Evolution of Agriculture in the High Barind Tract of Bangladesh

M Yusuf Ali, Chris Johansen and A M Musa

Evolution of Agriculture in the High Barind Tract of Bangladesh

Year of Publication : 2018

 : Contact address : **M Yusuf Ali**
D-186/7 (level 3)
Nazrul Sarani, Middle Sayabithy
Gazipur City, Gazipur-1701
Bangladesh
Email: yusuf709@gmail.com

Published by : **Moynul Islam**
Arik Prokashona
Sayed Grand Center (6th Floor)
Road # 28, Sector # 7, Uttara, Dhaka.
Bangladesh

Design : **Chris Johansen, Liton Mondal**

Printed by : **IDEA Printers**
290 Dhaka University Market
Katabon Road, Dhaka-1000

ISBN : 978-984-34-5158-3

Dedication

To the Farm Families of Barind Tract Whose Life is Written in Water

TABLE OF CONTENTS

Foreword iii
The Authors v
Acronyms and Abbreviations viii
Glossary x
Summary 1
1. Introduction 2
2. The Original Resource Base 5
    2.1 Geology and soils 5
    2.2 Climate 6
    2.3 Biodiversity 12
3. Human Occupation 14
    3.1 Original civilizations 14
    3.2 Destruction of forest and terracing of land 14
    3.3 Towards desertification 15
    3.4 Recent human populations 17
4. Traditional Rainfed Rice Farming 20
5. The Age of Irrigation 23
    5.1 Water resources 23
    5.2 Expansion of deep tube well irrigation 25
    5.3 Other types of irrigation 26
    5.4 Boro rice cultivation 26
    5.5 Impact of irrigation 27
6. Farming System Diversification – a Changing Landscape 31
    6.1 Changes in cropping patterns 31
    6.2 Changes in tillage methods 34
    6.3 Increasing chemical inputs 41
    6.4 Livestock components 43
    6.5 The return of trees 44
    6.6 Homestead vegetable gardening 47
7. Evolving Livelihoods 51
    7.1 Signs of improvement 51
    7.2 Risk management in rural households 54
    7.3 Diversified livelihood sources 57
    7.4 Rainfed cropping options 61
    7.5 Increasing market access 63
    7.6 Information and communication revolution 64
8. Climate Change Scenarios 66
9. Remedial steps 71
    9.1 Increasing water capture and use 71
    9.2 Increasing water use efficiency 76
    9.3 Trees 80
    9.4 Soil improvement 80
    9.5 Crop improvement and management 81
    9.6 Livestock and fisheries 83
    9.7 Value addition 83

9.8 Enhanced farmer services 83
9.9 Energy 84
9.10 OFR&D methodology 85
10. A Vision for the HBT 87
References 89
Acknowledgements 101

FOREWORD

This book aims at synthesizing research and development efforts in the High Barind Tract of Bangladesh which the authors have been associated with over the last four decades. This is a particularly challenging agroecosystem in that, compared to alluvial plain regions of the country, it has soils of low fertility, the lowest rainfall and least irrigation potential. Therefore, enhancement of livelihoods of the inhabitants depends largely on improvements to rainfed agriculture, and particularly on ways of improving water use efficiency. However, to set the scene we look back into the history of this ecosystem, to the origin of its soils, the transformation of a once densely forested area into one of predominant rainfed rice cultivation, and of the human populations involved. While focussing on the agricultural economy of recent times, and the advances being made, we also try to peak into the future, to explore possible pathways of environmental and livelihood improvement.

The Government of Bangladesh from its beginning realized the challenges of the High Barind Tract and that targeting and focussing of development efforts was required. One of its early initiatives was to establish the Barind Integrated Area Development Project which later became the Barind Multipurpose Development Authority. Further, the Department of Agricultural Extension and Bangladesh Agricultural Research Institute also ensured that agricultural research and development in the region was given due attention. For the latter institute, this was largely channelled through their On-Farm Research Division where AMM and MYA were originally employed. However, no research station specifically targeting this agroecology was established, which proved to be a considerable advantage. This required researchers to work directly with farmers, on their fields, thus facilitating farmers' ownership of successful outcomes and hastening their more widespread adoption. Thus the region became a leader in developing on-farm research techniques and has attracted global interest in that regard.

One such international organization that was attracted was ICRISAT, the International Crops Research Institute for the Semi-Arid Tropics, whose particular mandate is agricultural research for water-constrained areas. One of ICRISAT's mandate crops is chickpea, a crop particularly adapted to growing on receding soil moisture, and in the 1980's the High Barind Tract was considered as a particularly suitable area for this crop and worthy of targeted research input. Chickpea is an important pulse crop of Bangladesh, grown mainly on alluvial soil but constrained there by Botrytis Grey Mould, a foliar fungal disease. The High Barind Tract is less humid than elsewhere in the country during the winter growing season, and thus less conducive to this disease, and therefore a more reliable growing environment for chickpea. With CJ working for ICRISAT at that time, this is how the present authors met up, began working together, and attracting various international projects to the region.

Through this international collaboration, various types of innovative approaches were taken, of direct relevance to the High Barind Tract but also of global relevance. Innovative methods of on-farm research and development were evolved, including farmer-participatory varietal and agronomic research and conservation agriculture techniques based on two-wheel tractor powered planters. Possibilities for soil improvement, increasing water use efficiency, improving cropping system productivity and enhancing livelihoods of the local population were evolved. However, continuing efforts in this regard are required to maintain the momentum so far achieved. This is particularly so in view of the changing background circumstances – increasing, usually adverse, climate change effects, new technological innovations, particularly in information and communications technology, and changing socioeconomic circumstances of the country.

Although this book provides a snapshot of a particular agroecological region, and is in one sense specific for that region, it also provides a template for research and development in other defined agroecological regions dominated by resource-poor farmers in a deteriorating environment. There are many such regions of the planet with a once stable natural vegetation cycle, cleared for farming and facing degradation of soil and water resources.

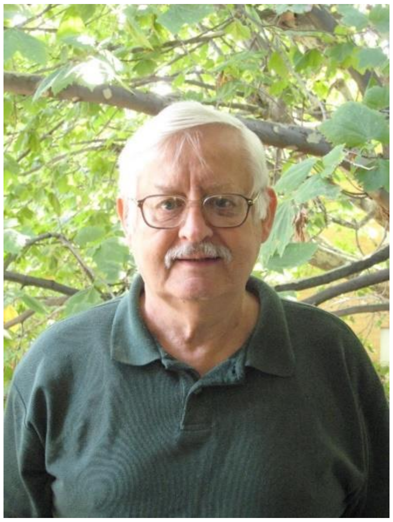
M Yusuf Ali, Chris Johansen and Abu M Musa

THE AUTHORS

M Yusuf Ali

M. Yusuf Ali was born in 1957. He took his Graduation and Master degrees in Agriculture from Bangladesh Agricultural University in 1981 and 1983, respectively, and did his Ph.D. in Agronomy in 2000 from Bangabandhu Sheikh Mujibur Rahman Agricultural University with dissertation research from International Crop Research Institute for the Semi-Arid Tropics (ICRISAT). He conducted his PhD research across India and Bangladesh in Vertisol and Barind soils respectively on chickpea root systems, moisture regimes, physiology and nutrition. He joined Farming Systems Division (known as On-Farm Research Division) of Bangladesh Agricultural Research Institute in 1983 and served up to 2009 as Principal Scientist. He was trained from IRRI, Philippines on Farming Systems Research and acted as Principal Investigator in different donor funded projects including FAO funded Livelihoods Adaptation to Climate Change, CIMMYT funded Maize Whole Family Training and Adaptive Research and SDC funded Homestead Agroforestry. In 2007 he worked as a Visiting Scientist of CIMMYT, Mexico through World Bank scholarship (IFAR Fellowship) and characterized the Rice-Maize Systems of Bangladesh which was published from CIMMYT, Mexico in 2008. He served as short term consultant for Australian Centre for International Agricultural Research in 2011. From 2012 to 2014 he worked as a Cropping Systems Agronomist of CIMMYT, promoting conservation agriculture. From January 2015 to December 2016 he served as a Focal Regional Research Manager of CGIAR funded Water, Land and Ecosystems (WLE) Program under IWMI/WorldFish and served in Bangladesh, India and Nepal. From January to March 2017 he worked as Consultant of CIAT, Colombia for profiling the Climate Smart Agriculture of Bangladesh. In 2017 he worked as a short-term consultant of WorldFish for its Climate Change, Agriculture and Food Security project. He penned a book entitled "Farming Systems of Bangladesh: Poverty Escape Pathways and Livelihoods Improvement".

Chris Johansen



He spent the first quarter century of his life, from 1945 to 1971, living in Perth, Western Australia, ending up with a B.Sc. Agric (Hons) and Ph.D. (Soil Science and Plant Nutrition) at the University of Western Australia (UWA). After undertaking a postdoctoral fellowship in Germany, he was a research scientist with the Commonwealth Scientific and Industrial Research Organization in Queensland, Australia, working on mineral nutrition of tropical pastures. He first came to Bangladesh in 1979, as a jute physiologist with the Food and Agriculture Organization of the United Nations (FAO). During 1983-4 he worked in Yunnan Province of China, again on fertilizer requirements of pastures, before joining the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), based in Hyderabad, India (1984-2000). He was recruited by ICRISAT as a legume physiologist, working on chickpea and pigeonpea, and then became a legume agronomist, and then a cropping systems agronomist. He was involved in projects in many countries in Asia and Africa, but took a particular interest, along with ICRISAT chickpea breeder Dr Jagdish Kumar, in better adapting chickpea to the High Barind Tract – perhaps also because his wife was from Bangladesh. Influenced by Barind researchers in the On-farm Research Division of the Bangladesh Agricultural Research Institute, as well as other international proponents, he became increasingly interested in developing farmer participatory approaches and on-farm research. To better further these on-farm research approaches, in 2000 he opted to become an independent consultant in on-farm research and development. Initially, he was based in Bangladesh (2000-6), and then relocated to Perth in 2006, but regularly travelled to Bangladesh with ongoing project work. He is currently an Adjunct Professor at the Institute of Agriculture, UWA, continuing with writing up of agricultural research and development experiences.

Abu M Musa

AM Musa was born in 1939 and obtained an M.Sc. (Chemistry) degree from Rajshahi University in 1965. During 1967-78 he worked as a Scientific Officer (FAO/UNDP) on the Fertilizer Project, Soil Science Division, Bangladesh Agricultural Research Institute (BARI). From 1979 to 1986 he was a Senior Scientific Officer, BARI, World Bank Extension and Research Project. During 1987-95 he was Senior Scientific Officer, On-Farm Research Division (OFRD), BARI and Site Coordinator, Barind, National Coordinated Farming Systems Research and Development Project, comprising crop, livestock, homestead fisheries and agro-forestry components. He was Principal Investigator and Project Leader of the fisheries component. In 1995-96 he was Principal Scientific Officer and Head, Region-1, OFRD, BARI. In 1997-98 he moved to CARITAS (an NGO) as Agricultural Adviser, working on agricultural R&D projects in the High Barind Tract (HBT) supported by Seed Industries Promotion Unit, Crop Diversification Program (Netherlands funding) and ICRISAT, India. During 1998-2006 he was Agricultural Adviser, PROVA (People's Resource Oriented Voluntary Organization; an NGO), implementing a DFID/ICRISAT project on "Promotion of chickpea after rainfed rice in the Barind of Bangladesh". He then became Executive Director of PROVA, implementing a CIMMYT/COB project on rice and an ACIAR project on minimum tillage entitled "Lentil and chickpea after rainfed rice in the Barind of Bangladesh" during 2006-2012, continuing an ACIAR minimum tillage project and implementing ACIAR-IRRI demonstrations on lentil and mungbean after rice during 2013-2015, and, in 2016-2017, implementing a Bread for the World (CCDB), Climate Resilient Agriculture (CRA) project on different low water requirement crops, different land races of rice, minimum tillage and suitable cropping patterns under farmers' conditions in the Barind of Bangladesh.

ACRONYMS AND ABBREVIATIONS

AWD	Alternative wetting and drying method of rice cultivation
BADC	Bangladesh Agriculture Development Corporation
BARC	Bangladesh Agricultural Research Council
BARI	Bangladesh Agricultural Research Institute
BBS	Bangladesh Bureau of Statistics
BDT	Bangladeshi Taka (Bangladesh currency)
BINA	Bangladesh Institute of Nuclear Agriculture
BMD	Bangladesh Meteorological Department
BMDA	Barind Multipurpose Development Authority
BRRI	Bangladesh Rice Research Institute
CA	Conservation agriculture
CEC	Cation exchange capacity
CIMMYT	International Maize and Wheat Improvement Centre
cm	centimeter
CST	Concentrated Solar Thermal (for electricity generation)
DAE	Department of Agricultural Extension (of Bangladesh)
DFID	Department for International Development (of the United Kingdom)
DTW	Deep tube well
FAO	Food and Agriculture Organization of the United Nations
g	gram
h	hour
ha	hectare
HBT	High Barind Tract
HYV	High yielding variety
IARC	International Agency for Research on Cancer
ICM	Integrated crop management
ICRAF	International Center for Research in Agroforestry
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
ICT	Information and communications technology
IPCC	Intergovernmental Panel on Climate Change
IPM	Integrated Pest Management
IR	Irrigated
IRRI	International Rice Research Institute
IWM	Integrated Weed Management
kg	kilogram
km	kilometer
L	liter
m	meter
meq	milliequivalents
mm	millimeter
NGO	Non-Government Organization
OFR&D	On-farm research and development
OFRD	On-Farm Research Division (of BARI)
PET	Potential evapotranspiration
ppm	parts per million

PROVA	People’s Resource Oriented Voluntary Association
PTOS	Power tiller operated seeder
PVS	Participatory varietal selection
RF	Rainfed
s	second
SD	Standard deviation
SOC	Soil organic carbon
SRDI	Soil Resources Development Institute
t	tonne
USDA	United States Department of Agriculture
VMP	Versatile Multi-crop Planter
WFP	World Food Programme
WUE	Water use efficiency

GLOSSARY

B. aus	Broadcast aus rice; generally directly seeded spring rice grown with natural rainfall when soil moisture reaches field capacity.
Beel	Lake-like wetland adjacent to a large river.
Ber	Jujube (*Ziziphus mauritiana*), a fruit tree.
Bigha	Unit of area used in Bangladesh agriculture. 1 bigha = 1,337 m^2 = one-third of an acre; 1 ha = 7.5 bigha.
Boro rice	Transplanted rice grown in rabi and Kharif-I season with frequent irrigation and having high yield potential. It needs 3,000-5,000 L water/kg rice.
Bund	Soil barrier to retain water within rice fields.
Byde	Valley land
Chara land	High land
Chola	The Bengali word for chickpea.
Decimal	Unit of area used in India and Bangladesh, equal to $1/100^{th}$ of an acre or 40.46 m^2
Dhan	The Bengali word for paddy rice (unclean rice).
Dheki	A wooden implement used for dehusking of rice
Dighi	Fish pond
District	Administrative unit comprising several Upazilas
Katcha	Dwelling made predominantly of mud and straw.
Khari	Small natural channel for draining rainfall water. However, if larger kharis are dammed they can store water for a few months.
Kharif-I	Pre-monsoon (spring) crop growing season: 16 March to 15 July
Kharif-II	Monsoon (summer) crop growing season: 16 July to 15 October
Khas pond	Government owned excavated water body.
Khira	Cucumber (*Cucumis sativus*).
Laddering	Drawing a wooden bar across a ploughed field to level the land.
Pucca	Dwelling with brick or concrete wall with corrugated iron, tile or concrete roofing.
Rabi	Winter crop growing season: 16 October to 15 March. Generally dryland crops are grown on stored soil moisture but often need based irrigation is applied where available. Irrigated boro rice is also grown.
Rainfed	Crop grown depending on natural rainfall or stored soil moisture
T. aman	Transplanted aman rice. Rice grown in the monsoon (Kharif-II) season (July-October) generally with natural rainfall but often supplementary irrigation is applied in case of drought.
T. aus	Transplanted aus rice. Rice grown in the pre-monsoon (Kharif-I) season (March-July) generally with irrigation.
Taka	Bangladesh unit of currency.
Upazila	Administrative unit under a district, a sub-district, comprising several sub-units called unions.
Zaminder system:	During the time of British India (1758-1947) most of the cultivable lands were placed under local elites or rich men (mainly Hindu) by the colonial ruler to collect revenue. Farmers (mostly Muslim)

cultivated the land on lease and paid revenue to the British ruler through the Zaminder. Local Zaminders also imposed many other taxes on poor farmers. This is called the Zaminder system. It was unjust and tyrannical. In 1938 it was amended through the Bengal Tenancy and Money Lender's acts by Mr. A.K. Fazul Haque the then Governor of Bengal province.

Summary

The High Barind Tract is a distinct uplifted agro-ecological zone in Bangladesh, originally densely forested but with a long subsequent history of rainy season, transplanted, puddled rice cultivation. This has resulted in severely degraded soil properties important for non-rice crops. Water-use-efficiency is a crucial consideration for the region due to the limited soil water-holding capacity, recent depletion of groundwater reserves, limited surface water catchment and increasing effects of climate change.

Research and development activities over the last four decades to alleviate these constraints are evaluated. Ever increasing demand for rice in Bangladesh has prompted double cropping of rainy season rice followed by irrigated post-rainy season rice. However, such double cropping further deteriorates soil properties, depletes groundwater reserves and is only marginally remunerative for resource-poor farmers. With appropriate agronomy and cultivar introduction various post-rainy season crops, including wheat, pulses, oilseeds and vegetables, can be more remunerative. Present status and future options for tree cultivation, livestock husbandry and homestead development are also given. Conservation agriculture techniques for soil improvement and improved methods of water capture and use are elaborated.

Through soil improvement, better management of water, appropriate crop rotation and effective exploitation of solar energy and communications technology it is envisioned that this region can become a sustainably productive agricultural region with substantially improved livelihoods for its inhabitants. This overview provides a case study applicable to other distinct agro-ecosystems cleared of natural vegetation for agriculture, resulting in a deterioration of natural resources, but its restoration through agronomic and other measures.

Chapter 1. Introduction

Among living organisms humankind has had the most profound effect in modifying the biosphere, usually to the detriment of the pre-existing natural resource base and biodiversity. These effects have intensified as the human population has grown, to now threaten the very life support system on which humans rely. Examples include anthropogenic effects on climate change, desertification of once-forested regions, diminution of fresh water resources and degradation of marine environments. However, it seems that most humans tend to be focused on the present and do not have an appreciation of the progression from human ancestors being minor components of an ecosystem to its domination and subjugation by humans. There is also a reluctance to examine consequences of continuing along this pathway as contemplation of pessimistic future scenarios is an unattractive pastime. However, specialists who have examined future scenarios with respect to climate change, declines in natural resources and biodiversity and increased environmental degradation usually predict grim to catastrophic future scenarios. If these scenarios are to be avoided then there must be much more appreciation among humans of their evolutionary consequences on this planet, such that they will be motivated to change their behaviour to ensure a more sustainable future.

One way of improving understanding of how humans progressively modify their ecosystems, with both advantageous and detrimental consequences, is to undertake a case study of historical effects of human influence of a distinct ecosystem. Most changes wrought by humans on ecosystems are mainly related to the evolution of agricultural practices. We have chosen the High Barind Tract (HBT) in the north-west of Bangladesh for this study, as we have been working for several decades in trying to improve the livelihoods of the rural population of this region through introduction of innovations in agricultural technology. Actually, this ecosystem extends into West Bengal state of India, where the history would be similar, but we are restricting our analysis to the HBT in Bangladesh due to our specific familiarity with it.

The HBT is situated in North-West Rajshahi Division of Bangladesh at 24.40-24.80 °N, 88.30-88.80 °E and occupies about 1,600 km^2 (159,964 ha) area (Figure 1.1). It is clearly differentiated from other parts of the country because of its terraced land with soil of low fertility, sparse vegetation, absence of major river channels, and comparatively low rainfall with a long dry period, during October-May. It is regarded as the most drought prone area of the country due to its relatively low (compared to the rest of Bangladesh) and erratic precipitation (average 1,440 mm average annual rainfall but this can vary spatially and seasonally between 790 and 2,200 mm), limited groundwater reserves and recharge, poor water holding capacity of surface soil in the post-rainy season along with high summer air temperature, with maximums usually 35-40 °C in April-May. The HBT is relatively uplifted (9-47 m above sea level) and not subject to annual inundation like the flood plain areas of Bangladesh. Lying mainly to the east of the HBT there is an area of level Barind (Figure 1.1). This area has similar soil to the HBT but it is flat and largely irrigated with double cropping of rice; but in our discussion we will focus primarily on the HBT.

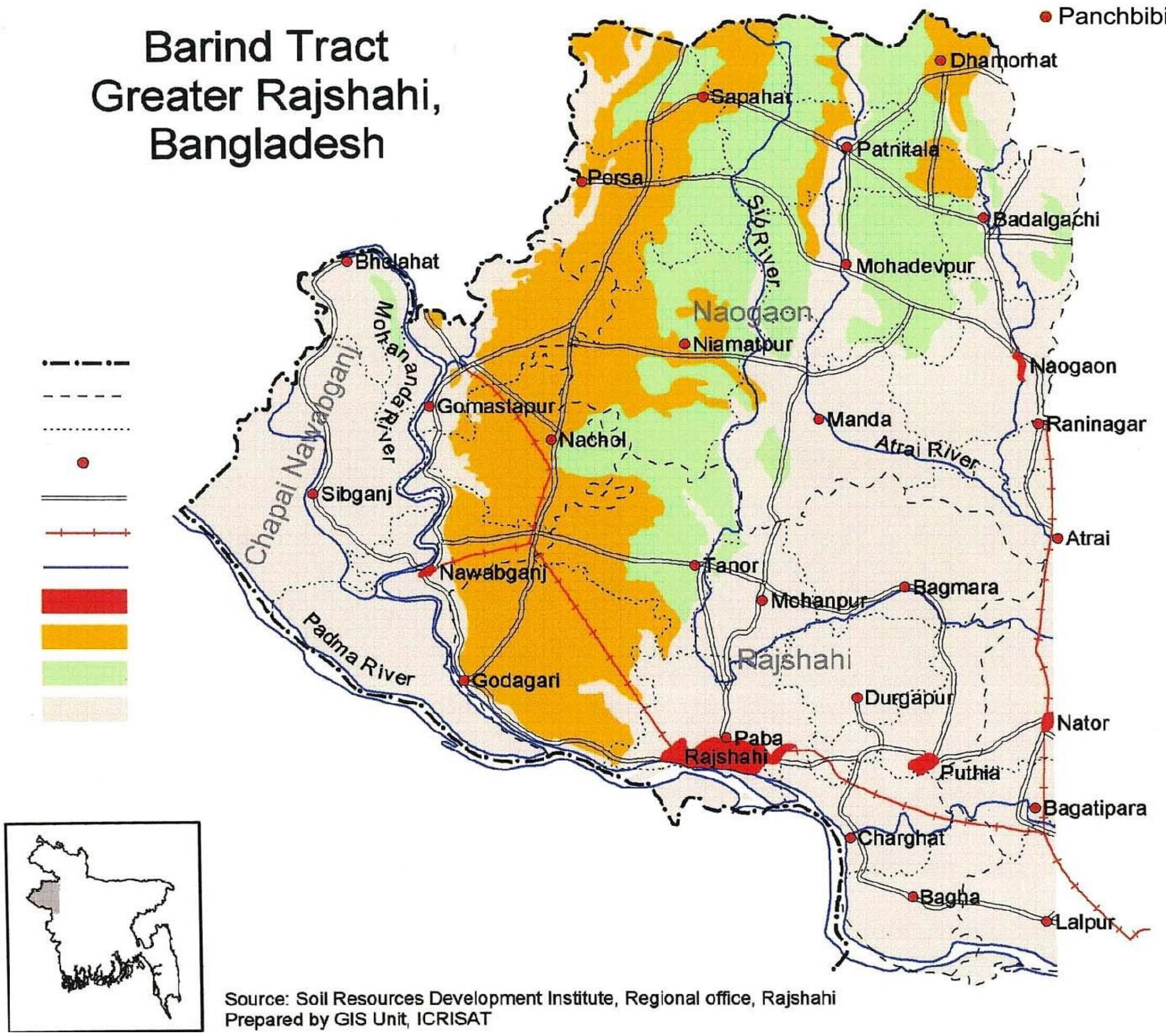


Figure 1.1. The High Barind Tract area of Bangladesh. Legend: red = urban area, orange = High Barind Tract, green = level Barind, cream = recent alluvial soil.

The current human population of the HBT relies predominantly on agriculture, mainly on the rainy season (monsoon) transplanted aman (t. aman) rice crop. The HBT can presently be divided into two parts, the major area of mainly northern HBT remains rainfed and covers about 55 % and the other 45 % of mainly southern HBT has irrigation facilities, mostly from deep tube wells, used predominantly for dry season (boro) rice cultivation. The northern parts have less ground water potential and there is little chance for them to come under irrigation in the future. The predominant cropping pattern of the rainfed area is a single crop of t. aman rice or t. aman followed by post-rainy season (rabi) crops such as chickpea, barley and linseed. These rabi crops are grown as mixtures or sole crops reliant on residual soil moisture and any winter rainfall. The irrigated area is dominated by a boro rice-t. aman rice cropping pattern. However, some area is under mustard-boro rice-t. aman rice, wheat-t. aman rice, t. aus (pre-monsoon) rice-tomato, boro-t. aman-watermelon/khira (cucumber)/onion/potato, or maize-potato/mung bean-t. aman rice.

Small areas in both the north and south HBT are partially irrigated from large ponds and khari (small natural water courses which hold water for several months after the monsoon). However, irrigation utilizing groundwater is creating increasing concern due to receding aquifers. To avoid drought due to uncertainty of rainfall and irrigation problems, the land use pattern is slowly changing. People are increasingly converting more rice land area to fruit gardens, mainly growing mango, ber (also known as jujube; *Ziziphus mauritiana*) and guava (*Psidium guajava*) as, once established, those gardens better ensure higher and more reliable economic benefit. Rearing of livestock like cattle, buffalo, goats, sheep and poultry remain integral parts of the farming systems of HBT farmers. Presently, increasing areas are being cultivated by two-wheel power tillers rather than with traditional bullock-drawn ploughing.

Over the last three decades, the Government has provided a network of bituminized roads in the HBT, considerably improving communication, marketing of agricultural products and other economic activities across the HBT. The tree population has also increased compared to 35 years ago through the Barind Multipurpose Development Authority (BMDA) roadside afforestation program, research and development activities by the Bangladesh Agricultural Research Institute (BARI), Department of Agricultural Extension (DAE), various non-government organizations (NGOs) and through farmers' interest and initiative. However, requirement of cooking fuel causes a major concern for sustainability of soil fertility because most cow dung and agricultural by-products, residual rice straw and tree loppings, are widely used as household fuel. After 35 years of research and development activities the HBT ecosystem and its agriculture still remain fragile with respect to long term sustainability and food security and is further threatened by climate change.

From the perspective of the present this study looks back to the beginnings of human influence on the then existing natural resource base of the HBT. It traces the successive changes wrought by humans leading to the present situation. With this knowledge we try to predict future trends and suggest measures that could avoid further degradation of the natural resource base while meeting human needs. We further suggest means of increasing ecosystem productivity in a sustainable way so as to improve the well-being of the human population of the HBT.

Chapter 2. The Original Resource Base

2.1 Geology and soils

The land form of the HBT developed during the Pleistocene age, the geological epoch which lasted from about 2.5 million to 11,700 years ago, and probably land formation in the Barind region ended around 10,000 years ago (Zakaria 2009). The 10-15 m thick surface layer of clay, or Madhupur Clay (Brammer 1996), and lack of alluvial characteristics in the deposits suggests that the area had developed under marine conditions. These marine sediments have since been uplifted, block faulted and eroded, resulting in present day terraced surface topography. The region has been tilted upward along its western edge gradually sloping towards the east. Its highest elevation in the western part is 40-50 m above sea level. The clay mineralogy of the HBT parent material and soils is dominated by illite and kaolinite, with a trace of montmorillonite (Brammer 1996).

Development of soils over the Madhapur Clay has largely occurred through ferrolysis (Brammer 1996). This process occurs with the alternate wetting and drying of topsoil, resulting in alternate cycles of reduction and oxidation. This removes cations and reduces the cation exchange capacity. On wetting ferrous ion is formed which displaces exchangeable cations. On re-oxidation after water recedes ferrous iron returns to the ferric form and hydrogen ions are released. The hydrogen ions attack clay minerals, reducing the clay content in the soil surface, releasing aluminium and acidifying the surface soil. Montmorillonite and part of the illite are destroyed during this process. Thus kaolinite becomes dominant, with illite contributing about 20 % and vermiculite 5-20 % of total clay minerals. The weatherable minerals range from 4-9 % in the eastern part to 8-14 % in the western part.

The soils of the HBT are described, by the Bangladesh Soil Resources Development Institute (SRDI), as Mainly Level Terrace soils or Closely Dissected Terrace soils. The SRDI soil map of Bangladesh can be found at The Bangladesh Network (2017). Brammer (1996) classifies these soils as either Shallow or Deep Grey Terrace Soils. He indicates that these soils are Eutric Planosols in the FAO Soil Classification and, in the USDA Soil Taxonomy, Shallow Grey Terrace Soils are Aeric Haplaquents and Deep Grey Shallow Soils are either Typic Albaquepts or Aeric Albaquepts. These soils have similar physical and chemical characteristics to those in the Madhapur Tract, located in the centre of Bangladesh, except that the latter soils have reddish coloration, rather than grey.

The texture of HBT soils ranges from silt loam to silty clay loam in the top soil (usually 0-20 cm), mainly silty clay loam or clay in the subsoil and the substratum is usually clayey (Brammer 1996). The substratum can be either partially weathered or unweathered Madhupur Clay and usually occurs at a depth of around 1 m. Top soil is not structured due to human interference. In the subsoil, the structure is moderately to strongly coarse and finely angular to sub-angular blocky. The peds are locally coated with fine clay, silt and humus. The substratum is partly structured or totally massive. The structural stability is weak and, as a result, the soils become soft and sticky in the rainy season and hard in the dry season.

Soil colour ranges from grey to mixed grey and brown, and locally pale brown to red brown (Brammer 1996). Locally, the color can be light grey or almost white indicating degraded soils (loss of clay, iron and aluminium). Soil porosity varies from layer to layer. The topsoil has 0.5-2 pores cm^{-2} compared to more than 2 pores cm^{-2} in the subsoil. Pores are usually fine or very fine causing HBT soils to be imperfectly drained with most poorly drained soils occurring in the deeper valleys. The HBT soil is highly compact hampering crop root penetration and soil moisture storage. Bulk density ranges from 1.4-1.7 g cm^3 compared to 1.2-1.3 g cm^3 in floodplain soils. The initial rate of permeability is within 2.5 cm per hour but after four hours of wetness this decreases in the grey terrace soils whereas it increases in the red brown soils. Permeability rate is higher below the ploughpan (at 10-15 cm soil depth) which indicates that the ploughpan reduces the infiltration rate. The high compactness of soil hampers root penetration of crops as well as water infiltration and soil moisture storage (Ali 2000).

The available soil moisture at the beginning of the rabi season (late October to early November) ranges from 150 to 200 mm m^{-1} soil depth (Joshua and Rahman 1983; Idris and Munirul Huq 1987; Hussain et al. 1991). Except for the highest and most steeply sloping areas, the valley sides have been terraced for paddy rice cultivation (FAO 1988), resulting in standing water in most fields during the monsoon period. However, as the HBT is not subject to inundation events as in floodplain areas, a relatively secure t. aman rice crop is ensured, unless the monsoon rains are abnormally low. The rice terraces are regularly leveled for ease of water and fertilizer management.

Because of low soil organic carbon content (<1 %), low cation exchange capacity (CEC; 10-15 meq/100 g soil) and low available nutrient content, soils in the HBT are considered as infertile to moderately fertile (Brammer 1996). Concentrations of soil organic carbon (SOC), phosphorus (P), potassium (K) and sulphur (S) are considered low and those of calcium (Ca), magnesium (Mg), zinc (Zn), boron (B) and molybdenum (Mo) low to medium (BARC 2005). Both physical and chemical properties are considered less than ideal for crop production or for woody vegetation (Hussain et al. 1991). It is likely that nutrient depletion and deterioration of physical properties will continue, as long as the present cropping system remains in practice, without increased recycling of crop residue and addition of organic amendments.

