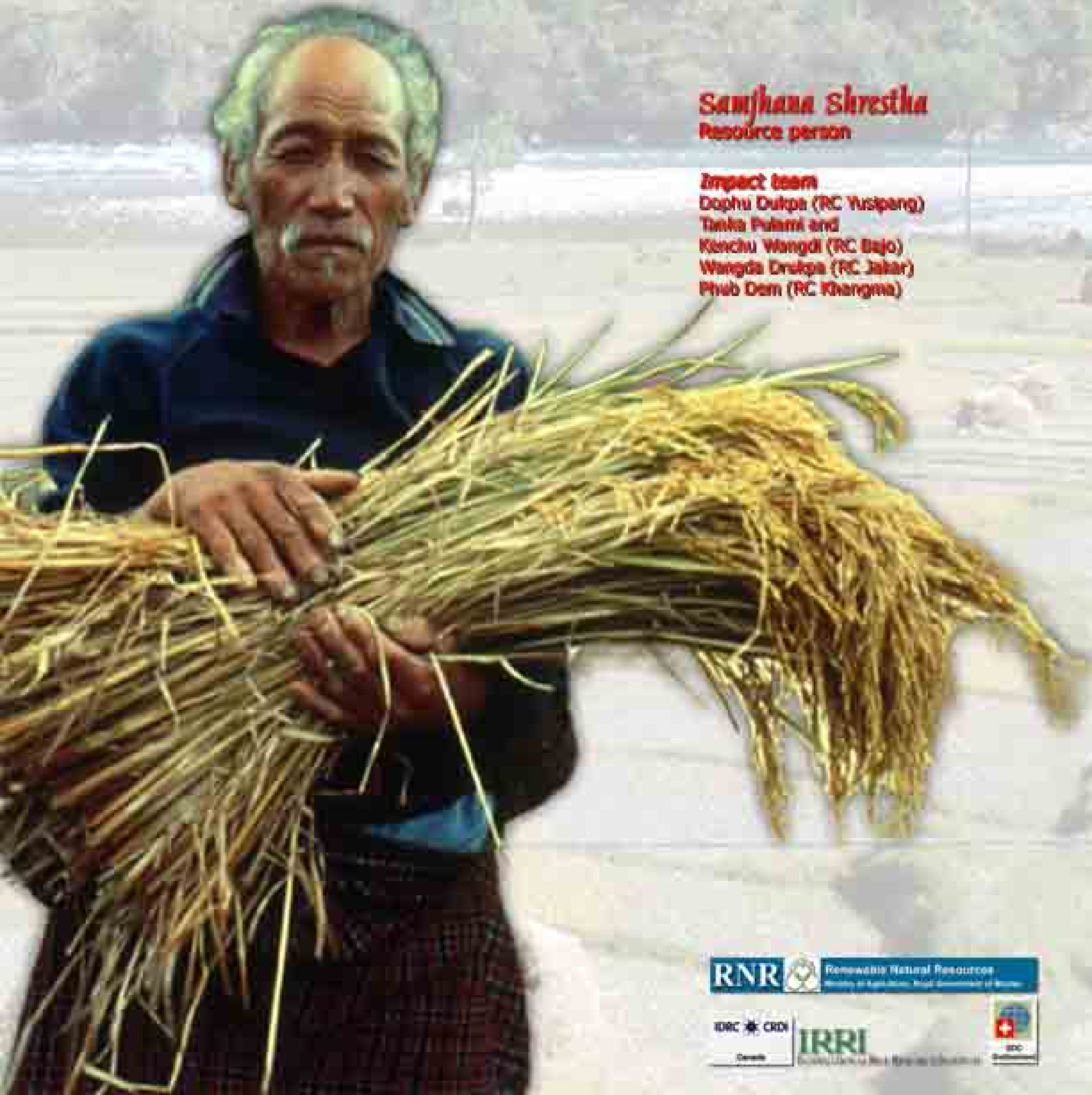
An Economic Impact Assessment of the Rice Research Program in Bhutan



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Ministry of Agriculture, Royal Government of Bhutan
IDRC CRDI Canada
IRRI

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The International Rice Research Institute (IRRI) was established in 1960 by the Ford and Rockefeller Foundations with the help and approval of the Government of the Philippines. Today IRRI is one of 15 nonprofit international research centers supported by the Consultative Group on International Agricultural Research (CGIAR). The CGIAR membership comprises Organisation for Economic Cooperation and Development donors, international and regional organizations, and private foundations.

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The responsibility for this publication rests with the International Rice Research Institute.

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Acronyms

AVRDC	Asian Vegetable Research and Development Center
BMVs	Bhutanese improved modern varieties of rice
CARD	Center for Agricultural Research and Development
CGIAR	Consultative Group on International Agricultural Research
CSO	Central Statistical Organization
FYM	farmyard manure
DRDS	Department of Research and Development Services
ICARDA	International Center for Agricultural Research in the Dry Areas.
ICIMOD	International Centre for Integrated Mountain Development
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
IDRC	International Development Research Centre
IFPRI	International Food Policy Research Institute
ILRI	International Livestock Research Institute
IMVs	IRRI improved modern varieties of rice
INGER	International Network for Genetic Evaluation of Rice
IPGRI	International Plant Genetic Resources Institute
IPMO	International Programs Management Office
IRRI	International Rice Research Institute
ISNAR	International Service for National Agricultural Research
MOA	Ministry of Agriculture
MOU	memorandum of understanding
MVs	improved modern varieties of rice
NGO	nongovernmental organization
NRM	natural resource management
OMVs	other improved modern varieties of rice
RNR-RCs	Renewable Natural Resources Research Centers
SAARC	South Asian Association for Regional Cooperation
SDC	Swiss Agency for Development and Cooperation
TVs	traditional varieties of rice

Nu Ngultrum (nu), Bhutan's currency, exchange rate is US$1 = Nu 44.

Foreword

Rice is indispensable in the Bhutanese diet and culture; without rice, hunger remains insatiable and divine offerings stay unfulfilled. In the good old times, there was enough rice for everyone, even a little extra for trading with neighboring Tibet. Now, we import about 38 tons of milled rice annually. The situation would have been worse if not for the national rice research and development program.

The remarkable journey of rice research in Bhutan began in 1984 in partnership with IRRI, and with the financial assistance of IDRC and lately that of SDC. We have come a long way, starting from scratch to now building a redoubtable national research system that has started paying rich dividends. This report attempts to document the impact in the country. As uncovered in the study, we are proud to note that rice production has been increasing steadily over the years, improved rice technologies have led to an increase in national rice output, farmers have been adopting improved technologies with high net returns, and household food security has improved markedly.

In the future, we hope to continue our efforts to fertilize rice research and reap an even richer harvest. In our endeavor, we also look forward to continued collaboration with IRRI, IDRC, SDC, and others.

D. PEMA CHOEPHYEL
Director
Council for Research and Extension

Acknowledgments

This report presents the results of an impact assessment of the rice research program in Bhutan. The program was implemented by the Renewable Natural Resources Research Centers (RNR-RCs) of the Royal Government of Bhutan. The report is based on the information gathered from a number of sources, including a field survey conducted in November-December 2002, secondary agricultural statistics, interviews with local and international officials working in the agricultural sector in Bhutan, and annual reports and documents of RNR-RCs.

It would not have been possible to uncover the success story of the rice research program without the cooperation and support of Mr. Sangay Duba (RNR-RC Bajo, program director) and Mr. Mahesh Ghimiray (program officer). We are grateful to the program directors of other RNR-RCs, Dr. Lungten Norbu (Yusipang), Mr. Kinzang Wangdi (Jakar), and Mr. Pirthiman Pradhan and Mr. Karma Tashi (Khangma), for their support in undertaking the study. We would also like to extend our appreciation to the staff of RNR-RC Bajo for their cooperation and general support during our training on impact assessment and during the preparation of the report.

We would like to thank the staff of the International Programs Management Office (IPMO) at the International Rice Research Institute for their administrative support, in particular Dr. Mark Bell (IPMO head) and Mr. Julian Lapitan (senior associate scientist and IPMO manager).

Finally, we appreciate the generous amount of time given by local and international officials and Bhutanese farmers while gathering the required information.

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Executive summary

Formalized agricultural research in Bhutan started with the establishment of the Renewable Natural Resources Research Centers (RNR-RCs, formerly CARD) in 1982. There are four research centers in the RNR-RCs, each with the national mandate for food crops, forestry, livestock, and horticulture and the regional mandate for other sectors within their region. The RNR-RC Bajo has the national mandate for food crops and rice research is one of the major components of its program. The objectives of the rice research program are to develop improved rice technologies for raising productivity and farm incomes so that the national food objective of 70% self-sufficiency in rice can be achieved. In addition, RNR-RC Bajo has the responsibility to coordinate rice technology development, provide policy advice, and develop and manage linkages with national and international institutes.

This study reports on economic impact assessments of research and technology development conducted during the last two decades. In addition, the institutional impact on capacity building for agricultural research is also briefly evaluated. The economic impact assessment is based mainly on a farm survey conducted in seven main rice-producing *dzongkhags* (districts) in November-December 2002.

The rice research and technology development program has been successful in increasing rice production and farm income, and in improving food security. These benefits are likely to increase as rice technologies continue to spread over time. Some of the major impacts produced so far are as follows:

- Rice production from 1989 to 1997 increased by 58% even while rice area decreased by 9%. The corresponding increase in yield by 75% was the main driving force for the production increase. As a result, annual rice imports stabilized, on average, at 33,000 t in recent years, despite the population growth.
- Improved rice technologies have led to an increase in national rice output by 5,000 to 10,000 t per year. Valued at the farm-gate price of Nu 11,980 per ton, the estimated increase in gross output is from Nu 60 million to Nu 121 million per year.
- Net returns from the adoption of improved rice technologies are estimated at 9,000 Nu ha^{-1}. This translates into a gain in net returns nationally of Nu 58 million to Nu 118 million.
- Fifteen improved modern rice varieties (MV) have been released during the last two decades in Bhutan. Two of these varieties were elite lines developed at IRRI (IMV), seven were developed in other countries (OMVs), and six varieties were developed specifically by the Bhutanese rice research program (BMVs).
- The MVs are now grown widely in all agroecological zones of Bhutan. Nationally, MVs are grown by 60% of the households and cover 35% of the rice area.
- Various improved crop management practices were also developed and disseminated. The most commonly adopted improved management practices are improved methods for controlling weeds, the application of inorganic fertilizers, improved land preparation, and improved nursery preparation methods.
- The weighted average yield of MVs is 27% higher than that of traditional varieties (TVs). The BMVs outperformed all other groups of MVs, indicating that these varieties are more suited to local conditions. The BMVs have a yield advantage of more than 40% over the OMVs, equivalent to a yield gain of 1.3 t ha^{-1}.
- Sixty-eight percent of the households are now self-sufficient in rice. On average, the households that grow MVs are less deficient in rice.
- The MV adopter households have 110% more cash income on average than the nonadopters. This higher cash income can be partly attributed to the improved rice productivity that enabled farmers to diversify to higher-valued cash crops without sacrificing food security.
- The rice research program played a critical role in building the research capacity of the country. A total of 182 training opportunities, covering a wide range of topics, were provided during the past two decades and the required infrastructure was developed. Planning, management, and implementation of research programs have improved considerably and become stronger over time. In addition, RNR-RCs now provide critical inputs to national-level planning and policy-making in the agricultural sector.

An Economic Impact Assessment of the Rice Research Program in Bhutan

Introduction

Rice is the preferred staple of Bhutan. Accordingly, the Royal Government of Bhutan has placed a top priority on increasing rice productivity. Agricultural research and technology development in the country started in 1982 with the establishment of the Renewable Natural Resources Research Centers (RNR-RCs, formerly the Center for Agricultural Research and Development). One of the primary objectives of these research centers is to develop rice technologies that will enhance productivity on a sustainable basis.

The main constraints to rice production in Bhutan are low soil fertility, the prevalence of pests and diseases, cold temperature, and the high labor requirement for rice production (RNR-RC Bajo 2001). Several rice technologies have been developed to overcome these constraints. Efforts have also been made to develop the infrastructure and human capacity for undertaking rice research. There are indications that these investments in rice research and capacity building have produced large gains (DRDS 2002). The success of rice research in the country is perceived as a role model and it has provided the impetus for research on other commodities. The Joint Director of Research and Extension, Mr. Ganesh B. Chettri, says, “The benefits of research in the country are realized through the effective rice research program, and this model has been used in initiating research in other sectors for forestry, horticulture, and livestock” (personal communication, 2002).

