 percent and 7.3 percent of agricultural credit, respectively, during the same period. Further, according to the Report of Task Force on Credit Related Issues of Farmers by NABARD, there has been a significant increase in borrowings of small and marginal farmers from non-institutional credit sources, in the recent years. This is despite doubling of agricultural credit by Government of India in the recent years.

Credit product design is one of the major issues that has been reported to be hindering investment in capital assets in Indian agriculture. One of the issues that Indian agriculture has been reported to be facing is also that of deploying the credit funds that are available to the sector. While there has been a manifold increase in credit flow to agriculture, the impact of credit flow on production and productivity may be limited.

Agricultural statistics system in our country has been evolving over a period of time reflecting the complexities in the agrarian economy. However, reliability, timely availability, and coverage of data are still a challenge in India. This has been significantly affecting resource mapping, assessment and planning in Indian agriculture. For example, the analysis of flow of agricultural credit and its impact on productivity is constrained by the limited availability of granular data on agricultural credit. Further, there is limited data on agricultural credit to various crops, horticulture and allied activities even on a consolidated basis. With the availability of granular data on agricultural credit, it would be possible for taking effective policy steps that would eventually contribute to growth in farm productivity.

5. CASE STUDY

India is one of largest producers of many food products in the Asian region. It is the second largest producer of rice, wheat, fruits and vegetables in the world. It also has the largest arable land in the world. Despite having large productions in several food products, its productivity in many of the food products is one of the lowest in the world, particularly in comparison to some of its neighbouring countries in the region, such as China and Viet Nam, which shares a similar agricultural system. Though scope of a country-wise crop by crop comparison is limited in the Study, an attempt is made to compare some of the factors that may be responsible for a relatively high productivity in India's peer countries in select crop categories.

Rice and Wheat

Rice is the staple food of Asia. South and East Asia are the largest producers of rice in the region. In South and East Asia, rice-based cropping systems accounts for more than half of the total acreage where rice is grown in sequence with rice or upland crops like wheat, maize or legumes. Most of the rice grown in the region is on irrigated land in double-and triple-crop monoculture rice systems (Intensified Irrigated Rice Production System) practiced on over 14 million ha in China, India, Indonesia, Viet Nam, Bangladesh, Thailand, Philippines, Myanmar, Malaysia and Sri Lanka. A double-crop rice-wheat system covers another 22 million ha in India, China, Pakistan, Bangladesh and Nepal. Together these two cropping systems account for over 50 percent of global rice supplies. Irrigated rice comprise of 75 percent of total rice production in the region.

India is the second largest producer of rice in the world after China, with largest area under rice cultivation. A comparison of production, area under rice cultivation, and productivity of rice in main producing countries indicates the low productivity of India in rice. India has the lowest productivity of rice among the leading producers of rice in the world (Table 5.1).

Table 5.1 Area, Production and Yield of Rice in Top Ten Producing Countries - 2009

Countries	Production (million ton)	% Share in World production	Area Harvested (million Ha)	% Share in World area	Yield (kg/ha)
China	196.7	28.7	29.9	18.9	6582
Japan	10.6	1.5	1.6	1.0	6521
Viet Nam	39.0	5.7	7.4	4.7	5237
Indonesia	64.4	9.4	12.9	8.1	4999
Brazil	12.7	1.8	2.9	1.8	4405
Bangladesh	47.7	7.0	11.4	7.2	4203
Myanmar	32.7	4.8	8.0	5.1	4085
Philippines	16.3	2.4	4.5	2.9	3589
Pakistan	10.3	1.5	2.9	1.8	3581
Thailand	32.1	4.7	11.1	7.0	2883
India*	99.0	14.5	41.9	26.4	2178
World (Total)	684.8	100	158.4	100	4324

Countries ranked based on productivities

*Source: FAOSTAT, 2011; * Agriculture Statistics-2008-09, Department of Agriculture and Cooperation, GoI*

Table 5.2 reveals that productivity of rice in all the leading Indian rice producing states is below the global average. Eastern states, most of which falls under the Indo-Gangetic Plains (IGP) and are predominantly rice producers, with over 40 percent of land under rice cultivation, have some of the lowest productivities of rice in the country. Among the Indian states, Punjab, which also falls in the IGP, has the highest productivity of rice, with almost all rice grown is under irrigation. Punjab also closely compares to that of productivity of rice in Bangladesh, the fourth largest rice producer in the world, where around 55 percent of rice is grown as irrigated rice. The Indo-Gangetic Plain (IGP) in the Asian region is large and fertile encompassing most of northern and eastern India, including the states of Punjab, Haryana, Uttar Pradesh, Bihar and West Bengal, the most populous parts of Pakistan, parts of southern Nepal and most of Bangladesh, with similar topographical features and agricultural system. Rice based cropping system is predominant in IGP, with all countries contributing significantly to global rice production.

Table 5.2 Area, Production and Yield of Rice in Leading Rice Producing Indian States: 2008-09

State	Area Million Ha	Production Million tonnes	Yield kg/ha	Rice Area Under Irrigation (%) 2008-09*
West Bengal	5.94	15.04	2533	48.4
Andhra Pradesh	4.39	14.24	3246	96.8
Uttar Pradesh	6.03	13.10	2171	78.8
Punjab	2.74	11.00	4022	99.5
Orissa	4.45	6.81	1529	46.8
Bihar	3.50	5.59	1599	57.2
Tamil Nadu	1.93	5.18	2683	93.3
Chattisgarh	3.73	4.39	1176	32.7
Assam	2.48	4.01	1614	5.3
Karnataka	1.51	3.80	2511	74.7
Jharkhand	1.68	3.42	2031	2.2
Haryana	1.21	3.30	2726	99.9
Maharashtra	1.52	2.28	1501	26.4
Madhya Pradesh	1.68	1.56	927	17.8
Gujarat	0.75	1.30	1744	63.3
Kerala	0.23	0.59	2519	72.2
Others	1.75	3.56	NA	NA
All India	45.54	99.18	2178	58.7

Source: Agriculture Statistics-2008-09, Department of Agriculture and Cooperation, GoI

Table 5.1 also reveals China to have the highest productivity of rice in the world, and productivities of rice in Viet Nam and Indonesia are revealed to be more than double to that of India. Higher crop productivity and productions are influenced by input implantation and input management. Some of the factors that might have helped achieving higher productivity in the leading rice producing countries are discussed below.

Hybrid Rice in Leading Rice Producing Regions

The spread of hybrid rice in South East Asia has been strong. However, in India considering the importance of rice in the economy and the land devoted to rice, the spread of hybrid rice has been relatively slow (Table 5.3).

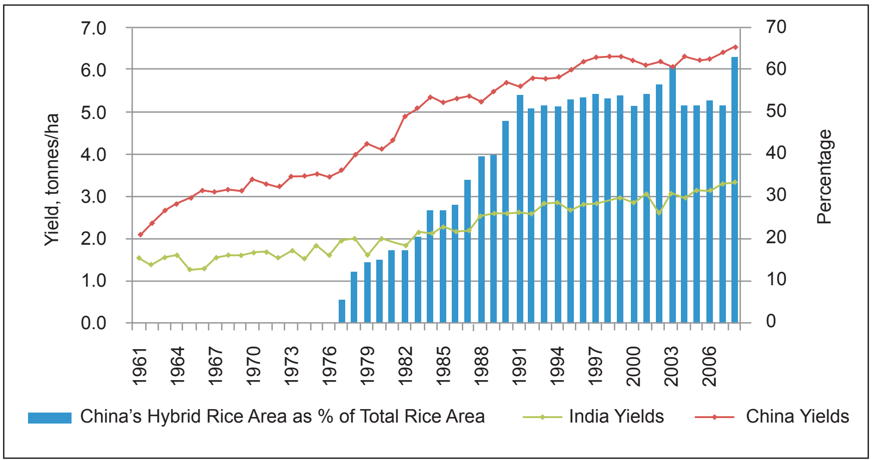
Table 5.3 Hybrid Rice Status in Major Hybrid Rice Producing Countries (2009)

Country	China	Bangladesh	India	Indonesia	Philippines	Viet-Nam	USA	Myanmar
Total Rice Area (million ha)	29.9	11.4	41.9	12.9	4.5	7.4	1.3	8.0
% Hybrid Rice in Total Rice	52.1	7.0	3.9	5.0	4.4	10.1	15.9	1.0

Source: International Rice Research Institute (IRRI)

China has been the pioneer in hybrid rice production and also the leading supplier of hybrid rice seeds to the world. Hybrid rice was first successfully developed in China in the 1970s. In 2003, an area of 15,210 ha was devoted to hybrid rice in the country, accounting for about 52 percent of the total rice area of the country and more than 90 percent of the total hybrid rice area planted in Asia. Average hybrid rice yield in China was recorded at 7 tons/ha, around 1.4 tons higher than inbred rice yield (Exhibit 5.1). China has developed super hybrid rice since 1996, which attained yields of 12 tonnes/ha. Hybrid rice is expected to attain yields of 13 tonnes/ha in the country in the near future. Through widespread multi-tiered research institutes, over 3000 seed companies have been created in China to cater to hybrid rice seed production and distribution.

Exhibit 5.1 Comparison of Paddy Yields in China and India and Share of Hybrid Rice in China s Total Rice Area



Source: FAOSTAT & Li, Xin & Yuan (2009)

Vietnam is considered the next "success story" in hybrid rice adoption, after China. First hybrid rice variety in the country was released in 1992, with a total area devoted to hybrid rice at 0.17 percent of the total rice production area. Currently, hybrid rice is planted in about 40 of the 64 provinces in the country covering an area of over 700,000 ha, gaining an average yield of 6.8 tonnes per ha, offering a higher yield of 1.5 tones in comparison with conventional rice cultivated under the same conditions. The Red River Delta (RRD), the main rice producing region of Viet Nam takes the lead in hybrid rice production with over 51 percent share in area.

Hybrid rice in Bangladesh was initiated in 1983. In 2001, about 20,000 ha was devoted to hybrid rice production in the country, this was raised to 49,655 ha in 2003, making up less than 1percent of the total rice area of Bangladesh. Currently, over 78 hybrid rice varieties are grown in Bangladesh in about 1 million ha, mostly in Boro rice season, the main rice producing season in the country, gaining a yield increase in rice of around 30 percent over inbred rice varieties.

Philippines became the fourth country to engage in hybrid rice and released its first hybrid seedling in 1993. Area under hybrid rice in

Philippines increased from 5,371 ha in 2001 to 192,600 ha in 2009, with yield advantage ranging from 8 percent to 14 percent over inbred rice, and an average yield difference of hybrid rice and inbred rice around 1.59 mt/ha.

Hybrid seed production for rice has also been expanding considerably in these countries (Table 5.4). For example, hybrid rice seed production in Bangladesh increased from 69 tonnes in 2009 to 400 tonnes in 2010, and is projected to grow up to 700 tonnes during 2011, which is further expected to reach 1,200 tonnes in 2012. However, annual consumption of hybrid rice seeds in Bangladesh is around 8,000 tonnes, and 90 percent of seed demand is met from import. Hybrid rice seed production in Viet Nam covers an area of 1,500 ha to 1,700 ha with an average yield of two tonnes/ha providing domestic contribution of approximately 20 percent of total seed demand.

Hybrid rice in India

Research on hybrid rice which was initiated in India in the 1980s with imported materials from China, however, had a low success rate. With support from FAO and UNDP, India developed its research network in hybrid rice since the early 1990s. However farmer's adoption of hybrids in the country is still at a low level. As of 2009, area devoted to hybrid rice was about 1.4 million ha, which is around 3.9 percent of the total rice area. In India, hybrid rice area has been reducing and is currently, mostly confined to small areas where there are on-farm demonstration programs by the Government and the seed industry. About 46 varieties of hybrid rice have been released for commercial cultivation till date. However, most of them are outdated and some have been not in the production chain.

Hybrid rice seed production in the year 2010 has been reported at 30,000 tonnes in 20,000 ha. The private sector actively participates in hybrid rice production, especially seed production, which is mostly exported to countries, such as Indonesia, Philippines, Viet Nam, Nepal, Myanmar and Bangladesh. It is estimated that about 800 to 1000 tonnes of hybrid rice seed is exported to the above countries annually.

Table 5.4 Performance of Hybrid Seed Production in Leading Rice Producing Countries - 2008

Country	Yield (kg/ha)	
	Range	Mean
China	1,500 – 6,000	2,750
Vietnam	1,500 – 3,500	2,000
India	1,000 – 4,500	1,600
Philippines	600 – 2,000	810
Bangladesh	600 – 2,000	800
Indonesia	300 – 1,600	500

Source: IRRI

At present, large scale hybrid rice seed production is concentrated in only two districts of Andhra Pradesh, viz., Karimnagar and Warangal. More than 80 percent of the hybrid rice seed is being produced in this region. The region has already reached saturation, with around 18,000 ha under seed production. Though potential of seed production lies is other States and regions, they have not been explored successfully. Performance of public sector in hybrid rice seed production has not been encouraging so far. Higher seed cost is another challenge faced by the hybrid rice farmers. Other challenges faced by the hybrid rice farmers are the time gap between availability of seeds between the seasons, quality of seeds, quality of the hybrid rice varieties, and marketability. Efforts for creating awareness and for technology transfer have also been inadequate.

Agricultural Mechanisation in Rice Based Cropping Systems in Asia

Although there has been a rapid economic development in Asian countries in recent years, the purchasing power of farmers in this region remains low, largely due to the predominance of small and marginal farmers. Therefore, the configuration of agricultural mechanization in the region, which mostly comprise of developing and least developed nations, is different from the developed nations of other regions.

At the same time, there have been varying levels of development of agricultural machinery industries and their use within the region. China and India have emerged as centers for large agricultural machinery manufacturers of the region. The agricultural machinery industry in China has been developed rapidly in the past two decades. Consequently, China has become a major producer of agricultural machinery along with its rapid development of agriculture. There are about 8,000 agricultural machinery manufacturers in China. Among them, 1,578 are large enterprises, including main machines' manufactures as well as the spare parts producers. In India, the number of agricultural machinery manufacturers has reached over 16,000. Though India has made remarkable advances in agriculture machinery industry, mechanization of farm operations remains low. Other rice economies in the South-East Asian countries, such as Cambodia, Thailand and Viet Nam have been rapidly adopting advanced machinery in farm operations in the recent years. But in most countries agricultural mechanization is still in its nascent stage.

According to research reports, there are two factors that determine the level of application of agricultural machinery: total percentage of mechanized field operations and the power of machines employed in unit of field operation (Kw/ha). In addition, there are two aspects that determine manufacturing capacity: number of manufacturers (including joint ventures) and the share of domestic and regional markets of agricultural machinery. Based on these criteria, the level of mechanization in the region is categorized as high, medium and low. Application of agricultural machinery over 20 percent is viewed as category I (high level); application of agricultural machinery between 10 per cent and 20 per cent is referred as category II (medium level); and application of agricultural machinery below 10 per cent falls under category III (low level). Table 5.5 presents a summary of these categories by select Asian countries.

Table 5.5 Farm Mechanization in Select Asian Countries (2007)

Country	Land Pre-paration (%)	Planting (%)	Threshing (%)	Harvesting (%)	Overall (%)	Machinery production	Categ-ories	Level of Mechani-zation
Bangladesh	180	low	> 80	low	low	Near Nil	III	Low
Cambodia	low	low	low	low	< 10	Near Nil	Nil	IIILow
China	60	35		30	42	Extensive	I	High
India	22	10	60	20	25-30	Extensive	I	High
Indonesia	Low	Low	Low	Low		Near Nil	Nil	IIILow
Republic of Korea	High	High	High	High	> 70	Extensive	I	High
Nepal	Low	Low	Low	Low	Near Nil	III	Low	
Philippines	13.2	0.2	69	Low		Few	II	Middle
Sri Lanka	80	Low	Low	Low	Low	Near Nil	III	Low
Thailand	High	Medium			Medium	Middle	II	Middle
Viet Nam	72 (Rice)	20	100			Middle	II	Middle

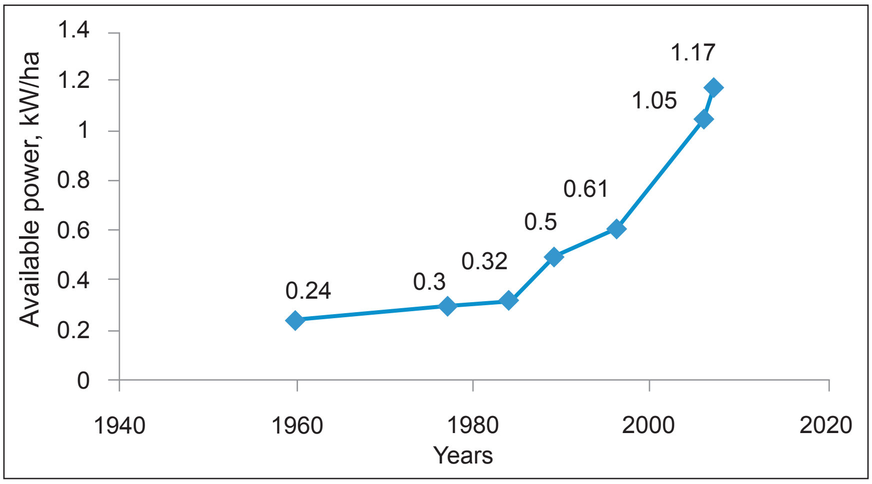
Source: United Nations Asian and Pacific Centre for Agricultural Engineering and Machinery (UNAPCAEM)

Definition and data on farm mechanization in the context of land-holding and farmers' demography in the region also varies considerably. This is an area where indicator and data collection challenges abound. According to FAO, tractors only include 4-wheel tractors (4WTs) and do not include 2-wheel tractors (2WTs), although they perform all the same tasks as 4WTs. Consequently, for instance, by this 4WT definition of agricultural mechanisation, Bangladesh's agriculture represents as hardly mechanised. However, several studies reveal that Bangladesh has one of the most mechanised agriculture in Asia, as a result of the spread of small-scale single cylinder diesel engines driven 2WTs, pumpsets and many other such types of equipments (Exhibit 5.2). Significantly, while most of the wheat and rice crop is threshed by machines, there are no combine harvesters in Bangladesh. Over 80 percent of primary tillage operations are mechanised, performed mainly by 300,000 small 2WTs and a few (3,000) 4WTs. There is a highly developed market for tractor services, pumpset services, threshing and other services derived from the use of small engines in Bangladesh. Over 55 percent of land cultivated in Bangladesh is under irrigation. Most of this is from ground water and surface water sources using small pumps.