2.2 Climate

The recent climatic pattern is described here and historical changes in climate pattern and possible future changes are presented in Chapter 8, on ‘climate change scenarios’. The mean annual rainfall of Rajshahi city, located on floodplain soil just to the south of the HBT but with temperature and rainfall representative of the HBT, is 1,443±320 mm (36 years average and standard deviation)(Figure 2.1). The rainfall distribution pattern is unimodal peaking in July (Figure 2.2) and with 70-80 % precipitation during June to September. Usually, more than 200 mm rainfall occurs in each month from June to September. The annual and seasonal rainfall in the HBT are closely related because most of the rainfall comes during monsoon season. The annual mean rainfall of around 1,443 mm is only 400-450 mm higher than rainy season average (1050-1100 mm). However, there is a high degree of yearly and monthly variation in rainfall (Figures 2.3, 2.4 and 2.5).

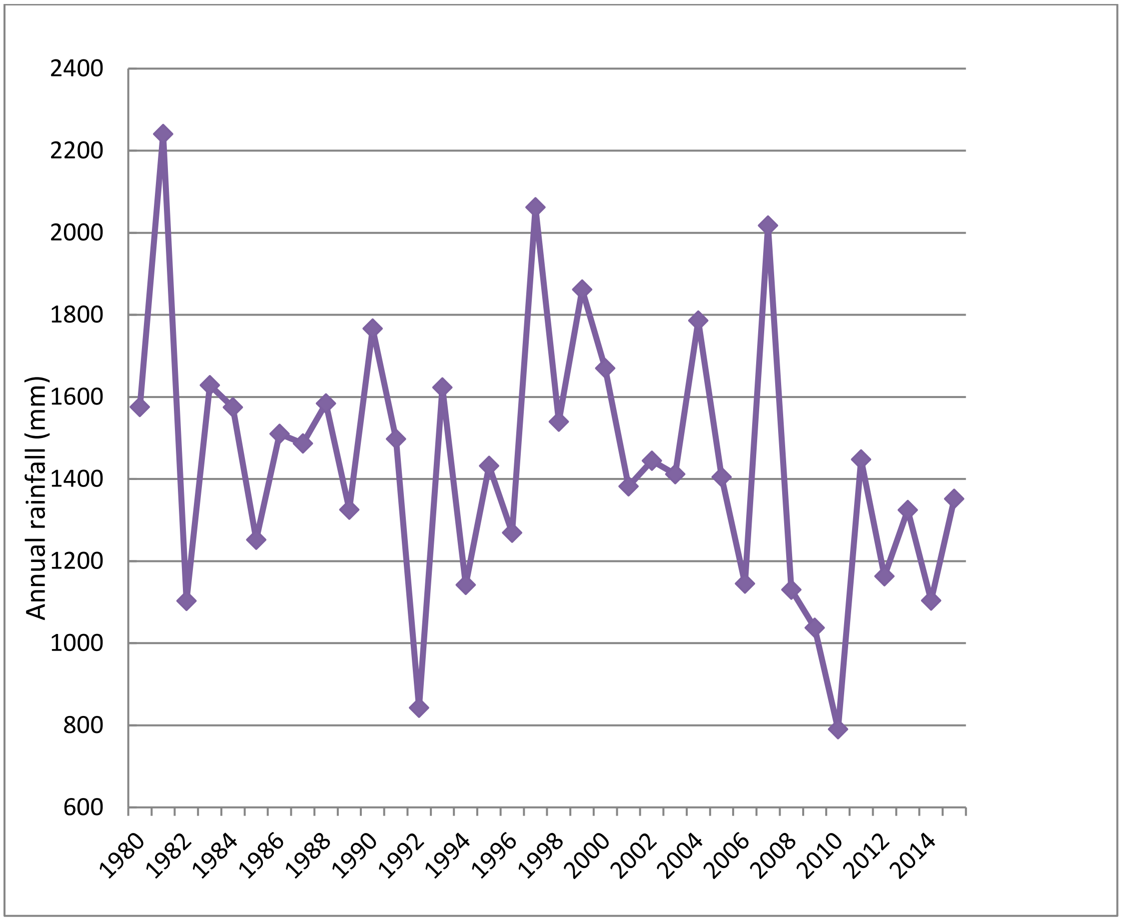


Figure 2.1. Thirty-six years (1980-2015) total rainfall of Rajshahi, Bangladesh (average 1,443 mm, standard deviation ±320 mm). Data source: Bangladesh Meteorological Department (BMD).

Over the period 1980-2015, there has been a declining trend in total rainfall at Rajshahi (Figure 2.5), consistent with climate change. Long term rainfall records for Rajshahi are not available but there is an indication of higher annual rainfall in the nineteenth century; Hunter (1876) reported total rainfall for Rajshahi to be 1,806 mm for 1871 and 1,536 mm for 1872.

Standard deviations (SD) are higher than mean rainfall during the entire rabi season, i.e. November to March (Figure 2.3), indicating unreliability of rainfall during this period. This creates uncertainty for rainfed rabi crop production. Over the 36-year period, rainfall was less than average in half of those years (Figure 2.4). Rainfall at more than 20 % below average would be expected in 15 % of years, resulting in drought conditions that would reduce crop yields, increase irrigation costs, restrict fishing options, limit water for household needs and generally adversely affect livelihoods. In one year, in 2010, it was 45 % less than the mean, resulting in severe drought for the t. aman crop. This caused failure of the rainfed t. aman crop, particularly in the northern HBT. Where irrigation was available, from deep tube wells (DTW) or ponds, production costs in providing that irrigation to t. aman were inevitably increased.

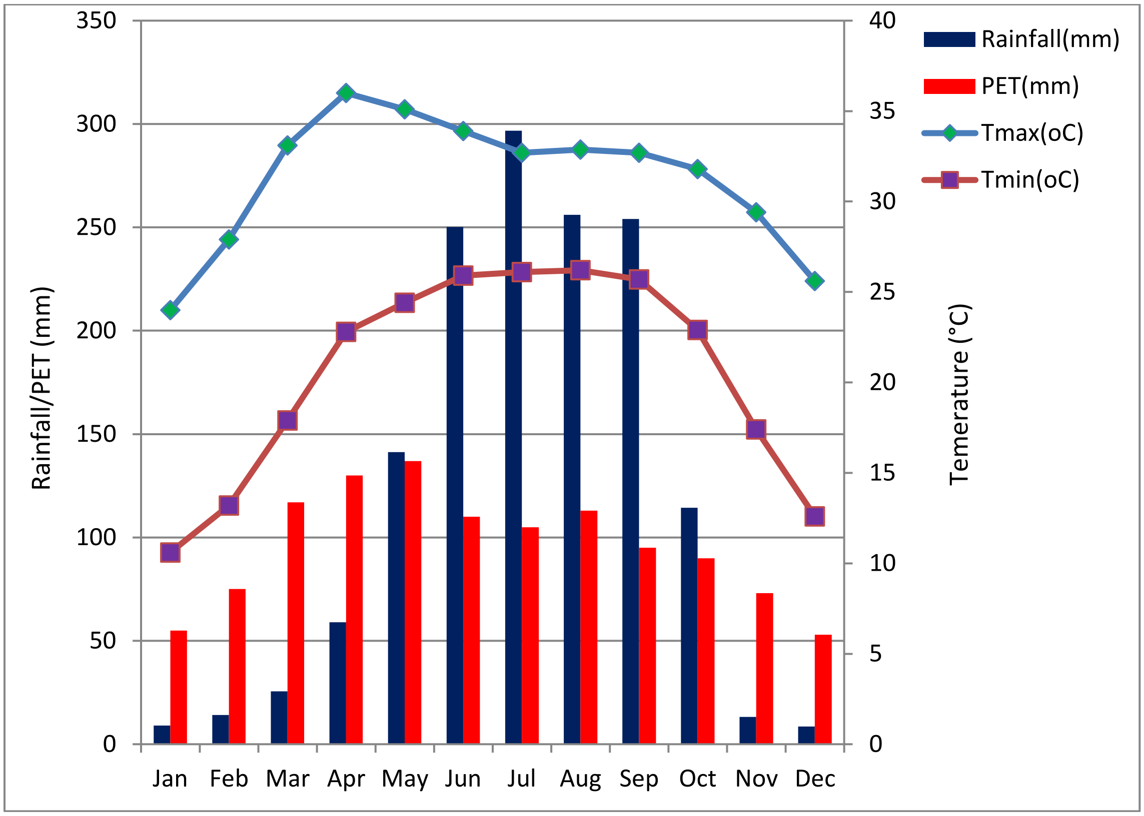


Figure 2.2. Thirty-six years (1980-2015) average monthly rainfall, maximum and minimum air temperature and potential evapotranspiration (Selvaraju et al. 2006) of Rajshahi, Bangladesh. Data source: BMD.

Rainfall in the northern HBT is considered to be comparatively lower than at Rajshahi, but reliable weather records over an extended period are not available for this region. Rainfall exceeds the potential evapotranspiration (PET) during June to October but is much lower than PET during November to April, and often in May also (Figure 2.2).

Droughts are more common in the HBT than elsewhere in Bangladesh, including during the rainy season (Shahid 2008; Shahid and Behrawan 2008). Probability analysis of rainfall (Selvaraju et al. 2006) indicates that chance of a dry spell exceeding five days is about 30-40 % in the first three months of the rainy season (June, July and August). The chance of it exceeding 10 days during the same period is only 10 %. The chances of extended dry spells increase from September. The dry spell length exceeds five to ten days in almost every year from October to December and it exceeds 20 days in about 20 % of years during October, when the t. aman crop is in the reproductive stage. In November, the dry spell length exceeds 25 days in 80 % of years, indicating the threat of terminal drought for long duration t. aman rice and of sub-optimal soil moisture for sowing of rainfed rabi crops. Thus short duration t. aman rice with reasonable yield potential could probably be a safer option for the HBT. Such varieties would also allow for timely seeding of rainfed or partially irrigated rabi crops like chickpea, lentil, wheat, barley, mustard, linseed, potato and maize.

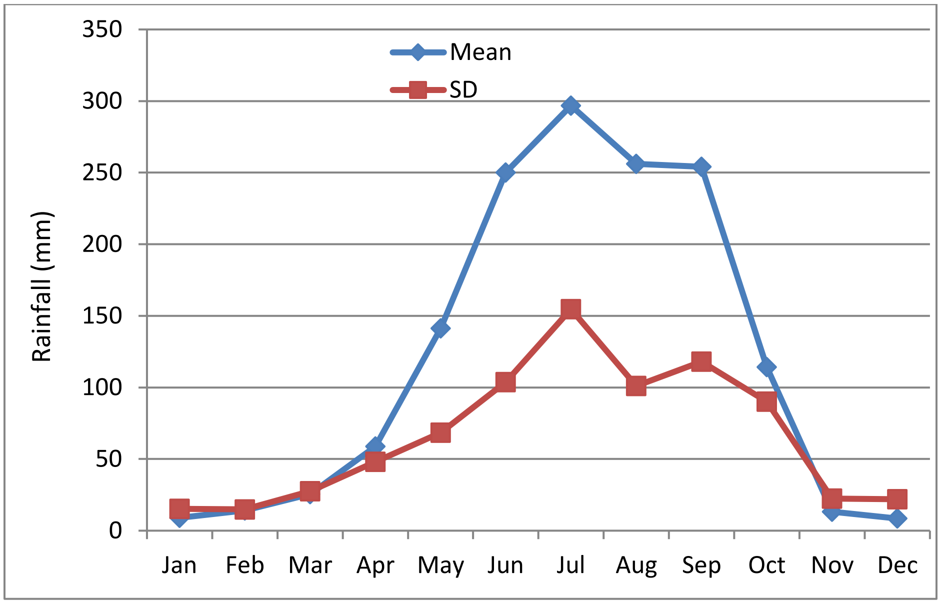


Figure 2.3. Thirty-six years (1980-2015) comparative mean monthly rainfall (mm) and its standard deviation, Rajshahi, Bangladesh. Data source: BMD.

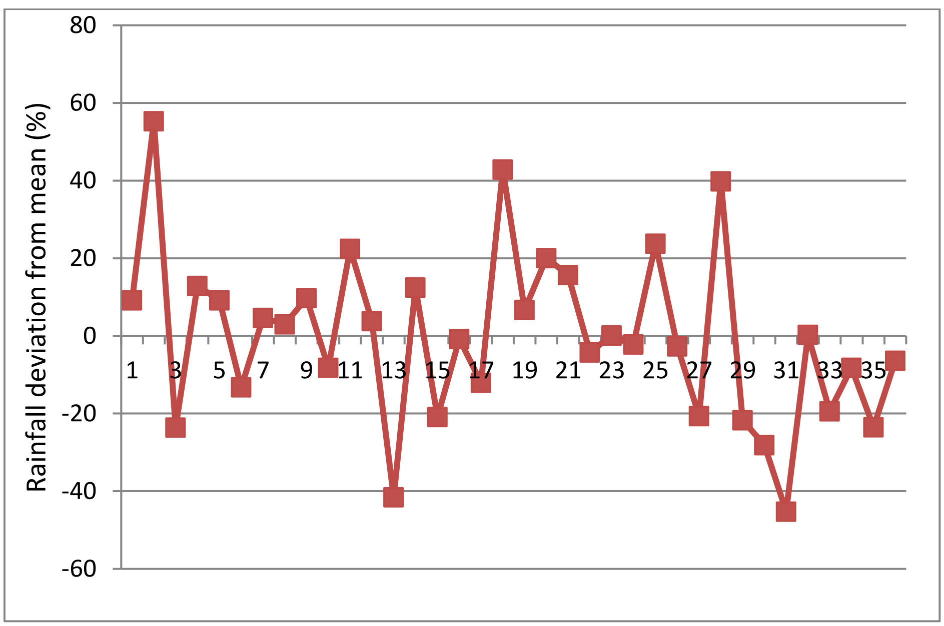


Figure 2.4. Annual rainfall deviation from mean (1,443 mm) for Rajshahi, Bangladesh (year from left to right – 1980-2015). Data source: BMD.

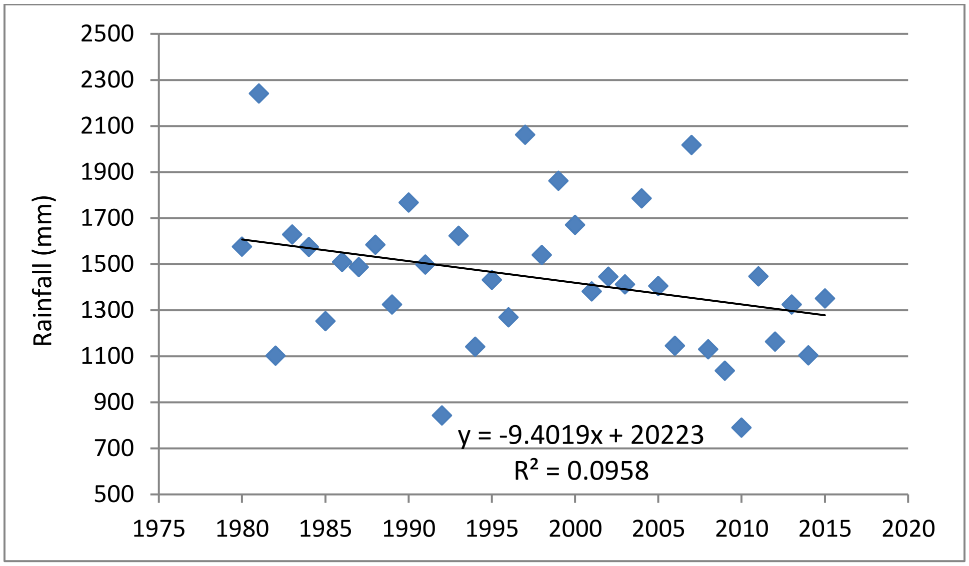


Figure 2.5. Relationship between year and total rainfall (1980-2015) for Rajshahi, Bangladesh. Data source: BMD.

Rainfall in February is particularly important for high value pulse crops in the HBT, as lentil normally ripens in February and chickpea flowers then. Low rainfall in February can cause drought stress but high rainfall can also be detrimental to pulses. When rainfall causes soil moisture to exceed field capacity (25 % soil moisture at 0-15 cm soil depth; Ali 2000), i.e. if more than 25 mm, it triggers diseases of lentil, chickpea and other pulses and deteriorates the quality of ripening pulse grain. This situation occurred in 10 of the years between 1980 and 2015 (Figure 2.6). But in most years February rainfall was <10 mm, particularly into the 21st century. Overall, for pulse crops, excess rabi season rainfall is more detrimental than low rainfall, as pulses are particularly adept at extracting stored soil moisture.

Average maximum temperatures at Rajshahi exceed 35 ^{o}C in April-May, with the highest maximum in April sometimes reaching 45 ^{o}C, whereas the lowest maximums are recorded in January, at <25 ^{o}C (Figure 2.7). Average minimums exceed 25 ^{o}C in the summer/monsoon season but reach near 10 ^{o}C in January, with the lowest temperature of 4.4 ^{o}C being recorded in January 2013 (Figure 2.8).

Comparing nine-year intervals of maximum temperatures at Rajshahi it is evident that the 2007-15 period was warmer than previous periods during the summer/monsoon season (Figure 2.7). March to November mean maximum temperature was 0.2-1.5 ^{o}C higher than in the previous period (1998-2006). There is an indication of higher minimum temperatures during the summer/monsoon season in the latest period also, but this is not so clear (Figure 2.8). Higher summer/monsoon temperatures would create more evaporative demand from crops and trees, exacerbating drought stress and increasing demand for irrigation. It would also cause more heat stress for farmers endangering their health and reducing their work efficiency.

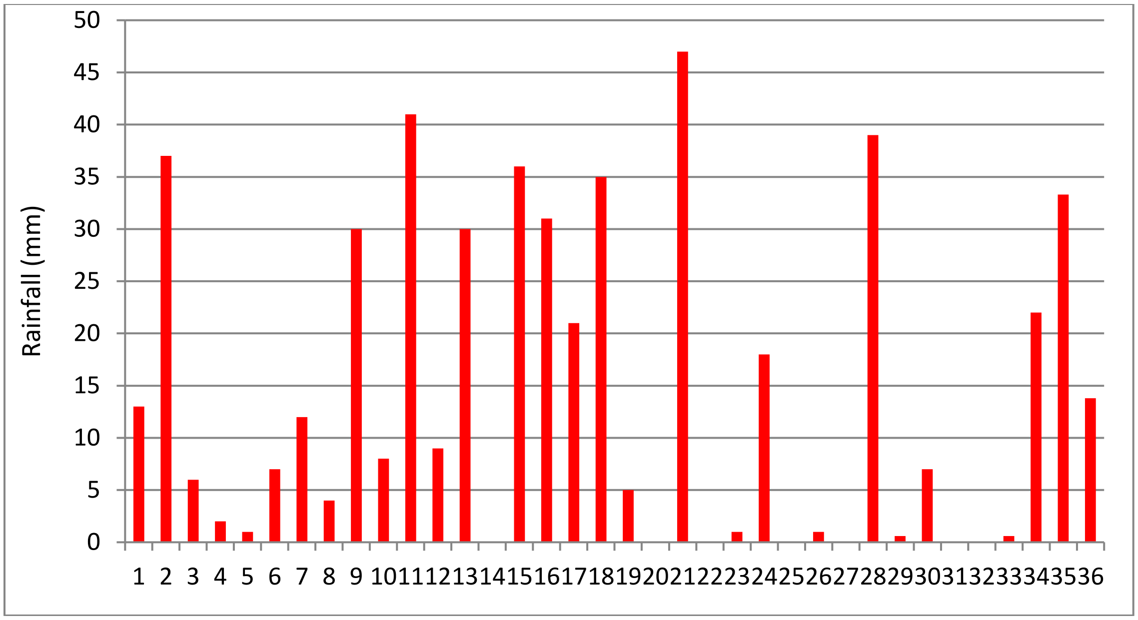


Figure 2.6. Thirty-six years (1980-2015) February rainfall of Rajshahi, Bangladesh (from left to right: 1980-2015). Data source: BMD.

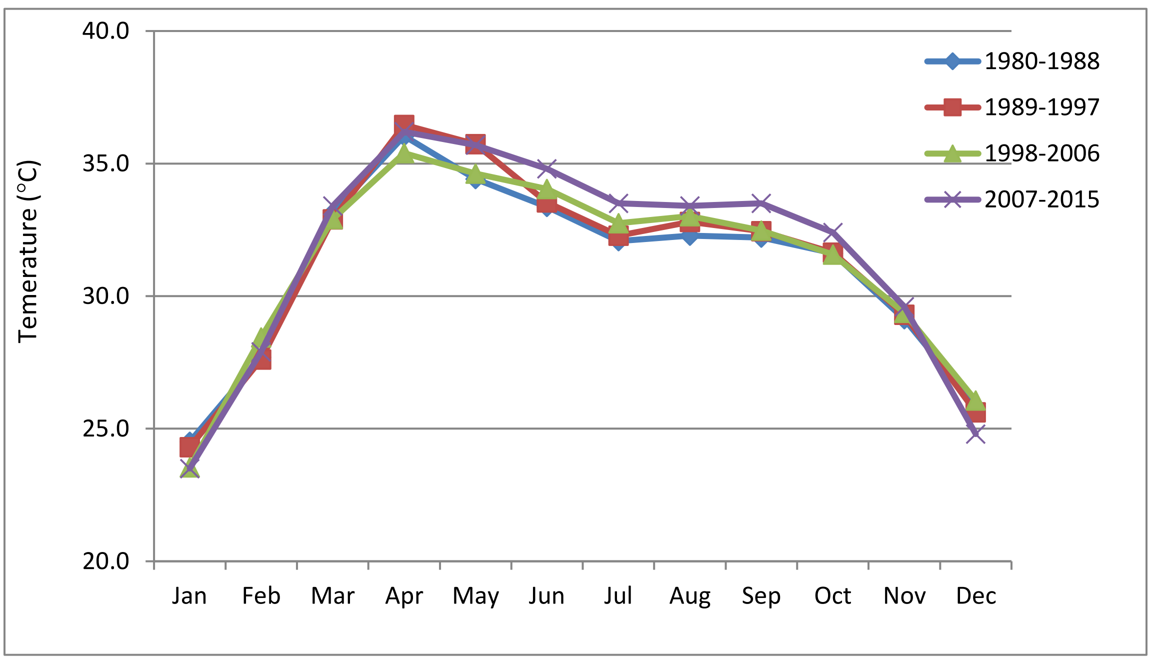


Figure 2.7. Average monthly maximum temperature (°C) of Rajshahi in nine-year intervals during 1980-2015. Data source: BMD.

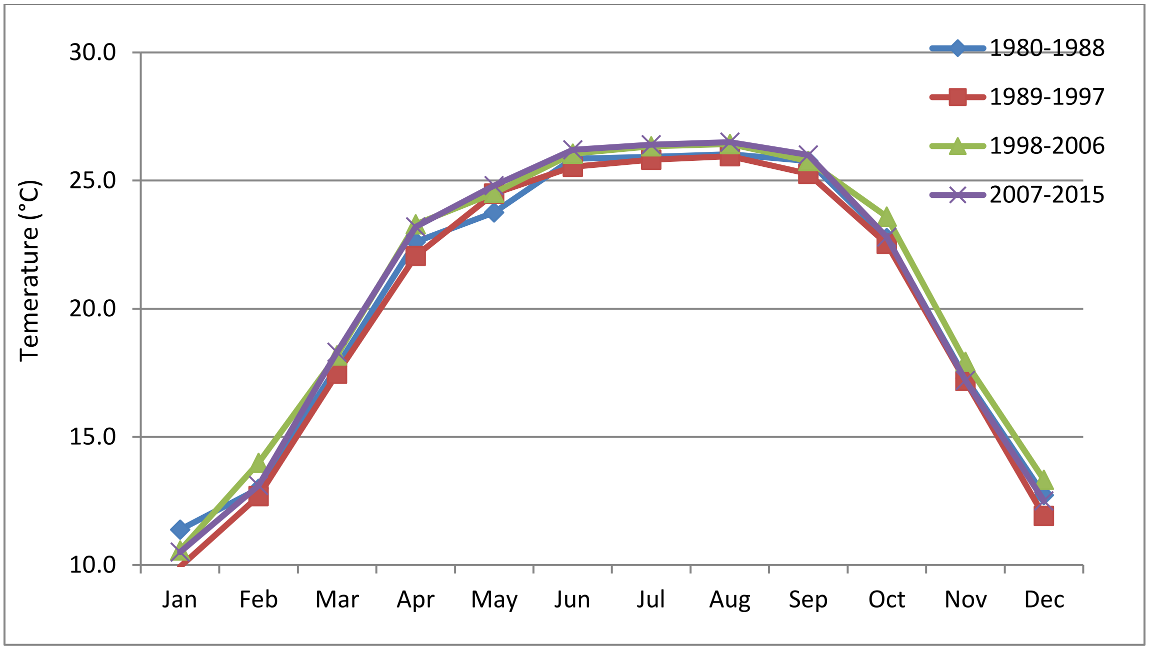


Figure 2.8. Average monthly minimum temperature (°C) of Rajshahi in nine-year intervals during 1980-2015. Data source: BMD.

The kharif (summer) and rabi (winter) growing periods are largely governed by rainfall distribution and temperature. The kharif growing period is 180-210 days while the rabi season prevails for 115-140 days (FAO 1988). Adequate rainfall is important for recharge of the groundwater level as well for long term sustainability of the environment for flora and fauna; however, crop performance largely depends on distribution and variability of the rainfall matching with the growth stages of the crop. Climate variability directly affects the agricultural systems and any consequent yield reduction thus affects the livelihoods of the 75-80 % of the HBT population that directly depends on agriculture and its related sectors.

2.3 Biodiversity

Hamid and Hunt (1987) have researched the original botanical history of the Barind region, mainly by examining documents from British colonial times. By the turn of the 19th century reports of the East India Company suggested that the Barind region was covered by thick, impenetrable jungle, as was much of interior Bengal then.

During the 19th century, reports on flora and fauna of the Barind region were mostly from the perspective of 'sports' hunting. The forest provided shelter for a wide range of mammals, reptiles and birds. Game animals included tigers, leopards, spotted-deer, mouse-deer, hog-deer, rabbits, wild hog, wild buffalo and nilgai (blue bull; *Boselaphus tragocamelus*). Other mammals included elephants, monkeys, porcupines (or sajaru; *Histrix indica*), pangolins (or bon rui; *Manis crassicaudata*), civets (*Viverricula indica*) and many species of bats (Khalequzzaman 2009). Birds included ducks, geese, water fowl, partridge, quail, kingfishers, various pigeons and vultures, among a large range of other big and small birds (Khalequzzaman 2009). Reptiles included snakes, crocodiles and tortoises. Hamid and Hunt (1987) report the writings of one such ‘sportsman’ hunter, Simson, who recorded that although these animals were abundant in the Barind forests hunting could only take place on the periphery as the jungles were essentially impenetrable. Tigers were reported to survive in the Barind region into the late 1890s.

Hamid and Hunt (1987) quoted a report from Simson in 1859 regarding the Barind region: “Here were large tracts of tree jungle, with palms, bamboos and all the common Bengal trees: at the foot of these trees shrubby, thorny jungle afforded the best cover for all game.” The local people called the area "Katal ban" (thorny jungle) as it was difficult to penetrate. Later, the British statistician Hunter (1876) described the HBT as “unbelievable” as it was covered by all types of trees. This mixed forest was apparently dominated by Sal trees (*Shorea robusta*) but with many other trees, shrubs, herbs and grasses. Sal can grow to heights of 35 m and is semi-deciduous, shedding leaves in the dry season of north Bengal (Figure 2.9). Among the thorny species probably common in the region since ancient times, fanimonosha (*Opuntia dillenii*) is still to be found in the HBT and is used for fencing. It is believed that up to 500 plant species were used for medicinal purpose in HBT area; most of them have been lost with forest clearing and change of ecosystems.

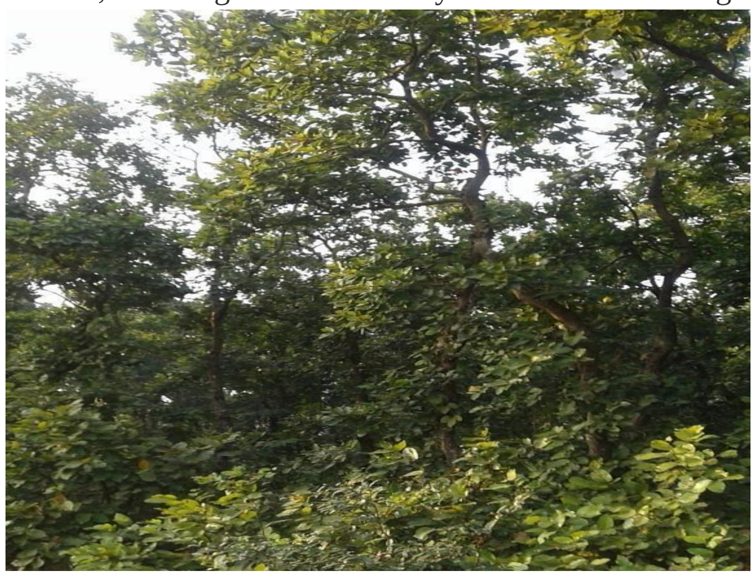


Figure 2.9. Sal forest typical of what once covered the Barind region. Photo: M Yusuf Ali

Although 19th century India was alive with natural history surveyors, botanists, etc., we can find no record detailing the botanical composition of the forests in the Barind region. Further we have no record of microscopic life forms, but can only speculate as to their infinite diversity and abundance. Nevertheless, the qualitative descriptions of forests and animals available at that time do suggest the Barind region supported a large biomass, with rapid turnover of organic matter in the relatively warm and moist climate.

Chapter 3. Human Occupation

3.1 Original civilizations

Stone Age tools dating back 20,000 years have been excavated in the Bengal region and remnants of Copper Age settlements date back 4,000 years (Bharadwaj 2003). There was clearer evidence of human settlement from around 1,000 BC, in the late Vedic period (Majumdar and Pusalkar 1951). A large and developed civilization was reported during the Morjo dynasty (200-300 BC). Civilization further developed in the vicinity of the HBT during the Gupta dynasty (300-600 AD). Stone plaques from this period indicated that rice was then regarded as the major food crop, as they recorded that the king exchanged rice seed with the tenants for cultivation in the next season when the crop was affected by drought (Majumdar and Pusalkar 1951). During the Pala dynasty (750-1,150 AD) the Barind civilization flourished and many Buddhist religious structures of burned brick were built along with big ponds for water supply (Chowdhury 1967). During the Sen Dynasty (1095-1200 AD), which was Hindu, the Buddhists were either killed or driven away and their religious structures destroyed, rendering the area barren and dilapidated (Zubari 2009). The British employee Renal was reported by Zubari (2009) to have, in 1771, found many destroyed buildings covered by jungle that were probably built during the Pala dynasty. This suggests that these early civilizations had made incursions into the existing jungle but that the jungle reclaimed the land when the civilizations declined.

A Mughal dynasty with a Muslim Sultan was established during 1205-1757 AD. It was a more or less social and religious equity based modern civilization, overriding the Hindu caste system. Then came British rule, from 1757 to 1947, and they ruthlessly changed the HBT ecosystems by indiscriminately destroying the forest to increase the area of cultivated land for the main purpose of revenue collection. To this end they enacted different types of legislation which was implemented mostly through Hindu landlords. With the partition of India in 1947 the British and Hindu landlords mostly abandoned the HBT and land assets were sold to absentee big farmers who generally lived in nearby towns.

3.2 Destruction of forest and terracing of land

Nelson (1923) described how successive increases in human habitation in and around the HBT increased the need to bring more land area under cultivation by clearing forest. However, there were pauses in this process, such as the great famine of 1770 which killed several hundred thousand people in Bengal and left the Barind region almost deserted. To perpetuate its rule and continue collection of revenue the British Government promulgated the Permanent Settlement Act of 1793 which resulted in most of the land coming under Hindu landlords and the peasants becoming landless. The peasant farmers cultivated the land with the requirement of paying high revenue to the landlord, who in turn was required to pay revenue to the British rulers (Misra 2009). Therefore, there was increased pressure to clear more land for rice cultivation, to meet revenue requirements.