Despite these positive indications of the impact of rice research, there has not been a systematic assessment of its impact in Bhutan. The purpose of this study is to assess the economic and institutional impact of the RNR-RCs’ rice research program. The impact analysis reported here is based on the quantitative and qualitative data gathered for the study in 2002.

The report is organized as follows. First, the institutional setup of RNR-RCs and the objectives of rice research programs are briefly described. Second, the main themes of the research programs, capacity-building efforts, and the nature of national and international collaboration are briefly described. This is followed by a discussion of the importance of rice in Bhutan and an analysis of recent trends in production and trade. A section on methodologies used for studying impact assessment is subsequently presented. Finally, the impact of rice research and technology is assessed in terms of increases in rice production, gains in income, and achievements in food security, at both the farm level and nationally. Impact in terms of institutional capacity building is also briefly assessed.

Many factors have contributed to the increase in rice production during the last two decades. The government’s policies to increase food production, commitment by extension agents to disseminate improved technologies to remote areas, and investment in infrastructure are some examples. It is neither possible nor desirable to separate out the contribution of individual factors involved in the development of the rice sector. The approach taken is to assess the overall impact in which RNR-RCs have played a critical role through rice research and technology development (Dorji et al 1989).

Renewable Natural Resources Research Centers

Institutionalized agricultural research in Bhutan started in 1982 with the establishment of the Center for Agricultural Research and Development (CARD). CARD evolved to become the Renewable Natural Resources Research Centers (RNR-RCs) in 1992. The RNR-RCs’ mandate is to improve the well-being of the Bhutanese people on a sustainable basis through integrative research and development in agricultural, livestock, forestry, and horticulture subsectors.

The Council of Research and Extension, Ministry of Agriculture (MOA), has four research centers (RCs) located at Yusipang, Bajo, Jakar, and

Khangma. Each center has the national mandate for different renewable natural resource (RNR) sectors. In addition, each center also has the regional responsibility to undertake research in all RNR subsectors relevant for its regional domain. Research on food crops is one of the major activities of all RNR-RCs.

Rice research objectives

The main objectives of the rice research program are to provide new and reliable information, technology, and materials to effectively overcome production constraints while raising farm productivity and income so that national food objectives can be attained. The major focus of the rice research program is to conduct applied research to develop improved technologies. In addition, the program is involved in producing policy advice, managing and developing linkages with national and international institutes, and managing information and regulation on rice technology development (MOA 2000).

The RNR-RC Bajo has the national mandate to plan, manage, and implement the rice research program. It formulates national strategic objectives and also provides technical support and guidance for regional rice research to other RCs. Its planning function is to ensure that rice research in all centers is consistent with the national and regional priorities, and each RC complements others while avoiding duplication. Table 1 shows the test locations and leading RCs for different rice agroecological zones.

International collaboration for rice research

The RC Bajo also coordinates and takes a lead role in international collaboration and donor relations for rice research. The International Rice Research Institute (IRRI), based in the Philippines, has been the main international partner in rice research since 1984. This collaboration has contributed to building the required research infrastructure and knowledge base. The International Development Research Centre (IDRC) of Canada has supported this international collaboration since 1984. The Swiss Agency for Development and Cooperation (SDC) has co-financed the collaboration since 1995.

The RC Bajo also has links with government institutes in the South Asian Association for Regional Cooperation (SAARC) member countries and Korea and Japan. Some of these countries have similar rice ecologies and, hence, have also been the source of new rice technologies for local adaptation.

Table 1. Test locations for different rice agroecological zones.

Lead research center	Agroecological zone (by altitude)	Test location
RC Bajo	Medium	Wangdue
RC Yusipang	High	Thimphu/Paro
RC Bajo	Low	Tsirang/Dagana
RC Jakar	Low	Bhur

Major themes of the rice research and capacity-building program

Varietal improvement

Initially, the varietal improvement program had been focusing on developing and releasing cultivars with high yield potential. In recent years, the focus has widened to include development of varieties that resist rice pests, tolerate cold, and have locally preferred traits such as red pericarp.[1] Efforts to conserve local rice genetic materials to safeguard the gene pool for rice improvement in the future are also being undertaken.

Varietal introduction. Since 1985, Bhutanese rice scientists have been evaluating elite rice varieties from international and national institutes for local releases. These improved rice varieties go through rigorous evaluations prior to release in the country. For example, the best elite lines are first evaluated on-station and further tested using on-farms trials in multiple locations. The on-farm evaluations consist of three stages, involving pre and post on-farm trials referred to as “researcher-managed trials,” “preproduction evaluation trials,” and “production evaluation trials.” In these progressive stages of trials, ranges of suitable varieties are narrowed down and the nature of trials changes from researcher to farmer management (Chettri et al 1999). The varieties selected through this process are then sent to the National Seed Board for a final evaluation and official release.

Cross-breeding. The main objective of the cross-breeding program is to develop elite cultivars that would outperform the introduced improved varieties by overcoming the constraints specific to Bhutanese conditions. Under this program, major efforts were directed to developing rice varieties with high yield and red pericarp. Other desirable traits that were incorporated into the cross-breeding program were improved grain quality, ease of threshing, cold tolerance, and resistance to rice diseases, especially blast.

The outbreak of blast in 1995 devastated rice producers in the affected areas and highlighted the

[1]Grains with red pericarp are considered as high-quality rice in the high-and medium-altitude zones.

necessity of the cross-breeding program. Local varieties were susceptible to blast and the available improved varieties bred elsewhere were not tolerant of cold temperature. Hence, significant efforts were directed at deploying varieties that are blast-resistant, tolerant of cold temperature, and adaptable to the high-altitude zone (1,500 to 2,600 m).

Conservation of local rice germplasm. Recent efforts have also been directed to collecting and conserving local rice germplasm to safeguard the gene pool. Both *ex situ* (storage in gene banks) and *in situ* (conservation through sustained use in farmers' fields) strategies are being used for conserving rice genetic diversity. These activities are supported by the International Plant Genetic Resources Institute (IBPGR) and IRRI-SDC projects. The PGR conservation project supported by the Norwegian Development Fund is expected to strengthen this effort.

Crop management

Research on crop management includes the management of nutrients, weeds, pests, and diseases, and crop establishment and improvement of cropping patterns. These component technologies are briefly described below.

Nutrient management. The research efforts at improving soil nutrient management include the appropriate level of application of organic and inorganic fertilizers, analysis of soil texture, appropriate use of tillage systems, and replenishment of soil fertility through green manure crops (*Sesbania aculeata* and *Astragalus sinicus*). As the main fertilizer used is still organic, extensive studies on the content and availability of organic fertilizers from community forest (forest litter) and domestic sources (from livestock and crop residue) have been conducted.

Intensive research on the responses of traditional and improved rice varieties to organic and inorganic fertilizers has been undertaken for different rice agroecologies. Recommendations for NPK, both in combination with organic fertilizers and separately, have been formulated for different parts of the country.

Farmers' use of inorganic fertilizers is reported to have increased over the years. In response to this and to stimulate further growth in rice production, research has also been undertaken to improve the yield response of popular rice varieties for different altitudes. Efforts are also under way to study the long-term effects of integrated plant nutrient management systems on rice and rice-based crop rotation systems.

Weed management. Common weeds in rice production are being identified and documented by different altitudes as part of the weed management program. Weed management methods such as hand-weeding, mechanical control, changes in agronomic practices, and chemical use are being evaluated.

In the high- and medium-altitude zones, *Potamogeton distinctus* (locally called *sochum*) remains the most problematic weed and is estimated to reduce rice production by around 37% (Ghimiray 1999). Two chemicals effective against sochum were identified, but their costs were prohibitive. The current technical recommendation for controlling sochum is to conduct intensive hand-weeding and deep-plowing.

Pest management. Rice diseases and insects and damage from wild animals and birds are some of the common pest problems. Major rice insects and diseases associated with rice both pre- and postharvest for different altitude zones have been identified and documented. Leaf defoliators (case worm, leaffolders), rice bug and armyworm, neck and node blast, stem borer, sheath blight, and seedling blast are some of the problematic parasites. Improved varietal resistance to blast has been developed. For other parasites, research has focused on evaluating protective methods and monitoring. Some examples of the protective measures promoted are treating seeds to ensure that they are disease-free, burning infected straw, and planting susceptible rice varieties in wide and open valleys.

Agronomic practices. Several different component technologies for general agronomic management were evaluated. Some examples of the research programs are

- Suitable planting times for different maturity periods of rice varieties,
- Better nursery preparation methods, such as raised seedbed preparation; wet, semidry, and dry bed; polytunnel seedling preparation; and appropriate level of seed rate use,
- Different tillage and crop establishment methods for efficient use of labor,
- Water management methods, and
- Rice ratooning.

Postharvest management. Past studies on postharvest management pertain to documenting current practices, identifying problems associated with grain storage in terms of pests and storage systems, preventing losses from postproduction processes, and evaluating postharvest technologies for labor saving during threshing and processing.

Ongoing and planned studies on postharvest management include evaluating rice varieties for nonshattering, identifying factors affecting head rice recovery in the period after harvest and prior to storage, evaluating milling equipment for effectiveness and efficiency in producing good grain quality, and selecting rice varieties with a higher market value.

Cropping systems. Although multiple cropping is possible in almost all rice areas, rice-fallow farming systems are still common in Bhutan. Research on crop intensification has focused mainly on fully using land for increasing and diversifying agricultural production. These programs have also been designed to improve soil nutrients through rotational cropping practices that include nutrient-supplementing crops such as legumes and green manure crops. The research has focused mainly on identifying suitable varieties and appropriate management practices for rice and rice-based crops.

Infrastructure and human capacity building

Agricultural research in Bhutan commenced with rice research. The initial stages involved setting up the required physical infrastructure, skill building, and developing plans and strategies for research to undertake and implement a coordinated research program.

From the initial stages, enhancing human capacity was recognized as an essential component for achieving a productive and sustainable research system. Capacity-building activities involved short- and long-term degree and nondegree training that included basic postschool diplomas as well as university degrees. The training focused on a wide range of topics on rice science, integrated cropping systems, biodiversity conservation, research planning and management, computer skills, and community management of renewable natural resources.

In addition, staff participation in various study tours, seminars, and national and international conferences was encouraged. Regular workshops were also organized among RCs for greater collaboration and integration of research programs.

Rice production patterns and trends in Bhutan

Increasing food production is one of the top national priorities in Bhutan. One of the targets of the ninth national plan (2002-07) is to achieve 70% self-sufficiency in food production. Food self-sufficiency is largely interpreted to mean self-sufficiency in rice (MOA 2000).

Rice area is classified into three distinct rice agroecologies: high-, medium-, and low-altitude zones. The high-altitude zone is in the range of 1,500 to 2,600 m and has a warm temperate climate. The medium-altitude zone consists of valleys and foothills of the Himalayas from 600 to 1,500 m. The low-altitude zone is mainly the southern rice belt with elevations of 160–600 m. Generally, 20% of the rice area is classified as high-altitude zone, with medium- and low-altitude zones accounting for 40% each.

The absence of reliable national-level data makes it difficult to ascertain trends in rice production over time. RNR statistics are the official data source for agricultural information. According to this database, Bhutan's rice area, production, and yield in 2000 were more than 19,000 ha, 44,000 t, and 2.2 t ha^{-1}, respectively (Table 2).

In addition to this official data source, several data sources are also commonly used in RCs and by government officials at all levels. Table 3 presents estimates of rice area and production derived from these commonly used databases.

The RNR database provides the lowest estimate of rice area and the second lowest estimate of production level. The rice area and production based on GIS/LUPP are almost twice the official estimates at more than 39,000 ha and 88,000 t, respectively. The estimate based on the Cadastral survey is in the mid-

Table 2. Rice area, production, and yield by *dzongkhag* (district) and altitude zone, 2000.