Furthermore, Bangladesh has been focused on the imports of smaller scale machinery from China, This has led to the present level of over one million small horsepower diesel irrigation pumpsets and nearly 400,000 diesel 2WTs, making it the most mechanised, and labour intensive agricultural sector in South Asia.

On the other hand, India has a long history in the development and promotion of tractors and tractor industry. India at present is the leading producer of 4WTs in the world, and its exports are growing with demand in the USA expanding rapidly. Presently, there are over 20 factories producing nearly 300,000 tractors per year with an estimated total population of 4WTs of 2.8 million. Interestingly, India's agriculture is less mechanised than its neighbours Bangladesh and Sri Lanka. While India has 22 percent of its area under mechanised tillage, Bangladesh and Sri Lanka both have about 80 percent mechanized. While India's agricultural conditions are far more diverse than that of Bangladesh and Sri Lanka, the low level of mechanisation can be explained by the low penetration of 2WTs in India. There are only 110,000, Two-wheeler tractors in India, which is a third of the number prevalent in Bangladesh.

Exhibit 5.2 Farm Power in Bangladesh Agriculture Sector During 1960 – 2007



Source: UNAPCAEM {Islam (2007)}

Farm Mechanization in China

According to the China Statistics Yearbook of 2008, in 2008, land preparation through mechanization in China, primarily tractor usage, reached 91 million hectares across the nation, accounting for 62.92 percent of the total farmland. Around 59 million hectares of farmland were sown by machines, and 47.5 million hectares were harvested by machines representing 37.74 percent, and 31.19 percent of the total cropped land, respectively. Farm mechanization level (powered tillage, sowing and harvesting) was around 45 percent, and mechanization level of rice harvesting was more than 50 percent. In 2009, the general agricultural mechanization level reached 48.8 percent, and the mechanization of plowing, sowing and harvesting, respectively, achieved 64 percent, 40 percent and 37 percent (Table 5.6). Meanwhile, China's three major crops also achieved rapid development in terms of mechanization level. Wheat production has almost achieved complete mechanization, and the production of both rice and corn achieved over 54 percent of mechanization. In 2009, the general agricultural mechanization level of wheat and rice were 89 percent, and 54.9 percent[12], respectively. (Table 5.6)

Table 5.6 Agricultural Mechanization in China

Year	Total power (KW)	Tractor (ten thousand)	Combine harvester (sets)	Tractor ploughing (%)	Mechanical sowing (%)	Mechanical harvesting	Total level of Mechani-zation (%)
1978	117,499,000	193.0	19000	40.9	8.9	2.1	19.7
2001	551,721,000	1388.1	282900	47.4	26.1	18.0	32.2
2002	579,299,000	1430.6	310100	47.1	26.6	18.3	32.3
2003	603,865,000	1475.8	365000	46.9	26.7	19.0	32.5
2004	640,279,000	1566.8	410500	48.9	28.8	20.4	34.3
2005	683,978,000	1666.5	477000	50.2	30.3	22.6	35.9
2006	726,359,600	1728.3	567800	55.4	32.0	25.1	39.3
2007	768,786,500	1834.3	632400	58.9	34.4	28.6	42.5
2008	821,904,100	2021.9	743500	62.9	37.7	31.2	45.9

Source: China Statistics Yearbook 2009

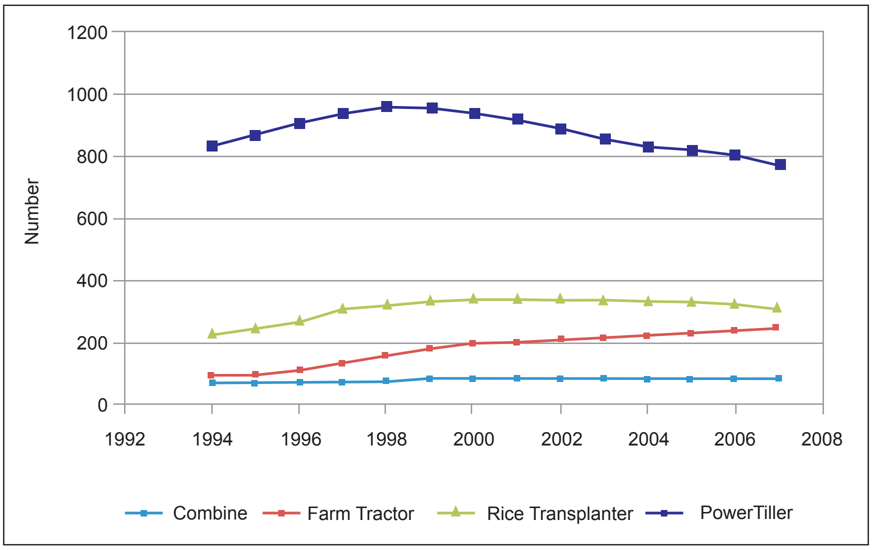
[12] *Global and China Agricultural Machinery Industry Report, 2009-2010*

Farm Mechanization in Republic of Korea

Republic of Korea is known to be one of the most mechanized countries in agriculture in the region, and also known to have one of the earliest advances in farm mechanizations. The Republic of Korea started its mechanization of agriculture in the late 1960s with the introduction of domestically-manufactured power tillers for agricultural operations. To accelerate the growth of industrialization and to maintain the required production levels in agriculture, in view of declining farm labour, the Korean Government actively promoted the agricultural mechanization program in the country. In late 1970s, rice farming was significantly mechanized with the help of domestically-manufactured power tillers, walking type rice transplanters and few designs of combine harvesters. The Korean Government played an important role by establishing the Agricultural Mechanization Promotion Act in 1978. In the early 1980s, the Government started promoting and distributing agricultural machinery, especially for rice cultivation with subsidized cost. Also, the facilities for the repair and maintenance of agricultural machinery were established during this period.

The total number of agricultural tractors in the country was about 12,389 in 1985, which reached to 258,662 in 2009. The use of cultivators and rice transplanters in agricultural production also increased. Before 2000, the use of walking-type rice transplanters was considerably higher than the riding type. However, in the recent years, walking-type transplanters are being increasingly replaced with riding type. The number of harvesting machinery, such as combines, binders and power reapers used in the country had also shown an increasing trend. Similarly, the number of power tillers used is also decreasing every year while use of small, medium and large farm tractors is increasing every year, indicating advances in mechanization in rice cropping system (Exhibit 5.3).

Exhibit 5.3 Trends in Number of Agricultural Machinery Holdings in Republic of Korea



Source: NAAS, 2009

Farm Mechanization in Thailand

Agriculture mechanization in Thailand started 50 years ago with land consolidating and leveling being the main operations and have been still continuing. At present, ratios of mechanization for land preparation and harvesting have reached 90 percent and 40 percent, respectively.

Mechanization has played a significant role in increasing agricultural production by increasing crop intensity, and also has been responsible for the development of modern agricultural production system in Thailand. The mechanization in Thailand started with power-intensive machines, such as irrigation pumps, power tillers and threshers. Most farm machinery used is locally manufactured, except some sophisticated machines which are imported. In the recent years, mechanization in Thailand is rapidly expanding both in terms of number and size of the machines in use; patterns of mechanization are also changing.

In rice harvesting, threshing machines are largely used in Thailand. Thai-made rice combine harvesters are adopted in the irrigated areas, the low land of the north and the northeast, accounting for 17 percent of the total cultivated land. Mechanical dryers have been playing an important role in maintaining and improving rice quality. In rice planting, transplanters are also popular. Machinery such as combine harvesters, power tillers and irrigation pumps are used significantly in the central plains of Thailand and use in other regions is rapidly growing.

Farm Mechanization in Viet Nam

In the recent years, agricultural mechanization in Viet Nam has increased manifolds particularly in the rice cultivation. From 2001 to 2009, number of tractors in Viet Nam has tripled, with smaller tractors dominating the sector (≤ 12 HP tractors: 65 percent; 12-35 HP tractors: 27 percent; ≥ 35 HP tractors: 8 percent). Around 70 percent of seedling production in rice is mechanized, and around 80 percent of the arable land is under mechanized irrigation, with 6 million ha of total rice area of 7.4 million ha under assured mechanized irrigation (Table 5.7).

Table 5.7 Mechanization in Agricultural Production Activities in Viet Nam

Agricultural Production Activities	Mechanization Rate (%)
Soil preparation for rice cultivation	72
Soil preparation upland crops	65
Active irrigation for rice	85
Transport in agriculture and rural areas	66
Rice drying in summer-autumn season in Mekong River Delta (MRD)(main rice region)	38.7
Rice harvest in MRD	15
Rice threshing	84
Rice milling	95

Source: Viet Nam Institute of Agricultural Engineering and Post Harvest Technology (VIAEP)

Fertilisation in Rice Based Cropping Systems in Asia

Fertilizer usage varies considerably in the region, reflecting factors, such as differences in agro-ecological resources (soil, terrain and climate) and economic incentives. Fertilizer productivity is related to soil moisture availability and, hence, to irrigation. In general, in developed countries, there has been a marked improvement in the efficiency of fertilizer use. However, in developing countries, fertilizer use is often inefficient, particularly in Asia; where, in rice cultivation the Nitrogen (N) losses are more than half of the quantity applied. Fertiliser use, especially in Asia has also been influenced by the Government policies, incentives and price interventions at large.

Consumption of N-fertilisers is highest in Asia, due to the existence of intensive irrigated rice-based cropping system. Table 5.8 provides the fertilizer use in rice by the major rice producing countries in Asia. An analysis of nutrient (NPK) uptake and productivities of rice in these countries also gives an indicative revelation on the extent of nutrient management in these countries, such as irrigation, and adoption of nitrogen management techniques.

Efficiency of fertilizer use largely depends upon on-farm fertilizer management. Table 5.8 shows that while India ranks second in application of fertilizer in rice, the productivity of rice is much lower than the other countries, indicating an inefficient fertilizer management, whereas countries with much lower fertilizer intake have higher productivities. For instance, fertilizer intake in rice in Bangladesh is a quarter of that applied in India; however, productivity of rice in Bangladesh is almost double to that of India. One of the success factors in Bangladesh's fertilizer management has been the Urea Deep Placement (UDP) technique. Bangladesh widely follows UDP technique in fertilizer application in rice, which is reported to be much efficient way of urea (nitrogeneous fertilizer) application in rice than commonly practiced broadcasting a basal application. Under UDP technique, compress prilled urea, called the urea super granules (USG), are inserted 7cm to10 cm deep in the soil between

Table 5.8 Fertilizer use in Rice Cultivation by Leading Rice Producing Countries in Asia

Country	N kg/ha	P kg/ha	K kg/ha	Total Fertilizer Use (000 tonnes)	Total NPK (kg/ha)	Productivity (kg/ha)
China	188.5	60.2	58.1	9168	306.8	6582
Viet Nam	103.8	61.0	38.5	1513	203.4	5237
India	104.9	34.2	21.6	6725	160.7	2178
Brazil	50.8	49.8	53.6	443	154.2	4405
Bangladesh	102.1	15.1	12.2	1468	129.3	4203
DPR Korea	87.8	14.8	20.0	--	122.6	2527
Pakistan	92.3	18.4	1.0	322	111.7	3581
Indonesia	90.7	8.7	9.2	1399	108.6	4999
Philippines	46.8	7.9	2.6	260	57.4	3589
Thailand	23.5	6.2	1.3	346	31.1	2883
World	99.0	30.6	24.2	24345	153.7	4324

Source: International Fertiliser Industry Association (IFA), FAOSTAT; Exim Bank Research

plants. UDP techniques double the percentage of nitrogen taken up by the plants. A higher fertilizer application rate in rice cultivation in Vietnam is explained by its efficient irrigation management in rice cultivation. Over 80 percent of rice grown in Vietnam is under assured mechanized irrigation.

Integrated Pest Management (IPM) in Indonesia

Government of Indonesia made rice as its top priority crop in foodgrain production since 1968 when it began a series of Five Year Development Plans. Rice plantation in Indonesia went through a series of serious pest attack in its initial years of intensive cropping, beginning late 1960s, resulting in large scale decline in rice yields and production. This encouraged overuse of pesticides in the Indonesian rice fields, with the Government considerably subsidizing pesticides in the country. Pesticide use continued to increase at a faster rate until late 1980s without much benefit in terms of pest control and production increase in rice. The overuse of pesticides not only killed the predators of the original crop pest, giving rise to their population, but also resulted in considerable increase in pest related hazards.

IPM was launched in 1979 and became an official government policy in Indonesia. Since 1989, the Government of Indonesia has been undertaking a large-scale IPM programme that works directly with frontline agricultural extension workers and a large number of farmer's groups across the country. IPM in Indonesia has honed the skills of fieldworkers and farmers in ecology-based methods. Decision making and field management are based upon agro-ecosystem analysis and hands-on fieldwork. In review and evaluations to date by international organizations, such as FAO and IRRI, the programme has been judged a success in institutionalizing safer and more environmentally friendly pest management techniques at the farmers' level. IPM also enabled Indonesian farmers to achieve significant increases in yield and production in rice.

The Rice-Wheat Cropping System in Asia

The Rice-Wheat (R-W) cropping system is mostly located in South and East Asia within subtropical to warm-temperate climates, characterized by cool, dry winters, and warm, wet summers. They extend across the Indo-Gangetic Plains (IGP) into the Himalayan foothills, spanning a vast area from Pakistan's Swat Valley in the north to India's Maharashtra State in the south, and from the mountainous Hindu Kush of Afghanistan in the west, to the Brahmaputra floodplains of Bangladesh in the east. The IGP in south Asia, where approximately 85 percent of R-W system is practised includes the Indus (areas in Pakistan, and parts of Punjab and Haryana in India) and the Gangetic Plains (UP, Bihar, and West Bengal in India, Nepal and Bangladesh). The remaining 15 percent is in Himachal Pradesh, Madhya Pradesh, and southwestern India, and in the hills of Nepal. In China, they are practiced widely in the provinces of Jiangsu, Zhejiang, Hubei, Guizhou, Yunnan, Sichuan and Anhui, along the Yangtse River Basin, and in the plains of Chengdu.

Though greatest yields in the R-W system are obtained from China, IGP has been important for R-W system due to its significant contribution to the world wheat production. The performance of R-W systems in the India's IGP in part reflects soil and climate-related constraints but there are also socio-economic and institutional impacts on productivity. For example, the previously wheat-dominant areas in the Upper-Gangetic Plains (most of Uttar Pradesh (UP), and parts of Bihar), and Trans-Gangetic Plains (Punjab, Haryana, and parts of UP) are generally mechanized and have good irrigation, infrastructure, and extension services. In contrast, the previously rice-dominant areas in the Middle-Gangetic Plains (most of Bihar) and Lower-Gangetic Plains (parts of Bihar, and West Bengal) have relatively less irrigation, depend more on animal power, and have less developed infrastructure and extension services. These areas also have greater socio-economic constraints related to fragmented land holdings, tenant farming, limited cash resources and limited inputs to production.

The use of technology and level of management vary widely across the R-W region. Rice is mostly transplanted by hand, although mechanical transplanters (Punjab province in Pakistan, China, and in parts of India) and broadcasting of rice seedlings (e.g. China) are being adopted in some areas. Machinery is increasingly available for sowing and harvesting and in the recent years, many small-scale farmers in the eastern IGP (e.g. Bangladesh) have access to small-sized machinery powered by two-and low power four-wheeled tractors.

Wheat production in R-W system in Asia has been largely benefitted from certain Resource Conservation Technologies (RCTs). Some of the RCTs, which have been significantly able to increase wheat yields in R-W System, are: Zero Tillage with Inverted-T openers-successfully practiced in Pakistan. To extend the technology in eastern parts of the IGP in Bangladesh, equipment is being modified for two-wheel hand tractors; Reduced Tillage – where seeders developed by China for 12 hp, two-wheel diesel tractor, prepares the soil and plants the seed in one operation. Besides China, the technology is also largely successful in Bangladesh, where imported hand tractors from China are used for the purpose; Bed-Planting – where wheat crops are planted on raised beds, practiced successfully in the high-yielding, irrigated, wheat-growing area of north-western Mexico; and Laser Leveling – practiced successfully in R-W cropping system for wheat in Pakistan as a means of improving water efficiency. Besides the number of RCTs that are practiced successfully in China, China has also been able to enhance and sustain productivity and soil fertility of the R-W cropping system by various other practices. The principal sustainable strategies used for rice-wheat cropping systems in China include: creating a favorable environment and viable crop rotations; balanced fertilization for maintenance of sustainable soil productivity; improvement of crop management for higher efficiency; and use of latest cultivars and cultivation techniques to upgrade the production level. A detailed description of RCTs is discussed in the subsequent Chapter, which suggests various technological interventions for enhancing foodgrain productivity in Indian agriculture.

6. STRATEGIES

The technological challenges facing agriculture in the recent years are probably even more daunting than those in past decades. With the increasing scarcity of land and water, productivity gains would be the main source of growth in agriculture and the primary means to satisfy increased demand for food and agricultural products. With globalization and new supply chain dynamics, farmers and countries need to continually innovate to respond to changing market demands and stay competitive, while remaining food secure. All regions, especially the heterogeneous and vulnerable rainfed regions need sustainable technologies that increase the productivity, stability, and resilience of production systems. These changes imply that technology for development must go well beyond just not raising yields but to saving water and energy, reducing risk, improving product quality, protecting the environment, and tailoring the gender differences.