Zuberi (2009) described that a British government Collectary report recorded that from 1795 the forest was slowly cleared for cultivation. From a Cadestral survey it was reported that within 1818-1856 almost half of the Barind region was brought under cultivation. Statistical reports of the land survey from 1849 indicated that forests covered about 55 %

of the Barind lands. But by 1874, about 70 % land of the region had been changed into cultivable land. The level areas were cleared first, and then the undulating HBT. At the end of 19th century only a few forest areas were left. Zuberi (2009) quoted a 1928 report by Carter indicating that within 1920-1928 most of the forest had been cleared and sloping land was terraced and leveled for rice cultivation, but there was still some mixed Sal forest present. Most of the cleared land was used for rice cultivation but a portion of it for indigo cultivation in the 19th century. By this process the entire HBT became shadeless with the appearance of a drought-prone desertified area during the dry season. Drinking water was scarce and it became difficult to move around in the summer due to the hot weather and lack of shade.

Land clearing and establishment of rainfed rice cultivation during British rule was done using the expertise of imported Santal laborers during the last quarter of the 19th century (Hamid and Hunt 1987). The Santals are a tribal group originally populating the region of Bihar in India (Jalil 1991). The British were unable to control Santal rebellions in West Bengal and Bihar. By pursuing a carrot and stick policy they dispersed the Santal to the Barind region to give them new land by clearing the jungle. The Santals were experts with axe and spade. The Malda collector described that as soon as the Santals cleared the jungle and then made the land fit for cultivation they sold these holdings to local cultivators and spent the proceeds in feasting and drinking; and then moved to clear new pieces of land. Later, through the Bengal Private Forest Act (1945) mostly Hindu landlords desperately felled and sold the remaining trees. After the partition of India, through legislation of state acquisition and tenancy act of 1950, Hindu landlords sold most of the remaining trees before they migrated to the new Republic of India. Thus 8,000 km^2 of forest in the Barind region was lost leaving only 0.2 % of tree covered area (Khalequzzaman 2009).

3.3 Towards desertification

During the period of British rule the landscape of the HBT was dramatically changed with almost all of the natural forest area indiscriminately destroyed for the purpose of cultivation without considering its environmental effects. Most of the original flora and fauna had disappeared by the time the British left in 1947. The whole ecosystem was changed, including creation of terraces on sloping land, primarily to grow t. aman rice during the monsoon season, mainly to increase revenue collection. This caused the HBT environment to have two distinct phases, i.e. greenish and moist during the monsoon period of June-October but harshly dry and resembling a desert landscape during November-May. The region became hotter and shadeless, and the soil less able to hold moisture. Run-off of rain water exceeded infiltration, causing erosion of surface soil and the nutrients therein.

In the 18th and 19th centuries, the river systems which were adjacent to the HBT, namely the Tista, Atrai, Koratoa, Punorvhoba and Mahananda rivers, replenished aquifers in the region. However, shifts in their courses of water flow had a large effect on HBT hydrology (Nisat and Khan 2009). This happened due to a major earthquake in 1812 and siltation at the mouth of the Atrai River caused by excessive silt carried from the Himalayan mountain range due to a major flood in 1820 (Rashid 1991). The Mahananda River shifted its course within West Bengal resulting in less flow of water in the north-western side of the HBT. Subsequently, on the western side of the HBT the Ganges (called “Padma” in Bangladesh) had a much reduced flow of water due to major withdrawal of water by India through the Farakka barrage from 1974, which has also hampered aquifer recharge.

Large dug ponds and water bodies became silted up and unable to hold water around the year. Sparse and erratic rainfall, sometimes with below average rain for 2-3 years continuously, and minimal winter precipitation caused the HBT to become more drought prone and desert-like in the summer months. This situation has been further exacerbated in recent times, since the 1970s, with the advent of deep tube well extraction of ground water for cultivation of boro rice This crop needs 3,000-5,000 L water kg^{-1} rice production in the dry season and the extraction of groundwater to meet this need has further reduced water table levels. Moreover, due to increase of population and development of urban areas demand for water has increased many-fold.

Loss of natural vegetation and incipient desertification in the HBT are interrelated, with four factors contributing to the decline. Firstly, the incidence of solar radiation per unit area of soil surface in the HBT is about the highest in the country (Datta et al. 2014). This increases soil temperatures, exacerbating soil drying and exposing seedlings to water and temperature stress. In the HBT, this is the case from November to June when there is little or no precipitation and minimal vegetation cover. Secondly, there is evidence that deforestation decreases rainfall (Los et al. 2006). Thirdly, the ongoing demand for fuel in the HBT mitigates against revegetation with trees, as any recently planted trees are prone to be pruned or cut for firewood. Further, the removal of rice stubble for fuel, building material or fodder purposes exposes bare soil by the hot summer period, from March. This amplifies the heating effects on the soil, causing feedback in further restricting growth of vegetation during the dry season. Fourthly, there is a social factor contributing to the desertification process. Large landowners, living away from the region, are often indifferent to land and livestock management, even against their best interests over a longer term. Their overriding interest is just the monsoon rice harvest. The collapse of vegetation, the derelict status of most ponds, kharis (natural canals) and khas land, and general neglect of the rabi season are related to this indifference (Hunt 1984).

There are also other consequences of the desertification process. The exposure of bare soil increases erosion, through wind during the hot summer period and through water during heavy pre-monsoon and early monsoon downpours. This reduces soil fertility due to removal of topsoil, which has the highest concentration of organic matter and plant nutrients. Irrespective of soil erosion losses, soil organic carbon is in any case lost as a result of deforestation. Wei et al. (2014) have reviewed the effects of converting forests to agricultural land in reducing soil organic carbon levels and have confirmed it to be a global phenomenon. Although we have no specific data for confirmation, we can assume that this process also occurred with deforestation of the Barind region. Wei et al. (2014) estimated a mean 41 % decrease in soil organic carbon (SOC) stocks in tropical regions. Of course, SOC is important in maintaining soil physical structure, binding plant nutrients and supporting a healthy soil microbial population. Its decrease inevitably results in reduced ability of the soil to support plant growth. Although we cannot find information on decline in rice yield over time since deforestation in the HBT, some data from last century suggest this trend. Hamid and Hunt (1987) report rice yields in Rajshahi District to be 1.75 t ha^{-1}

in 1939-40, but they were only 1.2 t ha^{-1} in 1980-81 and 1981-82. Thereafter, rice yields rose again, to >2 t ha^{-1}, due mainly to increased use of fertilizers, irrigation and improved varieties.

3.4 Recent human populations

Around 3 million people live in the region of the HBT. Table 3.1 gives population data, from the 2011 Bangladesh census, of the upazilas (sub-districts) covering the HBT (as shown in Figure 1.1) and including some adjacent level Barind and also some alluvial soil area within those upazilas. The total area covered is about 4,000 km^2. There are around 700,000 households in this region, which means that there are on average 4-5 persons per household, and 82 % of the population lives in rural areas, with the remainder in urban areas (Table 3.1). Across these upazilas in 2011, 60-67 % of the population was over the age of 18 years and literacy rates (for those over 7 years of age) were 40-69 % for males and 41-62 % for females (Bangladesh Bureau of Statistics, 2014). The rural population lives predominantly in village clusters, comprising 20-50 households, and some in small roadside towns. Village housing is mainly of mud wall and straw roof construction (kutcha), but with a gradual increase over time in pucca (brick or concrete wall with corrugated iron, tile or concrete roofing), or semi-pucca, buildings. In urban areas buildings are predominantly pucca. A majority of buildings are owner occupied, rather than rented.

Table 3.1. Households and population in upazilas covering the HBT and adjacent level Barind according to the 2011 Bangladesh census. Some upazilas also include portions of alluvial soil areas: see Figure 1.1. Source: Bangladesh Bureau of Statistics, 2014.

District	**Upazila**	**Area (ha)**	**No. of households**		**Population**	
			Total	**Rural**	**Total**	**Rural**
Rajshahi	Godagari	47,527	72,186	59,077	330,924	269,748
	Tanor	29,541	47,425	34,561	191,330	137,911
Chapai Nawabganj	Nawabganj	45,180	112,748	73,326	530,592	349,861
	Nachole	28,368	32,922	29,142	146,627	129,263
	Gomostapur	31,814	62,938	49,939	275,823	217,199
Naogaon	Niamatpur	44,911	61,811	60,276	248,351	242,398
	Porsa	25,284	30,773	28,250	132,095	119,677
	Sapahar	24,449	36,232	33,308	161,792	149,096
	Patnitola	38,240	58,661	53,346	231,900	210,230
	Dhamorhat	30,081	49,046	44,511	184,778	166,961
Joypurhat	Joypurhat	23,680	76,385	59,542	289,058	220,025
	Panchbibi	31,178	60,983	55,473	235,568	213,093
TOTAL		*400,251*	*702,110*	*580,751*	*2,958,838*	*2,425,462*

Like much of Bangladesh, the agricultural land tenure system comprises a mixture of absentee landlords with large holdings, owner cultivators, owner-cum tenants and a landless labour class. In their survey of 1985, Hamid and Hunt (1987) catagorized land tenure in the Barind region as follows:

a. Landless – no formal land ownership rights but just occupation of a homestead
b. Small farmer – owns up to 1 ha
c. Middle farmer – owns 1-3 ha
d. Large farmer – owns >3 ha.

In a detailed survey of Nachole, assessed as representative of the HBT, Hamid and Hunt (1987) found that the household ratio of a:b:c:d was 43:39:31:6. In the level Barind, as represented by Patnitola, however, the ratio was 26:58:24:11, suggesting a greater proportion of owner operated land in this region. We do not have any more recent data in this regard but observation suggests there would be an increasing proportion of large land holdings in the HBT over time.

Share cropping is a common feature of the Barind region, whereby larger landholders lease out part or all of their holdings, usually to landless or small farmers. Various forms of sharecropping arrangements apply. The land owners rarely supply inputs, apart from sometimes certain proportions of seed; thus tenant farmers usually decide on input levels, which are often well below optimum levels due to their limited capital available to purchase them. The harvest is shared in either proportions agreed-to beforehand or on the basis of a fixed amount going to the landlord, irrespective of seasonal yield. In the latter case, the tenant suffers most in drought or otherwise low-yield seasons. In addition to grain, there is also a sharing of the straw, which results in its almost complete removal from the field for animal feed, fuel or building material. In this system there is little incentive for either the landlord or the tenant to consider the longer-term sustainability of the production system, such as through build-up of soil organic matter, but just to get the maximum return on a year-to-year basis.

The large landholders are usually absentee landlords, who live in regional towns or cities. In Nachole in 1985 it was estimated that 80 % of land belonged to absentee landlords who lived mainly in Chapai Nawabganj or Sibganj (Hamid and Hunt 1987). They rely on the regular income derived from the usually reliable rainy season rice crop but have limited contact with the production system. They are therefore reluctant to partake of innovations to the traditional production system, that may pose a risk to the reliable income from traditional rainy season rice. Thus they are reluctant to try new rice cropping techniques (varieties, agronomy), undertake rabi cropping or consider long-term sustainability of the soil resource. They are also reluctant to see changes to social organization, which technological innovation can bring, as this could jeopardize the traditionally cheap labour and compliant workforce. Essentially this is a continuation of the traditional zamindari system predominant in the Barind region in British colonial times. Large land holdings were under the control of mainly Hindu landlords, who leased their land to tenant farmers primarily for rice production, the basis for revenue collection of the zamindars and, in turn, the colonial authority. This system entrenched social inequity and was not conducive to long-term sustainability of the land resource – it was essentially an annual mining the landscape.

The landless are occupied mainly as agricultural labourers, as sharecroppers or in other labouring jobs such as in public works or menial work in towns and cities. They usually live on a day-to-day subsistence basis. There is an increasing trend for larger farmers to also become involved in agricultural business enterprises, such as retail of agricultural inputs (seeds, fertilizers, agro-chemicals, etc.). Due to the larger farm size in the HBT, and the large proportion of absentee landholders, at busy times of the year, such as transplanting and harvest of rice, labour scarcity is a problem. It is therefore necessary to bring in labour from other parts of the country. Thus, contracts between landholders and organized labour gangs are common.

Chapter 4. Traditional Rainfed Rice Farming

Transplanted rainfed monsoon season rice (t. aman) has been the traditional main crop of the HBT and level Barind, as for most upland areas of Bangladesh. It has underpinned the economy of the region since ancient times to become a major source of revenue during the British colonial era. During that time the clearing of natural forest was for the prime purpose of establishing rice farming, so as to generate revenue for the colonial coffers via the zamindari system. The Bengal famine of the early 1940's exacerbated the need for increased rice production and prompted clearing of remaining forest area in the HBT. The method of t. aman cultivation has changed little over centuries and traditional methods are still largely practised to this day. The main changes in recent times have been use of improved rice cultivars, application of chemical fertilizers and other agrochemicals and the beginnings of mechanization.

In the HBT, longer duration rice varieties (harvested 140-170 days from sowing) are still grown, the most common one in recent years being Swarna. However, some farmers also grow BRRIdhan 33, 39, IR-50, some short duration varieties derived from Nepal and some fine rice. For rainfed t. aman, sowing of seed into the seed bed and transplanting of seedlings depends upon the vagaries of the onset of monsoon rain. Generally, seeds are sown in seed beds during June. The soil of the seed bed was traditionally thoroughly tilled though bullock cultivation, or by hoe for small areas, under saturated soil conditions. However, bullock cultivation has in recent years been largely replaced by tillage with power tillers (see Chapter 6.2). If pre-monsoon or early monsoon rain is insufficient then water from ponds or other nearby water sources is applied to saturate the soil. If the seedbed area is not already known to be fertile a small amount of farmyard manure, usually comprising mainly mulched cow dung, is applied, and more recently inorganic fertilizer, mainly urea. The seed bed area is levelled by laddering (drawing a wooden bar across the surface) with a film of standing water left on the surface. Before sowing seeds are soaked for 24 hours, in a jute sack or similar, to initiate germination. The germinated seeds are then hand broadcast on the prepared seed bed at the rate of 80-100 g seed per m^2 bed (BRRI 2016). About 26 kg seed is required for transplanting in 1 ha land. The water level of the seed bed is maintained at 1-5 cm, by adding water if rainfall is insufficient and by drainage if rainfall is in excess. In recent times, if the seedlings become yellowish then the practice is to apply 6 g urea and 9 g gypsum per 1 m^2 of seed bed.

Main preparation of fields begins after receiving enough monsoon rainfall in July-August. Fields are enclosed by bunds 20-30 cm high and are usually approximately 1 bigha in area (1 bigha = 1,337 m^2; 1 ha = 7.5 bigha). Two or three ploughings, traditionally by bullock mould board plough, but now increasingly by rotary power-tiller, are given with 5-10 cm standing water within the bunded plot. Before the last ploughing different fertilizers are applied at various rates depending on soil fertility and rice cultivar. In general, 45-60 kg urea, 52-105 kg triple super phosphate, 60-120 kg muriate of potash, 30-45 kg gypsum and 3.5 kg zinc sulphate fertilizers per hectare are recommended. However, apart from urea, farmers often apply less inorganic fertilizer than recommended to reduce production cost; resource poor farmers simply cannot afford the investment. These fertilizers are hand broadcast and thoroughly mixed in the soil with ploughing. Traditionally, before 50 years ago, only farmyard manure was applied as fertilizer. Very little of this is applied currently due to the use of cow dung and other organic manure components for other purposes, mainly fuel for cooking. After the final ploughing the soil is laddered such that the soil is evenly covered with a small amount of standing water.

Rice seedlings from seed beds are transplanted at 30-40 days after germination, within July-August depending on rainfall. Seedlings are transplanted into 1-2 cm standing water. In a hill, 2-3 seedlings are planted at 20 cm line to line and 15 cm hill to hill spacing (Figure 4.1). If transplanting is late farmers increase the number of seedlings per hill to 4-5 to compensate less tillering. Urea fertilizer is top-dressed in standing crops at 15-20 and 30-40 days after transplanting at the rate of 45-60 kg ha^{-1}. To increase the efficacy of this applied fertilizer it is mixed with the soil. Before or at the time of applying urea weeding is done to remove those weeds surviving the flooded condition.

Figure 4.1. Traditional t. aman rice cultivation. Puddled land ready for transplanting is in the foreground and transplanting is underway in the background. Field bunds are maintained to retain standing water.

Insects have traditionally been controlled by setting perches across the field to encourage predator birds. However, recently the use of insecticides, light traps or hand sweeping nets has become more common. For control of different diseases cultural methods and fungicides are used. For example, to control rice blast disease (*Magnaporthe oryzae*) a combination of recommended fungicides and maintenance of adequate hill spacing is used. The t. aman crop in the HBT generally depends on seasonal rainfall, but during dry periods in the monsoon season farmers apply irrigation where there is a source of water such as deep tube wells, ponds or kharis. However, much of the HBT, especially northern areas, is devoid of any irrigation options during the monsoon season when drought periods occur.

Rice is harvested manually, with hand sickles, during late October to early December, depending on cultivar duration. Farmers generally dry the harvested rice crop in the field before transporting to a homestead yard. This is a labour intensive period, making it difficult for farmers to consider planting of rabi crops at this time. The dried rice sheaves were originally threshed by beating on drums or by bullock trampling but threshing is now increasingly done by pedal or power thresher. The released grain is then manually winnowed and stored in hessian sacks or drums for local consumption or sale. Farmers also keep their own seed of the varieties they would intend to plant in the next season. Current rice yields vary in the range 2-4 t ha^{-1}, with time of transplanting and rainfall status during the season being the major determinants of yield.

Taking advantage of pre-monsoon rains, another type of traditional rice cultivation is also practiced in the HBT, but to a decreasing extent due to its low productivity. This is broadcast aus rice (b. aus). Land is cultivated and seed broadcast at the onset of pre-monsoon rains in April. Traditional varieties, selected by farmers to be better adapted to pre-monsoon sowing and broadcasting, but of low yield potential, are used. Little if any fertilizer is applied and rigorous hand weeding is required until the field floods as rainfall increases. However, seedling growth rate is rapid in the hot pre-monsoon period, if rainfall is adequate in this period. The crop is harvested around August, however, being in the midst of the rainy season, there is a hazard of grain sprouting or rotting, contributing to low yield. Yield of b. aus in the HBT rarely exceeds 1 t ha^{-1}.

After the harvest of t. aman rice, if there is sufficient soil moisture remaining, farmers have traditionally sown mixtures of local varieties of crops like barley (*Hordeum vulgare* L.), mustard (*Brassica campestris* L.), linseed (*Linum usitatissimum*) and chickpea (*Cicer arietinum* L.). The field is initially ploughed, seed and fertilizer (but rarely) hand broadcast, and the field again ploughed and laddered. The crops are grown on residual soil moisture, or aided by any rare winter rainfall events. Little further crop management is provided and yields are inevitably low. Ability of these crops to grow on residual soil moisture in the HBT depends very much on their rooting characteristics (Box 4.1).

Box 4.1. Root traits of rabi crops in the HBT

A study comparing root characteristics of barley, mustard, linseed, chickpea, lentil (*Lens culinaris* Medic.) and wheat (*Triticum aestivum* L.) was conducted in farmer's fields of the HBT during the 2000-01 and 2001-02 rabi seasons (Ali et al. 2007a). Grain yield of all crops increased as total root length increased above a threshold value of 0.05 to 0.1 km m^{-2}. Chickpea and barley were the highest yielders whereas lentil yielded lowest. Ability to send roots below 60 cm soil depth was another trait determining yield potential. This is particularly important in this soil of high bulk density, which impedes root penetration. Barley had an additionally useful trait in that its roots were relatively numerous and fine, resulting in a higher root length density and thus allowing it to access more water and nutrients per unit volume of soil. Although the above-mentioned trends were the same, actual root production and yields differed markedly between the two seasons of the study. This illustrated the overriding effect of local soil conditions, particularly the amount of residual soil moisture, on crop performance; and thus the degree of risk involved in cultivating rabi crops in the region. Logically, to minimize risk, farmers should favour deep and prolific rooting crops. However, farmers choose their rabi crops, whether to be grown as sole crops or in mixtures, based on household requirement and expected profitability. In this particular study, chickpea had by far the highest profitability, undoubtedly contributed to by its deep rooting ability. However, despite its deep rooting and high root length density profitability of barley was low due to its low relative grain price.

Chapter 5. The Age of Irrigation

There has been localized small-scale surface irrigation in the HBT and level Barind since ancient times. Small and large excavated ponds date back to the Morjo, Pala, Sen and Mughal dynasties. The zamindars created particularly large ponds. These ponds were used as a year-round water source for all purposes, including irrigation. They were particularly used for supplementary irrigation of t. aman rice during dry periods of the monsoon season, but also for irrigating high value crops such as vegetables and fruits in the post-rainy season. The capacity of these ponds probably set the limits for population growth from ancient times up to the end of the British period. Until then the people relied on manual methods of raising the water from the ponds to irrigation channels.

5.1 Water resources

The main source of water for the HBT is rainfall. As elaborated in Chapter 2.2, the annual rainfall is around 1,400-1,500 mm, which is quite substantial when compared with most agricultural regions of the world. However, there are no large river systems in the HBT, to retain rainwater or bring it in from elsewhere, and there is substantial runoff from the HBT towards the east. The groundwater potential of the HBT is generally much lower than other parts of Bangladesh, especially floodplain areas. Water bodies, that can hold water year-round, are limited to excavated ponds and kharis (small natural water channels that can be dammed), but these can only be used for irrigating small localized areas. Rainfall is captured in the ubiquitous bunded and terraced fields but infiltration is low and with heavy rainfall events water overflows from fields into kharis and, ultimately, flows out of the HBT.

A GIS and remote sensing study showed that about 85 % area of the HBT has low recharge potential and the remaining 15 % only moderate recharge potential (Adham et al. 2010). They estimated that only 8.6 % of the total precipitated water ($1{,}136\times10^{6}$ m^{3} $year^{-1}$) infiltrates downward to recharge the groundwater reservoirs, while the rest is lost either as evapotranspiration or surface runoff. However, there is large variation in estimation of groundwater infiltration/recharge rate among Barind Multipurpose Development Authority (BMDA) and other researchers. BMDA has estimated groundwater recharge in the area to be at least one-third of the annual rainfall, that is about 500 mm $year^{-1}$ (Asaduzzaman and Rushton 2006). Using a water balance study and aquifer simulation modeling Islam and Kanungoe (2005) estimated the long-term annual average recharge as 152.7 mm. A government report suggests that recharge to groundwater in the northwestern part varies from 210 to 445 mm. However, exploitation of groundwater in the area is proceeding on the basis of one-third rainfall recharge hypothesis of BMDA which is well beyond the sustainable amount according to Islam and Kanungoe (2005).

The overexploitation has caused the ground water level to decline to the extent of not being fully replenished in the recharge season. The groundwater-based irrigation system in the area has reached a critical phase as the phreatic water level has dropped below shallow wells in many places. A groundwater zoning map shows that a record high of 60 % irrigated croplands in Naogaon and 10 % in Rajshahi and Chapai Nawabganj districts have become critical for shallow tube well operation (BADC 2005). About 42 % area of HBT faces groundwater scarcity during the dry season for boro rice farming (Shahid and Hazarika 2010). Thus groundwater potential for irrigation of the HBT is yet to be estimated with reasonable precision. Moreover, in recent years rainfall in the HBT has been trending downwards (see Chapters 2.2 and 8), further reducing the potential for groundwater recharge. Our anecdotal evidence also supports the gradual reduction of aquifer capacity in older-established irrigated areas (Table 8.2). Thus there is increasing difficulty in meeting the irrigation requirement of boro rice production.

Traditionally, the HBT region has had a large number of ponds, with some of them quite large (khas ponds). It is estimated that there are about 70,000 ponds, from small to large, but most of these are derelict and become dry in summer months (February through May). This creates a severe water crisis for meeting household needs, bathing and livestock management. Nevertheless, such partially silted ponds can be used in the kharif and early rabi seasons for general household purposes and limited supplementary irrigation. Due to this scarcity of water in the HBT water has attained considerable commercial value. A deep pond of about 0.5 ha can be leased in the rabi season, to grow high value crops like vegetables and watermelon, for 60-80 thousand taka. Due to the retreat of the water table in summer months most of the hand-pump wells, usually near ponds, also dry up. People living in the northern HBT have been most affected by such problems, increasingly so in recent times.

The biological quality of water of most of the ponds is extremely poor due to unsanitary practices. Some traditional ponds are chemically and biochemically contaminated from aquaculture. The poor quality of surface water in the dry season (November to May) constrains development of dependable small- and large-scale surface water treatment plants for water supply. Therefore, groundwater is the most important source of water supply for the HBT. Groundwater is almost fully recharged between July and October in normal rainfall years but begins to recede in October. The rate of fall is highest in October and November but equally large changes may take place after January when withdrawal of groundwater through deep tube wells for irrigation begins. During the dry season most of the minor and major rivers adjacent to the HBT are also depleted due to large upstream withdrawal, siltation and the huge demand for irrigating boro rice. The depth of aquifers varies from zero to 54 m below ground surface. The continuous pumping of groundwater for boro rice leads to over exploitation during drought years. Using traditional practices, the boro rice crop needs as much as 3,000-5,000 L of water per kg grain production.

Groundwater in the region is mostly extracted from depths below 60 m in either the alluvial sediments or, in the east, from the aquifer confined beneath the Barind clay. The aquifer is mostly stratified and formed by alluvial deposits of sand and silt with occasional clay. The main constituent of the aquifer materials is the medium-grained sand deposited at the lower reach of the Padma (Ganges) River. In this case, a shallow aquifer, considered as the main aquifer lies within 150 m of the surface with an overlying clay/silt blanket less than 2 m thick. In the shallow aquifer, groundwater flows from north to south with localized outflows into the major rivers. Although the aquifer has high transmissibility, the horizontal flow of groundwater is very slow because of low groundwater gradient. Though aquifer characteristics are uniform throughout the Barind Tract, the total water availability in the HBT is limited and hence in many villages it was not possible to install deep tube wells. These villages are mostly in northern HBT and are predominantly rainfed and thus face frequent drought due to high rainfall variability. Moreover, the sediments in the top 26 m of the profile have been radiocarbon dated at 5,000 years old. The surface is thought to be the top erosion surface of the Barind clay and underlying sediments are therefore considered much older Barind sediments. These geological properties in the Barind Tract pose multiple problems related to water-holding capacity and recurring drought (Brammer 2000). A few hand-dug wells are present in the region, extending to around 10 m depth, but these have been largely superseded by hand-pump tube wells. In recent years, over exploitation has led to rapid fall in the groundwater table (Selvaraju et al. 2006). Future climate change coupled with socio-economic development with population pressure may further aggravate the situation. However, other researchers find mixed situations. Two major tube well irrigation blocks covering a large area showed positive maintenance and recharging of the aquifer in the monsoon season but in two smaller old blocks in the western HBT, the aquifer is drastically decreasing in the dry season due to massive uplifting of groundwater creating much concern among farmers and the BMDA authority (Jahan et al. 2004).

Thus promotion of optimal use of both groundwater and surface water with practices of appropriate application levels with greater use of lesser water requiring cropping systems is of increasing importance. Availability of groundwater is a very pertinent question and it is necessary to know more precisely the rate of groundwater recharge and at what level extraction exceeds recharge for a particular area. Indiscriminate proliferation of deep tube wells has had detrimental effects on the failure of hand tube wells used for drinking water and household purposes, soil moisture availability and much needed afforestation programs in the HBT.

5.2 Expansion of deep tube well irrigation

Prior to the 1980s, the only form of supplementary irrigation available in the HBT was with low lift pumps and manual removal of water from ponds and other water bodies by bucket. Marked change in irrigation came only in 1986 after genesis of the 'Barind Integrated Area Development Project" by the Government. It later became an autonomous organization under the Ministry of Agriculture with the new name 'Barind Multipurpose Development Authority' (BMDA). BMDA is fully government funded and has been sinking deep tube wells (DTW) in different areas where there is a potential aquifer. There are now more than 4,000 DTWs operating in the HBT area. Presently, about 45 % area (>64,000 ha) of the HBT is under DTW irrigation. However, command area of most deep tube wells is less than originally planned probably due to limited water extraction as a result of receding aquifers in the dry months, undulating topography and farmers' management.

Pumps used in deep tube wells are powered by either diesel fuel or grid-derived electricity, both of which are expensive commodities and unreliable in their availability. Water is distributed within the command area via cement channels and underground pipes. Also, farmers now use plastic pipes to carry water over longer distances and to elevated land. For ease of recovery of water surcharge BMDA sells coupons to farmers before the start of irrigation season. Generally, the rate is BDT 125 (approx. US$ 1.50) per hour, that is US$ 1.50 per 150 m^3 (discharge rate of DTW is about 55 L s^{-1}). BMDA earns >3.95 million US$/year through this sale of irrigation coupons. BMDA bears all costs including electricity, general maintenance and operator's honorarium. Nevertheless, the water price is highly subsidized and in future needs to be rationalized to promote more efficient use of irrigation water and avoid excessive groundwater depletion. BMDA does, however, try to promote water use efficiency and maintain appropriate well-to-well spacing in relation to aquifer capacity. Its governance structure is mostly democratic and participatory. It also runs associated command area development schemes aimed at environmental enhancement, such as water conservation by deepening existing canals and kharis, homestead and social forestry, promotion of integrated pest management, and farmers' training. In addition, BMDA has adopted an integrated planning approach that incorporates extending rural electrification, building rural infrastructure and an array of other support programs. As a result, the BMDA has emerged as a model of sustainable groundwater-based rural development initiative in Bangladesh (Faisal et al. 2005), at least for addressing current needs.

5.3 Other types of irrigation

Although deep tube wells are the major means of irrigation in the HBT, other forms of irrigation remain locally important, especially where deep tube wells cannot be sunk. As mentioned above, the traditional methods of manually extracting water from surface water bodies remain important for supplementary irrigation, especially for homestead gardens. There is 3-4 % area of the HBT under supplementary irrigation (one or two irrigations) from ponds, kharis, cross dams and beels. Low lift pumps, available on rent, are now in widespread use to irrigate from these water bodies, and for lifting water from the river Padma in Godagari Upazila. Low lift pumps with plastic hoses are particularly useful for cultivation of winter vegetables and for supplementary irrigation of wheat, mustard and drought-affected t. aman rice. Shallow tube wells, which are effective down to 7.5 m, can only operate where the water table remains near the surface. While they are commonly used mainly for boro rice in the dry season in alluvial soil areas, and parts of the level Barind, their use is very much limited in the HBT due to water tables being too deep. Recently, BMDA has excavated some canals to transport water pumped up from the river Padma in southern Godagari Upazila. They also deepen and clear khas ponds, kharis and dam them to trap monsoon rain water.

5.4 Boro rice cultivation

The main reason for expanding deep tube well irrigation in the HBT from the 1980s, and in other upland areas of Bangladesh, was to substantially increase boro rice production. This was necessitated by the ever-increasing population, whose staple food is rice. Irrigated boro rice provided the best option for increasing the country’s rice production because it introduced new land into rice production, land which could not otherwise grow rice during the dry season, and potential and actual yields were much greater than those of rainfed aus or t. aman rice.

Cultivation of boro rice uses essentially the same agronomy as that for t. aman (see Chapter 4), the main differences being growing period and the reliance on intensive irrigation. The main boro varieties grown are BRRIdhan 28 and 29. Time of sowing into seed beds in the HBT is late November through December, with transplanting from late January through February. Seedlings are transplanted after about 50 days, as seedling growth rate is slow during the winter period. Depending on local soil infiltration rate and evapotranspiration, up to 25 irrigations may be required during the course of crop growth. Fields are flood irrigated to 7-10 cm standing water and re-irrigated after disappearance of this water. Harvesting occurs through May-June, preferably before the onset of monsoon rains.