Dzongkhag[a]	Area (ha)	Production (t)	Yield (t ha^{-1})
High altitude	2,179	5,658	2.60
Bumthang	27	45	1.64
Gasa	87	194	2.22
Ha	105	186	1.77
Paro	1,269	3,083	2.43
Thimphu	690	2,151	3.11
Medium altitude	10,658	26,157	2.45
Chhukha	722	1,262	1.75
Dagana	1,143	2,233	1.95
Lhuentse	760	1,967	2.59
Mongar	445	888	1.99
Pemagatshel	20	46	2.35
Punakha	1,971	6,274	3.18
Trashigang	941	2,440	2.59
Trongsa	554	1,157	2.09
Tsirang	1,473	3,067	2.08
Wangdue	1,467	4,024	2.74
Yangtse	630	1,763	2.80
Zhemgang	532	1,036	1.95
Low altitude	6,558	12,484	1.90
Samtse	2,889	4,650	1.61
Sarpang	2,839	5,830	2.05
S/Jongkhar	830	2,004	2.41
National	19,395	44,298	2.28

[a]The rice-growing environment is divided into three distinct zones and associated with particular dzongkhags. However, a dzongkhag could contain one or more rice-altitude zones. The categorization of dzongkhags into different altitude zones is based on the Eighth Five-Year Plan for commodity programs.
Source: MAO (2001).

range and is considered to be more realistic by researchers at RCs. As per the Cadastral survey estimate, Bhutan's rice area and production are more than 26,000 ha and 60,000 t, respectively. There is also a time-series database with area and production estimates close to those of the Cadastral survey (cited in MOA 2000). Based on this estimate, rice area decreased by around 9% during 1989 to 1997, but production and yield increased by at least 58% and 74%, respectively, during the same period (Table 4).

Rice self-sufficiency

There are several estimates of the national self-sufficiency level and the main ones appear in Table 5. These different data sources indicate that domestic production fulfills 40% to 65% of the requirement. The remaining requirement is met by imports. India is the major source of imported rice.

The Food Corporation of Bhutan (FCB) and private enterprises are the main importing agencies. From 1995 to 2000, rice imports averaged approximately 33,000 t per year (Table 6). Variation in imported quantity was only slight among these years.

A relatively stable level of imports indicates that domestic supply has largely kept pace with the increased demand for rice over time. Available farm-level studies also support the notion that food availability has improved over time in rural areas. For example, household-level studies in the Wangdgu-Punakha valley indicate that rice surplus increased from 13% in 1992 to 40% recently (MOA 2000). As per the RNR statistics in 2000, around 44% of the households have attained self-sufficiency in food (MOA 2001).

On average, the national food shortage is estimated at 2.2 months. The statistics on household food shortage and household coping strategies by dzongkhag and altitude are presented in Appendix 1.

Future rice demand

Traditionally, rice was produced and consumed mainly in the western and southern regions of Bhutan. Over time, rice has become a major staple in most parts of the country. It is now the staple crop of more than 65% of the population. It is also the preferred cereal crop of people whose current diet is non-rice-based. In the western and southern regions, per capita milled rice consumption is one of the highest in the world at 167 to 262 kg per year (MAO 2000, 2001, GIS/LUPP 1995, Cadastral survey 1990), respectively.

Table 3. Rice area, production, and yield according to different data sources.

Data source	Area[a] (ha)	Production (t)	Yield (t ha^{-1})
CSO database[b]	26,010	39,790	1.53
RNR statistics (2000)	19,396	44,298	2.28
Cadastral survey (1999)	26,512	59,685	2.25
MOA (1997)[c]	23,679	63,065	2.66
GIS/LUPP (1995)	39,240	88,338	2.25
FAO database (2001)	30,000	50,000	1.67
Average	27,473	57,529	2.11

[a] Rice area is recorded as net area planted to rice for all data sources except for the GIS/LUPP method, for which it represents the gross area planted to rice.
[b] Agronomic survey conducted in 1988-89 cited in the Statistical Year Book of Bhutan, for 1999 and 2001.
[c] Data cited in MOA (2000). This database also has time-series data for 1989-97.

Table 4. Rice area, production, and yield, 1989-97.

Year	Area (ha)	Production (t)	Yield (t ha^{-1})
1989	26,010	39,790	1.53
1990	26,304	59,449	2.26
1996	23,777	65,576	2.76
1997	23,679	63,065	2.66
Average	24,943	56,970	2.30
Difference from 1989 to 1997	–9%	58.5%	74.1%

Source: Data cited in MOA (2000).

Table 5. National self-sufficiency in rice.

Data source	Self-sufficiency (%)
RNR statistics (2000)	39
Cadastral survey (1999)	46
MOA (1997)	56
GIS/LUPP (1995)	56

Source: MOA (2000).

Table 6. Rice imports to Bhutan, 1995-2000.

Year	FCB imports (t)[a]	Total imports (t)[b]
1995	11,780	31,227
1996	13,392	29,237
1997	15,862	29,026
1998	9,005	34,816
1999	13,226	38,709
2000	6,302	33,704
Average	11,594	32,787

[a] The FCB is a government cooperative institute. Rice imported through this channel is subsidized and based on a quota agreement with India.
Source: Food Corporation of Bhutan, cited in CSO (2001)[a] and Bhutan Trade Statistics, MOA (2000)[b].

The demand for rice is expected to increase in the future, driven mainly by factors such as growth in population of around 2.5% per annum, an increase in income, and rapid urbanization. With the increase in income, Bhutanese are increasing their consumption of rice—a preferred staple in urban and rural areas. The current urban population, estimated at 20%, is expected to increase annually at 6% to 7% during the next 20 years. This is expected to contribute to an increasing demand for rice since an increase in urban population is positively correlated with rice consumption (MOA 2000).

Methodology for impact assessment

Impact assessment is a process of estimating whether or not research, technology development, and capacity-building efforts have produced their intended effects in meeting the development objectives (Anderson and Herdt 1990). The assessment can be ex ante or ex post. The ex ante assessment is conducted prior to project implementation to estimate the likely impact on the target population. The ex post impact assessment measures the actual benefits realized.

The outputs of rice research are new and improved varieties, better crop management practices, and enhanced human capacity for research and development. These outputs have direct, indirect, and intermediate impacts. The direct impact refers to the impact on the welfare of people and the environment as a result of adoption of a technology. It is measured mainly as the increase in productivity, reduction in per unit cost of production, and/or reduced pressure for expansion into fragile ecosystems. Indirect impact includes spillover impacts on other crops and activities. An example of indirect impact would be diversification to high-value cash crops as rice requirements are fulfilled. Intermediate impact refers to increases in the knowledge base that could subsequently produce a direct impact. For example, information on an evaluation of the gene pool, prototype technologies, and new skills and knowledge of researchers are intermediate benefits.

Economic surplus model

An economic surplus model is widely used in quantifying the returns to investment in agricultural research (Alston et al 1995). The method is based on quantifying the increases in consumer and producer surpluses arising from the adoption of new technologies. This is the basic conceptual framework used in this study for impact assessment. A short description of the framework is provided here. For details, please see Shrestha et al (2002).

Figure 1 illustrates the basic framework. Initially, with the existing technique, Q_0 is produced at the P_0 price level on the supply curve S_0. The adoption of a new technology results in a shift in the supply curve from S_0 to S_1. As a result, rice production increases from Q_0 to Q_1 and the price decreases from P_0 to P_1.

The benefits to consumers and producers of the improved technology are

- Consumers benefit because they can purchase more output at a lower price. This increase in consumer surplus can be estimated by the area P_0abP_1.
- Producers benefit from higher output and a decline in the unit production cost. This benefit can be estimated by the area P_1bcd.

The total benefit from the research program is the sum of the producers' and consumers' surplus. The rectangle area P_0acd is often a close approximation because the triangle abc is relatively small. The distribution of the total benefit between producers and consumers depends on the size of the fall in price (change in P) relative to the fall in cost (R). In turn, this depends on the elasticities (slopes) of the supply and demand curves. When the absolute values of the elasticities are equal, the benefits from research are shared equally between producers and consumers.

Data sources and sampling procedures

Impact assessment conducted in this study is based on both quantitative and qualitative data. Primary data were collected through a household survey and secondary data were obtained from national statistics, RNR-RC documents, and other publications. Qualitative data were collected from various stakeholders through personal interviews and focus-group meetings.

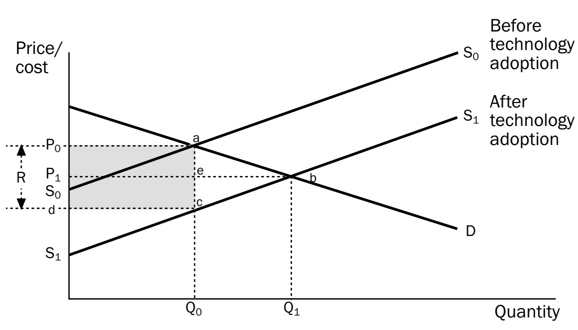

Fig. 1. The supply and demand model of research benefits.

A farm household survey was conducted in November-December 2002 (a "normal" year for rice production), soon after the harvest season. The survey included information on summer and winter crops. Household heads were interviewed using structured questionnaires to obtain required data (Appendix 2).

A stratified multistage random sampling method was used to draw representative samples. Seven main rice-producing dzongkhags from the high-, medium-, and low-altitude zones were selected. These dzongkhags account for 62% of total rice area and 64% of rice production in Bhutan (Appendix 3).

Twenty-seven *geogs* (blocks) were selected from these dzongkhags in consultation with RNR-RC staff and district government officials. These geogs were selected to represent different conditions such as access to markets, distance from roads, distance from the research centers, and farm size. The villages and households were then randomly selected from these geogs from the records of the dzongkhag offices. A total of 248 households from 104 villages were selected. The names of the dzongkhags by altitude and their corresponding number of geogs, villages, and households are illustrated in Table 7. (See Appendix 4 for geogs and villages included.)

The main sources of quantitative secondary information were the annual and technical reports of RNR-RCs and other government documents, UN and IRRI publications, and the database. The RNR statistics in the MOA (2001) database are the official data source for agricultural statistics. There are several other databases also. Considerable differences exist in the estimated statistics among these data sources. The Bhutanese research group favors the data based on the Cadastral survey method and hence it is the main data source used in this study to estimate the impact of research and technology development.

Table 7. Dzongkhags, geogs, and villages included in the impact assessment survey, 2002.[a]

Altitude/ dzongkhag	Number of geogs	Number of villages	Sample size
Low			60
Samtse	4	19	40
Sarapang	2	8	20
Medium			83
Punakha	3	6	30
Sarapang	1	5	10
Trashigang	4	21	33
Wangdue	1	3	10
High			105
Paro	5	19	50
Thimphu	2	11	21
Trashigang	3	10	14
Wangdue	2	5	20
Total	27	107	248

[a]High-altitude zone = above 1,500 to 2,600 m, medium-altitude zone = above 600 to 1,500 m, and low-altitude zone = from 160 to 600 m. Some geogs and villages in Trashigang, Sarapang, and Wangdue are represented in two altitude zones.
Source: Impact assessment survey, 2002.

Qualitative data were gathered from RNR-RC staff; high-level officials from central and district offices from agriculture, extension, marketing, and training centers; the donor community; and international research partners (see list in Appendix 5). Focus-group meetings and interviews were used to solicit the information. The interviews were focused on identifying the research programs that have had the most impact, on assessing the integration of research and extension in delivering research findings, and on identifying research programs that are likely to have a substantial impact in the future. Subjective assessments of the impact of the RNR-RCs were also obtained from these interviews.

The resource person (consultant in impact assessment) was mainly responsible for designing the survey, training the impact team (RNR-RC staff), gathering information for subjective assessment, analyzing the data, and writing up the report. The impact team coordinated the survey, and collected and compiled the data (see Appendix 6 for the list of enumerators).

Indicators of impact for the study

The benefits generated by the RNR-RCs' rice research program are assessed here using the following indicators:

- number of rice varieties released and crop management practices developed,
- extent of adoption of improved new rice technologies,
- magnitude of yield gain and increase in the value of production,
- increase in net income of farmers,
- increase in household cash income,
- achievement of rice self-sufficiency, and
- improvement in general welfare.

A general assessment of the capacity-building efforts was also undertaken. The indicators used to assess the institutional impact are

- number of people trained,
- effectiveness in disseminating research findings,
- effectiveness in research planning and implementation, and
- number of networks developed within the country and internationally.

Assessing the impact of research and capacity building

During the last two decades, the rice research system of Bhutan has evolved substantially. Early activities focused on conceptualizing and identifying the research program, establishing infrastructure, and developing human capacity for research. The research system now focuses on developing and testing technology packages, some of which are now widely adopted across the country.