Agriculture is a biological process, so technological innovations in agriculture are different from that in other sectors. Technological innovations in agriculture involve complex interactions among natural resources, biological and genetic resources, and social and environmental conditions, and thus, entail long gestation periods. The current chapter thus, discusses briefly some of the key technological innovations that may be adopted to address the current issue in question - productivity and sustainability in Indian agriculture.

Water and Irrigation Management

Technological improvements in irrigation systems increase production opportunities and productivities. Irrigation, being the major water user, its share in the total demand is bound to decrease from current levels of 83 percent to 74 percent by 2025, due to more pressing and competing demands from other sectors. Further, millions of marginal farmers world-over still depends on the rainfed agriculture, which makes it more important to conserve and utilise water resources.

Increasing water use efficiency

Water use efficiency in India is presently estimated to be only around 38 percent to 40 percent for canal irrigation and about 60 percent for ground water irrigation schemes. It is estimated that with 10 percent increase in the present level of water use efficiency in irrigation projects, an additional 14 million hectare area can be brought under irrigation from the existing irrigation capacities which would involve moderate investment as compared to the investment that would be required for creating equivalent potential through new schemes. One of the foremost effort to be made in this direction is to rehabilitate the existing community - based irrigation systems, which involves less capital outlay and maintenance costs. Secondly, evolve irrigation management techniques that are diverse and location specific, rather than spending resources on large scale irrigation project which takes years to complete. Thirdly, to promote irrigation policies that facilitate the community - based institutions for irrigation management, through a watershed approach. Finally, to build capacities of the irrigation departments that are able to promote a participatory governance system.

In order to increase the efficiency of the existing irrigation schemes, efforts at renewing and improving capacity of the schemes are necessary. Such a programme should focus on the following elements: reforestation of the catchment areas of the tanks; restoring the inlet channels to their original capacity by clearing them of weed and silt and removing encroachments; strengthening and improving the tank bunds and other associated structures; undertaking such improvements or corrections in the distribution network as the users feel to be necessary, and handing over the systems to local gramsabhas or user groups after bringing back the system in usable condition.

There is considerable scope for preventing and alleviating drainage problems by more integrated planning and water management. This may include integrated use of canal and groundwater for water table control, consideration of upstream and downstream relationships, adapting land use to the natural drainage conditions, exploration of opportunities of biological drainage and serial re-use of low quality drainage effluents.

Water harvesting and groundwater recharge

The decline in traditional irrigation systems like tanks and inundation canals has meant, besides reduction in irrigation benefits, substantial reduction in groundwater recharge. This has also implication for increasing the monsoon runoff, which in turn also accelerates soil erosion.

It is not often realised that of the total water resources of the country, estimated at 4000 BCM, over 40 percent (1700 BCM) is retained in the form of soil moisture. Water used for irrigation from surface and groundwater sources together, even at their fullest development, would come to less than 20 percent of the total (770 BCM). Therefore, new strategies need to be devised, which optimise the utilisation of soil moisture.

Various types of on farm soil and water conservation technologies and engineering measures can reduce peak runoff rates and soil loss by 60 percent to 80 percent and raise crop yield by 30 percent to 40 percent through a combination of mechanical and vegetative measures. These engineering measures may include brushwood check dams, contour bunding, gabion structures, loose boulder check dams and silt retention dams. For example, contour bunds can reduce soil loss by up to 78 percent and runoff by up to 63 percent. In addition, biological measures, such as plantation of shrubs and trees are also suggested.

Farm ponds are a low cost and labour intensive method of runoff harvesting for drought proofing in the dry regions. They provide a critical life saving supplemental irrigation (5 cm) in the years of drought. The effect of one 5 - cm irrigation from water harvested in farm ponds on various crops in a few dryland locations showed that yields were higher by 60 percent to 70 percent and Water Use Efficiency (WUE) averaged nearly 18 kg/ha/mm.

Projections made by scientists show that there exists potential to harvest 63.2 BCM of precipitation equivalent runoff at the farmer field level in regions receiving 1000 mm rain per annum. The runoff, if harvested, can provide two life saving irrigation of 5 cm each for more than 60 percent of the total rainfed area.

Other similarly relevant local water harvesting techniques include stop dams, Naala Bund, underground puddled dykes, and erosion control structures.

Technological Options

Modern irrigation technologies, such as treadle pumps and micro irrigation, increase water use efficiency. They have opened up opportunities to cultivate soils with low water-holding capacity (sandy and rock soils) and to culturate low quality lands and steep slopes. These technologies have also enabled regions facing limited water supplies to shift from low-value crops with high water requirements (e.g. cereal) to high value crops with lower water requirements, such as fruits, vegetables and oil seeds.

Micro-irrigation technologies can be broadly categorized into two types, based on their technical and socioeconomic attributes: low-cost micro-irrigation technologies and the commercialized, state-of-the-art micro-irrigation systems. Low-cost systems include the Pepsee easy drip technology, bucket and drum kits, micro sprinklers, and micro tube drip systems. The more sophisticated, capital intensive systems are conventional drip and sprinkler systems.

Treadle Pumps

One of the technological innovations in micro - irrigation in the recent years, has been the Treadle Pump (TP). It provides an efficient means to deliver water for resource poor small and marginal farmers who cannot afford wells and diesel pumps. The TP is a foot operated reciprocating pump. Two pedals connect twin cylinders through piston and lever mechanism. The operator pedals the lever in standing position, thus utilising the entire body weight to operate the pump. The TP was first introduced in Bangladesh in the 1980s. TPs are available in 3.5” cylinder diameter bamboo type, 3.5” and 5” metallic type, and 5” concrete type. These pumps can draw water only from a depth of 15-20 feet. They are thus, useful in areas where the water table is fairly high. They are now increasingly used in Eastern India, in the states of Bihar, UP, Orissa and Assam. The TP system has brought lands under irrigation in households that depended on rainfall previously, and has replaced other traditional manual systems and even hired diesel pump irrigation in some cases. The TP irrigates only about 0.1-0.2 Ha of land, and the investment per pump is between ₹ 1,000 and ₹ 2,000. The operating costs of the TP are significantly lower than that of hired diesel pumps. The operating costs of bamboo pumps are higher due to higher maintenance cost and lower discharge than those of concrete and metallic pumps. Most users of TPs are small and marginal farmers. Large farmers who use TPs prefer to use it for specific applications. The functionality rate of the device has been found to be 95 percent, which indicates high user acceptability of this system. The output of the TP varies from 33-56 litres per minute (lpm) for bamboo pumps, to 89 lpm for the metallic and concrete pumps. The environmental benefit of TPs is that it saves 114 to 132 litres of diesel in 100 hours. As the discharge of the TP is limited, the TP is used to irrigate crops with low but regular water requirements, such as vegetables. The rapid returns gained from vegetable crops have meant relatively quick prosperity for the farmers using TPs (Srinivas, et al, 1996).

Precision or Drip Irrigation

Used in diverse soil types, this system, however, is more suitable for porous soils, water scarcity areas and undulated lands. Since the water is applied daily/alternate days at low rate and at low pressure (up to 1 kg/cm2) over a long period of time and directly into the vicinity of plant roots, it maintains the soil moisture level around the root zone at/close to field capacity. Other advantage includes the use of saline water up to 8-10 dS/m without affecting the yield. In addition, fertilizers can also be combined and delivered simultaneously with irrigation water (drip-fertigation) more precisely to the root zone, which can increase the efficiency of fertilizer use substantially. Experiments have shown that use of drip irrigation can lead to cut in water use by 30 percent to 70 percent and to increase crop yields by 20 percent to 90 percent.

Low-cost micro-irrigation technologies are largely promoted for resource poor small and marginal farmers, hence they are competitive in pricing and compatible with smallholder farming systems. Farmers can generally recover their initial investment capital between one and three years, although the extent of economic gains from investment depends on the type of crop.

The technical, economic and social attributes that distinguish the low-cost irrigation systems from commercial state-of-the-art irrigation systems are as follows:

Criteria	Micro-irrigation Systems	
	Low-cost Systems	**Conventional Systems**
Affordability	Require little initial capital	Require high initial capital
Local manufacturing capacity	Based on local skills and materials	Require relatively sophisticated facilities
Payback period	Usually covers investment cost in one or two seasons	Require several years
Compatibility to the farming system	Available in a range of small packages and expandable	Generally adopted by large farms, but small versions of high-tech systems are also being marketed
Pressure requirement	Require low pressure	Require high pressure
Ease of technical understanding by users	Simple and easily understood	Sophisticated and need technical expertise
Operational convenience	Low operational conveniences	High operational conveniences
Compatibility with local micro-entrepreneurship	Compatible with local micro-enterprises and require limited skill and capital to design, service and maintain	Require special skill

Source: IWMI

Various low-cost and simple drip irrigation systems available are:

- Bucket Kit
- Family Kit
- Drum Kit
- Customized System
- Combo Kit

Potential advantages of Drip Irrigation

- Enhanced water utility - Irrigation water requirements can be reduced with drip irrigation over traditional one depending on the crop, soil, environmental conditions and the attainable on-farm irrigation efficiency. Primary reasons for water savings include precision irrigation, decreased surface evaporation, reduced irrigation-runoff from the field and controlled deep percolation losses below the crop root zone (Table 6.1).

- Better crop growth and yield - Under drip irrigation system, soil water content in the active portion of the plant root zone remains fairly constant because irrigation water can be supplied slowly and frequently at a predetermined rate. Here, the total soil water potential increases (soil water suction decreased) with elimination of the wide fluctuations in the soil water content. Proven results revealed that the benefits of drip irrigation includes frequent irrigation to crop as far as practicable, free from irrigation induced soil aeration, less plant disease and restricted plant root growth (Table 6.2).

- Reduced salinity - Evidences suggest that waters of higher salinity can be used in drip irrigation without greatly reducing crop yields. Minimizing the salinity hazard to plants by drip irrigation can be attributed to dilution of the salt concentration in soil solution following irrigation to maintain high soil water status in the root zone and movement of salts beyond the active plant root zone. Drip system suitable to use saline water has practical utility in cotton being the major crop cultivated using poor to very poor quality water in most of the parts in southern region of India.

- Higher fertilizer use efficiency - Drip irrigation offers considerable flexibility in fertilization. Frequent or nearly continuous application of plant nutrients along with the irrigation water is feasible and appears to be beneficial for crop production. The contributing factors for increased efficiency of fertilization include decreased quantities of applied fertilizer, improved timing of fertilization and improved distribution of fertilizer with minimum leaching or runoff.

Reduced weed competition - Since weed infestation depends on soil moisture content, drip irrigation reduces weed infestation due to limited wetting of root zone only. Significant reduction in weed biomass has been observed in drip irrigation plot as compared to surface irrigated plots.

Saving of labour - Drip irrigation systems can be easily automated where labour is limited or expensive. In addition to labour savings following automation, greater efficiency can be achieved through other cultural operations like spraying, weeding, thinning, and harvesting of row crops, while the crop is still irrigated. Moreover, labour and operational costs can be reduced by the simultaneous application of water, fertilizer, herbicide, insecticide, or other additives through the drip system.

Table 6.1 Water Productivity under Conventional and Drip Irrigation Methods in India

Crop	Water productivity (kg/m^3)	
	Conventional (flood irrigation)	Drip
Cotton	3.1	11.6
Mulberry	138.6	375.0

Source: Water Policy Briefing, IWMI

Table 6.2 Land and Water Productivity of Select Crops under Conventional and Drip Irrigation Systems in India

Crop	Yield (t/ha)		Yield (kg/m^3)	
	Conventional (flood irrigation	Drip	Conventional (flood irrigation)	Drip
Sugar cane	128	170	6.0	18.1
Cotton	2.3	3	0.3	0.7

Source: Water Policy Briefing, IWMI

Economics of drip irrigation system

For successful adoption, a technically feasible irrigation method should also be economically easier for adoption. Field trials have revealed that a low cost polytube drip system performed higher in terms of crop growth characters, yield attributes and seed yield, and in optimum efficiency through water use efficiency, uniformity coefficient, nutrient use efficiency and economics of nutrient use efficiency. Cotton being one of the crops where all kinds of drip systems has been successfully used, a comparative account of economics of Bt cotton production under various drip irrigation methods and conventional method is provided in Table 6.3.

Table 6.3 Comparative Account of Economics Involved in Conventional and Drip Irrigation Systems in Bt Cotton (Rs/ha)

Items	Existing Drip System	Low cost micro-tube	Low cost poly-tube	Ridges & furrow
Mains, sub-mains & accessories	***26,168***	***25,406***	***25,406***	**–**
Laterals	27,080	13,540	945	--
Drippers	20,832	--	--	--
Microtubes	--	6,250	--	--
Polytubes	--	--	4,901	--
Sub-total	***47,912***	***19,790***	***5,846***	**--**
Total system cost	**74,080**	**45,196**	**31,252**	**–**
Per annum irrigation cost	12,594	7,683	7,273	2,500
Saving in total cost of the system (%)	--	39.0	57.8	--
Saving in per annum irrigation cost (%)	--	39.0	42.3	--
CC excluding irrigation cost	20,271	19,561	19,917	23,050
Total cost of cultivation (CC)	32,865	27,244	27,190	25,550
Gross Return	67,625	63,367	65,500	60,300
Net Return	34,760	36,123	38,310	34,750
Benefit-Cost Ratio (BCR)	**2.06**	**2.33**	**2.41**	**2.36**

Source: Central Institute for Cotton Research, Coimbatore, India

In Table 6.3, costs pertaining to all the drip systems including low cost one had been arrived with higher irrigation cost and harvesting charges. The cost towards weed control and land shaping is less with all drip systems. Since weed infestation depends on soil moisture content, in drip irrigation, only a fraction of the soil surface is wetted, thus, reducing weeding cost. Perfect land shaping is not required in drip system, thus, lead to less cost on land preparation. Moderately higher yield (2620 kg/ha) with all the positive effects (of drip) along with lower cultivation cost (Rs 27,190/ha) were incurred in low-cost poly tube drip system, which further led to higher net return (Rs 38,310/ha) and BCR (2.41).

It has been assessed that there is a potential of bringing around 42 million ha under drip and sprinkler irrigation in India. Out of this, about 30 million ha are suitable for sprinkler irrigation for crops, such as cereals, pulses, and oilseeds in addition to fodder crops. This is followed by drip with a potential of around 12 million ha under cotton, sugar cane, fruits and vegetables, spices and condiments, and pulse crops, such as red gram.

Various water-saving and yield improving technologies for different crops, and crops conducive to water-saving technologies and their potential spread in India is provided in Annexure-IV.

Sprinkler Irrigation

Sprinkle irrigation has a distinct advantage, because good water management practices are built into the technology. Sprinkle irrigation technology can provide the flexibility and simplicity required for successful operation, independent of the variable soil and topographic conditions. Pumps, pipes and on-farm equipment can all be carefully selected to produce uniform irrigation at a controlled water application rate, and, provided simple operating procedures are followed, the irrigation management skills required of the operator is minimal. Sprinkle can be much simpler to operate and requires fewer water management skills. However, it requires sophisticated design skills and on-farm support in terms of maintenance and the supply of spare parts (Table 6.4).

Sprinkle is potentially less wasteful of water and uses less labour than surface irrigation (Table 6.5). It can be adapted more easily to sandy soils subject to erosion on undulating ground, which may be costly to re-grade for surface methods. There are many types of sprinkle systems available to suit a wide variety of operating conditions. The most common for smallholders is a system using portable pipes (aluminium or plastic) supplying small rotary impact sprinklers. Because of the portability of sprinkle systems they are ideal for supplementary as well as total irrigation.

Table 6.4 Summary of Sprinkle Irrigation Systems

System	Types		Use
Conventional systems	Portable	Hand-move Roll move Tow line	Uses small rotary impact sprinklers; Widely used on all field and orchard crops Labour intensive
	Semi permanent	Sprinkler hop Pipe grid Hose pull	Similar to portable. Lower labour input but higher capital cost
Mobile gun systems	Hose pull Hose drag		Large gun sprinklers that can be replaced by boom. Good for supplementary irrigation
Mobile lateral systems	Centre pivot Linear move		Large automatic systems. Ideal for large farms with low labour availability
Spray lines	Stationary Oscillating Rotating		Fixed spray nozzles. Suitable for small gardens and orchards

Source: Central Institute for Cotton Research, Coimbatore, India

System of Rice Intensification

"System of Rice Intensification (SRI)" involves the use of certain management practices, which together provides better growing conditions for rice plants, particularly in the root zone, than those plants grown under traditional practices. Four components of SRI include early planting (12 days old single seedlings, wider spacing), limited irrigation (2-3 cm depth after the appearance of hairline cracks), weeding and application of more compost and building soil organic matter content.

Table 6.5 Farm Research Data on Sprinkler Irrigation in Comparison to Conventional Surface Irrigation

Crops	Locations	Yield (q/ha)		Irrigation water (cm)		Water Use Efficiency (q\ha\cm)		Benefits over FIM (%)	
		FIM	SIM	FIM	SIM	FIM	SIM	Water	Yield
Wheat	Maharashtra	32.4	36.4	35.0	20.3	0.9	1.8	42.1	12.3
	Rajasthan	26.6	33.0	33.0	14.5	0.8	2.3	56.0	24.1
	Haryana	44.8	48.7	33.9	32.7	1.3	1.5	3.9	8.7
Bajra	Maharashtra	7.0	8.3	17.8	7.8	0.4	1.1	56.0	19.5
Jowar	Maharashtra	4.9	6.6	25.4	11.3	0.2	0.6	55.6	34.6
Sorghum (k)	Maharashtra	44.1	55.0	18.0	12.0	2.5	4.6	33.3	24.6
Maize (k)	Rajasthan	15.6	18.1	12.8	9.0	1.2	2.0	33.0	15.9
Barley	Rajasthan	24.1	28.2	17.8	7.8	1.4	3.6	56.0	16.9
Gram	Haryana	6.6	9.9	17.8	7.8	0.4	1.3	56.0	51.3
Foodgrains (Avg)		**24.1**	**27.9**	**23.5**	**14.5**	**1.1**	**2.0**	**40.0**	**20.7**

FIM: Flood Irrigation Method; SIM: Sprinkler Irrigation Method; k: Kharif; r: Rabi
Source: Indian National Committee on Irrigation and Drainage (INCID)

The principles of the SRI have been well taken care of and the management practices are appropriately adjusted to suit the farmers' need and local situations. Age of seedling, spacing, fertilizer application, inter cultivation for soil aeration and water management practices are suitably modified for farmer friendly adoption and yield improvement. SRI is currently practised by rice farmers in over 40 countries all over the world, including China, Indonesia, Cambodia, Bangladesh, Cuba, Myanmar, Nepal, Sri Lanka, Vietnam and West Africa. In India, SRI is being practiced mainly in Southern India in the states of Tamil Nadu, Andhra Pradesh, Karnataka, and sporadically followed in few Eastern states like Tripura and Assam. Given the present situation, faced by the country, growing rice with intensive use of scarce natural resources such as water, seed and labour is unsustainable. Simplification of SRI methodology and scaling up this innovative approach throughout the country alone may help sustain the irrigated rice cultivation in future (Table 6.6).