5.5 Impact of irrigation

The overall effect of irrigation has been to broaden cropping opportunities and thus financial return so as to improve livelihoods of a large section of the drought-affected population (Table 5.1). There has been increased agricultural production, economic return, employment generation, and creation of many backup linkages including transport businesses. Moreover, irrigation has ensured the availability of drinking water, water for household use, pond fishery and development of commercial fruit gardening, poultry and livestock farming. Enhanced food security and cash income from high value crops and business have brought considerable change to the society. More families are now able to send their children to educational institutions and invest more in quality education, have a more diverse and nutritious diet, construct brick and concrete houses (Figure 5.1) rather than the traditional mud-based dwellings and access electricity. With increased agricultural income, some are able to construct houses in nearby towns to facilitate children’s education and access additional employment. Wealthier farmers are also investing more for clothing, transport, ceremonial occasions, social communication and other modern technologies. However, landless and marginal farmers may not get this benefit apart from increased opportunity for day labour at enhanced wage rates. Impact of irrigated agriculture on farmer's livelihoods in comparison to rainfed agriculture is depicted in Table 5.2. Farmers practicing irrigated agriculture have been able to increase their income by 19-27 % compared to rainfed farming. Irrigated area farmers expenditure for livelihood is 20-21 % more than that for rainfed area farmers. Food security of the entire population has largely improved with creation of more jobs for daily labourers throughout the year at higher wage rates.

However, long term effects of increased ground water lifting need to be closely monitored. The concern is that failure of irrigation in the dry season in any way may reverse this production benefit and livelihoods improvement in a harsh way.

Table 5.1. Influence of the introduction of irrigation on different crops and its impact on production and income for farmers in the HBT. Source: estimates of MY Ali after interviewing farmers and BMDA officials.

Crop	Area before irrigation (ha)	Area after irrigation (ha)	Production benefit (t $year^{-1}$)	Economic benefit (million BDT $year^{-1}$)
Boro rice	Negligible area	53,568	305,338	3489.6
T. aus rice	None	7,000	21,000	240
Supplementary irrigation to t. aman[1]	Small area	26,748	18,749	213.6
Early hybrid tomato	None	5,000	175,000	1,400
Rabi hybrid maize	None	2,000	13,000	148
Potato	Small area	2,000	40,000	228.8
Mustard	Small area	3,000	4,200	192
Irrigated wheat	Small area	4,000	13,600	232.8
Commercial vegetables	Small area	5,000	90,000	720
Summer mung bean	None	700	490	24.8
Total	**-**	**-**	**-**	**6,889.6[2]**

[1] Assuming 0.7 t ha^{-1} production advantage due to supplementary irrigation in t. aman rice.

[2] Approx. US$ 86 million (US$ 1 ~ BDT 85).

Table 5.2. Comparative livelihoods (expenditure and income) of poor, average and well-off households[1] in the HBT with rainfed and irrigated farming, 2015. Source: estimated from field survey.

Livelihood item	Poor household		Average household		Well-off household	
	Rainfed	Irrigated	Rainfed	Irrigated	Rainfed	Irrigated
Yearly expenditure (BDT[2])						
Food	18,000	21,600	30,000	32,400	34,800	36,000
Clothing	3,600	4,800	4,800	7,200	9,600	12,000
Bazaar	12,000	15,000	18,000	24,000	31,200	36,000
Health	2,400	2,400	4,800	6,000	7,200	9,000
Education	2,400	3,000	9,600	12,000	12,000	14,400
Transport	1,800	1,800	3,600	3,600	6,000	6,000
Agricultural inputs	9,600	12,000	17,400	22,200	69,600	93,600
Labour	1,200	1,680	12,192	16,992	36,360	48,480
Festival/ guests	2,400	3,600	6,840	8,040	13,200	18,000
Others (e.g. mobile phone)	2,400	4,800	8,400	12,000	18,000	24,000
Total expenses	**55,800**	**70,680**	**115,632**	**144,432**	**237,960**	**297,480**
Yearly income (BDT)						
Field crops	22,400	32,000	90,000	120,000	211,100	264,000
Vegetables	10,000	18,000	23,000	30,000	35,000	45,000
Homestead fruits	1,500	1,500	5,000	4,000	7,000	5,000
Livestock	6,000	5,000	3,000	1,500	6,000	5,000
Labor, etc.	18,500	20,000	7,000	8,000	6,000	7,000
Total income	**58,400**	**76,400**	**128,000**	**159,500**	**265,100**	**326,000**
Yearly balance	***+2,600***	***+5,720***	***+12,368***	***+15,068***	***+27,140***	***+28,520***
Rice food security (months /year)[3]	**3-4**	**6-7**	**6-7**	**9-10**	**10-12**	**12**

[1] Calculated for 5-member family (Ali 2014).
[2] Bangladeshi Taka (US$ 1 ~ BDT 85).
[3] Period of affordable rice in a year.

Figure 5.1. Improved livelihoods of irrigated farmers – a recently constructed building at Godagari, HBT, 2010.

Chapter 6. Farming System Diversification – a Changing Landscape

Recent times have brought marked changes to the HBT landscape from its uniform, monotonous appearance prior to the 1980s – of a carpet of green t. aman during the monsoon season and a treeless, bare, desert-like landscape during the dry season (in a 1,500 mm rainfall zone!). Of course, the major factor causing this change was the introduction of deep tube well irrigation, and other irrigation methods. However, other factors have also changed, which will be elaborated on below.

6.1 Changes in cropping patterns

As boro rice cultivation expanded from the mid-1980s, increasing areas of the HBT changed to having green rice fields through much of the year. Although boro rice cultivation did ensure higher and more stable yields, the cost of cultivation has made the practice increasingly less profitable. This is because of the high and ever-increasing, and unavoidable, costs of irrigation, fertilizer, other agrochemical inputs and labour. Shrinking irrigation command areas, due to ground water depletion (Selvaraju et al. 2006) and intermittent electricity supply for pumping water, are limiting the area available to grow boro rice for some farmers. Yields are also stagnating, or even declining, despite recommended application of inputs, probably due to declining soil health. Therefore, farmers have been incentivized to seek alternative cropping options, to at least maintain financial viability.

The increased availability of water in the HBT, from deep tube wells and the advent of pumps, channels and pipes to distribute it more widely and efficiently across fields, has permitted winter cultivation of crops such as wheat, tomato, potato, rapeseed mustard, etc. These crops require much less water per unit of yield than does rice, thus increasing water use efficiency of crop yield.

Improvements in rainfed cropping techniques have also increased the scope for cultivation of winter crops. For example, in the case of chickpea, improved cultivars such as BARI chola 5 are better able to produce than traditional ones under receding soil moisture conditions. Seed priming permits improved crop establishment, ultimately leading to higher yields (Box 6.1).

Anecdotal data recorded in Table 6.1 indicates the changes in cropping patterns in highland and medium highland regions of the HBT over a 20-year period. The advent of irrigation has permitted wider cropping options and the use of improved varieties with higher yields. The extent of crop diversification over time can also be seen in Table 6.2, where the earlier winter fallow has been superseded by not only boro rice but also crops like wheat, mustard, tomato, potato and chickpea. However, although Table 6.1 is representative of the southern HBT, large areas of the northern HBT still remain fallow during winter due primarily to lack of irrigation potential. In 1985, cropping intensity (area of all crops grown in a year divided by land area) of the HBT was 117 %, rising to 166 % in 1992-93, whereas recent cropping intensity of this area is >200 % (BMDA 2006).

Farmers attribute these changes to their production systems primarily to the expansion of irrigation and the introduction of improved technologies (Table 6.2). This has increased their interest in further diversifying their farm enterprises, to include livestock rearing, aquaculture, vegetable cultivation, orchards, etc. It has thus increased their awareness of, and demand for, further improved technologies.

Box 6.1. Seed priming of chickpea

Seed priming simply refers to soaking seeds in water overnight, before sowing. This increases seedling establishment, enhances seedling vigour, including root penetration, ultimately resulting in earlier crop maturity and higher yield in a receding soil moisture environment. During 1998-99 and 1999-2000, on-farm trials on seed priming of chickpea were conducted in the HBT, involving University of Wales, DFID, ICRISAT, the local NGO PROVA and DAE (Musa et al. 2001). Farmers intending to grow rainfed chickpea were requested to prime seed to be sown on half of a field (usually of 1 bigha [666 m^2] total area) and sow the other half with non-primed seed. Thirty such trials were conducted in 1998-99 and 105 in 1999-2000, with further trials and demonstrations conducted in following years. In the first year priming increased yields by 47 % and in the second year by 20 % (there was winter rainfall in this year).

An impact assessment of the adoption of seed priming technology for chickpea in the HBT was conducted in January-June 2006 (Socioconsult Ltd. 2006). In areas where trials and demonstrations with seed priming had been conducted in previous seasons, 69 % of farmers practised seed priming. In control areas, where such trials and demonstration had not been conducted, farmers use of priming for chickpea was about half that level, indicating wider diffusion of the technology.

Surface soils of the HBT are usually acidic (pH 5-6), resulting in poor nodulation and N deficiency symptoms in legumes, particularly chickpea and lentil. This raised the suspicion of molybdenum (Mo) deficiency, along with inadequate rhizobial colonization of roots. During the 2003-04, 2004-05 and 2005-06 seasons on-farm trials with chickpea in operational scale (1 bigha) plots were conducted across the HBT (Johansen et al. 2007). Mo and rhizobial inoculum were added to the priming water and compared with priming in only water. Yield responses to these additions of 37-90 % in 2003-04 and up to 50 % in subsequent seasons were obtained.

Table 6.1. Changes in cropping patterns in the HBT from the mid-1980s to the present.

Cropping pattern	Area in ha (% total area)[1]	Rainfed (RF) or irrigated (IR)
Previous cropping pattern (mid-1980s)		
Fallow/barley/linseed-fallow-t. aman[2]	Most	RF
Present cropping patterns[3]		
Boro-fallow-t. aman	25,530 (18.9)	IR
Mango orchard	20,960 (15.5)	RF
Wheat-fallow-t. aman	18,500 (13.7)	IR
Potato-fallow/boro-t. aman	12,500 (9.2)	IR
Fallow-fallow-t. aman	10,000 (7.4)	RF
Lentil-fallow-t. aman	8,000 (5.9)	RF
Chickpea-fallow-t. aman	5,650 (4.2)	RF
Guava orchard	5,000(3.7)	IR
Tomato-fallow-t. aus	4,094 (3.0)	IR
Boro-t. aus-t. aman	4,000 (3.0)	IR
Boro-t. aus-blackgram	3,500 (2.6)	IR
Mustard-fallow/t. aus-t. aman	3,400 (2.5)	IR
Wheat-t. aus-t. aman	3,000 (2.2)	IR
Wheat-t. aus-blackgram	2,550 (1.9)	IR
Maize-fallow-t. aman	1,000 (0.7)	IR
Other	6,145 (4.5)	RF/IR

[1]According to BARC (2005) HBT area is 159,964 ha of which 6 %, or 9,598 ha, is homestead and water bodies. So, actual cultivable land of HBT in 1985 was 150,366 ha. Assuming 10 % land loss (15, 037 ha) due to housing, roads, markets and other commercial and infrastructure construction by 2017 cultivable land presently available is 135,329 ha.

[2] Slash indicates alternative crop/practice or intercrop and hyhen separates crop/practice in rotation.

[3] Cropping pattern based on OFRD, Barind Station, BARI, Rajshahi (Islam et al. 2011) and updated by authors.

Not only has increased access to irrigation in the HBT allowed for diversification of winter crops (e.g. wheat, tomato, potato, etc.) it has also increased yield stability of the t. aman crop. The flowering stage of t. aman rice is particularly susceptible to drought stress, resulting in a 11-34% yield loss for local varieties and a 43-50% yield loss for modern varieties (Selvaraju et al. 2006; BRRI 2016). The HBT regularly experiences breaks in the monsoon rains during this flowering period, in August and September, and most HBT farmers report yield losses of t. aman attributable to drought stress (Islam et al. 2011). In previous years farmers relied on any existing ponds or any other nearby water bodies to try to save at least part of their t. aman crop. However, in recent years many of the traditional ponds have dried up, or have reduced water holding capacity, due to declining rainfall, siltation and over-use. A mini-pond holding 300 m^3 (10 m x 10 m x 3 m) of water can prevent yield loss of t. aman due to terminal drought for an area of 1 ha of land (Anonymous 1991). If the t. aman crop is within a tube well command area, this water source can also protect the crop from terminal drought stress. It has also permitted irrigation of traditional, low yielding broadcast aus rice (b. aus), grown in the pre-monsoon to early monsoon period of April-August, leading to transplanted aus (t. aus) rice. Cultivation of boro rice, t. aus and supplementary irrigation to existing t. aman have largely contributed to food security, economic development and turning this flood free area into a national food granary.

Table 6.2. Farmers' explanation of causes of recent changes in agriculture in Godagari, Rajshahi and indicators of change.

Causes of change	**No. of respondents**	**Attribution (%)**
Development of modern agricultural technologies, particularly new crop varieties	46	82
Increased irrigation facilities	23	46
Increase in farmers' demands for options	14	28
Availability of treatment facilities for livestock	13	26
Increased awareness of cropping and tree plantation options	9	18
Indicators of change		
Introduction of modern crop varieties, resulting in increased yield	41	82
Increased irrigation facilities	23	46
Increased fish culture	14	28
Increased livestock rearing	13	26
Increased food security	10	20
More employment opportunities	9	18
Increased literacy	9	18

6.2 Changes in tillage methods

Traditionally, soil tillage before planting of all crops in Bangladesh was done using bullock- or buffalo-drawn ploughs having a wooden frame and single tyne (Figure 6.1). Originally, tynes simply comprised a wooden stick but, over the previous century, have evolved into iron mouldboard types. From the 1960s, some 2-wheel power tillers and 4-wheel tractors were introduced into Bangladesh by government organizations like BADC and sugar mills to enhance the tillage process. However, their proliferation was slow due to cost and limited local knowledge about machine operation and maintenance. Further, small field size used for rice cultivation (around 1 bigha) restricted the use of 4-wheel tractors, and power tillers were much better suited to these fields. However, from the late 1980s farm mechanization gained momentum (Islam 2009) because of increasing purchasing power of medium-income farmers, development of the private sector for importing, retailing and servicing such machinery, and government policies facilitating tax-free import and bank loans. There was also increasing demand for shortening of turnaround time between crops, to increase cropping intensity and thus total annual yield and income. This could only be achieved with mechanization.

Figure 6.1. A Bangladeshi farmer's family returning from field after sowing seed of a crop with traditional plough and ladder used for soil levelling. Photo credit: Anisur Rahman

Power tillers are imported mainly from China or South Korea while tractors are mostly of Indian origin. The current cost of a power tiller is around US$1,400, which is within the scope of even small farmers if they can secure a loan. Most farmers who do purchase a power tiller also hire them out to neighbours, creating an additional source of income. Indeed, some farmers receive more income from hiring out their power tillers than from cropping on their own land. The 2-wheel tractor component of power tillers is not only used for tillage but also for transport (with a trailer) and as a power source for threshing and milling of rice.

Moreover, many backward and forward linkages such as business and services have evolved through this significant socio-economic changing instrument. Expansion of power tillers in Bangladesh has been much greater than that of 4-wheel tractors (Table 6.3) not only because of general small field size but because of much lower capital cost of power tillers, putting them within the reach of many more farmers.

Table 6.3. Chronological increase of power tillers and tractors in Bangladesh[1].

Type	1977	1984	1989	1996	2006	2009	2013	2015
Power Tiller	200	500	5,000	100,000	300,000	400,000	460,000	500,000
Tractor	300	400	1,000	2,000	12,500	17,905	33,500	41,500

[1] Adapted from Shirazul Islam (2009) and CIMMYT (2012)(with 2013 and 2015 projections).

Alam et al. (2007) analyzed the economics involved for a power tiller owner, operator, diesel retailer and mechanical servicing provider. They found that all of them could earn a decent income through power tiller operation around the year, with income being higher in the rabi season. Through a power tiller about BDT 48-56,000/- (~US$600-700) can be earned in the boro season (November-January) after deducting all costs. It is possible for one power tiller to cultivate about 40-50 ha land in the boro season. For each ha of cultivation (two times ploughing and laddering) the charge is about BDT 1,600-1,700 whereas for bullock cultivation it may rise to double that amount and take much more time.

It is estimated that in 2003, 70 % of cultivated land in Bangladesh was tilled by power tiller, and only a small proportion by tractor (Quayum & Ali 2012). In 2009 it was estimated that about 90 % of soil tillage was done by power tiller in most parts of the country. Power tillers were introduced in the HBT later than elsewhere in the country due to the less intensive agriculture practiced there. However, with the development of irrigation, road infrastructure and particularly boro rice cultivation from 1986, use of power tillers increased rapidly for both tillage and transport. The HBT areas had had a greater density of bullock and buffalo than other areas of the country, mostly due to more extensive grazing opportunity and as an economic buffer in this drought-prone zone. Ready availability of animal power for ploughing delayed conversion to mechanical tillage but with declining area available for grazing and otherwise limited fodder sources animal numbers steadily declined. It is estimated that presently 95-98% of HBT farmers use power tillers for tillage. The few 4-wheel tractors in the HBT are mainly used for road transport or by farmers with large land holdings.

In the HBT, power tillers have proven to be particular useful for rabi cropping, in bringing more areas under cultivation for sowing of dryland crops like chickpea, maize, linseed, mustard, barley and wheat. In the HBT there is a particularly narrow window available between the harvesting of the traditional long duration t. aman rice and planting of a rabi crop into the rapidly drying soil. Use of power tillers reduces the turnaround time but there are still problems of retaining soil moisture. The thorough rotary tillage of the topsoil enhances moisture evaporation from the seeding zone, leading to poor establishment and drought stress to emerging seedlings.

A next step was the introduction of single-pass shallow-tillage planters, locally known as power tiller operated seeders (PTOS)(Figure 6.2). These were imported from China, as 2BG-6A seeders, beginning in 1995. This seeder accomplished three operations in a single pass – shallow tillage (to about 6-7 cm), placement of seed in a furrow and levelling (Miah Monayem et al. 2010). The PTOS is 120 cm wide allowing it to plant up to six rows of a crop at 20 cm row spacing. It provides full rotary tillage and covers 0.14–0.20 ha h^{-1}. It uses a fluted-type seed metering system, but has no fertilizer application capability.

Figure 6.2. A PTOS sowing wheat. Photo credit: M. Yusuf Ali

Initially, the PTOS was demonstrated to farmers through service providers in many areas of Bangladesh under a loan programme of CIMMYT (Roy et al. 2004). Compared with traditional broadcast sowing with tillage by a 2-wheel tractor, Wohab et al. (2007) reported that the PTOS required only about half as much time and fuel for sowing of wheat and jute (*Corchorus capsularis L.).* At an initial stage, efforts were taken to fabricate the PTOS locally, but the manufacturers were unable to maintain quality of the product at a standard comparable with the imported one. However, due to demand and increasing capability of the local manufacturers, several did begin commercial manufacturing and marketing. As of mid-2011, there were more than 1,000 units of PTOS in use in Bangladesh (Figure 6.2).

The PTOS should be considered a reduced tillage planter rather than a minimum tillage planter, as the one pass does involve considerable disturbance of surface soil due to the full rotary tillage. This, together with shallow placement of seed, renders germinating seed and emerging seedlings prone to moisture deficit when surface soil moisture is marginal or rapidly evaporating. Thus the PTOS is better suited to irrigated than rainfed situations, where optimum surface soil moisture can be assured.

Subsequent developments of planters for 2-wheel tractors have concentrated on planting into soils with sub-optimal soil moisture involving minimal soil disturbance and greater depth control of seed and fertilizer placement. These developments have been done within the context of conservation agriculture (CA). CA is defined as cropping systems based on minimal soil disturbance, permanent surface cover through crop residue retention and diverse crop rotations and associations (Hobbs et al. 2008; Kassam et al. 2009).

With the prime objective of introducing minimum tillage, as a component of CA, the next development was with respect to strip tillage. By setting rotary blades only directly in front of the furrow openers the PTOS could be reconfigured as a strip tillage planter (Justice et al. 2003, 2004; Roy et al. 2004, 2009). The rotating blades also displace the stubble in front of the furrow openers. Although original strip tillage units still disturbed up to 50 % of the soil surface (Justice et al. 2003), the angle of the rotary blades and furrow openers can be reduced to minimize the width of the strip tillage slit. CIMMYT, with BARI (Bangladesh Agricultural Research Institute), initiated development of a 2-wheel tractor based strip tillage planter in 2001 using a Chinese 2BG-6A seeder to plant seed on new beds and permanent beds with strip tillage (Hossain et al. 2005).

Minimum tillage planting can also be achieved by establishing permanent beds. Although initial bed formation necessarily involves major soil disturbance, once established the beds only require reshaping, with minimal soil disturbance. Bed shaping attachments for 2-wheel tractors developed at CIMMYT, Mexico were introduced into Bangladesh in the early 2000s and existing PTOS units modified to also include bed shapers (Hossain et al. 2004). Eventually, modified PTOS units were evolved that could make and shape beds and place seed and fertilizer in furrows on the bed in one pass (Wohab et al. 2009). Such beds were usually 60 cm wide and could accommodate two rows of most of the commonly grown crops in Bangladesh.

Further subsequent development of the original PTOS design trialled innovations such as replacement of the roller with adjustable press wheels, placement of separate seed and fertilizer boxes above the handle bars, more robust and effectively designed furrow openers and an adjustable tool bar frame for attaching tines (Johansen et al. 2012). A practical and sustainable outcome of these efforts was the Versatile Multi-crop Planter (VMP) (Bell et al. 2017; Haque et al. 2010, 2011, 2017; Haque & Bell 2017; Islam et al. 2010; Figure 6.3). This device is capable of applying seed and fertilizer in rows for: (a) single-pass shallow tillage; (b) strip tillage with adjustable width and depth of strips; (c) zero tillage; (d) bed planting for single-pass new bed making or reshaping of permanent beds with simultaneous planting and fertilizer application, and; (e) traditional full tillage following broadcast seeding. The design of the VMP allows for rapid and simple conversion between the different operating modes, necessary considering the wide range of field crops sown in Bangladesh and ever-decreasing turnaround times between crops. Implements of this type render introduction of CA practices into the HBT more feasible (Box 6.2).

Although such seeders as the PTOS and VMP were primarily developed for aerobic cultivation of post-rainy season crops like wheat, they also have relevance to the major crop of the HBT, and of Bangladesh, rice. Boro rice, grown in the post-rainy season, requires large quantities of irrigation if grown using traditional practices. However, if rice is direct seeded using PTOS or VMP, considerable amounts of water can be saved (Figure 6.4). This method obviates the need for puddling and transplanting of seedlings. It requires only 55 irrigation hours ha^{-1} whereas conventional puddling needs 184 irrigation hours ha^{-1}, for the entire crop. This amounts to only seven irrigations being required for direct seeding as compared with 25 times for conventional methods, resulting in saving of 92.7×10^5 L ha^{-1} of irrigation water, as well as diesel/electricity for pumping and labour for transplanting, without losing much yield (Table 6.4). Thus cost of production is only BDT 24,848 ha^{-1} (US\$355 ha^{-1}) with direct seeding compared to BDT 34,644 ha^{-1} (US\$495 $ha^{=1}$)

with conventional tillage (WRC 2008). Through minimum tillage water can be saved and cultivation cost reduced in other irrigated crops besides rice, such as wheat and maize, without sacrificing yield, but it requires application of herbicides (Table 6.4). Herbicides need to be used with caution due to inevitable development of herbicide resistance in weeds and possible toxic effects of these chemicals to other life forms.

Figure 6.3. A VMP sowing a rabi crop into rice stubble in the HBT. Photo credit: M. Enamul Haque

Table 6.4. Comparative water requirement of direct seeding method by PTOS and conventional tillage method.

Crop	**No. of irrigations required**		**Total volume of irrigation water (L ha^{1})**		**Irrigation water used (L kg^{1} grain)**	
	PTOS[1]	**Conven.**	**PTOS**	**Conven.**	**PTOS**	**Conven.**
Boro rice	7	25	39.7×10^5	132.4×10^5	722	2,037
Wheat	2	2	11.7×10^5	13.3×10^5	273	444
Maize	3	3	12.3×10^5	12.3×10^5	254	162

[1] PTOS = Power Tiller Operated Seeder (one time pass with full tillage); Conven. = Conventional tillage, i.e. 2-3 tillage for wheat and 2-3 puddling tillage for boro rice. Source: WRC (2008).

Box 6.2 Conservation agriculture particularly relevant to the HBT

It is important to promote CA in the HBT because of depleted state of soil organic matter over time, exacerbated by frequent full tillage, and its limited replenishment due to rigorous crop residue removal. Increasing soil organic matter levels is particularly important for increasing retention of soil moisture, as well for enhancing nutrient status. Thus seeders such as the VMP, combined with previous crop residue retention, have an important role to play. Indeed, much of the development and evaluation of PTOS and VMP versions has been done in or near the HBT and is thus directly relevant to that environment. Evaluations of the VMP, comparing strip tillage and conventional tillage, were done for wheat and chickpea in the HBT in 2010-11, as part of a wider evaluation of the VMP across several crops and 17 districts of Bangladesh (Bell et al., 2017). Similar plant populations and grain yields were obtained between the treatments in both crops (and yields were similar for bed-planted wheat also). Costs of crop establishment were also lower with strip planting. Further experimentation with a wheat-mung bean-t. aman rotation in the HBT over three years (2010-13) compared conventional tillage with strip planting and bed planting, with and without residue retention (Islam, 2016). Marginal yield increases occurred with strip and bed planting (7-10 %) over conventional tillage, and of high residue (1-3 %) over low residue, were detected in wheat by the third year, but not in the other crops in the rotation. Also, by the third year, significant increases in soil organic carbon levels were measurable (Islam, 2016). These results show promise that implementation of CA, facilitated by such implements as the VMP, can ultimately increase yields and at lower cost than conventional practice.

Figure 6.4. A boro rice crop directly seeded by PTOS. Photo credit: Dr Israil Hossain

Bed planting, particularly the use of permanent beds, can further reduce water requirement without hampering yield, as shown for wheat and maize in Table 6.5. Although farmers elsewhere in Bangladesh are accustomed to using bed planting for potato, some vegetables and maize, those in the HBT are not used to it for wheat and rice, due to lack of implements and extension of the technology. Particularly in view of likely water shortage in the rabi season in the HBT, machine-based bed planting (Figure 6.5) should be promoted.

Table 6.5. Bed planting of wheat and maize saves irrigation. Source: WRC (2008).

Method of planting	Wheat cultivation			Maize cultivation		
	Time per irrigation (h ha^{-1})	Number of irrig.	Total irrig. time (h ha^{-1})	Time per irrig. (h ha^{-1})	Number of irrig.	Total irrig. time (h ha^{-1})
New beds	6.4	3	19.2	6.4	3	19.2
Permanent bed	5.5	3	16.5	5.5	3	16.5
Conventional	8.6	3	25.8	6.4	3	19.2

Figure 6.5. Bed planted wheat (left)(Photo credit: Dr M. Yusuf Ali) and t. aman rice (right)(Photo credit: Dr M. Illias).

These new and evolving methods deserve due attention at policy levels to ensure robust research and extension programs along with increased availability of seeders, bed planters, spare parts, etc. and hands-on training for farmers and power tiller operators. Ongoing field demonstration is required following a community approach.

6.3 Increasing chemical inputs

In Bangladesh, the use of agricultural chemicals to increase yields and protect them from pest damage has dramatically increased over the last two decades. Of particular concern is the use of pesticides. For example, a survey by the Bangladesh Rice Research Institute (BRRI) recorded a 328 % increase in toxic pesticide use over the period 1997 to 2008 (AgroNews 2010). In 1997, the use of pesticides in Bangladesh was more than 8,000 t; it doubled to 16,000 t in 2000; in 2005-06, it increased to nearly 20,000 t and in 2008 it rose up to 48,690 t. These pesticides, especially insecticides, can be deleterious to human health, as well as to farm animals and beneficial natural organisms, unless adequately regulated and safely used. Unfortunately, regulation is lax and farmer training in safe use is rare. The Bangla word used for such pesticides is 'oshud', which also translates to 'medicine', leading farmers to consider these substances as benign. Major use of pesticides is in vegetable growing regions but their use on crops in the HBT has also rapidly increased.

Thus, agencies recommending use of particular pesticides in the HBT should take responsibility for training farmers and rural workers in their proper and safe use.

With the advent of reduced and minimum tillage as CA is introduced, the traditional option of weed control by tillage needs to be supersceded. Herbicides are the seemingly obvious choice and indeed they have become an integral part of CA wherever it is practiced throughout the world. However, there are two problems associated with their rapid and widespread deployment. Firstly, there is their possible toxicity. Glyphosate, the most widely used herbicide, is under scrutiny for its possible human, and other animal, toxicity effects. The International Agency for Research on Cancer (IARC) – the World Health Organization's cancer agency – have classified glyphosate as probably carcinogenic to humans (The Guardian 2015), although this has been disputed and toxicity effects of glyphosate are still under debate (Kelland 2017). In November 2017, the European Union considered the evidence to date and decided to license glyphosate for a further five years (Neslen 2017). However, a court in California recently found in favour of a litigant who sued Monsanto, the manufacturer of Roundup, which is glyphosate, claiming that its regular use had resulted in his cancer (Bellson 2018). This has opened the way for other legal claims around the world that glyphosate causes cancer, and highlights the need to find alternatives to glyphosate for weed management.

Secondly, a problem with herbicides about which is more definitively understood, is the development of herbicide resistance in weeds (Powles 2008). Regular use of the same herbicide induces rapid evolution of weed genotypes with varying degrees of resistance to that herbicide, eventually reducing and negating the effectiveness of that herbicide. With the introduction of minimum tillage techniques into the HBT, and consequent increased use of herbicides, this problem needs to be confronted. Integrated weed management strategies need to be adopted to obviate adverse effects of regular application of the same herbicide. These could comprise rotation of chemically dissimilar herbicides, crop rotation to expose weeds to different forms of crop competition, and adjustment of crop spacing and sowing time so as to increase crop competition with weeds (Harker and O'Donovan 2013).

Another chemical input that has rapidly increased in Bangladesh in recent times is chemical fertilizer. According to FAO, in 1990 1,266 t of active ingredient (mainly N, P and K) was used whereas in 2014 it was 15,857 t, a 12.5-fold increase. The main fertilizer used is urea, due to its relatively lower cost per kg than other fertilizers (mainly di-ammonium phosphate, single and triple superphosphate and muriate of potash) over the years and because of the visible and immediate response of cereals to urea application. This has led to an imbalance of nutrient application with induced deficiencies of P, K, S and perhaps other nutrients, the symptoms of which are difficult to recognize as compared with N deficiency (yellowing of older leaves). This situation applies in the HBT as well as elsewhere in Bangladesh. Further, due to acid soils in the HBT the trace element Mo can also limit the growth of legumes (Johansen at al. 2007).

Another problem with imbalanced and excessive use of N fertilizer is nitrate pollution of surface water bodies and ground water, as has been a long-standing problem in intensive rice and wheat cultivation in Punjab state of India (Bijay-Singh at al. 1991). With cropping intensification in the HBT regular monitoring of nitrate levels in surface and ground water is well warranted. Further, loss of N to water bodies results in low N use efficiency, to the detriment of the farmer who buys and applies the fertilizer.

As cropping intensity in the HBT increases, there is a requirement for intensified research and extension into providing the appropriate balance of nutrients to optimize yield and for maximum nutrient use efficiency, for each required nutrient. The introduction of CA has a particular role to play in this regard. Firstly, introduction of crop rotations will allow different crops to access different soil pools of nutrients, and recycle them for subsequent crops. Secondly, return of crop residues to the soil will build up soil organic matter levels, which generally improves soil fertility and residual value of applied nutrients. Thirdly, precision planting with minimum tillage allows placement of fertilizer where it is most effective for crop growth, thus increasing fertilizer use efficiency.

6.4 Livestock components

Livestock have for long formed an integral part of HBT farming systems. This region still has more cattle, buffalo, sheep and geese per unit area compared to other parts of the country. Livestock rearing is one of the more important risk management strategies against drought; the dung is also a source of cooking fuel and manure. However, health of most of the cattle is poor due to scarcity of green and nutritious forage and grains. Cash obtained from sale of milk and the animals themselves helps rural families to cover expenses throughout the year. This is particularly important during drought periods when income from cropping is minimal. However, especially when fodder becomes scarce, sale price of animals drops.


Figure 6.6. Sheep grazing on fallow land of the HBT. Photo credit: Dr M. Yusuf Ali

The paddy straw of t. aman rice is preserved and serves as major feed of cattle and buffalo. Green fodder such as palatable weeds from rice fields and leguminous tree leaves is provided when available. In winter through to summer free grazing of cattle, buffalo, sheep and goat remains common in the HBT (Figure 6.6), although the quantity of green feed diminishes as the winter progresses into the hot summer, as the soil dries out. However, land available for free grazing through winter is decreasing with the increase in rabi cropping. In the rainy season, when most land goes under t. aman rice, grazing area is further restricted to small areas of fallow lands and field bunds. But there is considerable scope to cultivate quick growing fodder crops like para grass (*Brachiaria mutica*) or napier grass (*Pennisetum purpureum*), tropical pasture legumes and other suitable species which are tolerant to drought. Some of these species are quite adapted to growing amongst trees, on pond banks and along road sides. Many of the tropical fodder grasses are perennial and can be grown for many years with regular cutting, including into the winter. In addition, such fodder has good market value.