Release of improved varieties

Fifteen improved rice varieties have been officially released. The names of the varieties, year released, their main traits, and suitability for different altitude zones are presented in Table 8. The released varieties have been categorized into three groups: IRRI MVs (IMVs), other MVs (OMVs), and Bhutanese MVs (BMVs). The IMVs are defined here as improved varieties that were developed at IRRI and directly released in Bhutan after screening. The OMVs are mainly improved varieties developed in countries such as Bangladesh, India, Japan, Korea, Nepal, and Sri Lanka. Some of these varieties were obtained through the International Network for Genetic Evaluation of Rice (INGER) managed by IRRI. The BMVs are crossbred varieties between Bhutanese TVs and IRRI's elite cultivars bred specifically for local agroecologies.

The OMV and IMV were evaluated in the varietal introduction program of Bhutan. Khangma Maap (locally known as Chumrro, from Nepal) is one of the OMV group of rice varieties officially released after local selection. It possesses major desirable traits (resistance to blast, with red pericarp and adaptable to high altitude). The variety BR 153 was selected for its adaptability to low-fertility soils with erosion that characterize the low-altitude zone.

The BMVs have locally preferred traits such as red grains, resistance to blast, and a shorter maturity period. For example, Bajo Maap 2 is a crossbreed between IR64 and a TV that is highly valued for its red pericarp. These are relatively new varieties released less than five years ago.

Of the 15 released varieties, nine were released for the medium-altitude zone, four for the high-altitude zone, and two for the low-altitude zone. Some of these varieties are now also being grown outside their target zone. The improved released varieties Barket, No. 11, and IR20913 are also recommended in double rice cropping.

Table 8. Nationally released modern varieties of rice in Bhutan, 2002.

Modern rice varieties	Year released	Released for altitude	Traits
IRRI's improved varieties (IMVs)			
IR64	1988	Medium	Good-quality white grain, semidwarf, 80–90 cm tall.
IR20913	1989	Medium	100 cm tall, matures in about 130–140 days.
Other modern varieties (OMVs)			
Milyang 54	1989	Medium	High-yielding, slender white grains, 95 cm tall, matures in 140–145 days.
No. 11	1989	High	Cold-tolerant, early maturing, 90 cm tall, matures in 160 days.
BR153	1989	Low	White grains, 100–110 cm tall, matures in 140–150 days.
BW 293	1990	Low	Slender white grains, 75–85 cm tall, matures in 140–150 days.
Barket	1992	Medium	Cold-tolerant, high-yielding, early maturing, 90–95 cm in height, matures in 155 days.
Khangma Maap	1999	High	Red grains, 90–100 cm tall, matures in 120–130 days, blast-resistant.
Khumal 2	2002	Medium	White grains, recommended specifically for eastern Bhutan.
Bhutanese modern varieties (BMVs)			
Bajo Maap 1	1999	Medium	Red grains, 100–105 cm tall, matures in 150–155 days, resistant to lodging, tolerant of blast.
Bajo Maap 2	1999	Medium	Red grains, 100–110 cm tall, matures in 145 days, tolerant of blast and stemborer.
Bajo Kaap 1	1999	Medium	White grains, 95–105 cm tall, matures in 145–155 days, resistant to lodging.
Bajo Kaap 2	1999	Medium	White grains, 90–100 cm tall, matures in 150–155 days, high yield and blast-tolerant.
Yusi Ray Maap	2002	High	Red grains, blast-resistant, cold-tolerant, 115–120 cm tall, matures in 170–180 days.
Yusi Ray Kaap	2002	High	White grains, blast-resistant, cold-tolerant, 90–95 cm tall, matures in 170–180 days.

Sources: RNR-RC Bajo (2001), Ghimiray and Pradhan (2002).

In addition to these varietal releases, the varietal improvement program also accomplished the following:

- More than 6,000 elite lines from IRRI and others countries have been evaluated at research centers and, of these, more than 300 entries were tested in farmers' fields.
- Some 5,740 breeding lines have been crossbred involving Bhutanese TVs and improved breeding lines (see list in Appendix 7). More than 140 crosses have been produced that show excellent performance in terms of suitability to local conditions with a performance superior to that of the varieties currently in use.
- Some 400 accessions have been collected from the major rice-growing regions of Bhutan. These are the working samples for RC Bajo. They have been sent to the IRRI Genebank for safeguard ing. A copy of these accessions will also be kept in the national germplasm bank currently being developed in Thimphu.

Highlights of crop management and cropping systems research

Several complementary crop management technologies have been developed. These technologies are designed for rice and rice-based cropping systems. Some highlights follow.

- Different packages for raising a nursery in a semidry bed, dry bed, and wet bed and polytunnel methods were developed.

  Semidry and dry method: Bed size of 1 m × 3 m, raised to 10–13 cm, 3 kg organic fertilizer, and a seed rate of 1.24 kg of seed for a 1 m × 6 m bed are recommended for semidry nursery preparation. For the dry-bed nursery preparation, the same procedures are to be followed without raising the bed.

  Wet-bed method: Seeds are to be soaked in water for 24 to 36 hours, incubated for 36 to 48 h, and the pregerminated seeds broadcast; 1.24 kg of seed is recommended for a 1 m × 6 m seedbed.

  Polytunnel method: recommended for the first crop in rice double cropping.
- Fertilizer recommendations for different dzongkhags for TVs and MVs have been developed (Appendix 8).
- Two species of green manure, Dhaincha (*Sesbania aculeata*) and Chinese milk vetch (*Astragalus sinicus*), have been identified as suitable green manure crops. The first type is recommended for altitudes of 150–1,300 m. The second is recommended for above 1,300 m for a winter crop.
- The released varieties were accompanied by comprehensive instructions on suitability for different altitudes, field preparation methods, nursery sowing, transplanting, and harvesting time, with other details. Pamphlets prepared for extension agents illustrate the details (Appendix 9).
- Several recommendations for crop intensification through double cropping of rice and rice with other crops, legumes, and vegetables were developed. The varieties specified for crop intensification with appropriate management practices are illustrated in Appendix 10.
- Recommendations for rice ratooning for areas with an adequate water supply are presented in Appendix 11.
- Effective chemicals to control *sochum*, such as Sanbird and NC 311, have been identified. Other control measures are being developed to reduce the cost of control.
- One of the strategies pursued for reducing the labor requirement in rice production was developing the direct-seeding method of crop establishment (Appendix 12).
- Grain moth (*Sitotroga cerealella*) and grain weevil (*Sitophilus oryzae*) were identified as two main rice insect problems during storage.
- IPM leaflets on blast have been developed and disseminated to farmers through extension agents. Several management practices were also released, which include using disease-free seed and proper water management and burning infected straw.
- The prevailing practices in various aspects of rice production from field preparation to grain storage methods were studied. Effective prevailing practices such as sealing the top of the basket with a thick cap of dung or mud for storing grains were considered to be appropriate and were supported.
- Several crop/vegetable rotation practices have been developed to replace rice-fallow farming systems. The main rotational packages consist of rice double cropping, rice-wheat, rice-mustard, rice-vegetables, and rice-green manure.

Farm-level analysis

There is a high degree of uniformity across the different altitude zones among the 248 households surveyed in terms of family size, age of the household heads, attainment of formal education and experience in farming of the household heads, and gender responsibility in farm household management (Table 9). The average household size is approximately 8 persons and women are the heads of 40% of the households. Farming is the main occupation for more than 90% of the households. The average age of the household head is approximately 50 and more than 80% of them do not have a formal education.

The farm households own both dryland and wetland (see Appendix 13). The survey data indicated that rice is cultivated in the wetland only. Overall, approximately 98% of the wetland is planted to rice. In the medium-altitude zone, 100% of the wetland is planted to rice, whereas small portions of the wetland in the high- (2.3%) and low- (4.8%) altitude zones were not planted to rice.

The average wetland farm size of the surveyed households is estimated at 0.32 ha. The farm sizes in the high- (0.27 ha) and medium- (0.22 ha) altitude zones are smaller than the farm size in the low-altitude zone (0.77 ha).

Adoption of modern rice varieties at the household level. Households often cultivate both modern and traditional rice varieties. Households that cultivate MVs on a part of their farm are considered as adopters here. Overall, approximately 60% of the surveyed households have adopted MVs of rice. The adoption rate is highest (77%) in the high-altitude zone, followed by the medium- (59%) and low- (32%) altitude zones (Table 10).

The data were disaggregated further to study the percentage of households that adopt only MVs and a combination of MVs and TVs (Appendix 14). The high-altitude zone has the highest percentage of households adopting MVs only (46%). In the medium-altitude zone, approximately 42% of the households plant both TVs and MVs. Some 17% of the households adopted MVs only. In the low-altitude zone, more than 68% of the households have not adopted MVs of rice.

Figure 2 illustrates the MV adoption pattern during the last two decades by altitude. The percentage of households adopting MVs in each year was cumulated to obtain the values on the vertical axis. This figure illustrates that there was a gradual increase in the cumulative percentage of adopters during the initial stages for all altitude zones during 1989-93. From 1994 to 1998, the MV adoption rate accelerated in the high- and medium-altitude zones. During this period, MV adoption increased in the low-altitude zone also, but the rate of adoption lagged behind. Since 1998, the adoption of MVs slowed as more than 90% of the households had already adopted MVs.

Rice cropping intensity. Only 6% of the surveyed households planted rice as a second crop in the winter season. Most of these households (67%) were from the medium-altitude zone. IR20913 was the most commonly planted MV of rice the season.

Double cropping of rice in Bhutan has declined considerably since the mid-1990s. This was confirmed by the focus-group meeting with extension agents and research staff from the medium-altitude zone, where double rice cropping was most prevalent (personal communications, see Appendix 5). The main reasons for the decline are as follows:

- lack of assured irrigation,
- a general decline in community adoption; hence, the double cropping suffers heavy losses from birds, rats, and livestock,
- a general improvement in household rice self-sufficiency, and
- increased diversification to high-value cash crops.

The last two factors suggest that there is a direct correlation between increased rice production and a reduction in double rice cropping. For example, in Rinchengang, a severe rice-deficit village, three out of four households continued double rice cropping.

In a society in transition from subsistence to semi-subsistence, households diversify their livelihood strategies. As rice production increased because

Table 9. Profile of the surveyed households, 2002.

Altitude	Family size (av)	Information on household head			
		Farmer's age (av)	Female head (%)	Nonformal education (%)	Farming main occupation (%)
High	8.4	51.0	46.7	84.8	94.3
Medium	8.1	55.6	38.6	78.3	95.2
Low	7.5	49.0	33.3	86.7	98.3
Overall	8.1	51.5	40.7	83.1	95.6

Source: Impact assessment survey, 2002.

Table 10. MV adoption at the household level, 2002.

Altitude	% of households	
	MV adopter	MV nonadopter
High	77.1	22.9
Medium	58.5	41.5
Low	31.7	68.3
Overall	59.9	40.1

Source: Impact assessment survey, 2002.

of the adoption of MVs, only one crop of rice became adequate to meet family food needs. Hence, farmers were able to diversify to higher-value cash crops during the second season without sacrificing food security.

Area occupied by modern rice varieties. Overall, approximately 35% of the rice area is planted to MVs (Table 11, graphically illustrated in Appendix 15). There is, however, a considerable difference in MV area across the three altitude zones. The high-altitude zone has more than 66% of its rice area planted to MVs vis-à-vis only about 17% in the low-altitude zone. In the medium-altitude zone, almost 38% of the rice area is planted to MVs.

Table 12 presents the rice area under different groups of MVs by altitude. The OMV is the most popular of the three groups of MVs adopted. It is planted in more than 60% of the area occupied by MVs. In the high- and low-altitude zones, OMV is the most dominant MV and is planted in more than 90% of the MV rice area.

The second most commonly planted group of MVs is IMVs. The IMVs account for 33% of MV rice area and are mostly planted in the medium-altitude zone (73%). In the low-altitude zone, IMVs account for only 9% of MV rice area.

The BMVs are planted to approximately 7% of MV rice area, with most of them being in the medium-altitude and some in the high-altitude zone. The BMVs are relatively new varieties, which were released less than five years ago. Two of the six BMVs were released only a year ago.

In summary, the high-altitude zone is planted mostly to OMVs, the medium-altitude zone is planted to IMVs and some BMVs, and the low-altitude zone is planted to OMVs and IMVs (Fig. 3).

Of the 15 varieties released, only 11 have been grown widely. The most popular adopted varieties are Khangma Maap, No. 11, IR64, Bajo Kaap 1 and 2, and Bajo Maap 1 and 2. Only one of the released BMVs is not adopted (Yusi Ray Kaap) and three varieties (Barket, BW 293, and Milyang 54) from the OMVs are not adopted. The percentage of area allocated to each variety by altitude appears in Appendix 16.