Benefits of SRI Technology

Less seed rate: A seed rate of 5-8 kg depending on 1000 grain weight is sufficient to plant one hectare of land under SRI while in conventional method depending upon the duration, 60 kg ha-1 short duration, 40 kg ha-1 medium duration, 30 kg ha-1 for long duration varieties, and 20 kg ha-1 for hybrids is recommended.

Less nursery area: A mat nursery area of 2.5 cents (100 sq.m) is sufficient to raise seedlings to cover one hectare of land in SRI while in conventional methods, 20 cents per hectare is required.

Labour saving: The labour required for nursery period is less (12 labourers) for SRI nursery compared to conventional nursery (30 labourers).

Water saving: Water requirement under SRI method is only 600 mm to 700 mm through intermittent irrigation while in conventional method, 1200 mm to 1500 mm of water is required for continuous flooding.

Aeration: Cono-weeding results in aeration to the root zone besides saving in labour to the tune of 50 percent.

Enhanced yield: The additional yield advantage in SRI ranges from 500 to 1500 kg / ha over conventional method of planting. The reason is mainly attributed to more number of lengthy productive tillers with increased number of filled grains per panicle.

Control of malaria: By avoiding flood irrigation and adopting limited irrigation, the breeding of malarial mosquito in rice fields can also be checked.

Table 6.6 Comparison of Rice Yields in Conventional and SRI Farming Practices

Parameters	Conventional	SRI
Trial area (m2)	25	25
Grain yield—minimum (kg/ha)	3,887	4,214
Grain yield—maximum (kg/ha)	8,730	10,655
Mean grain yield (kg/ha)	5,657	7,227
Standard deviation	1,108	1,379

Source: Thiyagarajan et al., 2005

Table 6.7 below summarises the impact in production, assuming that SRI is practised on 20 million ha under rice out of India's current area of around 43 million ha under rice.

Table 6.7 Impact of SRI on Rice Production System in India

	Level		Total estimate		Advantage due to SRI
	Conventional	SRI	Conventional	SRI	
Seed use	30 kg/ha	7.5 kg/ha	600m tonnes	150m tonnes	450m tonnes saved
Irrigation water	149 m^3	92 m^3	2,980mm^3	1,840mm^3	1,140mm^3 saved
Paddy Production	3.17 t/ha	4.17 t/ha	139m tonnes	183m tonnes	44m tonnes more production

Source: Gujja and Thiyagarajan; International Institute for Environment and Development (IIED)

Agri-Biotechnology

Agricultural biotechnology has the potential for huge impacts on many facets of agriculture crop and animal productivity, yield stability, environmental sustainability, and consumer traits important to the resource poor population.

The first-generation biotechnology include plant tissue culture for micro-propagation and production of virus-free planting materials, molecular diagnostics of crop and livestock diseases, and embryo transfer in livestock. Fairly less expensive and easily applied, these technologies have already been adopted in many developing countries. For instance, disease-free sweet potatoes based on tissue culture have been adopted on 500,000 hectares in China, with yield increases of up to 30-40 percent. However, in India, research and adoption of such biotechnological innovations have been low; with some break through obtained in the recent years, in horticultural crops, such as banana, where disease-free and high-yielding tissue culture varieties are being used commercially.

The second-generation biotechnologies based on molecular biology use genomics to provide information on genes important for particular trait. This allows the development of molecular markers to help select improved lines in conventional breeding known as marker-assisted selection. Though slow in spread, such markers have led to development of varieties, such as downy mildew-resistant millet in India; and bacterial leaf blight resistance rice in the Philippines. As the costs of marker-assisted selection continue to fall, it is likely to become a standard part of the plant breeder's programmes, substantially improving the efficiency of conventional breeding. With adoption of adequate safeguard measures for Breeder's rights under the IPR, India also needs to emphasize on such breeding programmes.

Though controversial, the most improved biotechnologies in the recent years have been the transgenics or genetically modified organisms, commonly known as GMOs. Transgenic technology is a tool for 'precision breeding', transferring a gene or a set of genes conveying specific traits within or across species. For instance, transgenic Bt cotton for insect resistance have reported to have substantially reduced yield losses from insects, increased farmers' income, and significantly reduced pesticide use in India and China. Adoptability of transgenic technology world over remains low due to perceived and potential environmental and health risks; however, it holds considerable potential in addressing productivity issue that has been pertaining in agriculture in majority part of the world.

Yield stability is important for all farmers, but especially for farmers in subsistence agriculture, whose food and livelihood security are vulnerable to pest and disease outbreaks, droughts and other stresses. Improved varieties can make yields more stable. Yield stability of improved varieties largely reflects long-standing efforts in breeding for disease and pest resistance. They must be periodically replaced to ensure against outbreaks from new races of pathogens. Without investment in such 'maintenance research', yields tend to decline. Underinvestment in maintenance research may leave significant negative impact on global food supplies. For instance, the emergence of Ug99, a new race of stem rust (Puccinia graminis tritici) in wheat, the world's second most important food staple. According to entomologists, Ug99 is expected to be carried by the wind through the Middle East to wheat-growing areas of South Asia and possibly to Europe and the Americas. Given the narrow base of genetic resistance to the disease in existing varieties of wheat, the spread of Ug99 could cause devastating losses in some of world's breadbaskets.

Similarly, farmers who use traditional varieties are also vulnerable to random outbreaks of disease. Thus, through new international effort, plant breeders and pathologists, in order to avoid such global epidemic, need to screen for resistant genotypes and get them to farmers' fields.

Progress in developing varieties that perform well under drought, heat, flood and salinity has been generally slower than for disease and pest resistance. However, recent research evidences points to significant yield gains in breeding wheat for drought and heat-stressed environments. Also new varieties of rice that survive flooding have also been identified. Such advances in drought, heat and flood tolerance will be especially important in adapting to climate change, particularly for India.

Large areas of major food crops are now planted each year in relatively few improved varieties, and generic uniformity can make crops vulnerable to major yield losses. However, in the recent decades, agriculturalists have been able to avoid major disasters from genetic uniformity in part, because of frequent turnover of varieties, which brings new sources of resistance. Even so, wider conservation and use of genetic resources are needed.

Biotechnology, thus, has great promise, but the current investments are concentrated largely in the private sector, mostly driven by commercial interests, and not focused on addressing issues of sustainability and food security. This indicates towards an urgent need to increase public investments in pro-sustainable traits and crops at international and national levels, and to improve the capacity to evaluate risks and regulate these technologies in ways that are cost effective and inspire public confidence in them.

Soil Health and Nutritional Management

Soil health is increasingly becoming an issue in the way of enhancing crop production and productivity. The main cause of soil degradation has been the accumulating nutritional deficiency over the years. One of the main factors for disturbed nutritional status of soil is the imbalance in the use of NPK in fertilizers. The balanced use of fertilizers, however, cannot be generalized to the entire agrarian space. It would depend upon the soil health and extent of imbalance to supplement proper nutrient ingredient.

Achieving balance between the nutrient requirements of plants and the nutrient reserves in soils is essential for maintaining high yields and soil fertility, preventing environmental contamination and degradation, and sustaining agricultural production over the long-term. In many cases, imbalances can be corrected through the application of appropriate inorganic and organic fertilizers.

Legumes and soil fertility

One of the input-saving and resource-conserving technology for improving soil fertility is introducing legumes in farming systems to provide multiple benefits, most notably biologically fixing nitrogen that reduces the need for chemical fertilizer (especially if the legume is inoculated with nitrogen-fixing bacterium Rhizobium). For instance, much of the yield gain in Australian cereal production over the past 60 years has been due to rotation systems that include legumes. In Southern Africa, fast-growing 'fertiliser' trees, such as Gliricidia, Sesbania, and Tephrosia have improved soil fertility, soil organic matter, water infiltration, and water holding capacity. Other benefits of legumes include reduced soil erosion and the production of fuelwood and livestock fodder. These technologies are quite location specific; however, research to adapt them to farming systems defined by soils, land pressure and labour availability may prove beneficial in addressing challenges related to fertilizer use and soil degradation.

Integrated Nutrient Management

Integrated Nutrient Management (INM) is an approach that seeks to both increase agricultural production and safeguard the environment for future. It is a technique that incorporates both organic and inorganic plant nutrients to attain higher crop productivity and prevent soil degradation. It relies on nutrient application and conservation, new technologies to increase nutrient availability to plants, and the dissemination of knowledge between farmers and researchers.

INM through judicious use of chemical fertilizers, including secondary and micro-nutrients, in conjunction with organic manures and bio-fertilizers, improves soil health and its productivity.

Benefits of INM

- Improves soil health through green manuring;
- Facilitates and promotes use of soil amendments for reclamation of acidic soils for improving their fertility and crop productivity;
- Promotes use of micro-nutrients for improving efficiency of fertilizer use;

Some of the key techniques used in INM are:

- Vermicompost
- On-farm Composting
- In-situ generation of green matter

Organic inputs for nutrient management in INM may include:

- Agricultural residues
- Sericultural residues
- Animal manures
- Dairy and poultry wastes
- Food industry wastes
- Municipal solid wastes
- Biogas-sludges from sugarcane factories

Other key inputs used in INM include Biofertilizers. Several studies indicate that among the different types of biofertilizers available at present, Rhizobium is relatively more effective and widely used. Considering an average Nitrogen (N) fixation rate of 25 kg N/ha per 500g application of Rhizobium, it is expected that 1 tonne of Rhizobium inoculants will be equivalent to 50 tonnes of nitrogen. Similarly, Blue Green Algae (BGA) and Azolla have been reported to be effective in certain traditional rice growing areas in the country. Meanwhile if BGA applied at 10 kg/ha fixes 20 kg N/ha, then 1 tonne of BGA has an equivalent fertilizer value of 2 tonnes of nitrogen. The beneficial effect of the organisms, like Azospirillum and Azotobacter in suppression of soil-borne pathogenic diseases of crops, has also been established. Another important role of biofertilizers is liberation of growth substances, which promote germination and plant growth. The usage of biofertiliser in India is still low as there are several constraints to effectively utilize and popularize the use of biofertilizers in the country. Some of which are:

- Unlike mineral fertilizers, use of the biofertilizers is crop and location specific. A strain found ideal at one location may be ineffective at another location due to competition of native soil microbes, poor aeration, high temperature, soil moisture, acidity, salinity and alkalinity, and presence of toxic elements;
- Low shelf life of the microorganisms;
- Unlike mineral fertilizers, biofertilizers need careful handling and storage;
- Lack of suitable carrier material, for restoration and longevity in actual field conditions.

In order to overcome the above-cited constraints and make biofertilizers an effective supplementary source of mineral fertilizers, these aspects need to be critically attended. Currently, against the total anticipated biofertilizers demand of 1 million tonne in the country, the current supply position is very low (<10,000 tonnes). Thus, the production capacity also needs to be scaled up adequately.

Box - IX

Effect of INM on Sustainable Yield Index (SYI) in Maize-Wheat System after 27 years at Ranchi

Comparative account of economics involved in conventional and drip irrigation systems in Bt cotton (Rs/ha)

Treatment	Grain yield (t/ha) (average of 27 years)		SYI	
	Maize	Wheat	Maize	Wheat
100% NPK	0.80	1.70	0.07	0.14
100% NP	0.55	1.20	-	-
100% N	0.11	0.12	-	-
100% NPK + FYM	2.80	2.50	0.30	0.23
No Fertilizer	0.50	0.76	0.06	0.09

Source: FAO & Indian Institute of Soil Science

Sustainable yield index (SYI) of maize-wheat cropping system after 27 years at Ranchi was the highest with integrated use of 100 percent NPK and Farm Yard Manure (FYM). Ranchi falls under Phosphorous (P) deficient zone in nutrient deficit classification of Indian soils. Organic manures alone cannot supply sufficient P for optimum crop growth because of limited availability and low P concentration. The organic manures, however, are known to decrease P adsorption/fixation and enhance P availability in P-fixing soils. Organic anions formed during the decomposition of organic inputs can compete with P for the same sorption sites and thereby increase P availability in soil and improve utilization by crops.

The INM strategies developed for different cropping systems all over the country are compiled and presented in Annexure-V.

Chemicals and Pesticides

Like the use of micro-nutrients and water in agriculture, the chemicals or pesticides are also used indiscriminately and un-judiciously. The use of un-prescribed pesticides in inappropriate doses has not only been disturbing the soil conditions but is also destroying the healthy pool of bio-control agents that normally co-exist with the vegetation.

Considering the global concern of ill-effects of chemical pesticides, Integrated Pest Management (IPM), inter alia, aims at employment of alternate methods of pest control like cultural, mechanical and biological control in a compatible manner. The chemical control is resorted to when other control methods fail to provide desired results. It is ecologically safe and economical.

IPM uses a combination of practices especially improved information on pest populations and predators to estimate pest losses and adjust pesticide doses accordingly. Adoption of IPM systems normally occurs along a continuum from largely reliant on prophylactic control measures and pesticides to multiple-strategy biologically intensive approaches. The practice of IPM is site-specific in nature, with individual tactics determined by the particular crop/pest/environment scenario. Where appropriate, each site should have in place a management strategy for Prevention, Avoidance, Monitoring, and Suppression of pest populations (the PAMS approach).

The PAMS Approach in IPM

Prevention is the practice of keeping a pest population from infesting a field or site, and considered to be the first line of defense. It includes such tactics as using pest-free seeds and transplants, preventing weeds from reproducing, irrigation scheduling to avoid situations conducive to disease development, cleaning tillage and harvesting equipment between fields or operations, using field sanitation procedures, and eliminating alternate hosts or sites for insect pests and disease organisms.

Avoidance may be practiced when pest populations exist in a field or site but the impact of the pest on the crop can be avoided through some cultural practice. Examples of avoidance tactics include crop rotation, such that the crop of choice is not a host for the pest; choosing cultivars with genetic resistance to pests; using trap crops or pheromone traps; choosing cultivars with maturity dates that may allow harvest before pest populations develop; fertilization programs to promote rapid crop development; and simply not planting certain areas of fields where pest populations are likely to cause crop failure. Some tactics for prevention and avoidance strategies may overlap in most systems.

Monitoring and proper identification of pests through surveys or scouting programs, including trapping, weather monitoring and soil testing where appropriate, is performed as the basis for suppression activities. Records are maintained of pest incidence and distribution for each field or site. Such records form the basis for crop rotation selection, economic thresholds, and suppressive actions.

Suppression of pest populations may become necessary to avoid economic loss if prevention and avoidance tactics are not successful. Suppressive tactics may include cultural practices, such as narrow row spacing or optimized in-row plant populations, alternative tillage approaches such as no-till or strip till systems, cover crops or mulches, or using crops with allelopathic potential in the rotation. Physical suppression tactics may include cultivation or mowing for weed control, baited or pheromone traps for certain insects, and temperature management or exclusion devices for insect and disease management. Biological controls, including mating disruption for insects, are considered as alternatives to conventional pesticides, especially where long-term control of an especially troublesome pest species can be obtained. Where naturally occurring biological controls exist, effort may be made to conserve these valuable tools. Chemical pesticides are important in IPM programs, and some use remains necessary. However, chemical pesticides are applied as a last resort in suppression systems using the following sound management approach:

- o The cost:benefit is confirmed prior to use (using economic thresholds where available);
- o Pesticides selected are based on least negative effects on environment and human health in addition to efficacy and economics;
- o Where economically and technically feasible, precision agriculture or other appropriate new technology are utilized to limit pesticide use to areas where pests actually exist or are reasonably expected;
- o Sprayers or other application devices are calibrated prior to

use and occasionally during the use season;

- o Chemicals with the same mode of action are not used continuously on the same field in order to avoid resistance development; and
- o Vegetative buffers are used to minimize chemical movement to surface water.

The Biological control agents available for certain pest varieties and crop diseases in India are compiled in Annexure VI A and B. IPM strategies are different for each crop, for a country, for a region, even for one location, depending on local varieties used, local agronomic practices and various crop protection options that are available. IPM can never be delivered in a "package"; it needs to be developed, adapted and tailor-made to fit local requirements. Designing and practicing effective IPM systems is about learning and continuously finding solutions to changing field situations and problems. Nonetheless, Indian scientists have developed certain IPM modules based on agro-ecological conditions of the country for particular crops; the module developed for rice is provided in Annexure-VII.

Farm Mechanisation

The present day need of the country is to increase the productivity and profitability of production and post-production agriculture. With shrinking rural population and consequently declining farm labour has raised the need of mechanization in agriculture for timeliness in operation. Effective engineering and technological interventions and inputs have the potential to raise the farm productivity and farm operational efficiency manifold.