6.5 The return of trees

Although the HBT was once densely forested, and then almost completely cleared of trees for rice cultivation, the return of trees is crucial for sustainable human habitation of the region. Since Bangladesh independence, the Bangladesh Agricultural Development Corporation (BADC), and over the previous 25 years the BMDA, have had programs of planting trees along roadsides and elevated areas not suitable for rice cultivation. An obvious advantage has been provision of shade for humans and animals, especially during the pre-monsoon season when temperatures can reach 40-45 °C. Other advantages include prevention of erosion, provision of building material and firewood, soil organic matter enhancement through leaf fall, fodder availability from palatable species and habitat for birds that prey on crop insect pests.

Initially, fast growing introduced tree species, particularly sissoo (*Dalbergia sissoo*), were favoured however, over time, sissoo has become prone to dieback, root disease and gummosis (excessive gum exudation due to bark wounds or adverse weather conditions). More recently tree species like Palmyra palm (*Borassus flabellifer*), date palm (*Sylvestris* sp.), babla (*Acacia nilotica*), neem (*Azadirachta indica*), ghora neem (*Melia azedarach*), river red gum (*Eucalyptus camaldulensis*), leucaena (*Leucanea leucocephala*), etc. have been favoured. These trees are also suitable for growing along crop field boundaries, on pond or stream banks and in homestead areas.

For homestead areas multi-strata home gardens are suggested, producing maximum benefit per unit area in villages (Hussain et al. 1991; Kar et al. 1998). However, such systems have only been implemented to the extent of 20-25 % in HBT villages/households, thus there is considerable scope for their expansion. Upper strata species are recommended to be kori (*Albizia lebbeck*), mango (*Mangifera indica*), Palmyra palm (*Borassus flabellifer*) and bamboo clumps (*Bambusa* spp); the mid strata neem, coconut (*Cocos nucifera*), jujube (*Ziziphus jujuba*), drumstick (*Moringa oleifera*), guava (*Psidium guajava*) and citrus (*Citrus* spp); and the lower strata papaya (*Carica papaya*), plantain banana (*Musa paradisiaca*), aroids (*Colocasia* spp), yam (*Dioscorea* spp), creepers on trellises and trees and leafy vegetables. For homestead as well as roadside and otherwise uncropped land trees such as raintree (*Samanea saman*), banyan (*Ficus benghalensis*), pakur (*Thespesia populnea*), wood apple (*Aegle marmelos*), akasi (*Acacia auriculiformis*), tamarind (*Tamarindus indica*), Arjun (*Terminalia arjuna*), perennial pigeonpea (*Cajanus cajan*), lotkon (*Baccaurea ramiflora*) (in acidic soil) and jackfruit (*Artocarpus heterophyllus*) could be planted for timber, fruit, fuel and/or shade.

Along with trees, different fodder species, such as para and napier grass, could be planted on field boundaries and amongst trees. Such fodder crops have a high market value all year round, but of course would need protection from free grazing. Pigeonpea was once cultivated as mixed crop with broadcast aus rice. It is also effective in controlling soil erosion on pond banks, along unpaved roads, at house boundaries and on terraced land. Local people also claim that its leaf sap is an effective medicine against jaundice and worms. Although perennial pigeonpea has a slow initial growth rate it is eventually able to develop a good canopy above 2 m and can yield 500 kg ha^{-1} grain and 5,000 kg ha^{-1} of fuel in a season (Hussain et al. 1991).

In the highland, less fertile soil of the HBT, fruit orchards are becoming more prevalent. This is because of increasing riskiness of t. aman cultivation due to declining reliability of opening monsoon rains, causing large areas to remain fallow. These orchards mainly comprise mango, guava (*Psidium guajava*), litchi (*Litchi chinensis*) and citrus as these trees are relatively drought tolerant. During the first 10 years of growth of mango orchards, before the tree canopy closes, it remains possible to cultivate t. aman between the trees. Black gram is also suitable for intercropping in both establishing and established orchards as it is somewhat shade tolerant.

Rajshahi Division is known for quality mango production along with higher yield. Farmers are thus realizing that they can stabilize their year to year income by converting at least part of their land, usually elevated portions, from traditional t. aman cultivation to mango orchards. Income from a mature mango orchard is many times higher and more assured than reliance on the t. aman crop. Harvesting of mango can start even from the second year of planting, as almost all mango saplings are grafted. There are about 100 varieties of mango that could be grown but the most popular, and remunerative, are Fazle, Langra, Gopalvogh, Kirsahpat, Amrapali (Rupali) and Ashwina. Farmers choose varieties of mango species for cultivation according to expected market price. However, the major harvesting period only lasts about two months (June-July) but can continue into August. Fazle and Ashwina can be harvested over a period exceeding a month but other varieties are restricted to a window of only about 15 days (Table 6.6). However, recently some unscrupulous traders have been harvesting immature mango much earlier than the normal season and marketing them at a high price by applying ripening hormone, which ultimately deteriorates the quality of the fruit.

Table 6.6. Harvest window of major mango varieties under ambient temperature.

Mango variety	Maturity group	Start of harvesting	Harvest window (days)
Gopalvogh	Early	June 1st week	15
Khirsahpat	Early	June 2nd week	15
Langra	Medium	June 3rd week	15
Amrapali (Rupali)	Medium	June 1st week	>30
Fazle	Late	July 1st week	>30
Ashwina	Late	July 30th	>30

When there are high summer temperatures and weak opening monsoon rains most of the mango cultivars ripen almost at a time, resulting in a glut and lower market price; there is no cold storage to preserve mangos in the HBT area. Thus, with the increasing of area of mango orchards, pulp and juice industry and cold storage is becoming important to ensure stable and fair returns to growers. Mango harvesting, processing, packaging and transporting creates large seasonal labor employment and generates a significant money flow. However, due to poor packaging a large quantity of mango loses its quality or is destroyed during road transportation over a long distance. Packaging has mostly been done using bamboo baskets with low bearing capacity, but now these are being replaced by reusable plastic crates.

Mango is the leading seasonal cash crop of the northwestern region, prominent in the overall economy of Rajshahi and Chapai Nawabganj districts. With the expansion of mango farming particularly in the HBT in recent years, increasing numbers of people are becoming engaged in related employment, like producing and marketing of tree saplings across the whole country. Good bearing and reasonable market price of mango has a large positive impact on the livelihoods of HBT residents allowing greater investment in agriculture, livestock, housing, education and business. Along with this economic benefit mango, as a nutritionally rich fruit, provides much needed nutrition for malnourished people at least for three months.

Jujube was popular with HBT farmers during 1995-2005 for commercial cultivation, on land marginal for t. aman cultivation because of drought risk. The two main grafted cultivars are BAU Kul and Apel Kul, which can withstand a wide range of temperatures and are drought tolerant, requiring minimal supplementary irrigation at initial stages. The main harvest time is March-April but jujube can produce fruit up to 2-3 times per year. Like other orchard crops farmers can also get high quality cooking fuel through pruning of the canopy after the main harvest. Farmers generally keep jujube trees for 5-6 years. However, recently different insects, such as weevils, and physiological disorders, such as flower and fruit drop, have been harming production and ultimately farmers have almost abandoned jujube. These problems need to be solved to ensure sustainability of the industry for future re-introduction. Grafted jujube needs intensive care compared to mango. Jujube has a good market price in the HBT itself but has a ready market throughout the country. Jujube fields can be readily intercropped with summer mung bean and/or t. aman rice.

Since 2006 farmers have been replacing jujube with guava (Thai varieties), particularly on upper terraces (Figure 6.7). Although the main harvesting season is July to September, the fruit can be harvested year-round by employing the 'branch bending technique' (which disturbs apical dominance). Farmers regularly irrigate the guava gardens in the dry season, and use fertilizers and pesticides to improve production. Farmers also bag fruits with white perforated polythene one month before harvesting to control pests and to induce good fruit colour. Thai varieties of guava have created a huge market across the country and can generate good income and employment opportunities for the HBT farming community and traders. One bigha of guava garden can net 100,000-150,000 BDT/year (US$1,180-1,770) with 50,000 BDT investment (US$590), facilitating employment of four persons around the year. This compares with the yearly return from a single crop of traditional t. aman which is only 11,000 BDT/bigha (US$129/bigha). HBT residents are prone to deficiencies of minerals and vitamins but can

Figure 6.7. Guava growing at top of terraced land with t. aman on lower terraces. Photo credit: M. Yusuf Ali

have them supplemented from consuming guava at small cost. This fruit is rich in vitamins A and C, lycopene (an anti-cancerous antioxidant), potassium and other minerals, fiber and has no cholesterol. However, guava gardens only remain viable for 6-8 years due to incursion of fusarium/bacterial wilt and possibly also poor drainage after irrigation and rainfall. Undiagnosed nutritional deficiency symptoms appear on leaves. Thus research on development of appropriate management packages for guava cultivation for the HBT region need to be expedited and updated. Farmers need hands-on training on guava management and marketing from concerned government agencies (BARI/DAE), NGOs and companies. Recently, to replace aging guava gardens, farmers have been planting commercial citrus gardens (fruit locally called Malta).

6.6 Homestead vegetable gardening

In rural Bangladesh the homestead, usually in a village cluster, is the centre of post-harvest processing of field crops, livestock rearing, vegetable and fruit production, and, in some homesteads, pond fish culture. In a nutshell it is the hub of all livelihood activities where women have a major role, along with the male family head and other family members. Further, due to absence or death of the male many households are headed by women. Homesteads are indeed the domain of women, who can manage activities with minimum support from their male counterparts. So, this helps to integrate gender concerns in the wider farming enterprise, particularly with their role in post-harvest processing of field crops. Poor farm households can get 50 % of their food and cash from the homestead. Homestead gardening is an age-old production practice in rural Bangladesh, creating opportunities for employment, increasing food security and earning year-round income, even when field crops are damaged by drought or other constraints.

Producing fruit and vegetables on homestead land can ensure the use of otherwise fallow and unexploited land and is a way of using homestead wastes, sweepings and debris as organic fertilizer, as well as of effectively using water from within or near the homestead as an irrigation source. For drought-prone areas such as the HBT, selecting vegetables that require comparatively less irrigation water is a step towards mitigating the drought risk. Proper utilization of the homestead area through niche-based management can help to increase production of vegetables and quick growing fruit significantly. Moreover, homestead vegetables are mostly safe food, as they are usually produced with minimal reliance on pesticides, whereas commercially produced vegetables and fruits are often contaminated by excessive pesticide application (Ali et al. 2009a). Except for some leafy vegetables, water use efficiency of vegetable and fruits grown on or near the homestead is high as they can utilize household waste water. Fruit trees like papaya, *Moringa*, plantain banana, mango, guava and jujube are relatively drought tolerant and can tap ground water. As resource poor farmers can usually not afford to purchase vegetables from the market, homestead production provides a crucial means of meeting their nutritional requirement. Ali et al. (2007b) reported that the sale proceeds of homestead vegetables generally remain with women, and they use it for children’s education as well as general household needs. Except for land preparation and marketing women are mostly involved in homestead gardening, thus promoting women’s empowerment and employment (Table 6.7; Figure 6.8).

Table 6.7. Average work distribution (%) among the family members for homestead vegetable production in the HBT (Nachole and Shapahar).

Operation	Men	Women and children
Land preparation	94	6
Seed/seedling sowing	60	40
Intercultural operation	20	80
Harvesting	6	94
Cooking	0	100
Marketing	82	18

Figure 6.8. Homestead vegetable gardening in the HBT; women have a major role.

Due to limited water availability in the post-rainy season, HBT farmers produces less vegetables compared to those in floodplain areas. They also consume much below (30-35 g/head/day) the required 200 g/head/day (Ali et al. 2009b) and thus children and women often suffer from malnutrition. Through promotion of homestead vegetable production, intake could be increased significantly. Moreover, opportunities are increased for free distribution amongst the community or income enhancement from sale of excess vegetables (Table 6.8). This small intervention has a good qualitative impact on family nutrition, social relationships and the micro-environment (Table 6.9).

Table 6.8. Average production and disposal pattern of kharif and rabi season (330 days) homestead vegetables of 12 farmers at four different upazilas of HBT, Bangladesh, May, 2006 to March, 2007.

Location	Total production in 330 days (kg)	Total own consumption (kg)	Own consumption (g/head/day)[1]	Free distribution (kg)	Sold (kg)	Total Cash income (BDT)
Porsha	320	272 (85)[2]	165	35 (11)	13 (4)	156
Shapahar	259	205 (79)	124	15 (6)	39(15)	468
Nachole	330	218 (66)	132	33 (10)	79 (24)	948
Gomastapur	257	198 (77)	120	41 (16)	18 (7)	216
Mean	292	225 (77)	136	29 (10)	38 (13)	456

[1] Five members in a family were considered
[2] Figure in parenthesis indicates percentage

Table 6.9. Observed impact of vegetable gardening on the cooperating household members, HBT (Nachole and Shapahar). Source: Ali et al. (2009b).

Area of consideration	Impacts created
Income and cost reduction	Cash income marginally increased but cost of purchasing vegetable significantly reduced.
Family nutrition and health	Consumption of vegetables increased. Positive change of consumption habit. Reduced disease infection. No or less constipation. No rupture of lips and tongue due to correction of Vitamin B-2 deficiency. Health visibly improved due to higher consumption of vegetables.
Resource use pattern	Introduction of new water efficient crops. Homestead area utilized more effectively including use of all niches. Effective use of farmyard and household waste.
Education and knowledge	Increased knowledge of family members regarding modern vegetable cultivation and nutrition.
Social status	Social status increased. Improved mental strength. Increased community harmony due to free distribution of vegetables.
Micro-environment	Household waste used for composting. New plantings of gardens and trees improves the environment.
Employment	Gainful utilization of family labor increased.
Women empowerment	Active participation from women. Mostly, women keep the proceeds from sale of vegetables.
Other	Productive utilization of family labour.

Based on available niches in the ecosystem of the HBT, OFRD of BARI has developed a Barind homestead vegetable model for mass dissemination and adoption (Ali et al. 2008). However, these vegetable patterns are not rigid, as they can be modified according to farmers' choice, availability of seed, local environment and market price. Suggested vegetable models are as follows (Ali et al. 2008):

Niche 1: Sunny land

Bed 1: Red amaranth+brinjal-kangkong-kangkong
Bed 2: Spinach-Indian spinach-red amaranth
Bed 3: Radish-stem amaranth (Katua Data)-jute sak
Bed 4: Carrot/batishak+onion-okra
Bed 5: French bean-chilli-chilli

Niche 2: On-roof: Country bean-sweet gourd
Niche 3: Trellis: Bottle gourd-white gourd
Niche 4: Tree support: Potato yam/Sponge gourd
Niche 5: Partially shady area: Elephant foot (locally called moulavi kachu) (*Colocasia spp.*)
Niche 6: Fence: Yard long bean/bitter gourd/country bean/cucumber
Niche 7: Muddy wall: Country bean-sponge gourd
Niche 8: Back yard: Drumstick (*Moringa*)/plantain banana/papaya/ber/guava.

Chapter 7. Evolving Livelihoods

7.1 Signs of improvement

Since independence in 1971, there has been a gradual improvement in rural livelihoods across Bangladesh. In the 1970s, national poverty levels were 70-80 % but by 2010 they had reduced to 31.5 %. The poverty rate is highest in rural areas, at 36 %, compared with 28 % in urban centres (IFAD 2018), but rural poverty has been declining along with urban poverty. Reasons for this improvement in rural livelihoods have been summarized by Kabeer (2004) as follows:

- A general improvement in national GDP, permeating to the countryside;
- Introduction and dissemination of improved agricultural technologies, particularly new crops and improved varieties, chemical fertilizers, irrigation, etc.;
- A decline in the fertility rate;
- A changing policy environment from state monopolies to economic liberalization, with resultant increased production efficiencies;
- Growth of the rural non-farm sector (e.g. food processing) and movement of landless labourers to employment in urban centres;
- Rural infrastructure development, particularly roads (increasing farmers' market access), electricity and irrigation facilities;
- State promotion of child immunization and other health services, family planning and education; and
- The role of NGOs, in providing microfinance as well as multiple other services for rural communities.

Kabeer (2004) confirmed these reasons with detailed surveys of changes in rural household livelihood status in Chandina thana in Comilla district and Modhupur thana in Tangail district. We are not aware of such detailed studies within the HBT but observational evidence indicates a similar evolution of rural livelihoods in this region, although at a slower pace than most floodplain regions.

Livelihoods in the HBT are very much determined by incidence and severity of drought events. Historically, these have been largely confined to the post-rainy season but increasingly, with the onset of climate change, they are increasing within the rainy season (as discussed in Chapter 8). However, the HBT avoids the increasing risk of excessive inundation to which the floodplain regions of the country are prone.

Farmers of the HBT are experienced in coping with the risk of drought and are thus to some extent prepared to face increasing risk. Coping mechanisms largely rely on diversification of cropping systems, as discussed in Chapter 6, but also diversification of the entire farming enterprise. A focus discussion group in 2009 elicited from HBT farmers their opinions on how best to cope with increasing drought events, as follows (Ali et al. 2009b):

- Cultivation of t. aman in rotation with chickpea, linseed, barley and black gram under rainfed conditions.

- Use of supplementary irrigation from ponds, kharis and nearby tube wells to cultivate water melon (*Citrullus lanatus*), khira (*Cucumis anguina)*, aroids (*Colocasia* sp), sweet gourd (*Cucurbita maxima*), mustard (*Brassica campestris*), potato (local) (*Solanum tuberosum*), onion (*Allium cepa*), garlic (*Allium sativum*), cabbage (*Brassica oleracea* var. capitata), cauliflower (*Brassica oleracea* var. botrytis), tomato (*Solanum lycopersicum*), brinjal (*Solanum melongena*), etc.
- In homestead gardens, along with leafy vegetables, cultivate drought tolerant crops like man kachu, moulavi kachu (aroids under different *Colocasia spp*)), drumstick and sponge gourd (*Luffa cylindrica)*.
- Planting of drought tolerant and income generating trees like Palmyra palm, date palm and neem.
- Mango and ber gardening in the homestead area and nearby crop fields which are more drought prone and less productive for field crops.
- Rearing of sheep, goats and geese as these can survive through grazing and foraging, with little requirement for supplementary feeding.
- For more effective rain water harvesting, deepening of existing ponds and kharis and digging of small ponds at the corner of rice fields for supplementary irrigation, vegetable cultivation and seasonal fish culture.
- Compost making and use of cow dung and other organic wastes in crop fields for improvement of soil fertility and soil moisture holding capacity.
- Improved management of bamboo clumps as they are drought tolerant and income generating and useful for a range of household purposes.

Indeed, HBT farmers are increasingly implementing these measures. In irrigable areas, instead of just a t. aman-boro rice rotation, farmers are adopting cropping options such as t. aus-early hybrid tomato, potato-maize, potato-mung bean, t. aman-maize, t. aman-potato, and t. aman-mustard-boro rice. The trend is towards low water requiring but high value crops like potato, onion seed, maize (*Zea mays*), mustard, black gram (*Vigna mungo*), mung bean (*Vigna radiata*), tomato, and other vegetables, along with mango, litchi (*Litchi chinensis*) and guava gardening. Increased cultivation of high value crops in the HBT is attracting commercial investors willing to lease land to grow them. Economic analysis of some the newer cropping patterns revealed that they can be 30-300 % more profitable compared to the traditional t. aman-boro rice cropping pattern (OFRD 2008). A main driver is the much greater return per unit of irrigation water used. Boro rice requires at least 20-25 times irrigations with 6-20 cm standing water in the field (depending on growth stages of the crop), whereas other crops require only 2-8 times irrigation for saturating the soil but no standing water is needed. Thus, with this type of cropping system diversification, farmers are improving their livelihoods through increased productivity and profitability and at the same time minimizing aquifer depletion.

A summary of changing scenarios, generally leading to livelihood improvements for men and women in the HBT, is given in Table 7.1. It is to be noted that their income sources are not only diversifying within their agricultural enterprises but also from other forms of economic activity.

Table 7.1. Change of livelihood means among households in the HBT area, Bangladesh, 2010. Adapted and updated from Selvaraju et al. (2006).

Livelihoods means	Previously (circa 1980)	At present
Farming on own land	Common	Decreasing
Sharecropping	Common	Less common
Farming on rented land	Less common	Common
2-wheel power tiller use for tillage	Absent	Common
Traditional plough of bullock/buffalo	Common	Rare
Agriculture day labor/contact labor	Common	Less common
Off-farm day labor	Less common	Increasing
Rickshaw-van pulling	Absent	Common
Votvoti[1]/Nasimon[1]/2-wheel tractor driving	Absent	Common
Mechanics	Rare	Common
Bus/truck driving	Absent	Less common
Fishing (capture)	Common	Less common
Fish culture	Rare	Increasing
Boat rowing	Small number	Rare
Grocery shop in village	Rare	Increasing
Mobile phone business	Absent	Common
Vending business	Rare	Increasing
Wholesale business	Rare	Increasing
Service in government office	Rare	Common
Service in NGO/private office	Absent	Common
Commercial fruit-timber/vegetable production	Rare	Common
Nurseries (fruit/timber trees, vegetable, flower)	Absent	Common
Cattle rearing	Common	Common
Beef fattening	Absent	Common
Commercial poultry rearing	Absent	Common
Goat rearing	Common	Less common
Sheep rearing	Common	Common
Dairy production	Common	Common
Tailoring	Less common	Common
Cutting of trees/bamboo for timber/fuel	Common	Common
Bamboo bush production	Common	Common
Pottery	Common	Rare
Crafts production	Less common	Common
Electrician	Absent	Increasing
Factory/industry worker	Absent	Increasing

[1] Locally made motorized vehicles, powered by diesel or batteries

Socio-economic transformation of the society and economic hardship are bringing many more women of landless and female-headed households into different economic activities.

Beyond the traditional household and farming activities women are engaging themselves in different commercial activities to increase family income for livelihoods improvement. An indication of these changes is given in Table 7.2

Table 7.2. Change of livelihood means among women in the HBT area, Bangladesh, 2010. Adapted and updated from Selvaraju et al. (2006).

Livelihoods Means	Previously (circa 1980)	At present
Paddy husking by dheki[1]	Common	Rare
Household maid	Common	Less common
Paddy winnowing and cleaning	Common	Less common
Boiling paddy and drying	Common	Common
Cooking for labourers during paddy harvest and processing	Common	Less common
Grocery shop plus mobile phone	Absent	Increasing
As laborers for earth-works	Rare	Increasing
Building construction laborers	Absent	Increasing
Embroidering and stitching garments	Rare	Increasing
Homestead vegetable management	Rare	Common
Harvesting root crops	Common	Common
Planting seedlings of trees	Absent	Less common
Government job (teaching and other)	Absent	Increasing
Regular private jobs	Absent	Less common
Poultry and goat rearing	Common	Common
Cattle rearing and beef fattening	Less common	Increasing
Geese rearing	Less common	Increasing
Commercial poultry rearing	Absent	Increasing
Small business enterprises in village market	Absent	Less common
Working as laborer in rice mill	Rare	Increasing
Become NGO member and taking loan for economic activity	Absent	Common
Pottery	Common	Rare

[1] A wooden instrument used for dehusking rice.

7.2 Risk management in rural households

Families or households can respond to risk in different ways (TANGO 2004). For most vulnerable households, risk management involves both pre-shock (*ex ante*) and post-shock (*ex post*) actions. Pre-shock actions are preventive measures taken to reduce risk (e.g., drought tolerant crops, diversified livestock production, fruit gardening, tree planting, etc.) or lower exposure to risk (e.g., livelihood diversification, off-farm employment). Households can also reduce risk through investment in insurance strategies such as precautionary savings or association with supportive social networks. Post-shock risk management refers to actions taken in response to the occurrence of shocks. Such actions are often referred to as coping strategies in that they are undertaken in an effort to manage the negative impacts and limit potential losses of food and livelihoods security posed by shocks that have already occurred (TANGO 2004).

Households in HBT employ a variety of strategies to cope with shocks, which include economic and socio-political shocks as well as natural disasters such as drought/cyclone/flood (Table 7.3). The most commonly employed coping strategies are: limiting food portions at mealtime, relying on cheaper or less preferred foods, purchasing food on credit, borrowing from relatives/friends/neighbours, seeking off-farm employment and reducing adult consumption to provide for children.

Table 7.3. Coping strategies of different categories of farmers against drought and other natural calamities in the HBT (percentages). Source: modified from WFP (2006).

Coping strategies	**Big farmer**	**Medium farmer**	**Small/ marginal farmer**	**Landless farmer**
Limit portion size at mealtimes	42.0	67.1	79.4	84.1
Reduce number of meals	36.5	67.4	63.2	82.6
Borrow food or rely on others	50.1	58.9	58.2	62.0
Rely on cheap or less preferred food	23.2	57.7	53.4	73.8
Purchase food on credit	36.2	47.4	52.7	69.9
Gather wild food	–	0.2	3.3	7.7
Send household member to eat elsewhere	6.5	17.5	13.9	23.9
Reduce adult consumption	16.6	40.0	39.1	41.8
Rely on casual labor for food	10.1	18.9	19.4	26.5
Abnormal migration for work	4.6	19.7	30.6	30.1
Skip entire day without eating	–	12.4	16.6	55.8
Consume seed stock	22.9	17.8	4.7	3.7
Borrow money from bank, NGO, relatives, money lender, etc.	8.3	17.2	30.5	55.3
Farmland mortgaged out	–	5.3	10.1	–
Sell animals	63.7	25.3	10.1	2.1
Sell trees/bamboo	25.5	10.1	2.5	–
Sell other household assets	–	–	10.5	20.3
Change occupation/van pulling	–	–	5.10	11.0
Begging	–	–	–	1.1

When farmers lose much of their crop(s) to drought or some other calamity their first reaction is to sell their livestock or trees. In a dire situation, they may also sell off their household assets, such as furniture and utensils, to cover food cost. However, many small and marginal farmers lose their land in extreme situations and thus become landless. There is now an increasing trend for small, marginal and landless farmers to cope by migrating to larger towns or cities to sell their labour or engage in rickshaw pulling, small business or transporting grocery goods, etc. Many landless, marginal and small farmers are tempted to avail small loans from different NGOs or money lenders. They are often caught in a debt trap as interest rates imposed by money lenders and some NGOs are high and if they cannot meet repayments they are tempted into a secondary loan, which usually worsens their plight. Interest rates of commercial and government banks are lower but require collateral to avail, which excludes most resource poor farmers. After a drought, most categories of farmers need a loan to purchase inputs like seed, fertilizer and irrigation for the next crop.

Thus, severe drought in rainfed areas has a drastic effect on the livelihoods of all categories of farmers but more so on resource poor farmers. It is assumed that for covering the loss due to severe drought in one year at least three years is required for farmers to restore their livelihoods status. However, when continuous drought or near drought occurs for 2-3 consecutive years many resource poor farmers cannot cope with the situation. They are thus forced to change their occupation, migrate to urban areas to seek employment or face complete destitution, as the Government's social security safety net is meagre. This situation also makes people more prone to illness and disease, which further exacerbates their financial circumstance.

Coping capacity is influenced by the degree of capital and resources held by the household. Livelihood security depends on a sustainable combination of each of these resources and that some are prerequisites to others. In all cases, the most vulnerable households are those that lack these resources and therefore have limited access to services and systems that sustain livelihoods (TANGO 2002). Forms of capital that influences coping capacity are described in Table 7.4.

Table 7.4. Forms of capital that influence coping capacity and livelihood security of a household. Source: WFP (2006).

Asset	Description
Natural	Natural resource stocks from which livelihoods are derived (e.g. land, water, wildlife, biodiversity, and environmental resources).
Financial	Cash and other liquid resources, (e.g. savings, credit, remittances, pensions, etc.).
Physical	Includes basic infrastructure (e.g., transport, shelter, energy, communications, and water system), production equipment, and other material means that enable people to maintain and enhance their relative level of wealth.
Human	Consists of skills, knowledge, ability to work and good health, which are important to the pursuit of livelihood strategies.
Social	The quantity and quality of social resources (e.g., network, membership in groups, social relations, and access to wider institutions in society) upon which people draw in pursuit of livelihoods. The quality of networks is determined by the level of trust and shared norms that exist between network members.
Political	Consists of relationships of power and access to and influence on the political system and governmental processes at the local and higher levels.

7.3 Diversified livelihood sources

Diversified income sources are regarded as the best way to fight against an uncertain climate, other natural hazards, and deaths, diseases and accident. Ali (2014) and Dixon et al. (2001) have identified diversification and intensification of agriculture and increased off-farm income as the major ways of reducing poverty for different farming systems of Bangladesh (Table 7.5).

OFRD of BARI have identified several potential cropping systems for the HBT based on their long experience of farming system and on-farm research in the context of prevailing frequent drought, scarcity of surface water and declining groundwater levels. For t. aman-boro cropping in the HBT they propose that boro rice be limited to valleys and elevated areas be used for high value and relatively water use efficient crops like potato, mustard, maize, onion, garlic and mung bean, to follow harvest of short duration t. aman. Indeed, several commercial enterprises have begun to follow these recommendations. For example, over the previous decade the 'Aman Group' has leased farmers' land at Amnura and Nachole, and elsewhere in the HBT, for potato seed cultivation. Recently they have put over 250 ha under a short duration t. aman (BINA Dhan 7)-potato pattern.

Table 7.5. Potential and relative importance of household strategies for poverty reduction in Bangladesh. Source: Ali (2014).

Farming Systems	Potential for agricultural growth	Potential for poverty reduction	Strategies for poverty reduction[1]				
			Intensif-ication	Diversif-ication	Increased farm size	Increased off-farm income	Exit from agriculture
Rice	Moderate	Low-moderate	2	3	0	3	2
Coastal Artisanal Fishing	Moderate	High	2	3	0	3	2
Rice-Wheat	Moderate	Moderate	2	2	1	2	3
Highland Mixed	Moderate	Low	1	3	0	2	3
Mean across farming systems	–	–	1.75	2.75	0.25	2.5	2.5

[1] Total score for each farming system equals 10. Assessments refer to poor farmers only.

OFRD have advocated that highest elevations should be confined to fruit or timber tree plantation. As well as improving the local ecology, trees provide a form of insurance for unforeseen and predictable future costs such as crop failure, marriage of daughter, education of children or Hajj expenses. Of course, rearing of livestock, from cattle to poultry, provides another form of insurance for periods requiring more than usual expenditure. This is particularly important for resource poor farmers and rural women as they usually do not have sufficient land on which to plant trees.

Dixon et al. (2001) predicted that farming systems in Bangladesh will increasingly and aggressively incorporate many forms of diversification, such as fruit gardening, vegetable production, agroforestry, fruit and timber tree nurseries, ornamental plants and flowers and different cash crops, by land owners themselves or by leasing to businessmen-cum-farmers. Diversification will generally require investments in marketing, transport, infrastructure, research, extension and support services. Government agencies will likely continue to supply more modern cultivars, management technologies, post-harvest processing technique but the private sector, NGOs and farmers' cooperatives would progressively involve themselves in these activities. Similarly, the demand for technical and market information could be addressed through public-private partnerships. Although the predominant risk for the HBT is water deficit, this region avoids the risk of flooding to which most of the lowlands of Bangladesh is prone, and in that sense offers a more predictable environment. Adaptation options at farm level for irrigated and non-irrigated areas of the HBT are summarized in Table 7.6.

Table 7.6. Options available for livelihoods adaptation to optimize farm production in the HBT.