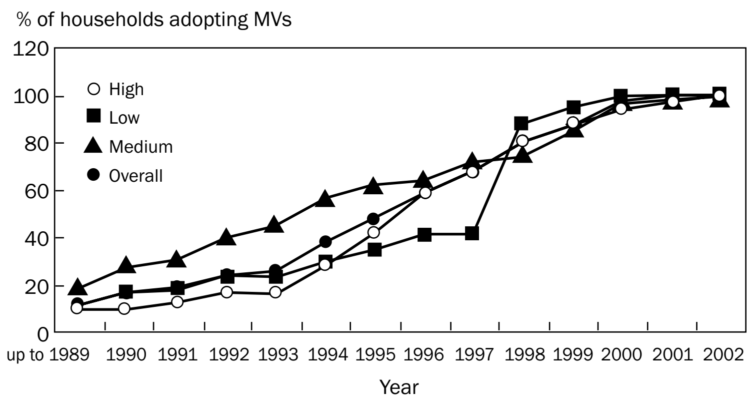

Fig. 2. Cumulative MV adoption patterns, 1989-2002.

Table 11. Rice area under different groups of rice varieties, 2002.

Altitude	% Wetland rice area under	
	TVs	MVs
High	33.8	66.2
Medium	62.5	37.5
Low	83.3	16.7
Overall[a]	65.1	34.9

[a]The area occupied by MVs for the overall estimations is derived by assigning weights (high-altitude zone 20% and 40% each to the medium- and low-altitude zones) according to the composition of the national rice area.
Source: Impact assessment survey, 2002.

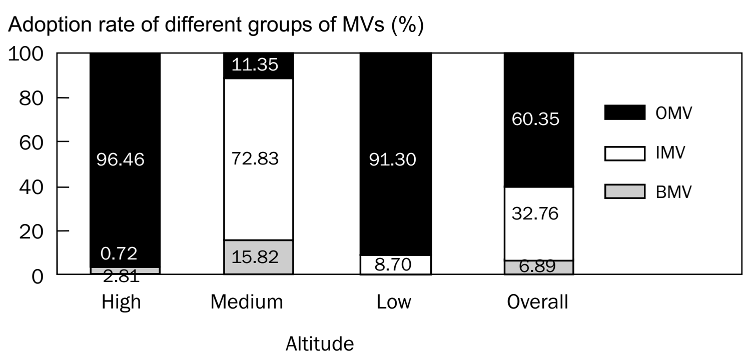

Fig. 3. Adoption of different groups of modern rice varieties by altitude, 2002.

Table 12. Adoption of different groups of MVs of rice, 2002.

Altitude	% MV rice area under		
	BMVs	IMVs	OMVs
High	2.8	0.7	96.5
Medium	15.8	72.8	11.3
Low	0.0	8.7	91.3
Overall[a]	6.9	32.8	60.4

[a]The overall estimation has been assigned weights as per Table 11.
Source: Impact assessment survey, 2002.

Adoption of improved crop management practices. Along with the adoption of MVs of rice, the survey data indicated that partial adoption of several other rice technologies has occurred. The adoption of various improved crop management practices ranges from approximately 8% to 60% (Table 13). The most commonly adopted management practices are for controlling weeds (60%), applying inorganic fertilizers (58%), land preparation (42%), mechanization (37%), and improved nurseries (24%). Other crop management practices, such as improved planting methods and pest control, have had limited adoption.

The adoption of improved management practices was higher in the high-altitude zone, followed by the medium-altitude zone (Fig. 4). The data indicated that, in the low-altitude zone, the adoption of improved management practices such as the application of inorganic fertilizers, improved weed management practices, and mechanization was limited.

For these widely adopted improved management practices, the data were disaggregated to identify individual components (Table 14). Data from the households that have adopted the technologies are included in the analysis. Raised-seedbed preparation was adopted by 45% of the households. Among the land preparation methods, the use of power tillers for deep plowing has spread widely (69%).

Of the farmers who applied organic fertilizers, 21% reported applying fertilizers at the recommended rate at transplanting, flowering, and panicle initiation. Herbicide use was the most common method of controlling weeds. The common herbicide used is butachlor, which gets rid of most weeds except for sochum. Farmers reported that, when weeds are killed off, it is easier to hand-weed sochum. Machinery use is more common for harvesting (58%) than for threshing (42%).

The survey data indicated that farmers are using purchased inputs such as herbicides and fertilizers for both MVs and TVs of rice (Table 15). Input use in the high- and medium-altitude zones is higher than in the low-altitude zone.

Generally, urea is applied as topdressing after transplanting. Overall, approximately 80 kg ha^{-1} of urea are applied to TVs and MVs of rice. There is

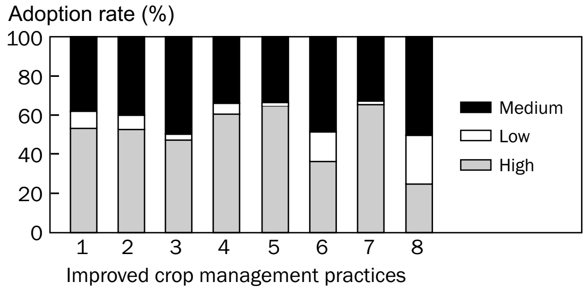

Fig. 4. Adoption of improved crop management practices by altitude, 2002. Improved crop management practices are referred to as follows: (1) improved methods of nursery preparation, (2) improved methods of land preparation, (3) use of inorganic fertilizers, (4) changed planting time according to variety, (5) improved weed control methods, (6) improved pest control methods, (7) farm machinery use, (8) intensified land use (cropping system).

Table 13. Adoption of improved crop management practices, 2002.[a]

Improved crop management practices	MV adopters	
	No. of households	% Adoption
Improved nursery preparation	60	24.2
Improved land preparation	103	41.5
Use inorganic fertilizers	143	57.7
Change in planting time	38	15.3
Improved weed control methods	149	60.1
Improved pest control methods	41	16.5
Use farm machinery	92	37.1
Intensified land use (cropping system)	20	8.1

[a]Total number of respondents was 248 (105 from the high-altitude zone, 83 from the medium-altitude zone, and 60 from the low-altitude zone) for all crop management practices except for intensified land use, for which only 78 responded from the medium-altitude zone.
Source: Impact assessment survey, 2002.

Table 14. Adoption of different components of improved crop management practices, 2002.

Improved crop management practices	MV adopters	
	No of households	% Adoption
Improved methods of nursery preparation		
Wet-bed nursery	17	28.3
Semidry nursery	16	26.7
Raised-bed seedling	27	45.0
Improved methods of land preparation		
Use power tiller	71	68.9
Plow land more than once	32	31.1
Use inorganic fertilizers		
Started application	117	81.8
Application as per recommendation	30	21.0
Improved weed control methods		
Herbicide applications	148	99.3
Intensive hand weeding	1	0.7
Farm machinery use		
Mechanical harvester	39	42.4
Mechanical thresher	53	57.6

Source: Impact assessment survey, 2002.

some variation in application levels across altitudes. Households in the medium- and low-altitude zones apply slightly more urea to MVs. Twice as much suphala is applied to MVs than to TVs, whereas there is little difference in herbicide application between the two groups of rice varieties. The survey data indicated that there is almost no application of herbicide in the low-altitude zone.

Increase in yield. MVs yielded more than TVs in all altitude zones (Table 16). The overall yield was estimated at 3.6 t ha^{-1} for MVs and at 2.8 t ha^{-1} for TVs. This represents a yield difference of MVs over TVs of 0.8 t ha^{-1}. The medium-altitude zone attained the highest yield for MVs at 4.3 t ha^{-1}. The low-altitude zone had the lowest yield for both groups of rice varieties. The yield advantage of MVs over TVs was 1.2 and 1.1 t ha^{-1} for the medium- and low-altitude zones, respectively. In the high-altitude zone, the yield difference between the two groups of rice varieties was less than 2%.

The BMVs outperformed all other groups of MVs in all altitude zones (Fig. 5, Appendix 17 for table). This indicates that BMVs are more suited to all three environmental conditions relative to other released varieties. Overall, the yield is estimated at 4.4 t ha^{-1} for BMVs, 4.3 t ha^{-1} for IMVs, and 3.2 t ha^{-1} for OMVs.

The yield level for each MV adopted is illustrated in Appendix 18. The highest yield was recorded for MV Bajo Kaap at 5.1 t ha^{-1} (BMV) and lowest yield for Khumal 2 at 1.9 t ha^{-1} (OMV). Both ranges were recorded in the medium altitude.

Table 15. Fertilizers and herbicide use (in kg ha^{-1}) in traditional and modern rice varieties, 2002.

Inputs	High		Medium		Low		All households	
	TVs	MVs	TVs	MVs	TVs	MVs	TVs	MVs
Urea	102.4	96.3	127.2	136.6	7.0	12.2	78.9	81.7
Suphala	3.4	25.5	13.3	10.2	3.8	0.0	6.8	11.9
Herbicide	39.7	29.7	26.0	44.9	0.3	0.0	22.0	24.9

Source: Impact assessment survey, 2002.

Table 16. Weighted average yields for traditional and modern rice varieties, 2002.

Altitude	Yield (t ha^{-1})		MVs over TVs	
	TVs	MVs	Difference (t ha^{-1})	% Difference
High	3.21	3.26	0.05	1.5
Medium	3.08	4.26	1.18	38.2
Low	1.64	2.76	1.12	67.7
Overall	2.84	3.62	0.78	27.3

Source: Impact assessment survey, 2002.

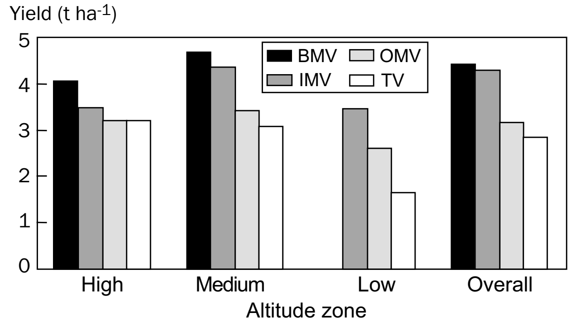

Fig. 5. Weighted average yields for different rice varieties by altitude, 2002.

In both the high- and medium-altitude zones, BMVs outyielded OMVs more than BMVs outyielded IMVs (Table 17). In the overall estimation, BMVs outperformed OMVs by 40%, which represents a difference in yield of almost 1.3 t ha^{-1}. Of the two altitude zones, the gains of BMVs over OMVs are estimated to be higher in the medium-altitude zone.

Increase in farmers' net income. The cost of production generally increases with the adoption of improved rice technologies. The additional expenses associated with the adoption of the new technologies are the additional costs of inorganic fertilizers, herbicides, farm machinery, and labor. In calculating the net income, these additional costs need to be accounted for.

The survey data indicated that farmers' cost of production increased for MVs by approximately Nu[2] 200 ha^{-1} (Table 18, see Appendix 19 for the detailed cost data). This represents an increase in cost of 17%. However, the net return increased by 28%, resulting in an increase in farmers' net income of more than Nu 9,000 ha^{-1}.

Net returns in the medium- and low-altitude zones are higher than in the high-altitude zone (Table 19). The net returns are highest in the medium-altitude zone by more than Nu 14,000 ha^{-1}. The considerable difference in net returns among the three altitude zones is driven mainly by the yield difference. For example, the percentage difference in net returns among different altitude zones is similar to the percentage difference estimated for the yield level in

Table 17. Weighted average yields for different groups of modern varieties, 2002.

Altitude[a]	Yield (t ha^{-1})			Difference (t ha^{-1})		% Difference	
	BMVs	IMVs	OMVs	BMVs over IMVs	BMVs over OMVs	BMVs over IMVs	BMVs over OMVs
High	4.07	3.49	3.20	0.58	0.87	16.8	27.1
Medium	4.67	4.36	3.43	0.31	1.24	7.2	36.3
Overall	4.43	4.29	3.17	0.14	1.26	3.2	39.7

[a]BMVs are not cultivated in the low-altitude zone.
Source: Impact assessment survey, 2002.