Engineering input on land leveling equipment, drainage equipment helps in disposal of extra water, provides better growing conditions for crop root zone and minimize water requirement for irrigation. Equipment for efficient irrigation, appropriate use of pesticides, micronutrients and minimizing their excessive use, and thereby to protect soil health and environment has been growing in adoption. The engineering input with electronic gadgets has been able to deliver the appropriate quantity of input at appropriate location to

Box - X

Comparative Economics of Integrated Pest Management (IPM) and Farmers Practices in Paddy Crop in Haryana

(Rs/ha)

Item	IPM practice	Farmers' practice
Field preparation	1,150	1,150
Seed	450	450
Seed treatment	100	-
Nursery raising and seedling transplanting	1,150	1,150
Fertilizer	2,005	2,338
Irrigation	4,000	4,550
Plant protection		
Weed management	500	463
Insect-pest Management Cultural		
Bund raising	120	60
Mechanical		
Use of sex pheromone traps	500	-
Light traps	180	-
Rope shaking	300	-
Chemical Pesticide	-	-
Biopesticide		
B.T.K & neem product (300 ppm)	950	-
Harvesting, threshing & winnowing	2,500	2,500
Miscellaneous	250	250
Interest on working capital @ 12%	849	838
Total cost of production	15,004	14,816
Yield (tonne)	6.64	4.96
Value of the product	32,536	29,204
Net returns	17,532	14,388
Increase in yield over traditional; %	33.9	-
Cost of production per tonne	2,260	2,987

Source: Proceedings 11 'IPM in Indian Agriculture', National Centre for Agricultural Economics and Policy Research (NCAP), India; National Centre for Integrated Pest Management (NCIPM), India

The unit cost of production using IPM technique was ₹ 2260/t, compared to ₹ 2987/t without IPM. The increase in yield due to IPM being 33.9 percent, the net returns were ₹ 17,532/ha, whereas in the case of farmers' practices (non-IPM), it was ₹ 14,388/ha. Thus, IPM in paddy appeared to be an economically profitable proposition.

improve factor productivity and soil health. It is being tried for control of depth of operation, application rate in case of seed drill and chemical applicators, control of clogging of furrow openers, and crop losses in harvesting, using combine harvester at controlled grain moisture. Use of these gadgets though involves additional cost on their installation on the equipment but can contribute in enhancing production and productivity by 20 percent to 50 percent and help in clean environment development. Some of the engineering interventions that may be used in some critical farm operations and can help the farmers in achieving timeliness and precisely measure and apply costly input for better efficacy and efficiency are given below :

Tillage and planting machinery - The traditional animal drawn country plough has low output (30-40 h/ha). Tractor drawn MB plough, harrows, cultivators and rotavator are machineries with higher efficiency in land preparation. For precise application of seed and fertilizer, mechanically metered seed drill and seed-cum- fertilizer drill operated by animal and tractor have been developed and are being manufactured to suit specific crops and regions. Zero till drill and strip till drill have also been developed to reduce energy inputs in crop production. Farm equipment, such as inclined plate planter and pneumatic planter for precision sowing are also available and can be used efficiently even by smallholders on custom hire services.

Interculture and plant protection equipment: Use of long handle wheel hoe and peg type weeders are being accepted as they reduce drudgery and weeding time to 25-110 hours from 300-700 hours in conventional practice. Animal drawn weeder and cultivator are also used for control of weeds. Self propelled and power operated weeders are being increasingly accepted on limited scale. Different designs of low cost hand operated sprayers and dusters are available for application of plant protection chemicals. Low volume and ultra-low volume (ULV) sprayers, which require comparatively smaller quantity of water, are also in use. However, there is ample scope of increasing the utilization of these equipments among Indian farmers.

Irrigation and drainage equipment: Diesel and electric pump sets are common. The shift from conventional flood irrigation to sprinkler, micro sprinkler or drip irrigation systems is apparently visible indicating the importance of water use efficiency for covering more area under irrigation. Though the Government support in the form of financial assistance is serving as a catalyst to compensate for the high initial cost of the systems, adoption of advanced micro-irrigation technologies in India is low and has to be enhanced considerably for a visible impact on farm productivity.

Importance of drainage for achieveing improved productivity is being realized by the Indian farmers, and in the recent years, progressive farmers are going for subsurface drainage, which is a cost intensive technology. The low-cost mole drainage technology and equipment has been developed for vertisols. The mole drain laying cost is ₹ 3,500 /ha and the same may be recovered in one crop season. Though the farmers are in favour of this technology, adoption of the technology is in beginning stage. Therefore, efforts through adequate extension, demonstrations and awareness programmes are required to popularize this technology among smallholding farmers, in particular.

Presently, a large number of improved agricultural tools and machineries are indigenously manufactured in India. Vertical conveyor reapers, rice transplanter, pregermianted-paddy seeder, zero-till drill, Strip-till drill, raised bed planter, high clearance self-propelled sprayer, aero blast sprayer, and combine harvesters are some of the successful recent introductions. In addition, there are several harvesting and threshing machineries available in India, such as self-sharpening sickle, walk-behind and self propelled reaper harvesters, power threshers, pedal operated paddy threshers, rasp bar type axial flow thresher, and combine harvesters, which can enhance farm productivity manifold.

Advantage of Farm Mechanisation

Efficient farm machinery helps in increasing productivity by about 30 percent, besides, enabling the farmers to raise the cropping intensity. Raising more crops with high productivity is a path for attaining food security and sustainability. Development and introduction of high capacity, precision, reliable and energy efficient equipment is the need for judicious use of farm inputs. In small and marginal farms, except for tillage, other operations, such as sowing/ transplanting, weeding, picking, harvesting and threshing are still performed manually. Mechanisation of all these processes may increase farm productivity substantially as well as help making agriculture sustainable.

Table 6.8 Economic Advantage of Farm Mechanization

(Percent)

Increase in Productivity	12.34
Seed-cum-fertilizer drill facilitates :	
Saving in seeds	*20*
Saving in fertilizer	*15-20*
Enhancement in cropping intensity	5-22
Reduction in cost of production	upto 20
Increase in gross income of the farmers	29-49

Adoption of mechanization in India is at various levels in different States in the country depending much on the land holding status of the farmers. To expand the spread of mechanization in the country and in order to have a tangible impact on crop and farm productivity there is a need to establish an efficient technology transfer mechanism. Following approaches may be considered as other means of effective technology transfer, besides institutional and formal extension:

Custom hire and service centers for machinery - One of the major constraints of increasing agricultural production and productivity is the inadequacy of farm power and machinery with the Indian farmers. The average farm power availability needs to be increased from the current 1.5 kW/ha to at least 2 kW/ha to assure timeliness and quality in field operations, and to undertake heavy field operations like sub soiling, chiseling, deep ploughing, and summer ploughing. All these agricultural operations are possible only when adequate agricultural mechanization infrastructure is created. Due to their economic conditions Indian farmers with small holdings utilize selected improved farm equipment through custom hiring as they are unable to purchase the required machinery set-up. Therefore, custom-hiring facility can be of significance to small and marginal farmers in India to adopt to much required farm mechanisation. Establishment of such facilities has potential for adoption of mechanization systems. Repair and maintenance service providers for agricultural machinery are required in developing countries, which can also help in expanding farm mechanization. Developing entrepreneurship on farm mechanisation at local levels, may include:

- Establishing agri-implement bank to provide machineries on custom hire basis to farmers when needed;
- Service, repair and maintenance facilities for agricultural machinery;
- Establishment of Agro-Service Centres, which may also impart training on agricultural machinery, and help in technology transfer.

Developing and promoting low powered tractors with small engines - Farm mechanization in India should focus on addressing small farmers' requirements. Developing and promoting low power and small engine driven tractors, such as two-wheeled tractors, and hand driven tractors with adequate policy support may increase the extent of mechanization in Indian agriculture, as well as address small farm requirements adequately.

Skill development training and employment generation - Entrepreneurship development in service sector in agriculture and allied sector has immense potential through engineering interventions. One such approach is skill development training in manufacture, repair, maintenance and related service support in farm machinery, irrigation, processing, energy equipment repair, maintenance and for primary processing of food grains, fruits and vegetables.

Information technology in agriculture for information dissemination- Information technology can play an important role in technology transfer in Indian agriculture, and has considerable potential to improve farm productivity. The linking of villages with wired network has been implemented in some places in India; for example, Warna Wired Villages and M.S. Swaminathan Info Villages. The info villages are networked in hybrid form of wired and wireless technologies for communications. They are able to provide information on agriculture technologies, weather, and markets. In addition, there are also several private sector interventions in this area, providing kiosks and mobile phone services for information dissemination. However, there is a need to broaden the reach of information technology in Indian villages to have tangible positive impact on farm productivity.

The Central Institute of Agricultural Engineering (CIAE), Bhopal was established in 1976 during Government of India's Fifth Five Year Plan to develop and popularise technologies for mechanization of production and post-production agriculture using conventional and non-conventional energy sources. Subsequently, irrigation and drainage related activities were included. CIAE, as the premier Agricultural Engineering Institute in India, is mandated to develop agricultural mechanization, which may help in enhancing agricultural productivity by achieving timeliness in agricultural operations though proper placement of inputs; reducing drudgery of agricultural workers; efficient energy and water use; converting plant and animal wastes into different forms of energy; minimizing post-harvest losses; producing value added quality products; and generating employment and income in the rural sector.

CIAE developed 67 technologies /equipments during the Tenth Five Year Plan for the use of farmers/ entrepreneurs. Some of the key technologies developed are provided in Annexure-VIII and some of technology output earmarked by CIAE for the Elventh Five Year Plan is provided in Annexure-IX. Key research gaps identified by ICAR and CIAE in the country that needs focussed attention are presented in Annexure-X.

Conservation Tillage

One of the most important technological development in crop management in the recent years has been conservation (or zero) tillage, which minimizes or eliminates tillage and maintains crop residues as ground cover. Conventional agriculture recommends extensive soil tillage and burning of crop residues. Such practices lead to soil degradation through loss of organic matter, soil erosion and compaction. Conservation agriculture is a range of soil management practices that minimize effects on composition, structure and natural biodiversity and reduce erosion and degradation. Largely, the conservation agriculture practices include (i) direct sowing / no tillage, reduced tillage / minimum tillage, (ii) surface incorporation of crop residues, and (iii) establishment of cover crops in both annual and perennial crops. As per FAO, the Conservation agriculture is based on enhancing natural biological processes above and below the soil surface. These go beyond zero tillage and provide a range of technology and management options. Conservation agriculture practices are applicable to virtually all the crops.

Energy can be conserved by less manipulation of soil for plant growth using zero- till drill, strip till drill, bed forming technique and less application of chemicals for weeds and management of pests. Upland paddy cultivation through seed drills involves less puddling, hence, results in better soil structure and less gas emission compared to flooded paddy field. In conservation tillage the soil surface is disturbed least and thus, significant amount of residue remains on the surface, which helps in reducing run off, sediment loss and loss of nutrients. The seed is directly drilled through the layer of residues. In no-till farming, soil preparation and planting are done in single operation; in reduced till farming there is limited preparation with disc, rotavator or chisel plough. Water harvesting, soil conservation and efficient irrigation techniques make the clean farming easy and improve the ecology and environment. Community participation is very often necessary in such cases. Mulch and cover crops also improve soil, water and nutrient conservation.

Box - XI

Benefits of Zero Tillage

South Asia's rice-wheat cropping systems have been in trouble, in recent years, with crop yields stagnating and soil and water quality declining. In response, the Rice-Wheat Consortium of the IGP of South Asia a network of scientists, extension agents, private machinery manufacturers, and non-governmental organizations (NGOs) has developed and has been promoting zero-tillage farming.

Under this programme the Consortium, besides promoting other farm management practices of zero-tillage, has been practicing and promoting planting of wheat immediately after rice without tillage so that the wheat seedlings can germinate using the residual moisture from the previous rice crop. Such zero tillage farming has increased wheat yield through timely sowing and has been able to reduce production costs by up to 10%, water use by about 1 million litres per ha (saving of 20% to 35 %). It has also helped in improving soil structure, fertility, and biological properties and has been also helpful in reducing incidence of weeds and other pests. Zero tillage with wheat succeeding rice is now the most widely adopted resource-conserving technology in the Indo-Gangetic Plain.

In Latin America (mainly Argentina and Brazil), zero tillage is used in more than 40 million ha (about 43% of total arable land). Originally adopted by large and midsize farmers, the practice has spread to small farmers in southern Brazil. Networks of researchers, input suppliers, chemical companies, and farmers have used participatory research and formal and informal interactions to integrate various parts of the technology (rotations, seeds, chemicals, and machinery) and adapt them to local conditions.

The approach has also been used by an estimated 100,000 smallholders in Ghana in the past decade.

Source : Consultative Group on International Agricultural Research (CGIAR)

Cropping System Approach

Traditionally, Indian farmers adopted integrated farming system approach for their livelihood.

However, with industrialization and advent of green revolution agriculture systems became more commodity-oriented. In the commodity oriented market scenario, the focus is usually on a singular production system. The crop based research and development approach further isolated farming system different from each other.

Integrated Farming System approach is another agricultural technological intervention, which can address the agricultural productivity issue to a large extent. Integrated approach has several distinct advantages as mentioned below:

1. Security against complete failure of a system.
2. Minimization of dependence for external inputs
3. Optimum utilization of farm resource
4. Efficient use of natural resources sunlight, water and land.
5. Efficient use of fertilization.

Integrated Farm Production Systems

The major production systems in agriculture sector are as under:

1. Arable farming system
2. Horticultural production system
3. Agro forestry production system
4. Livestock based farming system
5. Aqua production system (Fish production)
6. Pastoral production system

Indian Council of Agricultural Research (ICAR) has delineated the country into 20 agro-eco-regions (AER) and 60 agro-eco-subregions (AERS) using criteria of soils, physiography, bio-climate (climate, crops, vegetation) and length of growing period. ICAR under National Agricultural Technology Project (NATP) has identified five major agro-eco-systems, and within each of the major ecosystem 2 to 4 different production systems, which require support in an interdisciplinary mode has been identified.

Table 6.9 Different Production Systems within the Five Major Agro-Ecosystems

Major Eco-systems	Production systems
Arid Agro-Ecosystem	(i) Agri-silvi-horti-pastoral production system
	(ii) Livestock and fish production system
Coastal Agro-Ecosystem	(i) Fish and livestock production system
	(ii) Agri-horti production system
Hill and Mountain	(i) Agri-horti production system
	(ii) Livestock and fish production system
Irrigated Agro-Ecosystem	(i) Rice-wheat production system
	(ii) Cotton based production system
	(iii) Sugarcane based production system
	(iv) Dairying and fish production system
Rainfed Agro-Ecosystem	(i) Arable farming system
	(ii) Agroforestry production system
	(iii) Livestock based farming system

Extension and ICT

There is general agreement about the considerable productivity and profitability gaps in most smallholder farming systems relative to what may be economically attainable. Limited access to inputs and credit and the inability to bear risks explain part of the gaps. However, one major reason has also been information and skills gap that constraint the adoption of available technologies and management practices, or reduces their technical efficiency when adopted. Hence, emphasis should be on new approaches to demand-led extension and on application of new information and communications technologies (ICTs) to reduce these gaps.

The existing Training and Visit (T & V) system of extension practiced in India is top-down in its approach and there is little participation by the farmers. There is a need to take corrective steps to deal with the near collapse of the extension system in most states of the country. Therefore, there is an immediate need for reforming and revitalizing the existing agricultural extension system in the country. The main areas of reform may include:

i. Active involvement of farmers through user groups/ associations extension methods, including farmer-to-farmer extension, have become more diverse in many parts of the world. Informal networks among farmers have always been powerful channels for exchanging information on farm inputs. Several extension programmes are formalizing and linking such networks for knowledge and sharing and learning. For example, the Programa Campesino a Campesino in Nicaragua and the Mviwata network in Tanzania provide national coverage through farmer-to-farmer approaches.

ii The coverage and scope of Farmer Field School, originally designed as a way to introduce integrated pest management to irrigated rice farmers in Asia, has been broadened to other types of technology. Though impact evaluations have been limited, the approach may significantly improve farmers' knowledge on new technological options.

iii. Mixing public, private and NGOs, this new approach recognizes the significant private-good attributes of many extension services, such as technical advice delivered by processors and wholesalers to farmers producing high-value crops and livestock products under contracts. Mixed public-private systems involve farmer organizations, NGOs, and public agencies contracting out extension services. Such approaches based on public funding, but with involvement of the local governments, private sector, NGOs and producer organizations in extension delivery may be most relevant to subsistence-oriented farmers.

iv. Increasing use of media and information technology, including cyber kiosks to disseminate knowledge on new agricultural practices and information on output and input prices.

    Policies to improve ICT access in rural areas need to focus as much on content and education as on infrastructure. Education is one of the key factors affecting the return to ICTs in agricultural production, along with electricity, roads, and appropriate business models. Local content creation needs to be linked to institutional innovations to provide farmer-responsive extension services.

v. Building gender concerns into the system - In all the extension efforts, to make agricultural innovation systems more demand driven, there is a need to pay attention to how women's demands can be better represented, accommodating their time constraints, for example, by providing the extension services predominantly by women, and employing them in advisory services to increase effectiveness of service delivery.

Resource Conserving Technologies for Rice-Wheat Cropping System

A number Resource Conserving Technologies (RCTs) for Rice-Wheat Cropping System have been developed and practiced successfully. Some are based on reduced tillage for wheat, including zero tillage. Bed-planting systems are being promoted to increase water productivity and, when combined with reduced tillage in a permanent bed system, they provide even more savings. Laser levelling, combined with these tillage systems, provides additional benefits. Many of the benefits of the tillage options for wheat are lost when rice soils are traditionally puddled (ploughed while wet). System-based technologies are being developed and promoted that do away with puddling so that total system productivity is raised. The use of groundwater to obtain early rice planting and efficient use of rainwater could be another approach. The various technologies are briefly described in the following paragraphs:

Surface seeding - It is the simplest zero-tillage system. In this tillage option, wheat seed is placed on to a saturated soil surface without any land preparation. This is a traditional farmer practice for wheat, legume and other crops in parts of eastern India and Bangladesh. Wheat seed is broadcast either before (relay planting) or after the rice crop is harvested. The key to success with this system is having the correct soil moisture at seeding. In this case the roots penetrate the soil before the surface soil dries, and soil strength increases, enabling roots to follow the water table down the profile. In China, where surface seeding is also practised, farmers apply cut straw to mulch the soil, to reduce evaporative losses of moisture and to control weeds. The standing stubble also protects the young seedlings from birds. One of the major advantages of surface seeding is that no costly equipment is needed and any farmer can easily adopt this practice. The use of a drum or simple seeder for line sowing is found to be advantageous.