Technology/Options	Irrigated ecosystem	Partially irrigated	Rainfed	Farm category: Small/ Marginal (<1 ha)	Farm category: Large (>2 ha)
Crop diversification and intensification					
Mustard-boro-t. aman	Yes	-	-	Yes	Yes
Potato-mung bean-t. aman	Yes	Yes	-	Yes	Yes
Potato-maize-t. aman	Yes	Yes	-	-	Yes
Maize-mung bean-t.aman	Yes	Yes	-	Yes	Yes
Early tomato-t. aus	Yes	Yes	-	Yes	Yes
Wheat-mung bean/fallow-t. aman	Yes	Yes	-	Yes	Yes
Boro-t. aman	Yes	-	-	Yes	Yes
Chickpea/barley/linseed-t. aman (or mixed cropping)	-	-	Yes	Yes	Yes
Mustard (short duration)-t. aman	-	Yes	Yes	Yes	Yes
Lentil-t. aman	-	-	Yes	Yes	Yes
Black gram/horse gram-t. aus	-	-	Yes	Yes	Yes
t. aus-t. aman (Chiniatap – aromatic, long-duration variety)	-	Yes	Yes	Yes	Yes
Onion/garlic-fallow/t. aus-t. aman	Yes	Yes	-	Yes	Yes
Water melon/khira-t. aman	-	Yes	-	Yes	-
Vegetables-t. aman	Yes	Yes	-	Yes	Yes
Water use efficiency in rice					
Direct seeding of rice by PTOS or strip tillage in boro and t. aman	Yes	Yes	Yes	Yes	Yes
Dry seed bed method for t. aman	-	Yes	Yes	Yes	Yes
Manual closing of soil cracks for rice crops	Yes	Yes	Yes	Yes	Yes
Raising height of field bunds to retain rain or irrigation water	Yes	Yes	Yes	Yes	Yes
Supplementary irrigation in t. aman with plastic pipes from DTW or surface source	Yes	Yes	Yes	Yes	Yes
System Rice Intensification (SRI) in Boro	Yes	-	-	Yes	Yes

Table 7.6 *continued*

Technology/Options	Irrigated ecosystem	Partially irrigated	Rainfed	Farm category	
				Small/ marginal (<1 ha)	Large (>2 ha)
Water Harvesting					
Re-excavation of traditional ponds	Yes	Yes	Yes	-	Yes
Excavation of new pond/mini-pond	-	Yes	Yes	Yes	Yes
Re-excavation of khari/canal (by Govt.)	Yes	Yes	Yes	-	-
Construction of water control structure (by Govt.)	Yes	Yes	Yes	-	-
Excavation of dighi/sinking of DTW (by Govt.)	-	Yes	Yes	-	-
Diverting water from rivers (by Govt)	Yes	Yes	Yes	-	-
Other farming enterprises					
Bamboo clump in homestead/adjoining area and management of fungal diseases to which its is prone	-	-	-	Yes	Yes
Cattle/buffalo/sheep/goat/chicken/ geese/pigeon rearing	-	-	-	Yes	Yes
Layer/broiler chicken farming	-	-	-	-	Yes
Seasonal beef fattening/small dairying	-	-	-	Yes	Yes
Fodder cultivation on tree/road side/house boundary	-	-	-	Yes	Yes
Year-round or seasonal fish cultivation in pond/mini-pond/khari/depression	Yes	Yes	Yes	Yes	Yes
Off-farm employment, value addition of agricultural products, cottage industry	-	-	-	Yes	Yes
Soil fertility and erosion control					
Application of manure/compost/green manuring/brown manuring	Yes	Yes	Yes	Yes	Yes

Table 7.6 *continued*

Technology/Options	Irrigated ecosystem	Partially irrigated	Rainfed	Farm category	
				Small/ marginal (<1 ha)	Large (>2 ha)
Alternate fuel and energy sources and cultivation method					
Community or family based bio-gas plant	-	-	-	Yes	Yes
Mechanized minimum/strip/zero tillage and/or bed planting for crop production (conservation agriculture)	Yes	Yes	Yes	Yes	Yes
Watershed based farming	-	Yes	Yes	Yes	Yes

7.4 Rainfed cropping options

Resilience of agricultural production in the HBT is going to increasingly rely on expanding rainfed cropping options. The scope of bringing more area in the HBT under DTW irrigation is very limited because of the lack of suitable aquifers at reasonable depth. It is estimated that agriculture in 55 % of the HBT is carried out under rainfed conditions. This is mainly in the northern HBT but there are several pockets in the southern HBT devoid of DTW for different reasons.

Water from DTWs is generally used for rabi season crops and cultivation of t. aman largely needs to rely on monsoon rainfall. With increasing frequency of dry spells during the monsoon season, use of DTW water for the t. aman crop is an option but this would further hasten water table decline. Thus, supplementation of water requirements of t. aman is thought most prudent to come from harvesting of rain water, through re-excavation of existing ponds, kharis and excavation new ones, through private, community and government endeavor, and through diverting water from nearby rivers like the Padma or Mahananda.

To better exploit sporadic rainfall events during the kharif-I season (March-May), direct seeding of short duration aus rice, jute (*Corchorus* spp.), kenaf (*Hibiscus cannabinus*), dhaincha (*Sesbania aculeata)*(for fuel and organic matter) or pigeonpea (*Cajanas cajan*) could be considered. Vegetables have an important role in fulfilling the nutritional and health requirements. However, they are mostly only available through the winter period, and thus there is a need to increase their year-round availability. In homestead and adjoining areas different quick growing vegetables like Indian spinach *(Basella alba)*, kangkong *(Ipomoea aquatica*), amaranth (*Amaranthus spp.*), lady's finger or okra (*Abelmoschus esculentus*), chilli (*Capsicum* spp), early tomato, country bean (*Dolichos lablab*), different creeping vegetables and pit based vegetables (e.g. sponge gourd, ribbed gourd (*Luffa aegyptiaca*), snake gourd (*Trichosanthes cucumerina*), white gourd (*Benincasa hispida*), etc.) could be planted during kharif-I. Creeper sponge gourd is highly adaptable both in drought and marshy conditions and can climb onto trees, stakes and roofs, thus taking up minimal ground level area. In between kharif-I rain events, these vegetables can be supplemented by small amounts of water, normally available from homestead sources, such as ponds.

Plantain banana is a useful and highly drought tolerant species for use as a vegetable particularly at vegetable-scarce times as during September-October. It can be planted in backyards and house boundaries and requires almost no management beyond planting of the sucker. Pigeonpea can be planted along homestead boundaries, field bunds and in chara land (high land) for checking erosion as well as for grain, fuel and its leaves which have medicinal value. As a legume it also fixes N.

Planting of *baromasi* drumstick (*Moringa oleifera*) cuttings could be completed within April-May. Drumstick leaves and pods have high nutritional quality and medicinal value and also have good market price. Its leaves are popularly used in vegetable preparations in the HBT (Figure 7.1). Planting of potato yam (*Diascorea spp*) should also be completed within April-May in backyards and at the bases of trees forming boundary fencing. Cassava and different aroids (*mankachu, moulovikachu, panchamukhi kachu,* etc.) could also be planted in backyards, house boundaries and other otherwise unused spaces. All of these species are highly drought tolerant and are sometimes regarded as famine reserve crops.

Figure 7.1. Year-round production of pods by a *Moringa* tree in the HBT (left); and children washing *Moringa* leaves with pond water for cooking as vegetable (right).

In shady places near the homestead and adjoining areas turmeric or ginger may be planted to utilize vacant spaces. Bamboo is an important resource which should be managed (cleaning, soiling and fungicide spray) and planted to create new clumps in the homestead area and in less fertile areas. Sale of bamboo is a contingency option for farmers as it is rarely destroyed by natural calamities like flood, drought, etc. Moreover, it’s branches and leaves are an important source of cooking fuel. Bamboo has good market value in urban areas, particularly for construction work, and businessmen come to rural areas to purchase it.

Declining rainfall in the kharif-II season (June-September), including earlier cessation of monsoon rains (Chapter 8), along with the low water holding capacity of most HBT soils, is increasing the riskiness of rainfed t. aman cultivation. Swarna remains as the most widely grown t. aman variety; this is a longer duration variety, normally harvested from mid-November to early December, and therefore increasingly faces terminal drought stress. Many shorter duration rice varieties are now available (Table 7.7) and these deserve promotion amongst farmers. However, the yield potential of shorter duration varieties is usually less than for long duration varieties (provided the long duration varieties have adequate water well into grain filling) (Table 7.7) but they are more reliable in being able to complete grain filling before water becomes limiting. Basically, more research is needed into the development of locally adapted short duration, drought tolerant fine rice varieties.

Table 7.7. Comparative growth duration and yield of different t. aman rice cultivars, HBT, Rajshahi. Source: OFRD (2007).

Cultivar	Days to maturity	Yield (t ha^{-1})		Grain quality
		BARI expt.	DAE demo.	
Swarna (sada)	140	4.25	3.69	Medium
Swarna (lal)	141	4.12	3.55	Medium
BRRI dhan 39	119	3.86	3.55	Medium
BRRI dhan32	137	3.66	3.39	Coarse
BRRI dhan 33	118	-	3.36	Coarse
BINA 7	119	-	3.66	Medium
Pant-10	115	2.06	-	
Judi 567	117	2.72	-	
Barkhe 3004	135	3.41	-	
BRRI dhan 49	141	-	3.41	Coarse
IR 50	105	-	2.64	
Super 3004	134	4.19	-	

Along with development of t. aman varieties better adapted to the HBT, various agronomic means of combating drought stress remain important. For timely seed bed preparation for t. aman the dry seed bed method should be followed. Although, traditionally, rice seed beds are prepared under puddled conditions it is possible to raise rice seedlings in a similar manner to other crops with the soil maintained at no more than field capacity. To minimize evaporative loss the soil can be covered with banana leaves or polythene sheeting. Further, deep transplanting (4-6 cm) of t. aman seedlings promotes deep rooting and hence better access to soil moisture at late growth stages.

For supplementary irrigation, there is much scope for excavating mini-ponds by the side of fields, as elaborated in Chapter 9.

7.5 Increasing market access

Bangladesh has made considerable progress in most sectors from the 1980s, including in the HBT. However, North-West Bangladesh, and particularly the HBT, mostly depends on agriculture as almost no industry is located here. However, initiation of irrigation expansion, road development, electrification, afforestation since 1986 through BMDA has facilitated a large change in the agricultural production and economic development across the HBT. People are investing more for family food consumption, communication, clothing, recreation, schooling for children and for different types of electrical and electronic appliances. BMDA has invested more than US$155 million in development of the HBT. This has created a large money flow, significant local employment, service sectors with good backward and forward linkages and some small industries.

Moreover, the commissioning of Jamuna river bridge in 1998 has directly linked North-West Bangladesh with Eastern Bangladesh, particularly with Dhaka, thus opening up markets. Due to improvement of road communication within the HBT and increased production, the marketing sector has considerably developed. High value crops like early tomato, fruits (mango, jujube, papaya) and vegetables are packaged and directly transported to Dhaka by truck. Surplus rice is also being transported to Dhaka and other parts of the country mainly by road. This has also created many informal new jobs, though some are seasonal. Agricultural products from remote villages can now reach large and distant markets, initially via feeder roads, as discussed below.

Commercial organizations and businessmen from adjacent areas and cities have come forward to lease comparatively cheap land in the HBT to produce high value crops like tomato, potato, maize and mung bean, as well as HYV/Hybrid boro and t. aman rice. These business ventures have brought modern technology along with capital. Some are even sinking DTW at their own cost to produce different crops around the year, but without much concern about the sustainability of water extraction. Anecdotal information suggests that they are achieving good yields and desirable profits, and the land owners are also satisfied as they are receiving higher income compared to traditional t. aman farming. This phenomenon is transforming subsistence agriculture towards commercial agriculture, albeit slowly. It also hastens the dissemination of modern agriculture technology among the local farmers. Through increased research and development activities of different national institutes, like BMDA, BARI, BRRI and DAE, and NGOs modern technologies are being continuously transferred.

7.6 Information and communication revolution

From 2000 onward the mobile phone has brought an information revolution across Bangladesh. From farmer's field to house wife's kitchen, from rickshaw van drivers to small fish traders everybody is availing the use of cheap cell phones for their business and personal activities. Even illiterate men and women have adapted to use cell phones; some are only receiving the phone calls from their relatives and dear ones. Now almost each household has one to several mobile phones with different operators. Mobile phones are now frequently used for collecting information on all aspect of livelihoods including agricultural technology, market price and availability of products or services, education, office communication and so on. Traders are mostly benefited by this phone, as their purchasing, selling and exporting of products to Dhaka and other distance cities are through this medium of communication. A good number of people are involved in the service and business of selling, repairing and flexi-loading money to mobile phones. The influence of the mobile phone is likewise ubiquitous in the HBT. One example is that Rajshahi businessmen transport mango to the cities where there is a greater profit margin. Mobile phone and television based information has increased awareness and opportunity across the bulk of the population, except for the ultra-poor who are still unable to afford their use.

We could expect further and more sophisticated use of mobile and smart phones into the future, especially to assist farmers as more relevant applications are developed.

Increased access to mobile phones and television has not only increased awareness within the HBT population but also expectations regarding livelihood improvement.

Feeder roads constructed by BMDA have greatly helped to revolutionize communication for far-flung areas of the HBT. Earlier mainly bullock or buffalo drawn carts were the main mode of transport in landlocked muddy roads of the HBT. As HBT soil is clayey and sticky it becomes difficult to move along non-paved roads on rainy days and in summer due to dust and heat. This limited timely access to markets while draining the energy of the residents. However, this situation gradually changed after commissioning of government activities. Since 1986 BMDA has constructed 1,200 feeder roads with about 500 km now paved and the remainder planned to be paved in phases. As well as conventional transport means such as trucks, buses and auto-rickshaws, locally made vehicles also ply these feeder roads. These include three-wheel vans powered by a shallow-tube well engine and trolleys pulled by power tillers. These unconventional vehicles carry heavy loads across the HBT at a low cost, thus bringing a communication revolution to remote areas. These innovations have created jobs for village people, although these local innovations suffer from frequent mechanical difficulties and their drivers have little knowledge of traffic rules. Transport from feeder roads links with trucks on main roads to allow rapid marketing of agricultural products in major cities.

These transport innovations have helped remote HBT farmers and businessmen to link so as to achieve a better market price for agricultural produce as well as facilitate availability of agricultural inputs, and permit a fair price to consumers. All of these physical developments, along with DTW installation and electrification, have increased income of farmers and traders and contributed to improved livelihoods of the farming community of HBT. However, it has also created high ambition and expectation particularly among the youth, with most of them less inclined to take up direct agricultural work. Thus seasonal labor scarcity is an increasing problem and costly item for many farmers. Ultimately it may facilitate more use of power and mechanization in agricultural activities and this could lead to further growth of commercial agriculture. However, the information and communication revolution has facilitated better education among both boys and girls, although education has become costly and the poorest of the poor have almost no scope to move to moderate or higher education. Thus instead of going to school, boys of the poorest families are employed in different informal or manual jobs with minimum wage and girls work as maids or search for water, fuel and food for the family.

Chapter 8. Climate Change Scenarios

Since pre-industrial times global mean temperature has risen 1 °C, due primarily to the increase in atmospheric CO_2 concentration from below 250 ppm to beyond 400 ppm in 2017, along with increasing concentrations of some other greenhouse gases like methane and nitrous oxide. Increasing concentrations of greenhouse gases are due primarily to the burning of fossil fuels as well as deforestation and various agricultural practices such as excessive tillage and rumen fermentation in livestock. In a business-as-usual scenario, that is with continued industrialization reliant on burning of fossil fuels and unchanged land use practices, modelling suggests that global temperature rise will exceed 2 °C by 2050. This temperature increase may seem small but it has profound effects on the global climate and sea level rise. Even with the present 1 °C rise effects on glacial melting, sea level rise, changing climatic patterns, heatwaves, storm severity, etc. are readily apparent (IPCC 2014).

Bangladesh is considered to be one of the countries most likely to be adversely affected by climate change, primarily through sea level rise, salinity intrusion, periodic flooding of major water courses, disruption of historic rainfall patterns, increased severity of cyclones and rising temperatures (Karim and Iqbal 1997; Ahmed and Alam 1998; IPCC 2000). Low lying areas of the country will bear the brunt of these effects, some of which are already manifesting themselves. Sea level rise and salt water ingression along coastal areas are already apparent, as are changing rainfall patterns, severity of flooding (as in north-eastern Bangladesh in 2017) and increasing temperature stress.

However, the HBT region is the part of Bangladesh least likely to be affected by excess water problems due to its elevation above flood levels that are increasingly being breached in the central, low-lying parts of the country. It is predicted that global warming will increase total annual rainfall in Bangladesh, but with greater variability in incidence and distribution. However, total rainfall in the HBT is predicted to increase to a lesser extent, or even decrease. Bangladesh's drought-prone areas, such as the HBT, are indeed warmer and drier than 50 years ago (Selvaraju and Baas 2007). With rising atmospheric temperature in tropical regions, there is increased evaporation of water from the ocean into the atmosphere, leading to greater quantity and intensity of monsoon rains. Even though the HBT is the most drought prone area of the country, it is not prone to large scale flooding. This could be seen as a major advantage compared to low lying areas of the country, as time passes. Increasingly intense rainfall events in the monsoon season, however, may increase risk of local flooding along minor, usually dry, water courses (i.e. kharis) in the HBT.

There has indeed been a downward trend in annual rainfall at Rajshahi, as representative of the HBT, since 1980 (Figure 2.5). However, winter rainfall is predicted to further decrease over time and become increasingly erratic, thus further disrupting rainfed agriculture in the post-rainy season (Table 8.1). As can be seen from Figure 2.3 winter rainfall is already very erratic (as indicated by standard deviation exceeding mean) although a clear declining trend over time is not yet apparent.

Temperature rise increases evapotranspiration, exacerbating the effect of dry spells. Global Circulation Models project more warming for winter than for summer months. Indeed, Rajshahi meteorological data analysis indicates recent increases in maximum and minimum temperatures (Figures 2.7 and 2.8).

Table 8.1. Estimates of temperature and precipitation changes for Bangladesh (Agarwala et al. 2003).

Year	Temperature change (^{o} C) mean (standard deviation)			Rainfall changes (%) mean (standard deviation)		
	Annual	**DJF[1]**	**JJA**	**Annual**	**DJF**	**JJA**
Baseline	-	-	-	2,278 mm	33.7 mm	1,343.7 mm
2030	1.0 (0.11)	1.0 (0.18)	0.8 (0.16)	+3.8 (2.30)	-1.2 (12.56)	+4.7 (3.17)
2050	1.4 (0.16)	1.6 (0.26)	1.1 (0.23)	+5.6 (3.33)	-1.7 (18.15)	+6.8 (4.58)
2100	2.4 (0.28)	2.7 (0.46)	1.9 (0.40)	+9.7 (5.80)	-3.0 (31.60)	+11.8 (7.97)

[1] DJF-December, January, February; JJA-June, July, August.

Anecdotal accounts from older farmers (Table 8.2) also suggest that the HBT is gradually become hotter during summer months and winter is becoming less cool with shortening of duration. The break of the monsoon to signal planting of t. aman rice is also becoming more erratic over time. Generally declining rainfall in the monsoon season, and its increasingly erratic incidence, is seriously hampering t. aman cultivation causing reduced yield and necessitating supplementary irrigation, if available, which in turn further lowers the water table. Declining annual rainfall also contributes to increasing shortages of water for household use, due to ponds not filling (Figure 8.1) and kharis emptying. Farmers believe that, with declining rainfall incidence, soil heats up affecting both life forms dependent on it (crops, livestock, soil microorganisms) and radiating further heat to the air above it.

Figure 8.1. Pond water remaining at a low level just after monsoon of 2010 due to extremely low rainfall, Godagari, HBT, Bangladesh. Photo credit: M.Y. Ali

Table 8.2. Anecdotal data of elderly farmers (age in parentheses) on changes over time in climate, forest area, animals and rice yield of the HBT (data from survey by M. Yusuf Ali and A.M. Musa).

Factor	Nazma Khanam (77)	Md. Jajaluddin (67)	Abul Khair (52)	Abdus Samad (87)
Rainfall	Less than previous and not timely. Less heavy rainfall than previous.	Less than previous and not timely. Less heavy rainfall than previous.	Less than previous and not timely. Less heavy rainfall than previous.	Less than previous and not timely. Less heavy rainfall than previous.
Temperature	Very hot summer now, even wind is hot; winter is short and warmer than previously.	Now April-May temperature is unbearable if no rain. Winter is shorter and warmer than previously.	Hotter summer, shorter duration and warmer winter than previously.	Summer is long and hotter but winter is short and warmer than in earlier days.
Forest and big trees	There were many big trees	Many big trees[1] like simul, tamarind, kodbel, mango, kadam, etc.	Thorny bushes and big trees on field bunds.	Thorny bushes and big trees on field bunds.
Chala land/high land	–	In early days mostly remained fallow.	In early days mostly remained fallow.	Earlier mostly fallow and was sometimes used as grazing land.
Animals and birds	Lots of birds and monkeys and different cats.	Different types of cats, monkeys, snakes, crocodiles, birds.	Different birds were available.	Crocodiles, tigers, monkeys, cats, wild buffalo, tortoises, snakes, many types of birds and fish.
Traditional Rice yield/rice cultivar	–	T. aman yield is decreasing gradually because of low soil fertility.	T. aman yield is often decreasing gradually due to terminal drought.	T. aman yield is decreasing gradually.
Boro rice cultivation	–	Needed to ensure food security but costly.	Need huge irrigation, so costly, though yield is good	Needed to ensure food security but costly and often less profitable
Deep tube well water level	–	Receding each year.	Receding each year by about 3 m. Recharge rare.	Receding each year, problem in drought year.
Livelihoods	Improved, because of diversified income sources.	Better than previously due to other jobs and business income.	Better because of diversified income source, good communication and different project activities.	Better due to more production from land, business and service.

[1] Simal or red silk cotton tree (*Bombax ceiba*); Kodbel or elephant-apple (*Limonia acidissima*); kadam or burflower tree (*Neolamarckia cadamba*).

Residents of the HBT have long been aware that “Barind is a land where life is written in water”. Indeed increased agricultural production in the HBT over recent decades has mainly relied on the on the installation of DTW. These now provide irrigation for some 55 % of the HBT area, but mainly in southern areas (Ali 2000). The resultant irrigation water is used predominantly for the cultivation of boro rice, a high water requiring crop. However, once abundant aquifers are rapidly being drawn down, reducing the command area per DTW (Selvaraju et al. 2006). These aquifers have accumulated water over centuries and expected rates of recharge cannot possibly match the extraction rate. Some recharge of aquifers would have historically come from the Ganges (locally named the Padma) River on the southern edge of the HBT, but this prospect is diminishing primarily due to reduced river flows caused by diversion of Ganges water on the Indian side of the border. Melting of Himalayan and central Asian glaciers and increased monsoon rainfall in catchment areas in India and Nepal, as a result of climate change, have the potential to increase Ganges flows but this is of little avail to recharging aquifers in the HBT if Ganges flows remain diverted. A further impedance to HBT aquifer recharge is the low water infiltration rates of most HBT soils (Ali 2000; Ali et al. 2007b). When heavy monsoon downpours do occur, rainwater tends to run off the soil surface into seasonal streams and flow out the HBT region, rather than infiltrate into the soil to recharge aquifers.

Of course, these problems of aquifer recharge would also to some extent exist if climate change was not a factor, but they are generally exacerbated by climate change. Hence the necessity of being even more rigorous in allocation of water, including irrigation and rain water, to crops so as to achieve maximum sustainable agricultural production per unit of water available and ensure food security and reasonable livelihoods for the region. The monsoon rice crop, now almost exclusively transplanted (t. aman) but with potential for direct sowing with mechanization, remains the cornerstone of cropping in the HBT. Climate change is causing monsoon downpours to be increasingly erratic, with delayed breaks to the season and increasing periods of drought stress through the season. It is therefore suggested that priority for irrigation water be given to ensuring the rainy season rice crop, that it is available to ensure a timely start to planting and to protect crops from intermittent and terminal drought. Even though higher and assured yields can be obtained with fully irrigated boro rice, it would not be wise to rely on this crop as a cornerstone crop. It would seem more sustainable to allocate the declining irrigation resource to supplement and protect rainfed crops.

It is considered that boro rice cultivation should be confined to areas of the country where there is adequate and sustainable irrigation water available through the post-rainy season, that is, the lowland areas with good groundwater recharge prospects. Post-rainy season crops in the HBT should be confined to low water requiring crops that can reliably produce on stored soil moisture, occasional winter rainfall and limited supplementary irrigation as required. Such crops include wheat, short-duration maize, potato, a range of vegetables, pulses, onion and oilseeds, all of which are of potentially high value compared to rice.

Households solely dependent on agriculture, and least diversified forms of agriculture, would be most affected by climate change. This necessarily includes resource poor farmers, who also have least resilience capability to the extent that even minor deviations from ‘normal’ environmental conditions can have devastating impacts on livelihoods. First effects of an unusual dry spell are on crop performance, whether it be delayed sowing due to late arrival of monsoon rains or drought spells during crop growth. However, as ponds dry out and water tables decline water available for drinking and normal household use becomes an increasing problem. Poor farmers have little capability of buying in water from elsewhere. Health of livestock would also deteriorate due to both declining water and feed availability, and farmers would be forced to sell them at low prices. They would also be tempted to sell off any trees within their household for timber. Affected farmers would need to seek off-farm employment for survival. Of course, the aged and women would be most affected by such circumstances. Thus climate change in the HBT poses a major threat to the most vulnerable in rural communities and mitigates against any attempts to reduce the wealth gap in rural areas. It would likely enhance migration to urban areas, thus further exacerbating urban poverty. Contingency plans to assist resource poor farmers to manage environmental deviations resulting for climate change are thus well worth investing in, for the benefit of the entire society.

Chapter 9. Remedial Steps

A prime requirement for improving agricultural productivity in a sustainable manner in the HBT is to maximize capture and make optimum use of available water, primarily derived from current rainfall. This has become increasingly important in view of the changing weather patterns induced by climate change. This needs to accompany improved soil management techniques and more effective choice of crop, crop rotation and other agricultural and land use enterprises.

9.1 Increasing water capture and use

Watershed management and rainwater harvesting

Being largely undulating the HBT is amenable to a watershed approach, aimed at capturing the maximum amount of rainfall for the purpose of growing crops and trees. Due to the high bulk density and low organic matter content of HBT soils, the proportion of runoff to areas outside of the HBT is high. Adham et al. (2010) estimated that only 8.6 % of annual rainfall percolates to the sub-surface soil and thus contributes to groundwater recharging. If more rainfall can be captured at or near where it falls there would be a greater possibility alleviating the initial, mid and terminal drought stress regularly faced by the t. aman crop and allowing more assured post-rice cropping.

A first step in this regard would be a comprehensive topographic and groundwater survey of the HBT to identify optimum sites to establish water catchments, which could provide supplementary irrigation as needed. The south-western part of the HBT is particularly suited to watershed development. Such surveys would allow optimum excavation and re-excavation of ponds, kharis, canals, etc. and optimum placement of weirs. However, this approach requires the active participation of local farmers and landlords, government agencies, research and development organizations and NGOs. As most of the suitable lands are private property, resource and benefit sharing would be a key issue for its success. In a similar rainfall area of Telangana, India integrated watershed management has largely contributed to increased crop productivity, saving of rainwater, reduction of soil erosion and improvement of soil fertility resulting in overall improvement of farmer's income and livelihoods both in irrigated and rainfed areas (Wani et al. 2006).

Re-excavation of kharis and canals

Kharis are traditional channels for drainage of rainwater across HBT. BMDA has taken the initiative to excavate several canals such as the large Sormongla canal in Godagari Upazila. However, more intensive efforts are needed to excavate channels and create catchments for water storage for domestic and agricultural use. It is suggested that more canals up to 2-3 km long and 10-15 m wide be developed. This requires excavation, building up of embankments and planting of trees and shrubs on embankments to minimize erosion (Figure 9.1). This requires participatory involvement of local communities, government agencies and NGOs for the maintenance, sharing and use of the resultant water resource. Social forestry could be promoted on the banks of kharis for successful afforestation and sharing of resources among the local people.

Figure 9.1. Khari canal re-excavation and maintenance of water storage dams need attention. Photos: M. Yusuf Ali

Water reservoirs

There are potential areas where water reservoirs could be constructed for harvesting and capture of monsoon precipitation. These could be supplemented by pumping of water from nearby Padma and Punorvaba rivers to fill those reservoirs during the monsoon season (Figure 9.2). BMDA has taken such initiatives to divert water from the Padma in Godagari but on a small scale. Upscaling would require more investment into the future. Similarly, weirs could be strategically placed on natural seasonal waterways to capture rainfall so that it does not drain out to the floodplain area, as it currently does. The water thus stored could be leased out annually to local groups to cultivate fish and for irrigation. Such an approach would surely increase the scope and lower the risk of rabi cropping.

Figure 9.2. Collection of water from the river Padma flowing into a BMDA mini-dam at Godagari, HBT. Photo: M. Yusuf Ali

Re-excavation of traditional ponds

There are about 70,000 big and small ponds in the HBT, and of those some 14,000 are government owned but now controlled by BMDA. Most of traditional ponds are silted and possessed mainly by absentee landlords or the government. The government-owned big ponds were mostly excavated during the Paul and Muslim dynasties, and some of these have been re-excavated by BMDA to be leased out for fish culture. Earlier these ponds were used for irrigation of t. aman rice and for cultivation of rabi crops by big and small adjacent farmers. As fish culture requires large quantities and year-round presence of water, use of water from such ponds for irrigation is now restricted. Only when the water level is above the required depth of 2 m is it allowed to be used for irrigation. There is an instance in the non-DTW area of the northern HBT, in Bahapur village of Shapahar Upazila, where water in a large pond of 4,000 m^2 area by 2.5-3.5 m deep is sold for BDT 70,000-80,000 for cultivation of high value crops like watermelon or khira (a type of cucumber). Water is uplifted by a diesel low-lift pump.

Re-excavation of traditional ponds is hampered by joint and fragmented ownership, thus requiring social mobilization along with active participation of government agencies and NGOs. Besides irrigation and fish culture, residents depend on pond water for all household needs, bathing, and livestock management. Particularly in drought years, availability of pond water becomes ever more crucial, particularly in the predominantly rainfed areas of the HBT. Availability of pond water is also crucial for the survival of local fauna, particularly of birds which prey on crop pests. It is suggested that the BMDA or other government agencies come forward to re-excavate big ponds as insurance against the looming uncertainties of climate change. The reason why these ponds were originally built by ancient dynasties was as insurance against an uncertain rainfall regime, and this imperative needs to be repeated by present-day administrations. Also, the government could encourage and subsidize private land owners to re-excavate or dig big ponds to capture monsoon precipitation and maintain the ecological balance (Figure 9.3). However, to date no so such endeavor is visible.

Figure 9.3. A big pond, popularly known from ancient times as a *dighi*, supplies water for human use and maintains ecological balance of the locality. Photo: M. Yusuf Ali

Mini-pond excavation

Research and demonstration by OFRD of BARI has shown that digging of mini-ponds (Figure 9.4) alongside rice fields is particularly useful in alleviating drought stress faced by t. aman at flowering time in the HBT (OFRD, 1991). This form of drought stress can result in 11-34 % yield loss for local and 43-50 % yield loss for modern t. aman varieties. Supplementary irrigation with harvested run-off water in a mini-pond measuring 10 m x 10 m x 3 m (deep) at farmers individual level can prevent this yield loss over one hectare of land (OFRD, 1991). Although around 2.5 decimal (100 m^2) of potential cultivated area is lost to such a mini-pond, its benefits far outweigh that loss. Not only can the yield of t. aman be protected from drought but also vegetables can be cultivated on the pond bank and seasonal, fast-growing fish (e.g. rajputi, tilapia) can be cultured. However, mini-pond size may be increased or reduced depending on area of land to be serviced. Further, water remaining at the end of the t. aman season can be used for rabi cropping, such as with fast-growing, short-duration vegetables.

Figure 9.4. A mini-pond along-side a t. aman rice field in the HBT. Photo: M. Yusuf Ali

Raising and strengthening of field bunds

The most effect way of rainwater conservation at a micro level is to ensure that all of the rain that falls on a field actually stays there. For irrigated rice cultivation it is also necessary to ensure that all of the applied water remains on the field. Bunds in many HBT fields do not meet these criteria. They could be raised by about 10 cm and strengthened so as to prevent leakage. By doing so would extend the period of standing water from the present

5-6 days. Longer retention of standing water on the field delays the formation of soil cracks, which in turn enhance soil evaporation.