Table 18. Estimation of cost and net returns from traditional and modern rice varieties, 2002.[a]

Item	TVs	MVs	MVs over TVs	
	(Nu ha^{-1})		(Nu ha^{-1})	% Difference
Gross return	34,026	43,372	9,346	27.5
Paid-out cost	1,142	1,339	197	17.2
Net return	32,884	42,033	9,149	27.8

[a]The price of rice varies by region, color, and other traits. The regional difference is the main factor influencing the retail price of rice (Planning and Policy Division 2002, see Appendix 20 for data). The farm survey data indicated that the MV-red rice commanded a higher price than the MV-white in all altitude zones (Appendix 21). Although the price of MVs was higher than TVs, an average farm-gate price of Nu 11,980 per ton is used to derive a conservative estimation of net returns. The exchange rate of Bhutan's currency, the Ngultrum (Nu), is approximately US$1= Nu 44.
Source: Impact assessment survey, 2002.

Table 19. Estimation of net returns by altitude, 2002.

Altitude	Net returns (Nu ha^{-1})		MVs over TVs	
	TVs	MVs	Difference (Nu ha^{-1})	% Difference
High	36,756	37,381	625	1.7
Medium	35,318	49,408	14,090	39.9
Low	19,555	32,289	12,734	65.1

Source: Impact assessment survey, 2002.

[2] US$1 = 44 Ngultrum (Nu).

Table 16. The low altitude has the highest percentage difference (above 65%) for net returns and yield level.

Improvement in household rice self-sufficiency. Approximately 68% of the sampled households have achieved self-sufficiency in rice (Table 20). The households in the high- and medium-altitude zones have a higher rice self-sufficiency level at more than 70% than the low-altitude zone at 53%.

Overall, 32% of the sampled households did not have self-sufficiency in rice. A disaggregated analysis was undertaken to examine the relationship between the level of self-sufficiency and the adoption of modern rice technologies.

In the medium altitude, the same level of deficiency in rice (50%) was reported by households adopting and not adopting MVs (Table 21). The households in the low altitude had a substantially higher level of deficiency (79%) among the nonadopters. However, in the high altitude, MV adopters have a higher percentage (68%) of food deficiency than the nonadopters (32%).[3] Overall, MV adopters have a slightly higher level of rice self-sufficiency, indicating a positive contribution of MVs to household food security.

Increase in household cash income from rice. Overall, MV-adopter households have 110% more cash income from rice than nonadopter households (Table 22). This represents a difference of approximately Nu 2,400 per household. The MV-adopter households in the medium altitude earn approximately Nu 4,000 more cash income. There is no significant difference (difference of less than Nu 200) in cash income in the high- and low-altitude zones among the two groups of households.

Improvement in general welfare. To get a general impression of changes in rural livelihoods, the households were asked whether they felt that their welfare had increased, decreased, or remained constant during the last 5 to 8 years (Appendix 23). Different indicators of welfare were used for this analysis (Table 23).

Based on these indicators, most households reported that their welfare improved over time. The most significant improvement was reported for children's health (96%), overall income (79%), home renovation (79%), and farm knowledge (75%). More than 65% of the surveyed households also stated that their rice production and self-sufficiency improved. More households reported having increased ownership of farm machinery (36%) than livestock (25%).

Table 20. Household rice self-sufficiency, 2002.

Altitude	Total sample households	% of households	
		Self-sufficient	Deficient
High	105	73.3	26.7
Medium	83	71.1	28.9
Low	60	53.3	46.7
Overall	248	67.7	32.3

Source: Impact assessment survey, 2002.

Table 21. Household rice deficiency among adopters of modern varieties, 2002.

Altitude	% of households with deficiency	
	MV adopters	MV nonadopters
High	69.0	31.0
Medium	50.0	50.0
Low	21.4	78.6
Overall	46.9	53.1

Source: Impact assessment survey, 2002.

Table 22. Average household cash income (in Nu) from rice, 2002.

Altitude	Average household income		Adopter over nonadopter	
	MV adopter	Nonadopter	Difference (in Nu)	% Difference
High	4,344	4,185	159	3.8
Medium	6,027	2,091	3,936	188.2
Low	925	1,122	197	–17.6
Overall	4,616	2,199	2,417	110.0

Source: Impact assessment survey, 2002.

Table 23. Households reporting an increase in welfare in the last 5 to 8 years, 2002.

Welfare indicators	% Households reporting an increase
Self-sufficiency in rice	67.2
Rice production	65.6
Overall income	78.8
Home renovation	78.7
Children's health	95.8
Livestock number	24.8
Farm machinery	36.2
Farm knowledge	74.5

Source: Impact assessment survey, 2002.

[3] This result for the high-altitude zone may appear to be somewhat contrary to expectations. However, MVs and TVs have similar yields in the high-altitude zone, with MVs being valued mainly for their blast resistance rather than for their yield advantage. Furthermore, households that grew MVs had a smaller farm size but more people in the household than those that grew TVs (Appendix 22).

The households that reported having their welfare improved were categorized by adoption/nonadoption of MVs to observe whether there was any correlation. Consistently for all indicators, a higher percentage (over 55%) of MV adopters reported having improved their welfare than nonadopters (Fig. 6). Rice production and its self-sufficiency among the MV adopters (70%) are significantly higher than among nonadopters (30%).

National-level analysis

The results of the above analysis at the farm level have been extrapolated to estimate the benefits attributable to improved rice technologies at the national level.

Increase in rice production. The magnitude of increase in production depends on rice area, MV adoption rate, and the yield difference between the two groups of rice varieties. To estimate the increase in rice production for the whole country, estimates of the adoption rate of MVs and yield gains of MVs over TVs were derived from the farm survey data. It is assumed that the MV adoption rate is 35%, the yield difference between MVs and TVs is 0.8 t ha^{-1}, and the national estimated rice area is 26,500 ha (Cadastral survey). Using these estimates, the increase in national rice production attributable to improved rice technologies was estimated at more than 6,800 t in 2002 (Table 24). At the farm-gate price of Nu 11,980 per ton, the value of this increased production is estimated to be approximately Nu 82 million per year.

Approximately 69% of the increased production originated from the medium-altitude zone and nearly 29% from the low-altitude zone. Despite the highest MV adoption rate in the high-altitude zone (66%), its contribution to the increased national production is minimal (less than 3%). This is due mainly to the small difference in productivity between the two groups of varieties and a relatively smaller rice area in the high-altitude zone.

The estimation in Table 25 illustrates the relative share of different MV groups in the gain in rice production. When disaggregated by variety categories, IMVs contributed nearly 57% of the estimated 6,800 t increase in national production. Most of this originated from the adoption of IMVs in the medium-altitude zone. The OMVs and BMVs contributed approximately 27% and 16%, respectively. The gains from BMVs were lowest due mainly to the current low rate of adoption of BMVs at the national level.

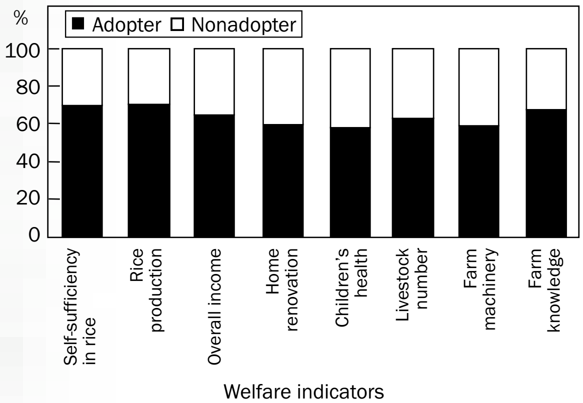

Fig. 6. Improvement in welfare among MV adopters and nonadopters, 2002.

Table 25. Estimation of the increase in rice production from different groups of modern varieties.

Different groups of MVs	Rice production (t)				% Contribution by different groups of MVs
	High	Medium	Low	National	
BMV	154	966	na[a]	1,120	16.4
IMV	12	3,561	300	3,873	56.8
OMV	7	154	1,670	1,831	26.8
Total MV	173	4,681	1,970	6,824	100.0

[a]na = not applicable.
Source: Impact assessment survey, 2002.

Table 24. Estimation of the increase in rice production at the national level.[a]

Altitude	National rice area (ha)	Area affected by MV adoption (ha)	Increase in production (t)	% Contribution by altitude
High	5,302	3,510	173	2.5
Medium	10,605	3,972	4,681	68.6
Low	10,605	1,771	1,970	28.9
National	26,512	9,252	6,824	100.0

[a]The increase in national production is derived by multiplying the percentage of MV adoption rate, yield difference of MVs over TVs, and Table 11 total rice area. The yield difference comes from Table 16, the MV adoption rate was presented in Table 11, and the Cadastral survey estimations of national rice area were used in deriving the total increase in rice production (refer to Appendix 24 for detailed calculations).
Source: Impact assessment survey, 2002.

Increase in net returns. The per hectare gain in net returns of Nu 9,000 translates into a gain of more than Nu 80 million at the national level (Table 26). Approximately 70% of the total net returns originated from the medium-altitude zone.

There is relatively little difference in the cost of production of MVs and TVs; hence, the net returns at the national level are close to the value of the gain in gross production. Alternative estimations of net returns assuming a substantially increased cost of production for MVs vis-à-vis TVs are presented later in this report.

Sensitivity analysis of benefit estimates

Production and net returns for different data sources. A sensitivity analysis was conducted to estimate a range of benefits using different sources of data. Table 27 illustrates the estimated value of the increase in national rice production and net returns attributable to new rice technologies when different data sources are used.

The estimated increase in rice production ranged from 5,000 to 10,000 t for different data sources. Its value at the farm-gate price is Nu 60 million to Nu 121 million. The estimated net returns range from Nu 58 million to Nu 118 million. The estimated benefits, increase in production, and net returns for GIS/LUPP are almost twice the level estimated based on RNR statistics.

Adoption of different rates of modern rice varieties. There have not been any other studies to determine the MV adoption rate at the national level. Our study collected data covering all three rice altitude zones from seven dzongkhags across the country. The MV adoption rate of 35% at the national level was derived by assigning weights to different altitude zones according to their percentage of the total rice area. To allow for possible inaccuracies in the sample data, the MV adoption rates of 25% and 50% were used to re-estimate the benefits (Table 28). For a conservative MV adoption rate of 25%, Bhutan would still gain in rice production by more than 5,000 t a year and net returns of almost Nu 60 million a year.

Adoption rates of different Bhutanese rice varieties. The IMVs and OMVs are varieties that were bred elsewhere and introduced in Bhutan through the varietal introduction program. Hence, it could be argued that, even without RNR-RC, the country would have adopted such MVs over time and benefited from them. In this scenario, there would have been no gain in yield from the adoption of

Table 26. Estimation of net returns at the national level.[a]

Altitude	Net returns (000 Nu)	Contribution by altitude (%)
High	2,195	2.7
Medium	55,967	69.3
Low	22,549	27.9
National	80,711	100.0

[a]Net returns at the national level are derived by multiplying the per hectare difference in net returns of MVs over TVs by the area affected by the adoption of MVs (see Appendix 24 for detailed calculations).
Source: Impact assessment survey, 2002.

Table 28. Production and net returns for different rates of MV adoption.

MV adoption rate (%)	Area occupied by MVs (ha)	Increased production (t)	Net returns (000 Nu)
25	6,628	5,141	60,294
30	7,954	6,170	72,353
35	9,252	6,824	80,711
40	10,605	8,226	96,471
45	11,931	9,254	108,530
50	13,256	10,283	120,589

Source: Impact assessment survey, 2002.

Table 27. Estimation of increases in rice area and production and increases in value of production and net returns for different data sources.

Different data sources	Rice area (ha)	Area occupied by MVs[a]	Gain in rice production (t)	Value of production gained (000 Nu)[b]	Net returns (Nu 000)
RNR statistics	19,395	6,769	4,992	59,814	58,341
Cadastral survey	26,512	9,252	6,824	81,762	79,748
GIS/LUPP	39,240	13,694	10,100	121,013	118,032
FAO	30,000	10,470	7,722	92,518	90,239
Average	28,787	10,046	7,410	88,777	86,590

[a]Estimated based on 35% MV adoption at the national level.
[b]The gains in rice production are valued at the farm-gate price of Nu 11,980 per ton (paddy price).
Source: Impact assessment survey, 2002.

OMVs and IMVs as these varieties would have been grown even without RNR-RC efforts. BMVs would represent the main output of research conducted in Bhutan under this scenario. The benefit from BMVs is estimated under the assumption that either OMVs or IMVs would have been grown had BMVs not been available. Under this scenario, the benefit attributable to RNR-RCs' cross-breeding program is estimated at over 1,100 t per year (Table 29).