Zero tillage with inverted-T openers - The seed in this technology is placed into the soil by a seed drill without prior land preparation. This technology is more relevant in the higher-yielding, more mechanized areas. This coulter and seeding system places the seed into a narrow slot made by the inverted-T opener as it is drawn through the soil by the four-wheel tractor. The coulters can be rigid or spring-loaded, depending on the design and cost of the machine. This type of seed drill works very well in situations where there is little surface residue after harvesting of rice, which occurs usually after manual harvesting.

Reduced tillage - In this system, two-wheel diesel tractors are used, which prepare the soil and plants the seed in one operation. This system consists of a shallow rotovator, followed by a six-row seeding system and a roller for compaction of the soil. This speeds up the planting and results in better stands with less cost than traditional methods. The seeder attachment does a better job, because the seeds are placed at a uniform depth in the single pass.

Bed-planting - In bed-planting systems, wheat or other crops is planted on raised beds. The benefits include: management of irrigation water is improved; facilitates irrigation before seeding and thus, provides an opportunity for weed control prior to planting; plant stands are better; weeds can be controlled mechanically, between the beds, early in the crop cycle; wheat seed rates are lower; after wheat is harvested, the beds are reshaped for planting the succeeding soybean crop; burning of crop residue can also be eliminated; herbicide dependence is reduced and hand-weeding and roguing is easier; and less water lodging occurs. The use of beds also provides a way for improving fertilizer-use efficiency. This is achieved by placing a band of fertilizer in the bed at planting or as a top-dressing. When combined with mulching or residue retention, bed planting has the potential to reduce evaporation losses from the soil surface and salinization and to further improve crop productivity in saline environments.

Laser leveling - All the above technologies can benefit from levelled fields. Laser land leveling is leveling the field within certain degree of desired slope using a guided laser beam throughout the field. Unevenness of the soil surface has a significant impact on the germination, stand and yield of crops. Laser leveled land optimize water use efficiency and saves 25 percent to 30 percent of water; improves crop establishment and improves yield up to 25 percent; reduces weed problems; and improves uniformity of crop maturity.

When laser leveling is combined with zero tillage, bed planting and non-puddled rice culture, wheat plant stands are better, growth is more uniform and yields are higher.

IN SUM

Science and technological innovation are critical for agricultural development, both to enhance crop and overall farm productivity. It is important to meet growing food demand in the face of rising resource constraints and energy costs. Innovation is also central for maintaining market competitiveness, both domestic and global.

Tailoring technologies to growing heterogeneity among farmers and to differentiated needs of consumers remains a scientific and institutional challenge. Technological innovation is also critical in adapting to and mitigating climate change and tackling environmental problems more generally. Continuing progress, especially in extending benefits of R&D to agricultural based regions, depends on research in the areas for improving crop, soil, water and livestock management and for developing more sustainable and resilient agricultural systems. These technological innovations, often location specific, must be combined with institutional innovations to ensure that input and output markets, financial services, and farmer organizations are in place for broad-based productivity growth.

Low spending on agricultural R&D is only part of the challenge. Many public research organization face serious institutional constraints that inhibit their effectiveness and thus, their ability to attract funds. Likewise, old-styled agricultural extension should give way to a variety of new delivery approaches involving multiple actors.

An increase in agricultural investments, especially in research and development, is urgently needed to stimulate growth in Total Factor Productivity (TFP) in India. Recognizing that there are serious yield gaps and that there are already proven paths for increasing productivity, it is highly pertinent for India to maintain a steady growth rate in TFP. As TFP increases, the cost of production would decline and the market prices would stabilize at a lower level. Both the producers and consumers will benefit.

More than half of the required growth in yield to meet the target food demand must be achieved from research efforts by developing location-specific and low input-use technologies with emphasis on the region/sub-regions/districts where the current yields are below the potential national average yields. The districts/sub-regions/regions where TFP stagnation or decline has taken place must get priority in agricultural research and development. Priority should also be given to developing and promoting technologies and equipments that can meet small farmers' needs.

Since agriculture is the major water-consuming sector in India, demand management in agriculture in water-scarce and water stressed regions would be central to reduce the aggregate demand for water to match the available future supplies and to counter any negative impact on crop production and yield levels. Thus, adopting appropriate technology would be key to optimizing water use and attaining optimal yield.

For sustainable productivity enhancement, with development and promotion of suitable technologies, adequate policy support and review of existing policies are binding. For example, to ensure balanced use of fertilizer, a review of government interventions in fertilizer sector may be pertinent. Similarly, to ensure sustainable use of groundwater and other water resources for irrigation, a review of Government interventions in farm power pricing may be relevant.

ANNEXURE - I : COMPARISONS OF AREA, PRODUCTION AND PRODUCTIVITY OF KEY PRODUCING COUNTRIES IN 2009

Paddy

Countries	Production (million ton)	Area Harvested (million Ha)	Yield (kg/ha)
World	684.8	158.4	4324
China	196.7	29.9	6582
Japan	10.6	1.6	6521
Viet Nam	39.0	7.4	5237
Indonesia	64.4	12.9	4999
Brazil	12.7	2.9	4405
Bangladesh	47.7	11.4	4203
Myanmar	32.7	8.0	4085
Philippines	16.3	4.5	3589
Pakistan	10.3	2.9	3581
Thailand	32.1	11.1	2883
India*	99.0	41.9	2178

Oilseed : Groundnut (in shell)

Country	Area ('000 ha)	Production ('000 tonnes)	Yield (kg/ha)
World	24590	38201	1554
U.S.A.	610	2335	3829
China	4623	14341	3102
Argentina	227	625	2750
Brazil	113	297	2623
Japan	8	19	2262
Vietnam	256	534	2085
Thailand	65	114	1754
Nigeria	2300	3900	1696
Myanmar	650	1000	1538
Indonesia	636	774	1216
India	6850	7338	1071
Senegal	670	647	966
Sudan	954	716	751
Uganda	244	173	709

Wheat			
Countries	Production (million ton)	Area Harvested (million Ha)	Yield (kg/ha)
World	687.0	224.8	3055
Germany	25.2	3.2	7809
France	38.3	5.1	7447
UK	14.1	2.0	7066
Egypt	8.5	1.3	6383
China	115.1	24.3	4739
Uzbekistan	6.6	1.5	4425
Poland	9.8	2.3	4173
Italy	6.3	1.8	3532
Ukraine	20.9	6.8	3093
USA	60.4	20.2	2990
India*	80.7	27.8	2839
Canada	26.8	9.6	2786
Argentina	8.9	3.3	2662
Pakistan	24.0	9.0	2657
Turkey	20.6	8.0	2566

Maize			
Country	Production (million tonnes)	Area (million Ha)	Yield (kg/ha)
World	820	158.8	5160
USA	333	32.2	10338
France	15	1.7	9101
Italy	8	0.9	8605
Canada	10	1.1	8372
Egypt	8	1	7818
Hungary	8	1.2	6395
Argentina	13	2.4	5576
China	164	31.2	5259
Ukraine	10	2.1	5020
South Africa	12	2.4	4964
Indonesia	18	4.2	4237
Brazil	51	13.7	3714
Romania	8	2.3	3417
Mexico	20	6.2	3237
India*	17	8.3	2024

Pulses			
Countries	Production (million ton)	Area (million Ha)	Yield (kg/ha)
World	63.1	68.7	919
France	1.0	0.2	4674
USA	2.3	1.2	2033
Canada	5.2	2.6	1992
Russia	1.6	0.9	1683
China	4.3	2.8	1567
Turkey	1.2	0.9	1366
Australia	1.8	1.4	1247
Ethiopia	1.8	1.6	1165
Myanmar	4.4	4.0	1114
Mexico	1.3	1.3	979
Nigeria	2.4	2.6	928
Brazil	3.5	4.1	847
Tanzania	1.3	1.8	718
Pakistan	1.1	1.6	702
India*	14.2	20.9	630

Sugarcane			
Country	Production (million tonnes)	Area (million Ha)	Yield (kg/ha)
World	1668	23.7	70274
Colombia	39	0.4	101448
Guatemala	18	0.2	86166
Argentina	29	0.4	81690
Philippines	33	0.4	80446
Brazil	672	8.5	78860
USA	28	0.4	78062
Australia	30	0.4	77395
Thailand	67	0.9	71656
Mexico	49	0.7	69651
China	116	1.7	68079
India	285	4.4	64486
Indonesia	27	0.4	63095
South Africa	19	0.3	59984
Viet Nam	16	0.3	58766
Pakistan	50	1.0	48616

Countries ranked in terms of crop productivity

*Source: FAOSTAT 2011; * Ministry of Agriculture, Govt. of India*

ANNEXURE - II : CONSUMPTION OF FERTILIZER IN SELECT STATES OF INDIA

(kg/Ha)

State/ Zone	2006-07				2007-08				2008-09			
	N	P	K	Total	N	P	K	Total	N	P	K	Total
South Zone												
Andhra Pradesh	109.7	51.3	24.9	185.9	116.8	52.0	30.9	199.6	134.3	66.5	38.7	239.7
Karnataka	58.1	33.7	22.4	114.1	60.7	29.7	25.4	115.7	69.5	44.9	32.9	147.3
Kerala	29.7	15.3	25.0	70.0	31.2	14.3	24.2	69.8	38.3	18.9	32.3	89.4
Tamil Nadu	97.0	44.7	44.8	186.5	90.1	37.8	50.4	178.3	110.7	43.6	62.2	216.5
Average (South Zone)	***82.3***	***40.9***	***27.5***	***150.7***	***84.7***	***38.4***	***31.8***	***154.9***	***98.6***	***50.7***	***40.2***	***189.6***
West Zone												
Gujarat	82.1	32.0	10.6	124.6	93.1	37.6	12.9	143.6	87.6	38.1	15.0	140.7
Madhya Pradesh	37.2	20.9	3.3	61.5	40.6	21.9	3.9	66.4	39.9	26.4	4.5	70.8
Chhattisgarh	47.4	20.2	8.4	75.9	47.4	20.4	9.2	76.9	46.7	23.4	10.6	80.7
Maharashtra	53.6	30.0	16.5	100.2	58.0	28.4	18.7	103.1	59.4	33.1	21.2	113.7
Rajasthan	30.6	11.9	0.6	43.1	32.5	12.0	1.0	45.5	33.0	14.8	1.1	48.9
Average (West Zone)	***46.0***	***22.5***	***7.6***	***77.1***	***50.5***	***23.1***	***8.9***	***82.5***	***50.9***	***26.7***	***10.2***	***87.8***
North Zone												
Haryana	132.6	37.5	2.8	173.0	144.5	39.6	3.6	187.6	148.0	49.0	4.6	201.6
Punjab	160.7	43.7	4.8	209.2	162.7	42.5	4.8	210.0	166.8	47.5	7.1	221.4
Uttar Pradesh	108.2	33.8	6.4	142.0	109.8	32.7	7.3	149.6	111.7	34.9	9.7	156.3
Uttaranchal	85.7	20.2	7.1	113.1	91.2	19.6	8.1	118.9	89.1	24.0	10.1	123.3
Himachal Pradesh	32.8	10.9	8.5	52.1	34.4	9.5	9.3	53.2	37.4	11.3	11.8	60.6
Jammu & Kashmir	50.9	21.8	6.3	78.9	51.7	15.7	4.4	71.8	61.1	24.8	7.5	93.3
Delhi	18.6	4.8	0.2	23.6	6.8	1.8	0.2	8.9	14.9	0.0	0.0	14.9
Chandigarh	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Average (North Zone)	***117.9***	***35.0***	***5.6***	***158.5***	***121.1***	***34.3***	***6.2***	***161.6***	***123.5***	***38.2***	***8.5***	***170.1***
East Zone												
Bihar	109.3	24.2	11.2	144.7	125.5	25.9	11.4	162.8	123.8	33.4	21.8	179.0
Jharkhand	43.6	19.9	2.0	65.5	42.3	21.7	4.6	68.5	33.5	17.4	4.8	55.7
Orissa	29.4	10.6	6.2	46.2	31.2	13.4	7.2	51.9	34.3	17.1	10.3	61.6
West Bengal	71.2	40.5	31.5	143.2	71.8	40.5	31.9	144.2	72.5	43.1	42.1	157.7
Average (East Zone)	***66.1***	***25.2***	***15.9***	***107.3***	***71.1***	***26.7***	***16.6***	***114.4***	***70.9***	***30.2***	***23.6***	***124.7***
North East Zone (NE)												
Assam	27.5	13.7	13.4	54.6	27.7	14.8	15.0	57.3	32.4	13.6	16.1	62.1
Tripura	24.1	12.9	8.4	45.3	25.2	8.7	7.3	41.2	25.7	12.1	9.5	47.2
Manipur	63.6	16.1	5.8	85.5	64.4	15.1	5.8	85.3	42.1	8.7	6.6	57.5
Meghalaya	11.4	7.6	0.9	20.0	9.8	4.7	1.3	15.8	9.8	2.6	1.5	13.9
Nagaland	0.8	0.6	0.2	1.7	1.2	0.7	0.3	2.2	1.2	0.8	0.3	2.2
Arunachal Pradesh	1.7	0.7	0.3	2.7	1.7	0.7	0.3	2.7	1.9	0.8	0.3	3.0
Mizoram	16.5	14.2	7.4	38.1	16.7	10.9	9.3	39.9	22.9	12.9	11.4	47.3
Sikkim	1.7	0.9	0.2	2.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Average (NE Zone)	***24.6***	***11.6***	***10.2***	***46.4***	***24.3***	***11.8***	***11.3***	***47.3***	***26.4***	***10.7***	***12.1***	***49.1***
All India (Average)	**71.4**	**28.8**	**12.1**	**112.3**	**74.8**	**28.6**	**13.7**	**117.1**	**77.9**	**33.7**	**17.1**	**128.6**

Source: Department of Agriculture and Cooperation, Govt. of India

ANNEXURE - III :
GROUND WATER STATUS IN INDIA

Sr. No	States/ Union Territories	Total No. Of Assessed Units	Sale		Semi-Critical		Critical		Over-expioited		Remarks
			Nos.	%	Nos.	%	Nos.	%	Nos.	%	
	States										
1	Andhra Pradesh	1231	760	62	175	14	77	6	219	18	-
2.	Arunachal Pradesh	13	13	100	0	0	0	0	0	0	-
3.	Assam	23	23	100	0	0	0	0	0	0	-
4.	Bihar	515	515	100	0	0	0	0	0	0	-
5.	Chattisgarh	146	138	95	8	5	0	0	0	0	-
6.	Delhi	9	2	22	0	0	0	0	7	78	-
7.	Goa	11	11	100	0	0	0	0	0	0	-
8.	Gujarat	223	97	43	69	31	12	5	31	14	Rest 14 talukas -Saline
9.	Haryana	113	42	37	5	4	11	10	55	49	-
10.	Himachal Pradesh	5	5	10	0	0	0	0	0	0	-
11.	Jammu & Kashmir	8	8	100	0	0	0	0	0	0	-
12.	Jharkhand	208	208	100	0	0	0	0	0	0	-
13.	Karnataka	175	93	53	14	8	3	2	65	37	-
14.	Kerala	151	101	67	30	20	15	10	5	3	-
15.	Madhya Pradesh	312	264	85	19	6	5	2	24	8	-
16.	Maharashtra	318	287	90	23	7	7	0	7	2	-
17.	Manipur	7	7	100	0	0	0	0	0	0	-
18.	Meghalaya	7	7	100	0	0	0	0	0	0	-
19.	Mizoramm	22	22	100	0	0	0	0	0	0	-
20.	Nagaland	7	7	100	0	0	0	0	0	0	-
21.	Orissa	314	308	98	0	0	0	0	0	0	Rest 6 blocks-Saline
22.	Punjab	137	25	18	4	3	5	4	103	75	-
23	Rajasthan	237	32	14	14	6	50	21	140	59	Rest 1 block-Saline
24.	Sikkim	1	1	100	0	0	0	0	0	0	-

Sr. No	States/ Union Territories	Total No. Of Assessed Units	Sale		Semi-Critical		Critical		Over-expioited		Remarks
			Nos.	%	Nos.	%	Nos.	%	Nos.	%	
25	Tamil Nadu	385	145	38	57	15	13	9	142	37	Rest 8 Blocks-Saline
26.	Tripura	38	38	100	0	0	0	0	0	0	-
27.	Uttar Pradesh	803	665	83	88	11	13	2	37	5	-
28.	Uttaranchal	17	12	71	3	18	0	0	2	12	-
29.	West Bengal	269	231	86	37	14	1	0	0	0	-
	Total States	5705	4067	71	546	10	226	4	837	15	-
	Union Temitories										
1.	Andaman & Nicobar	1	1	100	0	0	0	0	0	0	-
2.	Chandigarh	1	1	100	0	0	0	0	0	0	-
3.	Dadra & Nagar Haveli	1	1	100	0	0	0	0	0	0	-
4.	Daman & Diu	2	0	0	1	50	0	0	1	25	-
5.	Lakshdweep	9	6	67	3	33	0	0	0	0	-
6.	Pondicherry	4	2	50	0	0	0	0	2	11	-
	Total Uts	18	11	61	4	22	0	0	2	11	-
	Grand Total	5723	4078	71	550	10	226	4	839	15	-

Note :