Increasing infiltration

A particular problem of HBT soils is their high bulk density, which mitigates against infiltration of rainwater into the soil and thus depresses potential water holding capacity. In adequately bunded fields this assists retaining standing water in rice fields, but if water is allowed to flow off the field then this reduces potential for stored soil water. However, as discussed below, there are viable alternatives to retaining standing water throughout the rice crop. Conservation agriculture techniques, particularly the accretion of soil organic matter with residue return, increases soil permeability to water (Boyle et al. 1989).

In most parts of Bangladesh, organic materials such as manure, mainly based on cow dung, and compost, such as prepared from water hyacinth, are added to soils to effectively increase soil organic matter content. However, in the HBT, due to the scarcity of fuel sources, most cow dung is used as fuel (Figure 9.5), and there are few water bodies from which to harvest water hyacinth. Further, rice straw residue is removed from fields for use as fuel (Figure 9.6). Farmers who can prepare compost apply it at a rate of 700-1,100 kg bigha^{-1} (5-8 t ha^{-1}) before t. aman transplanting. This can permit the soil to supply water for t. aman for 10-12 days, even without rain, whereas, soils without adequate organic manure hold water for only about seven days in HBT conditions.

It is therefore proposed that efforts be put into increasing organic manure and compost production and application in the HBT. Biomass crops, also for use as fodder crops, could be considered for this purpose, examples being various tropical fodder grasses and fodder tree crops like leucaena.

Figure 9.5. Marketing of cowdung as fuel by rickshaw van in the Nachole area of the HBT. Photo: M. Yusuf Ali

Figure 9.6. Children collecting rice straw residue from HBT fields for use as cooking fuel. Photo: M. Yusuf Ali

9.2 Increasing water use efficiency

Having taken steps to maximize capture and storage of rainwater it is then obligatory to use that water most efficiently. A first consideration is to minimize losses, such as through evaporation, of the water captured. Then it is necessary to ensure that as much as possible of applied water is transpired, rather than otherwise lost from the agroecology. It is necessary to arrange crop choice, cropping rotations and crop management so as to maximize production of useful plant product per unit of water used. Further, there is scope for genetic manipulation of crop plants to increase their water use efficiency (WUE).

Minimizing evaporative loss

HBT soils of high clay content and high bulk density have the tendency to crack on drying (Figure 9.7). This greatly increases the surface area from which evaporation may occur, thus accelerating soil drying. This may be of advantage in allowing deeper percolation of subsequent rainfall but would be detrimental to seedlings reliant on moisture near the soil surface, such as t. aman seedlings. Once cracks are allowed to form, twice the amount of water is required to close the cracks. Traditionally, advanced farmers manually stirred the surface soil at early stages of t. aman crops to avoid development of cracks. However, this becomes more difficult to implement at later crop growth stages, when the crop canopy closes. However, it works well to minimize the effect of drought on t. aman at early stages to increase the efficiency of rain water use.

Figure 9.7. Development of soil cracks in t. aman rice causes rapid loss of soil moisture. Photo: M. Yusuf Ali

Evaporative soil water loss due to crack formation also needs to be considered for other crops, such as irrigated wheat. Although conservation agriculture techniques require minimum tillage it would be necessary to seek a compromise between avoiding deeper tillage (e.g. below 5 cm) and disturbing the surface soil enough to close cracks.

Accumulation of crop or plant residues on the soil surface, as part of conservation agriculture practices, would also reduce soil water evaporation. However, this would require a drastic culture change from the present practice of residue removal, mainly for fuel purposes.

To minimize evaporation from water bodies, such as ponds, used for irrigation it is possible to use monolayer organic films (Assouline et al. 2011). However, their efficacy in relation to cost needs to be evaluated under HBT conditions, as well as their safety when exposed to living organisms. In smaller ponds, evaporation could be minimized by the shading resulting from growing vegetables on trellises suspended over the pond.

Irrigation management

Due to the advent of PVC and soft plastic pipes to apply irrigation in the HBT, it has become much more feasible to apply required amounts of water to crops, to ensure that most of it passes through the transpiration stream rather than being lost to the system.

Traditional methods of flood irrigation from a channel allow less flexibility in timing and amount of irrigation application and result in considerable water loss.

Boro rice is by far the biggest user of irrigation water as farmers try to maintain 4-10 cm of water in the field, during the hottest period of the year. This not only wastes water but also hampers tillering. Use of PVC and plastic pipes permits implementation of the alternative wetting and drying (AWD) method for increasing WUE in boro rice. Use of AWD can reduce boro rice irrigation water requirement by as much as 27 % (Hussain et. al. 2009) but it needs social motivation and training, as well as the necessary pipes and pump. Soil water levels can be monitored relatively simply and cheaply by using perforated PVC pipes, 25 cm long and 7-10 cm diameter. They cost about BDT 60-70/pipe (about $1/pipe) and for a hectare 5-8 pipes are needed (BRRI 2016). Moreover, those pipes can be re-used in subsequent seasons. Need-based irrigation is applied by observing the water level of the plot through these tubes placed vertically in the soil (perforated 15 cm below the soil and non-perforated 10 cm above the soil surface); and maintaining minimal standing water until the flowering stage.

Crop choice and rotation

Due to the increasingly erratic rainfall and limited groundwater and surface water resources of the HBT, exacerbated by climate change, particular consideration needs to be given to low water requiring crops and crop rotations. Boro rice presents somewhat of a conundrum as it is fundamental to the food security of the country yet a prolific user of irrigation water. However, due to the water limitation of the HBT, it is proposed that boro rice cultivation be restricted to valley land (locally called byde) or plain land at low elevation. Higher terraced land should be reserved for vegetables, pulses, potato, maize, wheat, oilseeds, and other non-rice crops in the rabi season. However, t. aman rice could be grown across all land types, as it mainly depends on monsoon rain, but could be provided supplementary irrigation as necessary. Land zoning would help farmers to opt for alternative and better options.

The economic return from irrigated boro rice is very discouraging in Bangladesh. The marginal return on irrigation water is only 0.05, meaning that a BDT 1.0 increase in irrigation expenditure raises the value of rice output by only BDT 0.05. This suggests that Bangladeshi boro rice farmers are using water inefficiently. Overall, Bangladeshi farmers are more efficient in their use of land, labor, fertilizer, and ploughing with power tiller than in their use of irrigation water (Choudhury 2010). Presently boro is the major rice crop of Bangladesh with 55 % of total yearly rice production. In the HBT boro rice covers about 53,568 ha (37.6 % of HBT area and 83.6 % of irrigated area) and almost completely depends on DTW irrigation. So, increasing the WUE of boro rice by, say, 10-20 % would have a significant implication on water economy as well as on reduction of pumping of underground water. The amount of water needed just for land preparation (puddling) of boro rice is enough to support the full life cycle of most other crops, including maize, potato, wheat, chickpea, mustard, watermelon, onion and garlic. Therefore, increasing the WUE of boro rice should be a major concern for policy makers and farmers.

Rationalization of crops grown would not only optimize water use but would also maximize profit per unit area. Most of the non-rice crops are high value crops compared to rice, particularly boro rice, and with a significantly reduced requirement for water. Boro rice can require over 2,000 mm ha^{-1} of irrigation water, and up to 2,650 mm water ha^{-1} in some high land situations (WRC 2001). By contrast, t. aman rotating with onion, garlic, chickpea, chilli, cowpea or water melon needs only 400-600 mm water ha^{-1}. Average net financial return per unit of water use (\$ ha^{-1} cm^{-1}) is also lowest for boro rice (0.7-0.9), compared to 12.5 for mustard, 5.3 for chickpea, 6.4 for lentil and 5.2 for maize.

Nevertheless, the fact that boro rice is the prime food security crop of the country is a problem, making it very difficult to advocate a reduction in its area even though it is often uneconomic and not environment friendly when cultivated in terraced high land like the HBT. Increasing population and food demand will require increased national production of boro rice but also of other food crops, particularly wheat, vegetables oilseeds and pulses. With looming scarcity of irrigation water in the HBT it is inevitable that boro rice production will need to decline, but to be replaced by these high value, water-efficient, non-rice crops. However, the transition needs both policy recommendation and farmers' motivation in terms of immediate economic incentive. Assured and reasonable market price and limited incentive packages for inputs may help farmers bring more area under high value crops as an alternative to boro rice, and more diversified farming systems generally (e.g. with fruit trees, livestock rearing).

Genetic WUE

Within crop species there are genetic differences in WUE, i.e. grain yield per unit of water transpired. Biggest advantages are derived from varieties of short duration, especially when grown in terminal drought situations where they reach maturity before residual soil moisture is exhausted. However, their yield potential may be lower than longer duration varieties due to less time for yield formation (grain filling), but longer duration varieties have much less chance of approaching their yield potential in terminal drought environments and are thus more risk prone. For example, in the HBT chickpeas of shorter duration than those grown in floodplain areas are more suited (Ali et al. 2005).

For varieties of similar maturity duration differences in WUE can also be found (Richards et al. 2002), but these differences are usually of insufficient magnitude to be of practical, economic significance.

Swarna has been the main cultivar grown in the HBT in recent decades. This Indian-derived cultivar is high yielding with acceptable quality traits, however, it's yield is erratic from year to year due mainly to terminal drought stress. This is exacerbated by its relative long duration (>120 days), delaying its maturity into November-December. Shorter duration varieties, developed in Nepal, have been evaluated against Swarna and other locally used cultivars across the HBT using participatory varietal selection (PVS) techniques (Witcombe et al. 2005; Joshi et al. 2007). Judi 567 and Judi 582 were found to mature 2-4 weeks earlier than Swarna with higher yield and farmer preference. BRRI, in collaboration with IRRI, has been trying to develop drought tolerant, short duration and water-efficient rice cultivars for the t. aman season. PSRC80 could achieve 4.4 t ha^{-1} in 115 days growth duration (BRRI 2005). IR 50, a short duration variety (100 days), also produces good yield (4.2 t ha^{-1}) but farmers cannot procure pure seed, as it is not officially promoted.

There is large scope for evaluating and developing varieties of major crops (rice, wheat, chickpea) better suited to the rainfed situation of the HBT, preferably using client-oriented breeding (see Box 9.1) and PVS evaluation techniques to better ensure farmer adoption. This will mainly involve identifying higher yielding short duration varieties (i.e. as compared to the duration of current varieties). Identification of t. aman varieties of shorter duration than Swarna, but with yield and quality characteristics no less than Swarna, would also allow for timely planting of rabi crops. Swarna is often not harvested until beyond optimum sowing time of most rabi crops suitable for the HBT.

9.3 Trees

Particularly as the HBT has been denuded of trees over time, it is important to return them to the extent possible in order to improve the ecosystem in various ways. This can involve all manner of trees, from orchards to trees providing building materials, fuel and fodder. This includes bamboo clumps, which should get preference due to their drought tolerance, low management requirement and multiple uses as construction material, fuel, trellises and cash value. All land not allocated for cropping or infrastructure should be considered in a multi-strata homestead agroforestry farming approach. A greater tree population will also moderate ground temperature, likely to rise with climate change, and attract precipitation. Farmers need to be trained in establishing and managing tree nurseries to provide saplings of good quality.

A tree particularly suited to HBT homesteads and marginal land is the highly drought and heat tolerant drumstick (*Moringa* spp.). It is a tree full of nutrition as green leaves can be consumed as a vegetable, or leaves may be dried, processed and consumed, to alleviate malnutrition among children and women. Pods could be exported to foreign countries. The medicinal value (root, bark, leaf, flower and pod) of drumstick should be exploited to improve local health.

9.4 Soil improvement

To improve HBT soils, and reduce labour requirement and overall cost of crop cultivation, conservation agriculture techniques need to be promoted. This involves development and dissemination of the relevant seeding machineries, able to cope with the compact soil of the HBT. Also particularly important for the HBT is to encourage return of crop residues to build up soil organic matter and minimize erosion of topsoil.

Greater emphasis should also be given to including pulses in the crop rotation, to enhance both soil organic matter and soil N. Chickpea is well adapted to the region, mainly due to its deep rooting capability and the lesser incidence of Botrytis Grey Mould, which is a major constraint to chickpea elsewhere in the country. Farmers are by now well aware of this. However, they are not so aware of the potential of other pulses like black gram, mung bean, horsegram, lentil, lathyrus (grasspea) and pigeonpea. Promotion work is required to familiarize farmers with modern cultivars and improved management technologies.

As an example, black gram provides an important staple food source for the region. Black gram flour is mixed with wheat flour to prepare *'kalia ruti'*, a bread preparation popularly taken at breakfast or lunch with mashed brinjal (eggplant) or prepared with dry chilli paste.

Black gram is currently grown in the west of the HBT but mainly in the alluvial soils of Chapai Nawabganj Upazila further to the west. There is scope for it to be cultivated on a large scale across the HBT on homestead adjoining lands and high lands which are otherwise uncultivated. It needs almost no intercultural management, rather it suppresses weeds.

There is much scope for better defining soil nutrient requirements, including trace elements, of major crops so as to better rationalize fertilizer use and increase nutrient use efficiency. There should be greater reliance on legume cultivation to build up soil N reserves, and thus reduce the requirement for chemical N fertilizer, which is currently often over-supplied in relation to other major nutrients (P, K, S). However, successful legume cultivation relies on meeting their particular nutrient requirements, primarily ensuring that they are effectively nodulated, enabled by *Rhizobium* inoculation if required, and also meeting their requirements for P, S and Mo.

9.5 Crop improvement and management

To identify the best adapted cultivars for the HBT, much more use of participatory varietal selection techniques needs to be made – that is, implemented on-farm with farmers (Box 9.1). Varieties identified as superior in other parts of Bangladesh may not be the best for the HBT, due to the unique soil and hydrological conditions of that region. To further improve crop adaptation, client-oriented breeding is recommended, again, integrating farmers into the entire process (Box 9.1). Particularly for the HBT, options for genetic improvement of WUE need to be explored, for rainy season rice which faces end-of-season drought stress as well as all non-rainy season crops. Additionally, as climate change progresses heat tolerance of crop varieties will become important – research is needed on the identification and development of heat tolerant varieties.

Integrated management of pests and weeds (IPM and IWM) for all crops needs to be pursued, minimizing use of agro-chemicals but using bio-pesticides and ecological techniques where possible. Indeed, there is sufficient component knowledge on alleviation of constraints of particular crops to be able to formulate integrated crop management (ICM) packages. To be suitable for resource-poor farmers, however, inputs should not be aimed at maximum possible yield but at maximum benefit-cost to those farmers, and circumventing high cost inputs wherever possible. For example, ICM packages for lentil and chickpea were successfully demonstrated across north-west Bangladesh, including the HBT, during 2006-11 (Bell et al. 2011). Such endeavours, for pulses and other crops, need to be continued to ensure that farmers are familiarized with the latest technology available and how best to package it.

Box 9.1. Participatory Varietal Selection and Client Oriented Breeding

Participatory varietal selection (PVS) refers to a procedure of maximizing farmer input across a defined region in selecting crop cultivars best suited to their farming practice (Witcombe et al. 1996). A first step in this procedure is the conduct of participatory rural appraisal (PRA) surveys across the target region, to understand farmer's varietal preferences, short-comings of existing varieties, farmers' resources and the target environment in general. Then cultivars or germplasm that may have characteristics that would address some of the constraints of locally grown varieties are selected for farmer evaluation. This is done using mother and baby trial techniques (Snapp 1999).

Mother trials comprise adjacent plots comparing a range of test cultivars (e.g. 5-7) with a commonly used local cultivar, with one replicate in a farmer's field and in at least four farmer fields representative of the target region. Agronomic conditions are as normally used by farmers, rather than recommended optimum inputs, and all cultural operations are conducted by participant farmers. This is to ensure that selection is done in the actual target environment, i.e. in farmers' fields rather than research station fields where higher levels of input and management in general are likely. Near crop maturity, host and neighbouring farmers are interviewed to elicit their opinions on performance of the different cultivars and at harvest grain yields are quantified.

Baby trials allow more widespread evaluation in that seed packets of a single cultivar, or at most two, are distributed to a large number (preferably >50) of farmers across the target region. The participant farmers are requested to plant the test cultivar in the same field as their usual cultivar and apply their normally used agronomic conditions to both. During growth and after harvest, farmers are interviewed as to their opinions on the test cultivar in comparison with their usual cultivar, in terms of constraints (pests, diseases, etc.), maturity duration, yield, grain characteristics, etc. Quantification of yield of test and control cultivars is not necessary, although such information provided by the farmer is welcome. The main purpose of this exercise is to obtain widespread farmer opinions of introduced cultivars, and thus their potential future acceptance.

Information from mother and baby trials is used to select test cultivars worthy of seed production for future dissemination among farmers of the region. To enhance this process it is desirable to have the cultivar(s) entered in the official national varietal release program, provided the test environment of that program reasonably matches the target farmer environment.

Cultivars found to perform well in PVS, but with scope for further improvement, can be used as parents in a crossing program. To maximize adoption of any improved products of a breeding program by resource poor farmers, their involvement in the breeding process itself is recommended – i.e. client-oriented breeding (COB; Witcombe et al. 2005; Witcombe and Yadavendra 2014). In addition to their prior involvement in the initial PRA and PVS exercise, farmers can be involved in making crosses (only a few are recommended), growing segregating populations in their fields, selection of promising progeny and their subsequent testing via PVS. In this way farmers gain ownership of any successful breeding products, with consequent greater likelihood of their widespread dissemination.

9.6 Livestock and fisheries

Farmers' livelihoods could be diversified with intensive livestock farming including beef cattle fattening, sheep and goat raising, poultry farming and dairying. Ability to sell livestock provides insurance against crop failure, or other crises. However, to be viable, veterinary services would need to be markedly improved across the HBT, with creation of Para-Vets at community level. Further, targeted fodder production would be needed, with fodder grasses, legumes and trees, utilizing road sides, pond banks and marginal land.

With increased livestock farming it would become feasible to consider community-based bio-gas installation to address the endemic fuel shortage. The resultant bio-slurry/compost could be applied to homestead gardens or crop fields.

Increased water capture in ponds, dighis and reservoirs would permit increased fisheries practice thus considerably widening livelihood options.

9.7 Value addition

Given the good scope for mango orchards and tomato cultivation in the HBT it would seem feasible to consider value addition, through introduction of modern methods and facilities for packaging and despatch of fresh fruit and facilities for processing of pulp and juice.

9.8 Enhanced farmer services

Weather forecasting systems need to be improved and made readily accessible to farmers, particularly to provide early warning on approaching extreme weather, like heat waves, dry spells and storms. As part of this weather information system farmers should be instructed on the longer term effects of climate change so that they can adjust their farming enterprises accordingly, rather than simply wait for climate shocks to arrive.

With the rapid expansion and increasing availability of information technology and management (ICT) it becomes increasingly feasible to undertake capacity building of farmers on advanced agricultural production methods relevant to the HBT, and particularly with respect to adaptation to drought and water use efficiency. This would build upon traditional field demonstrations and travelling workshops. Mobile phones already play an increasing role in allowing even poorer farmers to access services and in providing marketing information.

There should be government oversight and monitoring that quality inputs of seed, fertilizer, pesticide, fungicide, herbicide, agricultural machineries, fuel and accessories remain available at fair price. During times of drought, or other extreme weather events, there should be government provision of basic amounts of agricultural inputs, subsistence amounts of food items and some cash to affected, already poor, farmers to allow continuation of their rural livelihoods and prevent exploitation by informal money lenders charging high interest rates.

Nevertheless, credit and micro-credit facilities with minimal interest rates should be available to interested resource poor farmers. The process of credit sanction by government and commercial banks should be made easier and quicker. In this respect government soft loan provision for high value crop cultivation should be made available across the HBT through locally available banks. NGOs, social workers and government should come forward to provide interest-free small loans (perhaps up to BDT 40,000) to women and poor farmers. Already in a few locations NGOs like Muslim Aid, UK, are distributing low interest and charge free loans which are having a favourable impact on poverty reduction, with satisfactory loan recovery percentage. Government Zakat (obligatory on rich Muslims) funds could also be used for this purpose.

Although there has been considerable infrastructure development in the HBT over the years, more is required in terms of electrification, health facilities and services, sanitation services, schools, technical schools, employment services for local and remote jobs, markets, seed processing centres and cold storage facilities.

Agricultural research and extension services need to be enhanced for the HBT, considering the special challenges, and opportunities, for the region. Attempts are needed to service even the most remote locations, to ensure equitable development across the HBT. Concerted efforts are required to provide HBT households with training in all of the options for year-round homestead gardening, and cottage industries like handicrafts, sewing, etc., particularly to give women further livelihood, employment and empowerment options.

9.9 Energy

The HBT has scope for providing a commodity very much in demand across Bangladesh, and becoming increasing difficult to supply – electricity. Most of the electricity on the national grid of Bangladesh is generated from natural gas, with a small amount from hydro, liquid fuel (diesel, furnace oil) and coal. As Bangladesh is one of the countries most vulnerable to climate change, it is not prudent that it continue burning fossil fuels, the main culprits in creating greenhouse gases. If Bangladesh expects other countries which are major contributors to greenhouse gases to reduce their emissions in order to mitigate climate change consequences for Bangladesh then it also needs to convert to renewable energy. Furthermore, gas reserves in Bangladesh are finite, the limited coal deposits are not likely to be mined and liquid fuels need to be imported at high cost. But, most importantly, as is now happening elsewhere in the world, as renewable energy sources scale up they are proving to be cheaper than fossil fuel sources of energy. There are plans to build a nuclear power plant in Bangladesh but such installations pose the highest cost of all energy-generating sources, along with safety and nuclear waste disposal issues still unresolved at a global level.

It is suggested that Bangladesh aggressively join the now accelerating global transition to renewable energy, to help address climate change and, eventually, lower the cost of electricity while broadening its accessibility. Already, household scale solar panels (albeit usually with just one panel) have been adopted by the millions in Bangladesh and a move to large scale solar power to supply the national grid seems feasible. Prospects for profitable wind power only exist near the coast where winds are stronger and more reliable. However, as it receives less rainfall, incident sunlight radiation is higher in the HBT than in other parts of Bangladesh, especially during the monsoon season (Sadrul Islam et al. 2010). This makes the region well suited to solar power development.

It is thus proposed that northern parts of the HBT, where there is insufficient water to sustain year-round cropping, would be ideal locations to host commercial scale solar generation plants. These could either be concentrated solar thermal (CST) plants (Figure 9.8) or utility scale solar farms with battery storage (Figure 9.9). CST plants reflect sunlight from banks of mirrors to a collector with molten salt on top of a tower; the molten salt is stored in tanks at ground level and can be released to power steam turbines (as used in coal-fired power plants) in the daytime or through the following night. With declining costs of installation, these types of facilities are rapidly being established around the world, to replace fossil-fuel powered facilities at economic rates.

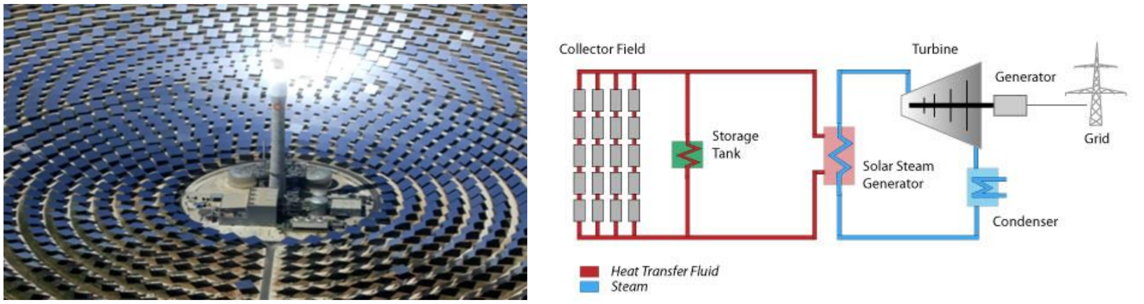


Figure 9.8. Concentrated solar thermal power installation (Source: https://www.youtube.com/watch?v=8sLej0oD1Ak) with a summary of how it works (Source: http://www.greenrhinoenergy.com/solar/technologies/images/cst_systems-01.jpg).

Figure 9.9. A utility scale solar farm (Source: https://recsolar.com/utility-scale-solar-solutions/) and the Tesla lithium battery bank, South Australia (Source: https://www.gizmodo.com.au/).

There is also much scope for utilizing solar panels at household and village level in the HBT, to at least supplement grid-supplied electricity during daylight hours. Solar energy could also be used to power irrigation pumps, rendering irrigation independent of connection to what continues to be an unreliable grid supply. Battery storage could extend use of solar energy into the evening. However, upfront capital costs would be prohibitive for most of the population and thus loan schemes tailored to establishing solar energy capture at household and village level are advocated.

9.10 OFR&D Methodology

It is suggested that the entire agricultural development process for resource-poor farmers in the HBT can be accelerated by completely moving to an on-farm approach. Box 9.1 outlines the procedure for evaluating alternative varieties and breeding for improved ones (PVS and COB) in a completely on-farm context. This approach can also be used for agronomic improvement (Johansen and Siddique 2018). It is based on the 'mother and baby trial' concept developed by Snapp (2002), and is indeed the basis for PVS. A mother trial comprises all of the treatments of interest (whether they be varieties or agronomic treatments, such as fertilizer rates) being placed in adjacent plots in several different farmers' fields, as replicates. There is researcher involvement in design and layout but non-treatment factors are as close to usual farmer practice as possible. Mother trials are farmer managed but individual plot yields are finally measured. Baby trials consist of comparisons of likely best one or two treatments with local practice on as may farms as possible across the target region. Seed of the test variety or the test agronomic input is provided to farmers and they manage the side-by-side comparison with the local practice. Baby trials are conducted completely with farmer management; comparative yields are measured by farmers, if practicable, or otherwise farmers are requested to rank the test treatment in comparison with local practice. Indeed, this baby trial method was used in the chickpea seed priming evaluation as referred to in Box 6.1; there were no mother trials in this case as it was a simple with and without comparison.

The advantage of the OFR&D approach, over the traditional top-down approach of handing down research station results via extension agencies, is manifold. Initiation of an OFR&D exercise requires thorough survey of the target region to determine constraints from the farmers' points of view, and thus a more likely chance of identifying possible solutions worth testing. Experimentation is done against the background of local agronomic conditions and within likely farmer resources. Thus any treatment advantages found are likely to be more relevant than those handed down from a research station, where optimum agronomy is usually followed. Farmer involvement throughout the entire process means that they acquire ownership of the process and are thus more likely to adopt any technologies showing promise. The process takes account of the inevitable environmental variability across a target region to eventually evolve location-specific best practice.

Evidence that varietal improvement is more effective and faster using PVS and COB is now appearing Witcombe and Yadavendra (2014). However, there is still much convincing to do about moving agronomic research on-farm. The HBT is a suitable location to further this approach as farmers there have proved most cooperative in implementing mother and baby trial approaches, such as seed priming (Box 6.1) and PVS of rice (Joshi et al. 2007) and chickpea (PROVA 2003). However, viable implementation of OFR&D depends on longer term project funding that has hitherto been available, to span from an initial problem evaluation phase to assessment of adoption and livelihood improvement.

Chapter 10. A Vision for the HBT

As can be gauged from the previous chapters there are many component technologies that can increase the agricultural productivity, and improve the livelihoods of the inhabitants, of the HBT. Further, implementation of these technologies will substantially increase the vegetative biomass, and thus carbon sequestration capacity, of the region; not to the extent that it once was when covered by forest some 200 years ago but certainly orders of magnitude more than its recent condition. However, realization of these outcomes will require concerted efforts at assembling and integrating these technologies. Such integration would rely on the joint, coordinated efforts of all stakeholders – farming communities, government agencies, research and extension bodies, NGOs, financial institutions, private businesses and entrepreneurs, etc. If such an effort were to be made we can envisage a promising future for the HBT, for both the livelihoods of the inhabitants and the ecology in general.

We envisage what the HBT might look like some quarter century hence. Broadly, we see the region as a net exporter of agricultural produce, and considerably more green than it is now during both the rabi and summer seasons. An aerial view of the HBT during the monsoon season some 25 years from now might see most of the region covered in rainy season (aman) rice but with many more trees than now apparent, as orchards, along roads and waterways, shading homesteads, etc. There would also be also be many more water bodies visible, from mini- to large ponds, canals leading from the Padma river and dammed natural waterways capturing monsoon rainfall that would otherwise flow out of the HBT.

An aerial view in the rabi season would note that boro rice is only apparent in lowland areas of the southern HBT. However, the remaining agricultural fields, previously under aman rice, would be a mosaic of less water requiring crops like wheat, oilseeds, pulses, onion/garlic, tomato, etc. Those rabi crops that could not rely on stored soil moisture alone would receive supplementary irrigation from deep tube wells (but without depleting them) and surface water catchments, with irrigation water precisely delivered by pipe and pumped by solar-powered pumps.

Typical villages and homestead areas would more resemble those in southern, well-watered regions of Bangladesh. There would be several canopy levels of productive vegetation – from tall trees providing shade to dwellings and wood products, to an intermediate canopy of mainly bamboo clumps and fruit trees like mango, lime and banana, and at ground level year-round vegetable gardens for home consumption. There would be numerous livestock in the vicinity of the homestead, from cattle and goats for meat production to poultry. Villages with larger water bodies holding water for at least 4-5 months to year-round may undertake aquaculture. Each village area would be adequately supplied with water, from wells if available or captured rain water – this water would service human needs as well as sustain village vegetation. Electricity needs, for households and for pumping water, would be met by a microgrid, or individual household installation, powered by solar panels plus batteries. Biogas facilities would service cooking needs as well as provide manure for improving soil fertility. Indeed, there would be composting of all waste organic materials, destined for soil fertility improvement.

In the fields, conservation agriculture practices would be followed, implementing minimum tillage, residue return and diverse crop rotation, to result in improved soil fertility and minimal use of chemical fertilizer. Chemical fertilizer would only be applied on a needs basis to supplement only those elements that are deficient, as determined by regular soil testing. Use of other agrochemicals, such as pesticides, fungicides and herbicides, would also be judicious and needs-based, and applied taking the necessary safety precautions.

At strategic locations throughout the HBT there would be modern market facilities for agricultural produce, including silos for storage, and some food processing industries, such as for mango and tomato juice and pulp. And roads would be maintained in good order to ensure rapid access to markets beyond the HBT.

In our flight over the HBT in 25 years' time we would expect to see utility scale solar farms and concentrated solar thermal facilities (Figures 9.8 and 9.9) dotting the northern parts of the HBT, and making significant contributions to the national grid.

The energy from the sun is currently perceived as making life more difficult for the inhabitants of the HBT at the end on the monsoon season (Oct-Nov) and in the late rabi to summer season (Feb-Jun). It exacerbates evaporative loss and causes heat stress to humans, farm animals, crops and most life forms, especially during April-June. However, it is possible to harness this abundant energy from the sun to markedly improve livelihoods and well-being. Firstly, by increasing photosynthetic conversion of this energy into agricultural produce and ecological rehabilitation, as outlined in earlier chapters. Secondly, by directly converting some of it into electricity to meet the needs of the people of the HBT and even beyond.

This visualization does not rely on any yet-to-be invented technologies – only technologies already functioning in parts of the HBT or elsewhere in the world. However, to realize this visualization would require coordination at a regional level – the agro-ecological region of the HBT. Although the relevant technologies exist, it would also require ongoing research, development and local adaptation of the relevant technologies, and wise investment for their upscaling. Most importantly it would require that the farming community feel themselves as an integral part of the development process, and not just recipients of technology being handed down to them – that is, they need to feel ownership of the process.

The suggested pathway for development of the HBT could serve as a case study, which could provide guidance to the coordinated development other distinct agro-ecological zones. It would be particularly relevant to other agro-ecological zones around the world facing increasing water deficit and rising temperatures with climate change and where livelihoods are in urgent need of improvement. However, innovations in the HBT also have immediate spillover potential to other agro-ecological zones of Bangladesh, particularly adjacent ones (e.g. level Barind), and hilly areas in the south and east of the country.

References

Adham, MI, Jahan, CS, Mazumder, QH, Hossain, MMA & Haque, Al-Mamunul 2010, 'Study on ground water recharge potentiality of Barind Tract, Rajshahi District, Bangladesh using GIS and remote sensing', *Journal of Geological Society of India*, 75: 432-438. doi10.1007/s12594-010-0039-3

Agarwala, S, Ota, T, Ahmed, AU, Smith, J & van Aalst, M 2003, *Development and climate change in Bangladesh: Focus on coastal flooding and the sunderbans*, Document: COM/ENV/EPOC/DCD/DAC(2003)3/FINA, Organisation for Economic Co-operation and Development (OECD), France.