Currently, only 2.5% of the national rice area is occupied by BMVs. The increase in the adoption of BMVs over time is expected as these are the newest varieties that have become available only during the last five years. These varieties are higher yielding than other groups of MVs and have locally preferred traits. Hence, as farmers become more familiar with these varieties, it is reasonable to assume that their adoption and benefits will also increase over time.

The production gain if BMV adoption increases from the current 2.5% to 30% is presented in Figure 7 (see Appendix 25 for data). The figure illustrates the magnitude of the gain in production as a result of BMV adoption. If we assume a 15% adoption of BMVs (replacing OMVs) in the high- and medium-altitude zone only, the gain is estimated at 3,000 t. If BMVs are assumed to replace TVs in 30% of the area in the high- and medium-altitude zones, this would lead to an increase in production of more than 7,500 t.

Net returns for different rates of production cost. The earlier estimates of the gain in net returns were derived under the assumption that the cost of inputs increased by 17%. How sensitive would the results be under the extreme assumption that the cost increased by 100% or more? The estimated net returns for the increase in cost from the current rate of 17% to 200% are illustrated in Figure 8 (see Appendix 26 for table). If we assume that the cost of production increases by 100%, the estimated net returns under this assumption are Nu 8,200 ha^{-1}. At the national level, this translates into a gain of almost Nu 76 million. Even with such a level of increase in cost, the benefits decreased by 12% only. This indicates that the results are not very sensitive to assumptions about the increase in cost of inputs.

Table 29. Increase in rice production attributable to the adoption of BMVs.

Increase in production (t)	Rice production (t)			% Contribution by different groups of MVs
	High	Medium	National	
BMVs over IMVs	57.7	197.9	255.6	22.8
BMVs over OMVs	84.8	781.9	866.7	77.2
Overall	142.5	979.8	1,122.3	100.0

Source: Impact assessment survey, 2002.

Impact of institutional capacity building

The establishment of RNR-RCs has been the principal source of capacity building in agricultural research for the country. Their capacity to plan, undertake, and implement agricultural research was the direct result of the efforts made in human capacity development. The types and the timing of the training undertaken are viewed as essential in supporting the institute, which has expanded from one to four separate research centers. The food crops research, which had less than 10 qualified staff members, has

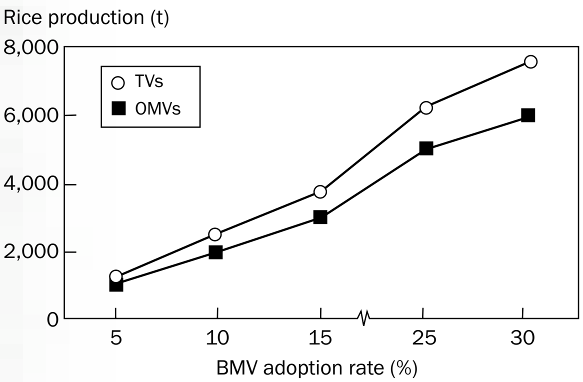

Fig. 7. Estimation of the increase in rice production with different BMV adoption rates. This estimation is based on the rice area of the high- and medium-altitude zones. The BMVs are not adopted in the low-altitude zone. The yield difference of BMVs over IMVs is small (0.14 t ha^{-1}). Source: Impact assessment survey, 2002.

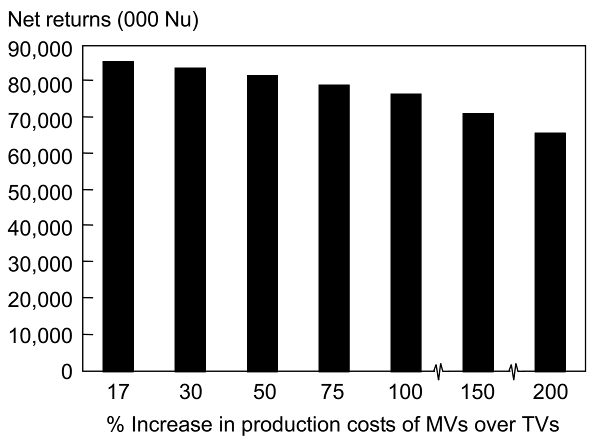

Fig. 8. Changes in net income for different production costs.

expanded to a current staff of more than 30 with university degrees in diverse disciplines among biological, agronomic, engineering, and social sciences.

Training. IRRI and other institutes, mostly from SAARC countries, have been the main providers of training to the Bhutanese (Table 30). A total of 182 capacity-building opportunities (training, seminars, and conference participation, etc.) in agricultural research and management have been provided so far. Almost half of the training activities were conducted at IRRI and included mainly nondegree training on specific topics. Two staff completed an M.Sc. with supervision from IRRI's senior staff. These training activities focused mainly on rice during the early stages of the RCs.

The nature of the training activities evolved with the expansion of the mandate and increasing demand for other aspects of research and management. The RCs also invested in training on research management and technical training on computers and other skills needed to support the growing centers. Training programs involved problem-oriented, multidisciplinary, and integrative research on various aspects of farming systems. The themes included cropping systems, socioeconomic analysis, and gender studies. Rather than relying on one or two centers of excellence, training is increasingly obtained from multiple suppliers, including the neighboring countries. This has encouraged a healthy cross-fertilization of ideas and perspectives among the staff. Overall, these training programs played a key role in building a critical mass of skilled staff within a relatively short period of time.

Some 18% of the training activities were targeted to building research management and leadership skills. Some of the trainees are now in a leadership position at RNR-RCs. The RCs' development during the last two decades can be traced to the improved research and management capacity of its staff.

Research program. The germplasm improvement program has progressed from the evaluation of elite lines from outside sources to cross-breeding with local parents. Under the cross-breeding program, scientists in Bhutan lead in the collection, evaluation, and identification of parent materials. These are then sent to IRRI for actual crossing only. Progenies from crosses are sent back to Bhutan for various stages of evaluation and final introduction to the country. Most of the varieties released nationally during the past five years originated from this cross-breeding program. Improved varieties of rice for the high-altitude zone with tolerance of cold temperature have been developed for the rice agroecologies that are considered to be the most challenging for rice breeders.

With improved capacity, the research focus has become much more integrative of different aspects of rice technologies during both the experimental stage and field-testing. New varieties are often evaluated in

Table 30. Number of agricultural research capacity-building opportunities at RNR-RCs, 1983-2002.[a]

Course category	Training at IRRI	Opportunities at other institutes[b]		Total capacity-building opportunities	Percentage of total
		Nondegree training	Study tours/ conferences/ seminars		
Varietal improvement	6	4	7	17	9.4
Crop management					
Nutrient	9	2	3	14	7.8
Pest	6	–	1	7	3.9
Water	10	5	4	19	10.6
Agricultural engineering	7	–	–	7	3.9
Rice production technology	9	2	–	11	6.1
Research management and leadership	3	2	27	32	17.8
Technology transfer	20	1	1	22	12.2
Others					
Social sciences	1	–	–	1	0.6
Cropping systems	2	3	19	24	13.3
Technical training	1	5	2	8	4.4
Natural resource management	0	1	1	2	1.1
On-the-job training	16	–	–	16	8.9
Total	90	25	65	180	100.0

[a]In addition to these capacity-building activities, there were also six degree programs (four M.Sc. and two diplomas). [b]The RNR-RC capacity-building opportunities (training, workshops, seminars, and conferences, etc.) are compiled from RNR-RC annual reports. All opportunities from RNR-RC Bajo and training on food crops from other RCs are listed.
Source: IRRI alumni database, 2002, and RNR-RC annual reports, 1993-2002.

combination with alternative treatments for nutrient management that also include rotational cropping. The research program has also expanded to include broader issues such as the conservation of biodiversity and natural resources. Overall, the research approach has matured considerably from being narrowly focused on one or two disciplines in the early years to being truly multidisciplinary and systems-oriented.

Research planning, management, and implementation. Planning, management, and implementation of research programs have improved considerably and become stronger over time. The programs are led by strong and capable leaders with foresight and are based on the real needs of the country. The program directors' (center heads) training matches the centers' national mandates well and the directors are often directly involved in research. This direct involvement has helped them to obtain first-hand knowledge of the opportunities and constraints of the centers and their staff.

The infrastructure and research facilities have also improved over time. This infrastructure includes new office complexes and research equipment. Almost all research staff have individual computers and the RNR-RCs are one of the first government institutes to have full access to the Internet.

Several mechanisms are also in place to have the four centers work more effectively in pursuit of their national and regional mandates. There are regular joint training and workshop opportunities for the staff from different centers to work and learn from one another. The biannual workshops among the center heads and key staff members have contributed to developing more integrative research programs. Regular workshops are also organized with extension departments to facilitate information sharing.

Improved national, regional, and international collaboration. The RNR-RC Bajo has evolved to become a major player in important aspects of agricultural planning and development in the country. This center is consulted and its advice sought by government departments. Its personnel are often given the lead roles in national-level planning and policy-making in the agricultural sector. The centers have developed strong collaborative networks with various government agencies. There is a regular exchange of visits among research and support staff of various institutes.

The centers have also started to take lead roles in initiating collaboration with donors and international institutes as well as in managing international relations. The donor community and international research and development institutes are seen as fundamental to establishing research systems and maintaining the information flow. The research centers are now taking the lead role in planning and managing Bhutan-IDRC-IRRI collaboration. This collaboration has expanded and is co-funded by IDRC and SDC. The RCs are also able to promote themselves to new donors and UN agencies such as IFAD and FAO, which are now contributing loans and grants to support agricultural research and development.

Strong linkages have also been developed with other Consultative Group on International Agricultural Research (CGIAR) institutions such as the Asian Vegetable Research and Development Center (AVRDC), the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), the International Service for National Agricultural Research (ISNAR), and the International Centre for Integrated Mountain Development (ICIMOD). Recently, a memorandum of understanding (MOU) was signed with the International Food Policy Research Institute (IFPRI) and International Plant Genetic Resources Institute (IPGRI). Strong collaboration has been established with the agricultural research systems of several Asian countries such as Bangladesh, India, Japan, Korea, Sri Lanka, Taiwan, Thailand, and Nepal.

Subjective assessment of the research and capacity-building program

A subjective assessment based on interviews with some major stakeholders was conducted to complement the quantitative analysis presented above. High-level government officials, key research staff, international partners, and extension personnel were interviewed to elicit their broader impressions of the impact of the overall program (see list of people interviewed in Appendix 5). During the interviews, these people were also requested to provide comments/suggestions regarding program balance and strategies so that future impact could be further increased.

The responses obtained grouped by major themes are summarized in Box 1. The subjective assessment of the general magnitude of impact for different components of the research and technology development program is ranked at four levels. The symbols represent as follows:

**** = Excellent impact, consistently performed well.
*** = Good impact, could improve substantially with some changes.

Box 1. Subjective assessment of the rice research and capacity-building program, 2002.