Blocks-Bihar, Chhattisgarh, Haryana, Jharkhand, Kerala, madhya Pradesh, Manipur, Mizoram, Orissa, Punjab, Rajasthan, Tamilnadu, Tripura, Uttar Pradesh, Uttaranchal,

West Bengal

Mandals (Command/non-command) - Andhra Pradesh

Talukas - Goa, Gujrat, Karnataka, Maharashtra

Districts - Arunachal Pradesh, Assam, Delhi, Meghalaya, Nagaland

Districts (Valley) - Himachal Pradesh, Jammu & Kashmir

State - Sikkim

Islands - Lakshdweep

UT - Andaman & Nicobar, Chandigarh, Dadra & Nagar Haveli, Daman & Diu, Pondicherry

Source : Ground Water Year Book 2009-10, Central Ground Water Board, Ministry of Water Resources, Government of India

ANNEXURE - IV A : WATER SAVING FOR DIFFERENT CROPS UNDER DIFFERENT TYPES OF EFFICIENT IRRIGATION TECHNOLOGIES

Water-Saving and Yield Enhancing Irrigation Technology	Crops for which the technology can be used ideally	Nature of Saving in Applied Water
Pressurized drip systems (inline and on-line drippers, drip taps)	Maize; Rice; Sugarcane	Reduces non-beneficial evaporation (E) from the area not covered by canopy; Reduces deep percolation; Water saving also comes from reduction in evaporation from fallow after harvest; Extent of water saving higher during initial stages of plant growth; Yield growth significant
Overhead sprinklers (including sprinkler guns)	Wheat; Pearl millet; Sorghum; Mustard; Cow pea; Chick pea	Reduces the losses in conveyance Improves the distribution efficiency slightly Reduces deep percolation Yield growth marginal
Micro sprinklers	Wheat; Pearl millet; Sorghum; Mustard; Cow pea; Chick pea Ground nut; Alfalfa;	Reduces the seepage and evaporation losses in conveyance through open channels. Reduces deep percolation over furrow irrigation and small border irrigation Yield growth significant

Source: M. Dinesh Kumar, Executive Director, Institute for Resource Analysis and Policy (IRAP), India

ANNEXURE - IV B : CROPS CONDUCIVE TO WATER-SAVING TECHNOLOGIES IN INDIA AND THEIR POTENTIAL SPREAD

Crop Category	Different crops conducive for WSTs	Type of WSTs that can be used	Regions*
Row field crops	Potato and Groundnut	Drips; and also mulching (for groundnut and potato)	Gujarat, Maharashtra and Punjab
Field Crops	Wheat, Pearl millet, Sorghum, Maize, Alfalfa, Mustard, and Rice	Overhead sprinklers (wheat, pearl millet, maize and sorghum) and mini and micro sprinklers for alfalfa. Drips (maize, sorghum, rice and mustard)	Punjab, Haryana, Gujarat, Maharashtra, Rajasthan and Madhya Pradesh, Andhra Pradesh, and Karnataka
Cash crops	Cotton, Castor, Sugarcane	Drips for sugarcane and cotton	Maharashtra, Tamil Nadu and Gujarat (for cotton, sugarcane and ground nut)

Note: Drips include pressurized drips (integrated drips, emitters, drip taps); easy drips; micro tube drips;
*Regional priority are only indicative, any of these crop types could be grown there and not all the crops under the category WST- Water Saving Technologies

Source: M. Dinesh Kumar, Executive Director, Institute for Resource Analysis and Policy (IRAP), India

ANNEXURE - V : INTEGRATED NUTRIENT MANAGEMENT (INM) STRATEGIES FOR MAJOR CROPPING SYSTEMS IN INDIA

Cropping system	INM Strategy
Rice-wheat	Green manuring of rice with sun hemp equivalent to 90 kg fertilizer N along with 40 kg N/ha produces yield equivalent to 120 kg N/ha. In an acid Alfisol soil, incorporation of lantana camera 10-15 days before transplanting of rice helps to increase the N use efficiency. Apply 75% NPK + 25% NPK through green manure or FYM at 6 t/ha to rice and 75% NPK to wheat. Inoculation of BGA @ 10 kg/ha provides about 20-30 kg N/ha.
Rice-rice	Use of organic sources, such as FYM, compost, green manure, and Azolla meet 25-50% of N needs in kharif rice and can help curtailing NPK fertilizers by 25-50%. Apply 75% NPK + 25% NPK through green manure or FYM at 6 t/ha to kharif rice and 75% NPK to rabi rice. A successful inoculation of BGA @ 10 kg/ha provides about 20-30 kg N/ha.
Rice-potato-groundnut	Use 75% NPK with 10 t FYM/ha in rice and potato.
Sugarcane based cropping systems	Combined use of 10 t FYM/ha and recommended NPK increases the cane productivity by 8-12 t/ha over chemical fertilizer alone.
Maize based cropping systems	Apply 50% recommended NPK as fertilizer and 50% of N as FYM in maize and 100% of recommended NPK as fertilizer in wheat.
Soybean-wheat	To get 2 t soybean and 3.5 t wheat, apply 8 t FYM/ha to soybean and 60 kg N + 11 kg P/ha to wheat or apply 4 t FYM + 10 kg N + 11 kg P/ha to soybean and 90 kg N + 22 kg P/ha to wheat.
Pulses	Integrated use of FYM at 2.5 t/ha and 50% recommended NPK fertilizers plus Rhizobium inoculation helps in saving of 50% chemical fertilizers.
Sorghum based cropping system	Substitute 60 kg N through FYM or green leuceana leaucocephala loppings to get higher yields and FUE.
Cotton	50% of recommended NPK can be replaced by 5 t FYM/ha.
Oilseeds (Mustard, Sunflower etc.)	Substitute 25-50% of chemical fertilizer through 10 t FYM/ha to get higher yield and FUE.

Source: FAO and Indian Institute of Soil Science, Bhopal, India

ANNEXURE - VI A : BIOCONTROL AGENTS/ BIOPESTICIDES AVAILABLE FOR VARIOUS PEST SPECIES

Crop	Pest	Biocontrol agent/ Biopesticides	Dosage	Remarks
Sugarcane	Stalk borer, Chilo auricilus; Internode borer, C.schhariphagus indicus Shoot borer C. infuscatellus and, Gurdaspur borer, Acigona steniellus	Egg parasitoid, Trichogramma chilonis (Sugarcane strain)	50,000/ha	Remarks
	Chilo spp	Sturmiopsis inferens Allorphogas pyralophagus	125 gravid female/ha -	Sequential release
	Pyrilla (Pyrilla perpusilla)	Epiricania melanoleuca	2-3 egg masses or 5-7 cocoons in 40 selected spots/ha	Release should be made during the humid periods
	Scale insect Melanaspis glomerata	Metarhizium anisopliae Chilocorus nigrita Sticholotis madagassa Pharoscymnushorni	1500 beetles/ha	Release at the first appearance of the pest
Cotton	Sucking pests: Aphids (Aphis gossypii, Myzuz persisue), white fly (Bemisia tabaci) and thirps (Thrips tabaci)	Chrysoperla cornea Cheilomenes exmaculata	2 larvae/plant in early stage of the plant and 4 larvae/ plant in later stage 1.5 lakh adults ha	Release at random on the crop canopy
		Neem 1500 ppm	-	-
	Bolloworms (Helicoverpa armigera, Pectinophora gossypiella and Earias spp)	Trichogramma chilonis Bacillus thuringiensis	150000/ha 1kg/ha	 Apply during
	Helicoverpa armigera	Helicoverpa armigera, NPV	500 LE/ha is with 0.5% jagery and 0.1% ranipal	6x109 PIB/LE sprayed along
		Helicoverpa armigera, NPV	500 LE/ha is with 0.5% jagery and 0.1% ranipal	6x109 PIB/LE sprayed along
		Cotesia marginiventris	3000 adults/ha	Release at random on the crop canopy
	Pectinophora gossypiella	Bacon hebetor	3000 adults/Ha	Release at random on the crop canopy
		Bessa kirkpatricki	3000 adults/Ha	-do-
	Earias spp.	Chlonus blackburni	3000 adults/Ha	-do-

Crop	Pest	Biocontrol agent/ Biopesticides	Dosage	Remarks
Rice	Stem borer, Scripophaga Incertulas	T.japonicum	50,000/ha	
	Leaf folder, brown plant hopper Naliparvata lugens	Cyrotorhinus lividipennis	100 adults or 50-75 nymphs/m2	If the predatorhost ratio reaches 1:4, no action is required
Tobacco	Ahpid Myzuz nocotianae	Chrysoperla carnea or Apertochrysa sp.	6 larvae/plant	
	Leaf caterpillar Spodoptera litura	Spodoptera litura NPV	250 LE/ha three times along with 0.25% boric acid	
		Telenomus remus Steinernema spp. Beauveria spp. Nomouraea rileyi		
Maize	Stem borer Chilo partellus	Trichogramma chilonis	75000/ha	
Chickpea and pigeon pea	Helicoverpa armigera	Helicoverpa armigera, NPV	250 LE/ha along with 0.25 boric acid	
Groun-dnut	Aphidis Aphis craccivora	Cheilomenes sexmaculata Brumoidessuturalis, Ischiodon scutellaris		
Soybean	Caterpillars	Trichogramma B. thuringiensis		
Mustard	Aphids	Chrysoperla Neem 1500 ppm		

ANNEXURE - VI B : BIOCONTROL AGENTS AVAILABLE FOR VARIOUS CROP DISEASES

Crop	Pest	Biocontrol agent/ Biopesticides	Dosage
Cotton, groundnut, chickpea, pigeon pea, sunflower, etc.	Seed borne and soil borne pathogens	Trichoderma viride/ T.harzianum/ Pseudomonas flurescens	Seed treatment @ 5 to 12 g/kg of seed
Rice	Sheath blight, leaf spots	Trichoderma viride/ T. harzianum/ Pseudomonas flurescens	Foliar application 5 g/litre
Cotton	Wilt, rot, leaf spot	T. viride, T. harzianum Gliocladium virens	
Pulses (gram, arhar, moong, urad)	Wilts	Trichoderma	
Sugarcane	Wilts, red rot, smut	Trichoderma, Bacillus subtilis, Pseudomonas spp.	
Mustard	While rust & leaf spots		
Wheat	Loose smut Spot blotch	Trichoderma viride, Chaetomium globosum, Aspergillus niger	
Maize	Sheath blight	T. viride	

ANNEXURE - VII : INTEGRATED PEST MANAGEMENT (IPM) MODULES FOR RICE

IPM Module for Rainfed Upland Rice		
Pest	**Name**	**Control measures**
Nematode	Root-knot	Use of neem cake Soil incorporation of carbofuran @ 1.0 kg a.i./ha at the time of sowing
Insects	Termite	Seed dressing with chlorpyriphos @ 0.75 kg a.i./100 kg seed
Weeds	Echinocloa, Digitaria, Sanguinalis & Cyperus etc	Practice of summer season ploughing and line sowing Apply moderate levels of N40 kg/Ha, avoid basal apply on N, apply N after weeding in two splits Use finger weeder, and wheel hoes, etc. Spray pre-emergence herbicide butachlor @1.5-2.0 kg a.i./ha, and one hand-weeding at 40 DAS Anilfos as post emergence is also effective
Diseases	Brown spot Leaf and panicle blast Sheath rot	Apply potash @ 20 kg/ha, spray Dithane-M 45 @ 2 mL/litre Prophylactic treatment with Bavistin panicle blast @ 2/kg of seed or if it is above ETL, spray Bavistin 2g/litre or Hinosan 1.5 mL/litre or Beam 75 @ 0.6g/litre Spray sheathmar/Validamycin @ 2mL/litre for sheath rot control
Insect	Gundhi bug	Apply Chlorpyriphos/Follidol or Malathion dust @ 25kg/ha or spray Monocrotophos @ 0.5 kg a.i./ha
Storage pest	Rats grain moth and rice weevil	Zinc phosphide 1% (W/W) as bait Treat jute bags with malathion 50 EC @ 5 mL in 20 litres of water and also spray the storage godowns with Melathion or Fenitrothion or Deltamethrin

IPM Module for Rainfed Lowland Rice, Drought Prone Ecology		
Pest	**Name**	**Control measures**
Nematode	Root-knot	Use of neem cake Soil incorporation of carbofuran @ 1.0 kg a.i./ha at the time of sowing
Weeds	Chara, Nifella, Monocoria, Ludvigia, Cyperus, wild rices	Practice summer ploughing Hand weeding Herbicide use. Butachlor or Anilfos
Insects	Yellow stem borer	During tillering period: apply carbofuran @ 1.0 kg a.i./ha if standing water is available otherwise spray monocrotophos @ 0.5 kg a.i./ha During heading stage: monitor YSB using pheromone traps @ 5 traps/ha. If it is above ETL, apply monocropophos @ 0.5 kg a.i./ha
Diseases	Brown spot	Apply potash @ 30 kg/ha and apply Dithane-M-45 @ 2mL/litre
	Sheath rot	Apply sheathmar/validamycin @ 2 mL/litre spray Dithane-M-45 @ 2 mL/litre
	Leaf and panicle blast	Prophylactic treatment with Bavistin @ 2 g/kg of seed or if it is above ETL, spray Bavistin 2g/litre or Hinosan 1.5 mL/litre or Beam 75 @ 0.6 g/litre
Storage pests	Rats, grain moth and rice weevil	Treat jute bags with malathion 50 EC @ 5 mL in 20 litres of water and also spray the storage godowns with Melathion or Fenitrothion or Deltamethrin

IPM Module for Rainfed Lowland Rice, Shallow Favourable Ecologies		
Pest	**Name**	**Control measures**
Weeds	Chara, Monocori, Vaginalis, Cyperus difformis, Wild rice	Summer ploughing, purple leaf base varieties, hand weeding. Butachlor @ 1.5 kg a.i./ha as pre-emergence, Anilophos as post-emergence
Insects	Gall midge	Seedling root dip with chlorpyriphos @ 0.02% for 12 hours Nursery treatment with Carbofuran @ 1.5 kg a.i./ha one week before uprooting Apply phorate @1.0 kg a.i./ha
	Stem borer	During tillering period: apply carbofuran @ 1.0 kg a.i./Ha if standing water is available otherwise spray monocrotophos @ 0.5 kg a.i./Ha During heading stage: monitor YSB using pheromone traps @ 5 traps/Ha. If it is above ETL, apply monocropophos @ 0.5 kg a.i./Ha
	BPH	Spray at the base, imidacloprid @ 0.2 kg a.i./Ha
	WBPH	Apply choropyriphos/monocroptophos @ 0.5 kg a.i./Ha
	Case worm Leaf folder	Apply monocrotophos @ 0.5 kg a.i./Ha. Apply quinalphos or monocrotophos @ 0.5 kg a.i./Ha
	Hispa Mites	Apply phosphamidon @ 0.5 kg a.i./Ha Apply kelthane (Dicotol) @ 0.5 kg a.i./Ha
Diseases	RTD	Apply carbofuran @ 1.0 kg a.i./Ha or spray imidacloprid @ 0.2 kg a.i./Ha
	Sheath blight BLB	Apply sheathmar/validamycin @ 2mL/litre Apply mixture of Streptocycline 50g/litre and copper oxychloride 500 mg/litre
	Brown spot False smut	Apply Dithane-M-45 @ 2 mL/litre Kalisena foliar spray @ 2g/litre or foliar spray of Dithane-M-45 (1%) at the time of grain discolouration
	Grain discolouration	Foliar spray of Dithane-M-45 (1%) at the beginning of grain discolouration
Storage pests	Rats, grain moth and rice weevil	Treat jute bags with malathion 50 EC @ 5 mL in 20 litres of water and also spray the storage godowns with Melathion or Fenitrothion or Deltamethrin

IPM Module for Rainfed Lowland Rice, Medium-deep Waterlogged and Flood-prone Ecology		
Pest	**Name**	**Control measures**
Weed	Chara	Mechanical weeding
Insect	Yellow stem borer	Monitoring of YSB @ 5 traps for ha. If it is above ETL, use 20 traps/ha for mass trapping and use Trichocards; T. japonicum @ 50000/ha 3 times at 10 days interval Summer ploughing
	Caseworm	Apply monocrotophos @ 0.5 kg a.i./ha
	Hispa	Apply phosphomidan @ 0.5 kg a.i./ha
Disease	RTD	Apply carbofuran @ 1.0 kg a.i./ha as granules or spray imidacloprid @ 0.2 kg a.i./ha
	False smut	Kalisena foliar spray @ 2g/litre or foliar spray of dithane M-45 (1%) at the time of grain discolouration
Nematode	Ufra	Hot water treatment of seeds before sowing. Apply carbosulfan spray 0.04% once at PI stage and other at heading stage
Storage pest	Rats, grain moth and rice weevil	Treat jute bags with malathion 50 EC @ 5 mL in 20 litres of water and also spray the storage godowns with Melathion or Fenitrothion or Deltamethrin
	Sheath blight BLB	Apply sheathmar/validamycin @ 2mL/litre Apply mixture of Streptocycline 50g/litre and copper oxychloride 500 mg/litre
	Brown spot False smut	Apply Dithane-M-45 @ 2 mL/litre Kalisena foliar spray @ 2g/litre or foliar spray of Dithane-M-45 (1%) at the time of grain discolouration

IPM Module for Deepwater Rice		
Pest	**Name**	**Control measures**
Insects	Yellow stem borer (YSB)	Ploughing of field after harvest of deep-water crop in December- January Monitoring of YSB @ 5 pheromone traps/ha and of above ETL use 20 traps/Ha for mass trapping Release T. japonium @ 50000/Ha 3 times during Egg lying period
	Mealybug Hispa	Phorate spot application @ 1.0 kg a.i./Ha Apply phosphamidon @ 0.5 kg a.i./Ha
Disease	Bacterial leaf blight	Apply cow dung slurry @ 2 kg/litre as foliar spray before water accumulation in the field
	False smut	Kalisena foliar spray @ 2 g/litre or foliar spray of dithane M-45 (1%) at the time of grain discolouration
	RTD	Grow resistant varieties like Durga (Orissa), Sabita (West Bengal)
Nematode	Ufra	Hot water treatment of seeds before sowing Apply carbosulfan spray 0.04% once at PI stage and other at heading stage
Rodents	Rats	Zinc phosphide 1% (W/W) as bait

IPM Module for Coastal Wet Land Rice		
Pest	**Name**	**Control measures**
Weeds	Chara	Summer ploughing
	Typha and water hyacinth	Remove mannually
Arthropods	Crabs	Bunds can be treated with Thimet @ 5 g/hole
Insects	Stem borer Leaf folder and Case worm	As in case of deepwater Spray with monocroptophos @ 0.5 kg a.i./ha
Diseases	RTD	Grow resistant varieties like Durga, Sabita, Lunishree
	BLB	Apply cow dung slurry @ 2kg/litre as foliar spray before water accumulation in the field
	Sheath rot	Spray sheathmar/validamycin @ 2 mL/litre
Rodents	Rats	Zinc phosphide 1% (W/W) as bait

Source: B.N. Singh and S. Sasmal; Central Rice Research Institute, Government of India

ANNEXURE - VIII : KEY TECHNOLOGIES DEVELOPED BY CIAE FOR CROP MANAGEMENT DURING X^TH FIVE YEAR PLAN

Agricultural Mechanization

Light weight power tiller (140 kg) having a field capacity of 0.08 ha/h is suitable for hill agriculture and orchards. Cost of operation ~ Rs 70/ h.