AgroNews 2010, *Pesticide use in Bangladesh tripled in 10 years*, viewed 14 July 2018, http://news.agropages.com/News/NewsDetail---3862.htm

Ahmed, AV & Alam, M 1998, 'Development of climate change scenarios with general circulation models', in S Huq, Z. Karim, M Asaduzzaman & F Mahtab (eds.), *Vulnerability and adaptation to climate change for Bangladesh*. Kluwer Academic Publishers, Dordrecht, The Netherlands, pp. 13-20.

Alam, MM, Sattar, MA, Faruque, MO, Hasan, MS & Chowdhury, MG 2007, 'Manufacturing of agricultural machinery: its problems, prospects and quality assurance', in *Proceedings of the National Workshop on Strengthening Agricultural Mechanization: Policies and Implementation Strategies in Bangladesh,* held at Dhaka on 11 June 2007, Bangladesh Agricultural Research Council, Farmgate, Dhaka, Bangladesh.

Ali, MY 2000, 'Influence of phosphorus fertilizer and soil moisture regimes on root system development, growth dynamics and yield of chickpea' PhD thesis, Bangabandhu Sheikh Mujibur Rahman Agricultural University, Salna, Gazipur. Bangladesh.

Ali, MY 2014, *Farming Systems of Bangladesh: Poverty Escape Pathways and Livelihoods Improvement*. Muktochinta Prakashone, 253-254, Elephant Road, Katabon, Dhaka, Bangladesh. ISBN 978-984-90597-0-7.

Ali, MY, Ahmed, S, Islam, MS & Hossain, MF 2005, 'Evaluation of chickpea genotypes through growth analysis and thermal time under rainfed conditions in the High Barind Tract', *Bangladesh Journal of Agricultural Research*, 30(1): 65-75.

Ali, MY**,** Ahmed, S, Johansen, C, Harris, D & Kumar Rao, JVDK, 2007a, 'Root traits of different crops under rainfed conditions in the High Barind Tract of Bangladesh', *Journal of and Plant Nutrition and Soil Science*, 170: 296-302.

Ali, MY, Rahman, MA, Quayyum, MA & Islam, MB 2007b, 'Improved adaptive capacity to climate change for sustainable livelihoods in the agricultural sectors – The case of High Barind Tract: BARI-FAO collaborative program' On-Farm Research Division, Bangladesh Agricultural Research Institute, Gazipur-1701, Bangladesh.

Ali, MY, Ahmed, MM & Islam, MB 2008, 'Homestead vegetable gardening: meeting the need of year round vegetable requirement of farm family', in *Proceedings of a National Workshop on Multiple Cropping* held at Bangladesh Agricultural Research Council, Farmgate, Dhaka-1215, Bangladesh on 23-24 April, 2008.

Ali, MY, Ali, M., Islam, MB, Zaman, SM, Hossain, MM, Hossain, MS, Hossain, MF & Islam, MS 2009a, 'Intensive vegetable production in homestead for adaptation to climate change and improvement of farmer's livelihoods', BARI-FAO collaborative program (LACC-II). On-Farm Research Division, Bangladesh Agricultural Research institute, Gazipur-1701, Bangladesh.

Ali, MY, Islam, MB, Zaman, SM, Islam, MS, Hossain, MF, Hossain, MS, Hossain, MM & Sarder, PK 2009b, 'Livelihood adaptation to climate change in coastal area of Khulna and drought prone High Barind Tract area of Bangladesh', BARI-FAO collaborative program (LACC-II), On-Farm Research Division, Bangladesh Agricultural Research Institute, Gazipur-1701, Bangladesh.

Anonymous 1991, 'Annual Progress Report for 1990-91', Farming System Research Programme, On-Farm Research Division, Bangladesh Agricultural Research Institute, Barind Station, Rajshahi, Bangladesh.

Asad-uz-Zaman, M & Rushton, KR 2006, 'Improved yield from aquifers of limited saturatedthickness using inverted wells', *Journal of Hydrology,* 326: 311–324. https://doi.org/10.1016/j.jhydrol.2005.11.001

Assouline, S, Narkis, K & Or, D 2011, 'Evaporation suppression from water reservoirs: Efficiency considerations of partial covers', *Water Resources Research,* 47(7): 1-8. https://doi.org/10.1029/2010WR009889

BADC (Bangladesh Agricultural Development Corporation) 2005, *The minor irrigation surveyreport of 2005,* Dhaka, Bangladesh, viewed 7 February 2018. https://trove.nla.gov.au/version/30721001

BARC (Bangladesh Agricultural Research Council) 2005, *Fertilizer Recommendation Guide – 2005*, Bangladesh Agricultural Research Council, Farmgate, New Airport Road, Dhaka, Bangladesh.

Bell, R, Johansen, C, Haque, ME, Musa, AM, Neogi, MG & Hossain, MD 2011, *'Assessing constraints to pulses in cereals-based cropping systems, with particular reference to poverty alleviation in north-western Bangladesh'*, Final Report for ACIAR Project LWR/2005/001, ACIAR, Canberra ACT 2601, Australia.

Bell, RW, Haque, ME, Johansen, C, Vance, W, Kabir, ME, Musa, MA, Mia, MNN, Neogi, MG & Islam, MA 2017, 'Mechanised minimum soil disturbance establishment and yield of diverse crops in paddy fields using a two-wheel tractor-mounted planter for smallholder cropping', *Experimental Agriculture*, Published online: 31 July 2017. https://doi.org/10.1017/S0014479717000370

Bellon, T 2018, 'Monsanto ordered to pay $289 million in world's first Roundup cancer trial', Reuters, 11 August 2018, viewed 21 August 2018. https://www.reuters.com/article/us-monsanto-cancer-lawsuit/monsanto-ordered-to-pay-289-million-in-worlds-first-roundup-cancer-trial-idUSKBN1KV2HB

Bharadwaj, G 2003, 'The Ancient Period', in RC Majumdar (ed), *History of Bengal*, B.R. Publishing Corporation, Delhi, India.

Bijay-Singh, Sadana, US & Arora, BR 1991, 'Nitrate pollution of ground water with increasing use of nitrogen fertilizers in Punjab', *Indian Journal of Environmental Health*, 33(4): 516-518.

BMDA (Barind Multipurpose Development Authority) 2006, *Barind Authority – Past Present* (A book on history of BMDA), Rajshahi, Bangladesh, pp. 11, 103, 262.

Boyle, M, Frankenberger, WT & Stolzy, LH 1989, 'The influence of organic matter on soil aggregation and water infiltration, *Journal of Production Agriculture*, 2: 290-299. doi 10.2134/jpa1989.0290

Brammer, H 1996, *The Geography of the Soils of Bangladesh*, The University Press Limited, Dhaka, Bangladesh.

Brammer, H 2000, *Agroecological aspects of agricultural research in Bangladesh*. The University Press Limited, Dhaka Bangladesh.

BRRI (Bangladesh Rice Research Institute) 2005, *Annual Report for 2005*, BRRI, Gazipur, Bangladesh.

BRRI (Bangladesh Rice Research Institute) 2016, *Modern Rice Cultivation*, 19th edition, BRRI, Gazipur, Bangladesh.

Choudhury, NA 2010, 'Tackling water scarcity in Bangladesh – A lesson from the country's rice fields', Sandee online, no, 44 (10 June 2010), viewed 7 February 2018. http://www.sandeeonline.org/uploads/documents/publication/887_PUB_Policy_Brief_44_Nasima.pdf

Chowdhury, AM 1967, *Dynastic History of Bengal: (c. 750-1200 AD)*, Asiatic Society of Pakistan.

CIMMYT (International Maize and Wheat Improvement Center) 2012, 'Study into the commercialization of selected agricultural machines in Bangladesh', CIMMYT, Dhaka,

Bangladesh, viewed 12 February, 2018.
http://repository.cimmyt.org/xmlui/bitstream/handle/10883/3394/98527.pdf

Datta, D, Chowdhury, S, Saha, AK, Islam (lalan), MM & Rahman, MM 2014, 'Tilted and horizontal solar radiation for 6 zones in Bangladesh', *International Journal of Scientific & Technology Research*, 3(2): 98-102.

Dixon, J, Gulliver, A & Gibbon, D 2001, *Farming Systems and Poverty. Improving farmers' livelihoods in a changing world*. FAO, Rome and World Bank, Washington D.C.

Faisal, IM, Parveen, S & Kabir, MR 2005,' Sustainable development through groundwater management: a case study of Barind Tract', *International Journal of Water Resources Development*, 21(3): 425-435. https://doi.org/10.1080/07900620500160800

FAO (Food and Agriculture Organization of the United Nations) 1988, *Land Resources Appraisal of Bangladesh for Agricultural Development. Report-2. Agroecological regions of Bangladesh*, prepared by H Brammer, J Antoine, AH Kassam, & HT van Velthuizen, UNDP/FAO, Rome.

Hamid, A & Hunt, JM, 1987, *Poverty and Nature: A socio-ecological analysis of the Barind Tract*, A report prepared for the Agriculture Sector Team, Ministry of Agriculture and Forestry, Government of Bangladesh, CIDA (Canadian International Development Agency), Dhaka, Bangladesh.

Haque, ME, Esdaile, RJ, Kabir, ME, Vance, W, Bell RW, Musa, AM, Shahidullah, AKM, Maruffuzaman, M & Johansen, C 2010, 'Minimum tillage, mechanized sowing of pulses with two-wheel tractors, in RJ Gilkes & Prakongkep Nattaporn (eds), *Proceedings of 19th World Congress of Soil Science. Soil Solutions for a Changing World, Brisbane, Australia, 1–6 August 2010*. Division Symposium 3.2 Nutrient best management practices, International Union of Soil Science, Wageningen, The Netherlands, pp.156–159.

Haque, ME, Bell, RW, Islam, AKMS, Sayre, K & Hossain, MM 2011, 'Versatile multi-crop planter for two-wheel tractors: an innovative option for smallholders', in RJ Gilkes & Prakongkep Nattaporn (eds), *5th World Congress of Conservation Agriculture incorporating 3rd Farming Systems Design Conference, 26–29 September 2011 Brisbane, Australia*.

Haque, ME & Bell, RW 2017, 'Versatile Multi-crop Planter for smallholders' conservation agriculture in Asia and Africa', in *Proceedings 7th World Congress on Conservation Agriculture, 1-4 August 2017, Rosario, Argentina*, pp.101-104.

Haque, ME, Islam, AKMS, Hossain, MM, Bell, RW & Sayre, KD 2017, 'An innovative Versatile Multi-crop Planter for crop establishment using two-wheel tractors', *Agricultural Mechanization in Asia, Africa, and Latin America*, 48(3): 34-39.

Harker, KN & O'Donovan, JT 2013, ‘Recent weed control, weed management, and integrated weed management’, *Weed Technology*, 27(1): 1-11. https://doi.org/10.1614/WT-D-12-00109.1

Hobbs, PR, Sayre, K & Gupta, R 2008, ‘The role of conservation agriculture in sustainable Agriculture’, *Philosophical Transactions of the Royal Society London, B, Biological Sciences*, 363: 543-555. doi 10.1098/rstb.2007.2169

Hossain, MI, Sufian, MA, Sarkar, MAZ, Haque, ME & Rahman, ABMM 2004, ‘Power tiller operated bed planter for improved crop establishment’, *Journal of Science and Technology,* 2: 23.

Hossain, MI, Haque, ME, Meisner, CA, Sufian, MA & Rahman, MM 2005, ‘Strip tillage planting method for better wheat establishment’, *Journal of Science and Technology,* 3: 91-95.

Hunt, J 1984, *Area development of the Barind Tract. Preliminary assessment of research and planning needs*, Bangladesh Agricultural Research Council, Dhaka.

Hunter, WW 1876, *Statistical Accounts of Bengal. Vol. VIII Rajshahi and Bogra*, Calcutta (as cited in Hamid and Hunt 1987).

Hussain, MM, Alam, MS, Kabir, MH, Khan, AK & Islam, MM 2009, ‘Water saving irrigation in rice cultivation with particular reference to alternate wetting and drying method: An overview’, *The Agriculturists*, 7(1&2): 128-136. http://dx.doi.org/10.3329/agric.v7i1.5591

Hussain, MS, Rahman, MZ, Ahmed, FU, Haque, F, Quddus, MA, Musa, AM, Islam, S, Dey, MM, Momin, MA, Alam, MK, Siddique, AB, Kar, NK, Abedin, MZ & Torquebiau, E 1991, *Agroforestry research planning for the High Barind Tract, Rajshahi, Bangladesh. Report of diagnostic and design survey* (edited by E Torquebiau), pp. 18-21, BARI, BARC and ICRAF, Dhaka.

Idris, KM & Huq MM 1987, *Soil moisture status of Barind Tract*, Soil Resources Development Institute, Regional Office, Rajshahi, Bangladesh.

IFAD (International Fund for Agricultural Development) 2018, *Rural poverty in Bangladesh*, viewed 22 July 2018. https://asia.ifad.org/web/bangladesh/rural-poverty-in-bangladesh

IPCC (Intergovernmental Panel on Climate Change) 2001, *Climate change 2001: Synthesis report. Contribution of working group I, II and III to the Third Assessment Report of the Intergovernmental Panel on Climate Change*, RT Watson and the core writing team (eds), Cambridge University Press, Cambridge, United Kingdom, and New York, USA.

IPCC (Intergovernmental Panel on Climate Change) 2014, *Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, Core Writing Team, RK Pachauri & LA Meyer (eds), IPCC, Geneva, Switzerland.

Islam, AKMS, Haque, ME, Hossain, MM, Saleque, MA & Bell, RW 2010, 'Water and fuel saving technologies: unpuddled bed and strip tillage for wet season rice cultivation in Bangladesh in RJ Gilkes & Prakongkep Nattaporn (eds), *Division Symposium 3.2 Nutrient Best Management Practices, Proceedings of 19th World Congress of Soil Science. Soil Solutions for a Changing World, Brisbane, Australia, 1–6 August 2010*, International Union of Soil Science, Wageningen, The Netherlands, pp. 169-172.

Islam, MA 2016, 'Conservation agriculture: its effect on crop and soil in rice-based cropping systems in Bangladesh', PhD Thesis. Murdoch University, Western Australia.

Islam, MB, Ali**,** MY, Amin, M & Zaman, SM 2011**,** **'**Climatic variations: farming systems and livelihoods in the High Barind Tract and coastal areas of Bangladesh', in R Lal, MV Sivakumar, SMA Faiz, AHM Mustafizur Rahman & KRR Islam (eds), *Climate Change and Food Security in South Asia*, part 7, pp. 477-497, Springer, Dordrecht, The Netherlands. https://doi.org/10.1007/978-90-481-9516-9_29

Islam, MM & Kanungoe, P 2005, 'Natural recharge to sustainable yield from the Barind aquifer: a tool in preparing effective management plan of groundwater resources', *Water Science and Technology*, 52(12): 251-258. https://doi.org/10.2166/wst.2005.0475

Islam, MS 2009, *Farm mechanization for sustainable agriculture in Bangladesh: problems and prospects*, viewed 7 February 2018.
www.un-csam.org/Activities%20Files/A09105thTC/PPT/bd-doc.pdf

Jahan, CS, Mazumder, QH & Asaduzzaman, M 2004, 'Long term water level in Barind Area of Bangladesh: A statistical analysis for groundwater potentiality study', *Bangladesh Journal of Geology*, 23: 55-69.

Jalil, MA 1991, *Bangladesher Saontal: Samaj O Sanskriti*, A book on the Santals, a tribe in Bangladesh, their Society and Culture, Bangla Academy Press, Dhaka, pp. 26-48.

Johansen, C & Siddique, KHM 2018, 'Grain legumes in integrated crop management systems', Chapter 10, pp. 219-24, in S Sivasankar, D Bergvinson, P Gaur, S Kumar, S Beebe & M Tamò (eds), *Achieving Sustainable Cultivation of Grain Legumes, Volume 1: Advances in breeding and cultivation techniques*, Burleigh Dodds Science Publishing, Cambridge, UK.

Johansen, C, Musa, AM, Kumar Rao, JVDK, Harris, D, Ali, MY, Shahidullah, AKM & Lauren, JG 2007, 'Correcting molybdenum deficiency of chickpea in the High Barind Tract of Bangladesh' *Journal of Plant Nutrition and Soil Science*, 170(6): 752-761. https://doi.org/10.1002/jpln.200700249

Johansen, C, Haque, ME, Bell, RW, Thierfelder, C & Esdaile RJ 2012, 'Conservation agriculture for small holder rainfed farming: Opportunities and constraints of new mechanized seeding systems', *Field Crops Research,* 132: 18-32. https://doi.org/10.1016/j.fcr.2011.11.026

Joshi KD, Musa AM, Johansen C, Gyawali S, Harris D, Witcombe JR 2007, 'Highly client-oriented breeding, using local preferences and selection, produces widely adapted rice varieties', *Field Crops Research,* 100(1): 107-16. https://doi.org/10.1016/j.fcr.2006.05.011

Joshua, W & Rahman, M 1983, *Physical properties of soils on the Tista River floodplain and Barind Tract,* Soil Resources and Development Institute, Dhaka, Bangladesh.

Justice, SE, Meisner, CA, Sarkar, D, Haque, ME, Islam, MS & Abdullah, M 2003, *Seed drill use, repair and maintenance,* CIMMYT, Dhaka, Bangladesh.

Justice, SE, Haque, ME, Meisner, CA, Hossain, I, Sah, G, Tripathi, J & Rashid, MH 2004, 'Giving South Asia farmers a choice: a single drill for reduced and strip till crops for 2-wheel tractors', in *Proceedings of the CIGR International Conference, Beijing, China, 11-14 October 2004*, pp. 230-237.

Kabeer, N 2004, *Snakes, ladders and traps: changing lives and livelihoods in rural Bangladesh (1994-2001)*, CPRC Working Paper 50, Institute of Development Studies, University of Sussex, Brighton, UK, published in association with the Institute of Development Studies.

Kar, NK, Islam, SMF, Rahman, MS, Rahman, MS, Abedin, MZ, Musa, AM & Khair ABM 1988, 'Homestead plantations and agroforestry systems in Barind Tract Area of Bangladesh', *National Workshop on Homestead Plantation and Agroforestry in Bangladesh, 17-19 July, 1988,* Bangladesh Agricultural Research Institute, Gazipur, Bangladesh.

Karim, Z & Iqbal A 1997, 'Climate change: implications on Bangladesh agriculture and food security', *Journal of Remote Sensing and Environment,* 1: 71-83.

Kassam, A, Friedrich, T, Shaxson, F & Pretty, J 2009, 'The spread of conservation agriculture: justification, sustainability and uptake', *International Journal of Agricultural Sustainability*, 7(4): 292-320. https://doi.org/10.3763/ijas.2009.0477

Kelland, K 2017, *Cancer agency left in the dark over glyphosate evidence*, viewed 14 June 2017. https://www.reuters.com/investigates/special-report/glyphosate-cancer-data/

Khalequzzaman, M 2009, 'Animal and plant of Barind area', in C Saifuddin, T Islam, A Fazal & S Rahman (eds) *Varenra Anchaler Itihas* (in Bengali – A history of Barind region), Gatidhara, Banglabazar, Dhaka, Bangladesh, pp.77-89.

Los, SO, Weedon, GP, North, PRJ, Kaduk, J., Taylor, CM & Cox, PM 2006, 'An observation-based estimate of the strength of rainfall-vegetation interactions in the Sahel', *Geophysical Research Letters,* 33(16): L16402. https://doi.org/10.1029/2006GL027065

Majumdar RC & Pusalker AD 1951, *The History and Culture of the Indian People.* Bharatiya Vidya Bhavan, Bombay [Mumbai], India.

Miah Monayem, MA, Haque, ME, Baksh, M & Hossain, MI 2010, 'Economic analysis of power tiller operated seeder operation at farm level', *Journal of Agricultural Engineering* (Bangladesh), 38/AE 1: 19-24.

Mirza, MQ & Dixit, A 1997, 'Climate change and water management in GBM Basins', *Water Nepal,* 5: 71-100.

Misra, C 2009 'Some economic aspects of ancient Bengal: Epigraphic evidence', *Journal of Varendra Research Museum,* 9: 17-21.

Musa, AM, Harris, D, Johansen, C & Kumar, J 2001, 'Short duration chickpea to replace fallow after aman rice: the role of on-farm seed priming in the High Barind Tract of Bangladesh', *Experimental Agriculture*, 37(4): 509-521. https://doi.org/10.1017/S0014479701000448

Nelson, WH 1923, *Final report on the survey and settlement operations in the district of Rajshahi*, The Bengal Secretariat Modern Depot, Calcutta, India.

Neslen, A 2017, 'Controversial glyphosate weed killer wins new five-year lease in Europe' *The Guardian* 28 November 2017, viewed 14 July 2018. https://www.theguardian.com/environment/2017/nov/27/controversial-glyphosate-weedkiller-wins-new-five-year-lease-in-europe

Nisat, I & Khan, M 2009, 'River systems of Barind area', in C Saifuddin, T Islam, A Fazal, & SA Rahman (eds), *Varenra Anchaler Itihas* (in Bengali – A history of Barind region), Gatidhara, Banglabazar, Dhaka, Bangladesh, pp. 47-58.

OFRD 1991, *On-Farm Research Division, Barind Station, Rajshahi, Bangladesh Agricultural Research Institute. Annual Report for 1990-91*, BARI, Gazipur, Bangladesh.

OFRD 2007, *On-Farm Research Division of Bangladesh Agricultural Research Institute. Annual Report for 2006-07*, BARI, Gazipur, Bangladesh.

OFRD 2008, *On-Farm Research Division of Bangladesh Agricultural Research Institute. Annual report for 2007-08*, BARI, Gazipur, Bangladesh.

Powles, SB 2008, 'Evolution in action: Glyphosate-resistant weeds threaten world crops', *Outlooks on Pest Management*, 19(6): 256-259.

https://doi.org/10.1564/19dec07

PROVA (People's Resource Oriented Voluntary Association) 2003, *PROVA Annual Report 2003,* Rajshahi, Bangladesh.

Quayum, MA & Ali, AM 2012, 'Adoption and diffusion of power tillers in Bangladesh', *Bangladesh Journal of Agricultural Research*, 37(2):307-325.
http://dx.doi.org/10.3329/bjar.v37i2.11234

Rashid, HER 1991, *Geography of Bangladesh*. The University Press Limited, Dhaka, Bangladesh.

Richards, RA, Rebetzke, GJ, Condon AG & van Herwaarden AF 2002, 'Breeding opportunities for increasing the efficiency of water use and crop yield in temperate cereals', *Crop Science*, 42(1): 111-121.
doi:10.2135/cropsci2002.1110

Roy, KC, Meisner, CA & Haque, ME 2004, 'Status of conservation tillage for small farming of Bangladesh', in *Proceedings of the CIGR International Conference, Beijing, China, 11-14 October 2004*, pp. 426-432.

Roy, KC, Haque, ME, Justice, S, Hossain, I & Meisner, CA 2009, 'Development of tillage machinery for conservation agriculture in Bangladesh', *Agricultural Mechanization in Asia, Africa & Latin America*, 40: 58-64.

Sadrul Islam, AKM, Mondal, MAH & Ahiduzzaman, M 2010, 'A case study of grid connected solar PV irrigation system in semi-arid region of Bangladesh', *International Journal of Sustainable Water & Environmental Systems*, 1(1): 33-38.

Selvaraju, R & Baas, S 2007, *Climate variability and change: Adaptation to drought in Bangladesh: A resource book and training guide,* implemented under the project "Improved adaptive capacity to climate change for sustainable livelihoods in the Agriculture sector-DP9/1-BGD/01/004/01/99", Asian Disaster Preparedness Centre and Food and Agriculture Organization of the United Nations, Rome. ISBN 978-92-5-105782-7.

Selvaraju, R, Subbiah, AR, Baas, S & Juergens, I 2006, *Livelihood adaptation to climate variability and change in drought-prone areas in Bangladesh: Developing institutions and options*, implemented under the project "Improved adaptive capacity to climate change for sustainable livelihoods in the Agriculture sector-DP9/1-BGD/01/004/01/99", Asian Disaster Preparedness Centre and Food and Agriculture Organization of the United Nations, Rome. ISBN978-92-5-105602-8.

Shahid, S. 2008, 'Spatial and temporal characteristics of droughts in the western part of Bangladesh', *Hydrological Processes,* 22(13): 2235-2247.
https://doi.org/10.1002/hyp.6820

Shahid, S & Behrawan, H 2008, ‘Drought risk assessment in the western part of Bangladesh’, *Natural Hazards*, 46(3): 391-413. https://doi.org/10.1007/s11069-007-9191-5

Shahid, S & Hazarika, MK 2010, ‘Groundwater drought in the Northwestern districts of Bangladesh’, *Water Resources Management*, 24(10): 1989-2006. https://doi.org/10.1007/s11269-009-9534-y

Shirazul Islam, M 2009, *Farm mechanization for sustainable agriculture in Bangladesh: problems and prospects*, viewed 13 July 2018. www.un-csam.org/Activities%20Files/A09105thTC/PPT/bd-doc.pdf

Snapp, S 2002, ‘Quantifying farmer evaluation of technologies: the mother and baby trial design’, pp. 9-17 in MR Bellon & J Reeves (eds) *Quantitative Analysis of Data from Participatory Methods in Plant Breeding*, CIMMYT, Mexico. ISBN: 970-648-096-X.

Snapp, S 1999, ‘Mother and baby trials: a novel trial design being tried out in Malawi’, in *Target*: The Newsletter of the Soil Fertility Research Network for Maize-Based Cropping Systems in Malawi and Zimbabwe, vol.17, January 1999 issue.

Socioconsult Ltd. 2006, *Report on Impact Assessment Study on Chickpea in the High Barind Tract (HBT)*, for DFID Plant Science Research Programme, Centre for Arid Zone Studies (CAZS), University of Wales, Bangor, UK, Socioconsult Ltd., Dhanmondi, Dhaka, Bangladesh.

TANGO (Technical Assistance to NGOs) International 2002, *Household Livelihood Security Assessment. A Toolkit for Practitioners*, prepared for CARE USA, PLHS Unit, CARE, PLHS Unit, Atlanta, Georgia, USA.

TANGO (Technical Assistance to NGOs) International 2004, *Northwest Bangladesh Livelihoods Survey Panel Data Analysis – Livelihood Change in Northwest Bangladesh: Pattern and Processes*, prepared for the Livelihoods Monitoring Program, CARE Bangladesh.

The Bangladesh Network 2017, *General Soil Map: Bangladesh*, viewed 5 July 2018. https://www.thebangladesh.net/general-soil-map-of-bangladesh.html#map-1

The Guardian 2015, *Roundup weedkiller 'probably' causes cancer, says WHO study*, published Sunday 22 March 2015, viewed 14 July 2018. https://www.theguardian.com/environment/2015/mar/21/roundup-cancer-who-glyphosate-

Wani, SP, Sreedevi, T., Pathak, P, Rego, TJ, Shiferaw, B & Iyer, SR 2006, ‘Farmer-participatory integrated watershed management: Adarsa watershed, Kothapally, India – an innovative and upscalable approach', *SAT eJournal* (ejournal.icrisat.org)., August 2006, 2(1).

Wei, X, Shao, M, Gale, W & Li, L 2014, 'Global pattern of soil carbon losses due to the conversion of forests to agricultural land', Scientific Reports, vol. 4, no. 4062. doi 10.1038/srep04062

WFP (World Food Programme) 2006, *Rural Bangladesh. Socio-Economic Profiles of WFP Operational Areas & Beneficiaries*, a co-publication of WFP, Bangladesh and TANGO International USA, IDB Bhaban, E/8-A Rokeya Sarani, Dhaka-1207, Bangladesh, pp. 90-91.

Witcombe, JR, Joshi, A, Joshi, KD & Sthapit, BR 1996, 'Farmer participatory crop improvement. I. Varietal selection and breeding methods and their impact on biodiversity', *Experimental Agriculture*, 32(4): 445-460. https://doi.org/10.1017/S0014479700001526

Witcombe, JR, Joshi, KD, Gyawali, S, Musa, AM, Johansen, C, Virk DS & Sthapit BR 2005, 'Participatory plant breeding is better described as highly client-oriented plant breeding. I. Four indicators of client-orientation in plant breeding', *Experimental Agriculture*, 41(3): 299-319. https://doi.org/10.1017/S0014479705002656

Witcombe, JR & Yadavendra, JP 2014, 'How much evidence is needed before client-oriented breeding (COB) is institutionalised? Evidence from rice and maize in India', *Field Crops Research*, 167: 143-152. https://doi.org/10.1016/j.fcr.2014.06.022

Wohab, MA, Roy, KC, Haque, ME, Abedin, MJ & Islam, MS 2007, 'Field performance evaluation of BHT seeder for sowing and tilling'. *Journal of Socioeconomic Research and Development*, 4: 116-119.

Wohab, MA, Ziauddin, ATM, Haque, ME, Sayre, KD & Hossain, MI 2009, 'Development of single pass bed planter for small holders' farming, crop diversification and resource conservation. Innovations for improving efficiency, equity and environment', in *Proceedings of the 4th World Congress on Conservation Agriculture*, New Delhi, India, p. 302.

World Bank 2000, Bangladesh – Climate change and sustainable development (English), Report No. 21104 BD, October 10, 2000, World Bank, Washington, DC, USA, viewed 8 February 2018. http://documents.worldbank.org/curated/en/906951468743377163/Bangladesh-Climate-change-and-sustainable-development

WRC (Wheat Research Centre of Bangladesh Agricultural Research Institute) 2001, *Annual report for 2000-2001*, WRC, Dinajpur, Bangladesh.

WRC (Wheat Research Centre of Bangladesh Agricultural Research Institute) 2008, *Annual report for 2007-2008*, WRC, Dinajpur, Bangladesh.

Zakaria, AKM 2009, ‘Geographical and geological introduction of Barind area’, in C Saifuddin, T Islam, A Fazal & SA Rahman (eds), *Varenra Anchaler Itihas* (in Bengali – A history of Barind region), Gatidhara, Banglabazar, Dhaka, Bangladesh, pp. 33-46.

Zuberi, MI 2009, ‘Environment of Barind: past and present’, in C Saifuddin, T Islam, A Fazal & SA Rahman (eds), *Varenra Anchaler Itihas* (in Bengali – A history of Barind region), Gatidhara, Banglabazar, Dhaka, Bangladesh, pp.59-76.

ACKNOWLEDGEMENTS

This book is dedicated to the farming families of the HBT who willingly collaborated with researchers in the joint endeavour to improve the livelihoods of those families.

The Bangladesh organizations contributing to the work discussed in this book include BARI, in particular the OFRD, Pulses Research Centre (PRC) and Wheat Research Centre, DAE, Soil Resources Development Institute, BMDA, Rajshahi University and the NGO PROVA (Peoples Resource Oriented Voluntary Association). Although we are space-constrained to mention all of the willing participants from these organizations we must mention some who played critical roles – such as Dr Md. Shakhawat Hossain, Dr Mohammad Shahjahan, Nirmal Kar and Shafiqul Islam of OFRD, Barind Station, Md. Saiful Islam of DAE, Drs Mathiur Rahman and Md. Ariful Islam of PRC, Dr Monzur Hossain of Rajshahi University, and AKM Shahidullah, Bubul Akhtar and Md. Nur Nobi Mia of PROVA.

International organizations involved in the HBT research and development efforts described here include ICRISAT, the Centre for Arid Zone Studies – Natural Resources (CAZS-NR) of the University of Wales, UK, the University of Western Australia (UWA), Murdoch University (MU), CIMMYT, IRRI and Cornell University CU). As well as direct funding from these organizations funding also came from the Department of International Development (DFID) of the UK and the Australian Centre for International Agricultural Research (ACIAR). Major research and conceptual contributions from members of these organizations came from Drs Jagdish Kumar and JVDK Kumar Rao (ICRISAT), Drs Dave Harris, John Witcombe and Krishna Joshi (CAZS-NR), Prof. Kadambot Siddique (UWA), Prof. Richard Bell and Drs Wendy Vance, Md. Enamul Haque and Md. Enamul Kabir (MU), Dr Craig Meisner (CIMMYT) and Dr Julie Lauren (CU).

Last but not least we thank our respective families for providing us the necessary support, and their patience, in facilitating our efforts in the HBT.