Tractor operated lug wheel puddler is suitable for high speed shallow puddling in rice fields where higher soil dispersion is desirable especially for mechanized transplanting.

Self propelled biasi cultivator was adapted from the commercial light weight power tiller to achieve timeliness of operations and overcome the problems associated with the animal based biasi cultivation.It is commercially available and recommended for adoption where high coverage rate is desirable.

Tractor mounted plastic mulch laying machine is an improvement over manual mulching where labour requirement is reduced by 96%.

Tractor mounted strip till drill is suitable for seeding in fields with stubbles, which saves 60% time, 50-60% fuel and 50% cost of operation. It has a field capacity of 0.45 ha/h.

Tractor mounted 6 row inclined plate planter is suitable for all types of seeds and the saving in cost of planting over traditional method is over Rs 125/ha. It has field capacity of 0.45 to 0.65 ha/h and operating cost of Rs 300/ha.

Sugarcane cutter planter performs many unit operations in a single pass and is a versatile labour saving device. It has a field capacity of 0.20 ha/h. The saving in labour and time are 78 and 58%, respectively.

Tractor mounted vegetable transplanter suitable for bare root saplings have a field capacity of 0.1 ha/h and requires 30-38 man-h/ha. The cost of transplanting is Rs 1800/ha.

Tractor mounted inclined plate planter for intercropping on raised bed farming system is suitable for intercropping. The cell fill for soybean was 99.3% and for pegion pea 98.9%. The field capacity of the machine is 0.4 ha/h.

Tractor operated aeroblast sprayer is suitable for orchards. The discharge rate is 3 m3/s and deposition of chemical is 84%. The field capacity of the sprayer is 1.5 ha/h.

Self propelled vertical conveyor reaper is suitable for harvesting of wheat, rice, soybean and lentil. It saves 50% in time, 50% in labour and 75% in cost of harvesting over manual method. The capacity of reaper is 0.20 ha/h with two operators.

Pigeon pea thresher is suitable for whole stalk threshing. The feed rate is 1750 kg/h and output is 440 kg/h. The threshing and cleaning efficiencies are 96 and 94% respectively.

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Manual 4-row sprouted rice seeder is suitable for seeding sprouted rice in puddled soil. It saves on the cost of raising nursery and subsequent transplantation by which 72% labour and 87% energy are saved.

Tractor mounted till plant machine suitable for seven-rows has field capacity of 0.4 to 0.5 ha/h. It saves fuel, cost of operation and time taken to complete the operation over the conventional method of seedbed preparation and planting.

Animal drawn 3-row raisedbed former suitable for dryland agriculture can form furrow of size 300 mm, raisedbed of height 50-130 mm and of width 430-700 mm. The spacing between rows is 250- 350 mm.

Manually operated cono weeder reduces drudgery and increases operator's efficiency. Time saving is 50% compared to hand weeding.

Straight flow paddy thresher is suitable for threshing paddy. It saves 80% labour, 70% operating time and 50% cost of operation as compared to conventional methods. The cost of operation is about Rs 40/h.

Technology

Turning indicator on tractor trolley

Research Aids

Human strength measuring set up

Portable animal weighing system

Mini soil bin

Rotary soil bin

Calibration set up for seed drills

Animal tread mill

Hydraulic nozzle test set up

Sticky belt test set up

Swath testing apparatus

Irrigation and Drainage Engineering

Equipment

Low friction foot valve increases discharge from 12.0 to 13.6 l/s, decreases head loss from 0.69 to 0.28 m and friction coefficient from 2.52 to 0.76.

Mole plough having capacity of 0.42 ha/h at 2 m spacing has been developed and its cost of operation is Rs 1080/ha.

Automatic irrigation pump switch off device switches off the pump when the optimum moisture level is attained in the field.

Automatic water level indicator is used for indicating drain water level in the channel.

Technologies

Water harvesting and recycling system for vertisols

Drainage in vertisols

Surge irrigation system for vertisols

Ground water recharge in vertisols

Research Aids

Test set up for drippers

Test set up for centrifugal pump sets

Drip irrigation system for orchard in 7 ha

Technology Transfer

Equipment

Barrow type fertilizer spreader is suitable for spreading of granular fertilizer. The spreading efficiency was 81.4%.

Technologies

Manufacturing package for Serrated Sickle

Upgraded material for rotavator blades with product process and heat treatment

Appropriate material for sickle blade and thresher pegs with heat treatment

ANNEXURE - IX : TECHNOLOGY OUTPUT EARMARKED BY CIAE IN SHORT, MEDIUM AND LONG TERM FOR THE XITH FIVE YEAR PLAN WITH IMPLICATION FOR CROP MANAGEMENT

Pneumatic planter for light weight and irregularly shaped seeds. Intra-canopy sprayer Sprayer for bio-pesticides Bulb crop planter Self propelled weeder with crop sensor High-speed tillage and seeding equipment Cup type vegetable transplanter Mechanized nursery raising system Seed pelletizer Vertical sleeve sprayer Robotic fruit and vegetable transplanter Check row cotton planter Rotary zero till slit drill Residue incorporator Technology for controlled traffic cultivation Expert and decision support system for precision farming Skidless drive system for metering unit Conservation agriculture technology	Billet type sugarcane harvester Onion harvester Database on soil, crop and climatological parameters Check row cotton planter Rotary zero till slit drill Residue incorporator Technology for controlled traffic cultivation Expert and decision support system for precision farming On-off water control device for pulse mode Pressure compensated micro sprinkler Precision fertigation system Bubbler irrigation technology Decision support system for irrigation water management Expert system for design of surface and sub surface drip irrigation system Gravel mole drainage technology Process for continuous production of bio-diesel GPS and DGPS controlled tractor implement system

ANNEXURE - X : KEY RESEARCH GAPS IN INDIAN AGRICULTURE HAVING IMPLICATIONS ON FIELD CROP PRODUCTIVITY

Issues	Research Gap
Agricultural Mechanization	
Crop establishment and protection	Lack of mechanization of crop management in rain-fed agriculture under moisture stressed conditions. Non-availability of machinery for space planting of costly, small, light weight and irregular shaped seeds. Need of machinery for manure spreading and its incorporation in the soil to reduce human drudgery and nitrogen losses, which is about 21%. Non-availability of suitable pesticide sprayers to reach underside of plants. About 80% of the total pesticide applied reaches to soil instead of being retained on the plant, which is a serious problem in cotton.
Harvesting, threshing and straw management	Lack of viable equipment for retrieval/ incorporation of straw Lack of harvesting equipment for sugarcane, cotton and horticultural crops (mango and sapota) Need for equipment for reaping standing straw from combine harvested rice fields Improving field maneuverability of tractor-reaper-trailer system.
Conservation agriculture	High Rainfall Problem of rapid soil erosion, nutrient loss and land degradation. Low rainfall Problems of late sowing, drought stress, low soil fertility and high weed intensity. Dryland Problems of moisture stress and soil erosion. Irrigated Problems of depletion of ground water, high cost of crop production and irrigation water pumping, scarcity of labour and soil compaction.

Issues	Research Gap
Precision farming	Lack of farm equipment with high precision for enhanced input use efficiency taking into account their spatial variability. Database on spectral signature to correlate imagery to crop condition and deficiency levels. Need of farm equipment for variable rate application of seed, fertilizer, chemicals and irrigation water. Adoption of GIS/ GPS/ DGPS with satellite and remote sensing monitoring systems for application of inputs and harvesting of crops for use on minimum manageable zone (MMZ).
Irrigation and Drainage Engineering	
Improvement in on-farm water management practices	Losses in pumping systems such as foot valve, strainer, management practices impellers and belts are as high as 40% due to poor design/material, causing low (60%) pumping system efficiency. Need for a state-of-the-art testing facility for irrigation equipment for design refinement in existing systems/components. Lack of drainage facilities restricting the productivity of kharif crops in vertisols. Need for different surface and sub-surface drainage technologies for enhancing productivity.
Water harvesting and recycling	Non availability of technology for water harvesting and recycling for improving ground water availability.
Agricultural Energy and Power	
Energy efficient utilization and management of power sources	Lack of information and decision making tools for energy management of power sources and farm machinery management for optimal use of available farm power sources and improvement in their design based on ergonomics for their enhanced efficiency.
Thermo-chemical conversion of biomass	Need for biomass based proven system with unit operations and their gadgets for decentralised electricity generation using gasification/bio-methanation routes.
Liquid fuel from biomass (bio-diesel, alcohol)	Need for technologies and gadgets for efficient conversion and use of biomass through pyrolysis and alcoholic fermentation.
Transfer of Technology	
Promotion and commercialization of equipment and technology	Lack of awareness on available improved technologies equipment and technology among the farmers, entrepreneurs and officials. Lack of awareness or training of extension workers on the new technologies and the latest developments. Need to strengthen linkages with manufacturers for transfer of new technologies and commercialisation. Lack of mechanism to get continuous feedback information for initiating R&D activities, linkages with State Departments, ICAR Institutes and AICRP centres, KVKs and other organizations. Need for entrepreneurship development for custom hiring.

Source: Indian Council of Agricultural Research and Central Institute of Agricultural Engineering, Government of India

APPENDIX 1A : TRENDS IN TOTAL FACTOR PRODUCTIVITY FOR VARIOUS CROPS IN SELECTED STATES OF INDIA, 1971-86

Crop	Total Factor Productivity				
	Increasing			No Change	Decreasing
	< 1%	1-2%	> 2%		
Paddy		Andhra Pradesh, Assam	Haryana, Punjab, Tamil Nadu, Uttar Pradesh	Bihar, Karnataka, Madhya Pradesh, West Bengal	
Jowar	Rajasthan, Tamil Nadu	Andhra Pradesh, Karnataka, Maharashtra			
Bajra		Rajasthan	Gujarat	Haryana, Uttar Pradesh	
Maize		Himachal Pradesh		Madhya Pradesh, Rajasthan	
Ragi		Tamil Nadu		Karnataka	
Wheat		Punjab, Rajasthan	Haryana, Uttar Pradesh	Madhya Pradesh, West Bengal	Bihar
Barley			Rajasthan		
Moong			Andhra Pradesh, Orissa	Madhya Pradesh, Rajasthan	
Urad				Andhra Pradesh	Madhya Pradesh, Tamil Nadu
Arhar					Karnataka, Madhya Pradesh
Gram			Uttar Pradesh	Haryana, Madhya Pradesh, Rajasthan	
Groundnut			Karnataka	Andhra Pradesh, Gujarat	Tamil Nadu
Rapeseed & mustard			Haryana, Rajasthan	Assam	
Sunflower			Maharashtra		
Soybean			Madhya Pradesh		
Sugarcane			Andhra Pradesh, Karnataka	Haryana, Maharashtra, Tamil Nadu, Uttar Pradesh	Bihar
Onion				Maharashtra	
Potato				Bihar, Uttar Pradesh	

Source: Agricultural Economics Research Review, 2006

APPENDIX 1B : TRENDS IN TOTAL FACTOR PRODUCTIVITY FOR VARIOUS CROPS IN SELECTED STATES OF INDIA, 1986-2000

Crop	Total Factor Productivity				
	Increasing			No Change	Decreasing
	< 1%	1-2%	> 2%		
Paddy	West Bengal	Andhra Pradesh, Bihar, Madhya Pradesh, Tamil Nadu		Assam, Karnataka, Uttar Pradesh	Haryana, Punjab
Jowar	Tamil Nadu	Andhra Pradesh		Madhya Pradesh, Maharashtra	Karnataka, Rajasthan
Bajra			Harayana, Rajasthan	Gujarat, Maharashtra	
Maize		Madhya Pradesh		Rajasthan, Uttar Pradesh	Himachal Pradesh
Ragi					Karnataka, Tamil Nadu
Wheat	Madhya Pradesh, Rajasthan, West Bengal	Haryana, Punjab			
Barley			Uttar Pradesh	Rajasthan	
Moong				Andhra Pradesh	Madhya Pradesh, Orissa, Rajasthan
Urad			Maharashtra	Madhya Pradesh, Uttar Pradesh	Andhra Pradesh, Orissa, Tamil Nadu
Arhar		Gujarat	Madhya Pradesh		Karnataka, Uttar Pradesh
Gram	Madhya Pradesh, Uttar Pradesh			Haryana	Rajasthan
Groundnut		Andhra Pradesh, Tamil Nadu		Gujarat, Maharashtra, Orissa	Karnataka
Rapeseed & mustard	Rapeseed & mustard			Assam, Haryana, Rajasthan, Uttar Pradesh	Punjab
Sunflower				Maharashtra	Karnataka
Soybean			Madhya Pradesh		
Sugarcane			Bihar	Andhra Pradesh, Haryana, Karnataka, Maharashtra, Tamil Nadu	
Onion		Maharashtra			
Potato			Uttar Pradesh		Bihar

Source: Agricultural Economics Research Review, 2006

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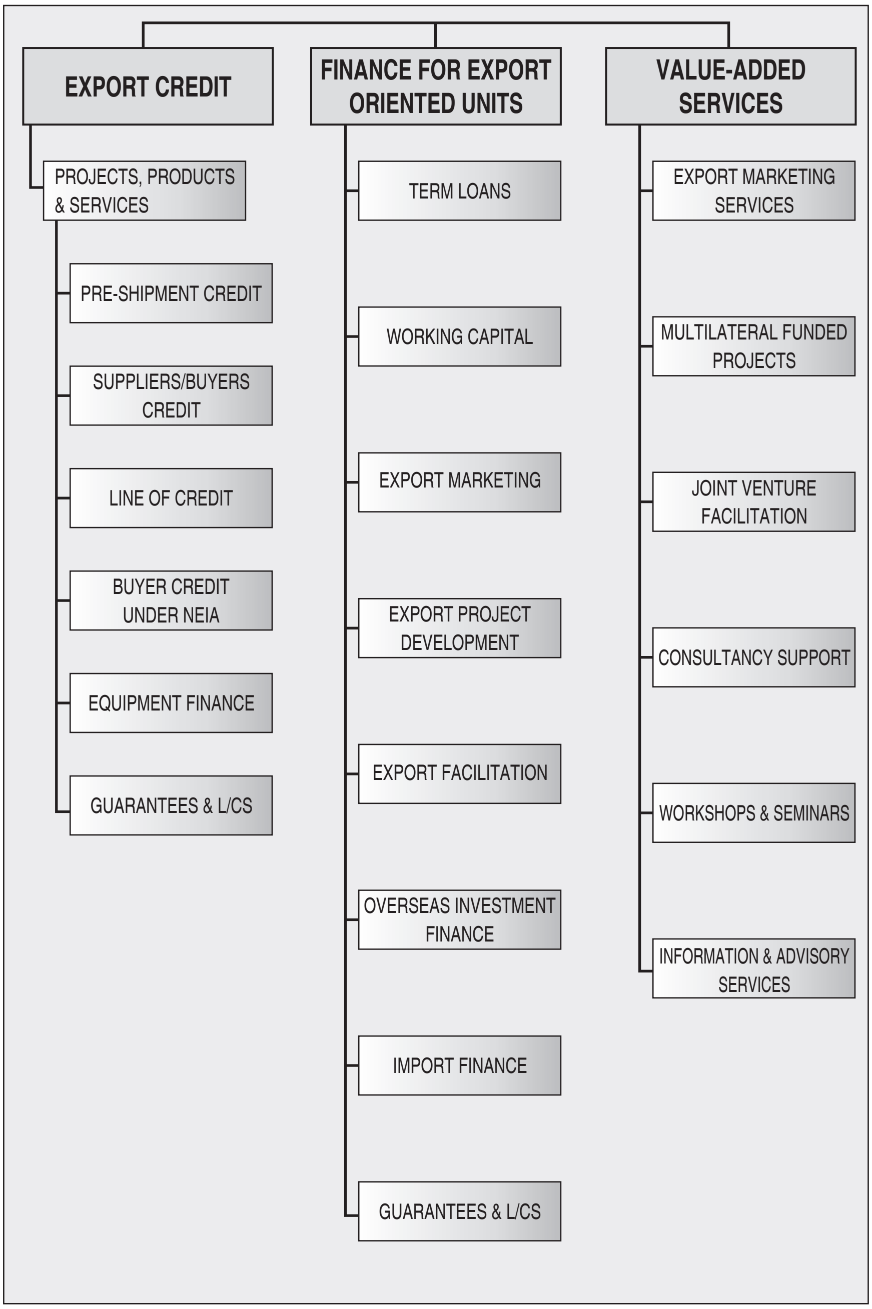

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