Rice research program	Magnitude of impact	Comments/suggestions/ concerns
Research		
Improved varieties	****	• Effective in selection and breeding of locally adapted varieties that are high-yielding and have disease resistance with locally preferred quality traits for the challenging and highly variable ecosystems. • Postharvest concerns such as ease of threshing and nonshattering traits have also been incorporated in developing newer improved varieties. • Need to develop BMVs for the low-altitude zone.
Crop management practices	***	• Research on integrated nutrient management that includes a balanced use of organic and inorganic sources is in line with the broader national objective of conservation farming. • Inorganic fertilizer recommendations are developed to suit different categories of farmers. • An environmentally and socially responsible attitude toward not using pesticides to eradicate rice insects and diseases developed. • Rice breeders have done well in developing diverse improved agronomic practices despite the shortage of qualified agronomists in recent years. • A need to develop improved agronomic practices that reduce the labor requirement. • Wide use of butachlor to get rid of other weeds may be promoting the spread of sochum. • Rice research program is heavily tilted toward breeding improved varieties and not enough efforts placed on developing other rice technologies. • Studies need to be strengthened to reduce postharvest losses, improve red-rice milling recovery, and improve grain quality.
Cropping systems	***	• Changes in the traditional rice-fallow cropping pattern toward more intensive and diversified cropping patterns are due to cropping systems research and the introduction of new and different varieties of vegetables and other cereal crops.

continued

Box 1. continued

		• Effective strategies (and research) need to be developed that do not put pressure on labor in peak seasons to further expand multiple cropping.
Technology transfer	**	• In addition to information leaflets, efforts are needed for a more effective and comprehensive dissemination process. • Extension agents need to improve their knowledge in technical aspects of their area of responsibility. • Reward systems need to be institutionalized for better integration of research with district-level extension officers who are mainly in the frontline of the technology dissemination process. • Extension groups appreciate research staff involvement in regular problem diagnosis. However, the research groups would prefer that they be called on only for complex and unusual problem situations as these visits are time-consuming and take away time from research. • During annual meetings between research and extension management teams, extension staff need to specify and prioritize problem areas that require research interventions.
Research capacity	***	• Accelerated the development of research capacity within two decades. Staff performance is above average and the recent hiring of staff with specialized skills is expected to further improve the impact. • Research center staff members are some of the best-qualified ones in the country. The food crops program is managed and led by the country's most qualified personnel in their area of expertise. • Capacity building needs to focus on opportunities closer to Bhutan and that have training activities more relevant to the local conditions, and that can be achieved much more cost effectively.
Research planning, management, and implementation	***	• Research programs are consistent with the national food policies and goals of other sectors. • The research groups provide critical inputs to planning and policy designs at the national level.

continued

BOX 1. continued

		• Plans and policy designs are implemented with speed and efficiency. For example, once biodiversity was recognized as a priority issue, research capacity in the area was quickly built up and steps were taken to safeguard the diversity of the rice gene pool. • There is a general camaraderie and high level of understanding between the management and staff. • Research performance could be improved further if the centers were consulted on staff allocations and transfers. • The food crops research program needs to have a balanced research focus on other major food crops such as wheat, maize, etc. • Production constraints in the low-altitude zone, which accounts for 40% of the rice area, have not been adequately examined in research programs.
Collaboration	****	• Effective in developing and managing the linkages with international and regional centers outside Bhutan. • The international staff indicated that Bhutanese scientists collaborating with them are hard-working and committed. • Collaborative activities with international partners involving the exchange of materials and information have been mutually beneficial. • RNR-RC Bajo is supportive and works effectively with other government agencies working on programs of common interest.
Publications	*	• Need to institutionalize the reward system to improve scientific exchange and reporting at RCs, nationally, and internationally. • Some form of media outlet needs to be established to disseminate and update research findings regularly.

Source: Impact assessment survey, 2002.

** = Positive impact, prioritizing and reorganizing could further improve the impact.

* = Recently undertaken efforts or those that may need major changes to obtain the desired impact.

More than 90% of the people interviewed considered improved rice technologies as the main source of increased production. The varietal improvement component was considered to have had the most impact. The contribution of varietal improvement to the production gain was estimated to be 25% to 80%, with most of the estimates centered around 50%. Improved nutrient and weed management practices were mentioned as other factors that were important for the increased production. The research on weed management practices, in particular on sochum, was highly regarded. The release of a blast-resistant variety was considered to have significantly contributed to preventing yield loss from the blast-prone high-altitude zone.

Conclusions and recommendations

The rice research program of Bhutan has made a substantial impact as documented in this report. Fifteen modern varieties have been officially released and a suite of complementary crop management technologies has been developed. The MVs have a yield advantage of more than 27% over TVs. The BMVs, a group of MVs crossbred specifically for Bhutan, outperformed all other groups of MVs. Under farmer management, BMVs yielded 40% more than OMVs. The increase in rice production from the new rice technologies was estimated to be 5,000 to 10,000 t per year for the country as a whole. This is equivalent to a gain in net returns of Nu 58 million to Nu 181 million per year. The improved rice technologies have contributed to improvements in household and national-level rice self-sufficiency. As rice production is one of the main activities in the rural economy, increases in its productivity have also made a positive impact by facilitating crop diversification and cash cropping.

The rice research program has also had a major impact in capacity-building. A substantial pool of scientific skills has been developed through more than 180 training and other skill-building opportunities. Within a relatively short period, the centers have been able to develop a critical number of staff possessing both technical and management skills. This cadre of staff is now contributing to the overall development of agriculture through a greater ability to plan, prioritize, and implement research and technology development. In addition, the research infrastructure needed for the efficient functioning of a research system has been established.

The benefit of the new rice technologies is apparent in all rice altitude zones. However, the extent of benefit varies greatly across the three different altitude zones. Most of the research efforts went into generating technologies for the medium-altitude zone and thereby the households in this altitude benefited the most. By comparison, the data indicated that the low-altitude zone did not fare as well.

Reinforcement of the impact documented here will require multiple interventions that encompass agricultural research, extension, and policy support for agricultural development. Clearly, a discussion of the design of such wide-ranging interventions is beyond the scope of this study. Nevertheless, the following suggestions specifically related to rice research and technology development are made on the basis of the findings of this study.

- Despite having a 40% share of rice area, the low-altitude zone has contributed to only 29% of the increase in production. The relatively smaller contribution of this zone is due to the low yield and low adoption of MVs (only 17% of the rice area) in this zone. With suitable technologies, the zone can contribute substantially to the national food supply and help reduce dependence on imports. For example, the national output of rice could increase by an additional 5,000 t (or by 8%) if the area under the currently grown modern varieties expanded to 60% of the rice area. If the yield of MVs could also be raised simultaneously, this contri bution would further increase. Marginal returns to additional investments in rice research targeted to this region are, hence, likely to be substantial. A thorough analysis of the desirability of reallocating additional research resources to this region is suggested.
- Research and extension both have critical roles to play in producing the desired impact. Over the years, extension agents have performed an important role in taking information about new technologies and other opportunities to remote parts of the country. Given the important role of extension in bridging the two-way flow of information between farmers and researchers, further strengthening of the skills and capacity of the extension system seems desirable.
- The positive impact documented here resulted mainly from the adoption of improved varieties.

Although some complementary crop management technologies are available, there is a need to more effectively integrate the various components of rice technologies in the form of a "basket of options" suitable to different agroecological and socioeconomic domains.

- Rice yield in Bhutan is limited by several biotic and abiotic stresses. Research resources are currently being allocated to examining these constraints. Socioeconomic analyses to serve as a basis for prioritizing these constraints for a more efficient allocation of limited research resources seem desirable.

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Appendix 1. Households with food grain shortages and coping mechanisms.

Dzongkhag[a] (districts)/ altitude	Housheolds with food grain shortage (%)	Food grain shortage (no. of months)	Food grain shortage and coping mechanisms by households (%)					
			Purchase			Borrow from neighbor	Barter with livestock products	Exchange for labor
			FCB[b]	Market	Neighbor			
High								
Bumthang	67.9	2.7	60.8	85.2	6.2	19.2	10.5	18.5
Gasa	74.2	6.4	84.2	81.0	4.3	9.2	56.5	37.0
Haa	73.7	2.7	85.2	59.3	11.7	19.4	13.0	18.3
Paro	59.8	2.7	87.6	86.2	9.4	17.6	11.4	25.0
Thimphu	58.9	2.9	84.8	84.9	6.4	16.5	11.4	27.7
Medium								
Chhukha	79.9	3.1	71.5	81.6	12.4	25.5	9.8	33.0
Dagana	63.0	2.5	55.8	95.4	13.9	17.2	4.4	27.1
Lhuentse	41.7	1.0	67.0	52.1	19.0	47.5	5.4	14.1
Mongar	33.8	0.8	63.7	54.8	31.0	53.5	4.3	40.5
Pemagatshel	58.1	1.8	80.3	76.4	15.6	38.5	2.5	27.4
Punakha	47.3	1.5	72.8	52.0	14.5	37.7	8.6	26.3
Trashigang	44.0	1.3	78.4	66.1	21.2	40.5	14.8	31.1
Trongsa	59.4	1.6	73.0	79.0	7.5	24.2	9.1	23.2
Tsirang	71.1	3.2	61.9	93.3	12.7	14.5	5.0	29.1
Wangdue	55.4	1.7	64.7	57.3	14.0	28.4	19.1	24.0
Yangtse	43.0	1.2	66.3	64.4	22.0	44.0	5.7	24.6
Zhemgang	56.4	1.5	85.1	77.8	13.8	26.8	11.5	19.8
Low								
Samtse	84.8	2.9	28.7	97.9	15.4	27.1	6.3	28.4
Sarpang	61.8	2.7	66.4	94.7	12.8	15.9	3.9	20.1
S/Jongkhar	43.6	1.1	44.8	74.7	21.6	48.4	1.9	39.9
National	56.1	2.2	65.9	72.1	13.6	27.2	10.2	25.5

[a]The rice-growing environment is divided into three distinct zones and associated with particular dzongkhags. However, a dzongkhag could contain one or more rice altitude zones. The categorization of dzongkhags into different altitude zones is based on the Eighth Five-Year Plan for the commodity program. [b]FCB = Food Corporation of Bhutan.
Source: RNR Statistics 2002, electronic database.

Appendix 2. Survey questionnaire.

Renewable Natural Resources Research Centers, Bhutan

Impact assessment of agricultural technologies

Field survey questionnaire

Farmer name ____________________ Farmer code ____________________

Dzongkhag ____________________

Altitude ____________________ Geog and village name ____________________

Interview date ____________________ Enumerator ____________________

A. General information

1. Demographic information about the farmer interviewed

Information about interviewee (head of the household)				Number of household members			
Age	Sex	Education[a] (years in school)	Occupation (primary)	Male (15 and older)	Female (15 and older)	Children	Total

2. Agricultural land holding and land use

Parcel no.	Parcel name	Wetland or dryland	Parcel area (ld)	Land ownership	Land quality	Summer crop (July-Oct/Nov 2002)		Second crop (March-June/July 2002)	
						Rice (area, ld)	Name of other crop	Rice (area, ld)	Name of other crop

[a]Also includes education in monastery.

Land area
Wetland (irrigated), 1 langdo (ld) = 0.25 acre = 0.10 ha.
Dryland (nonirrigated), 1 langdo (ld) = 0.33 acre = 0.13 ha.

Land ownership
Own = 1
Share-in = 2
Share-out = 3

Land quality
Raap = 1 = high
Dring = 2 medium
Tha = 3 = low

B. Adoption of agricultural technologies

3(a). Rice varieties planted in summer (June-Oct/Nov 2002)

Name of rice variety		Area under the variety (ld)	Production (dre.)	Year first planted	Reason for planting the variety	Original seed source	TV/MV
Parcel no.	Variety name						

3(b). Rice varieties planted in second crop (March-June/July 2002)

Name of rice variety		Area under the variety (ld)	Production (dre.)	Year first planted	Reason for planting the variety	Original seed source	TV/MV
Parcel no.	Variety name						

RNR-RCs MVs:
IR64, *IR20913*, *No. 11*, *Khumal 2*, *Barket*, *Milyang 54*, *BR153*, *BW293*
Bajo Maap 1 and 2, *Bajo Kaap 1 and 2*, *Khangma Maap*, *Yusi Ray Maap*, *Yusi Ray Kaap*

Some popular TVs are
Zakha
Tan Tshenring
Local Maap
Local Kaap

1 dre. = 1.24 kg for rice

4. Adoption of other rice technologies

Over the last 5–8 years, what other major changes in rice production have you adopted?

Activity	Nature of change	Year adopted	% of rice area adopted	Reason(s) for	
				Adopting	Not adopting
Seedling production[1]					
Land preparation[2]					
Time of planting[3]					
Plant spacing[4]					
Chemical fertilizer application[5]					
Pest control[6]					
Weed control[7]					
Harvesting/threshing[8]					
Cropping systems[9]					
Other					

Some of the changes in rice technologies could be as follows:

[1]Shorter seedbed preparation, e.g., semidry, wet-bed methods.
[2] Machine use in land preparation, number of times you plow the land before planting rice.
[3] Change in timing of transplanting for MVs , e.g., 6–7 Bhutanese months.
[4] Adoption of new plant spacing, e.g., 20 × 20 cm, other agronomic changes.
[5] Start in application of chemical fertilizer, application at transplanting and/or at flowering stage, spot application of chemical fertilizer.
[6] Spot application as insects are seen, identification of rice insects and diseases, etc.
[7] Use of herbicide before transplanting rice, application of herbicide within 3–6 days of transplanting rice, hand pulling sochum weed.
[8]Adoption of machinery for threshing and harvesting, identify method used, e.g., power thresher.
[9]Start of double rice cropping, planting a second crop following rice, etc.

5. Other crops planted in winter

Name of the crop	TV/MV	Total area (ld)	Total production (dre.)	Year first planted	Reason for planting the variety	Original seed source
Wheat						
Maize						
Mustard						
Buckwheat						
Barley						
Other (crop name)						
Fallow						

1 dre. = 1.56 kg wheat, 1.42 kg mustard, but for maize and buckwheat, the number of kg varies across districts.

C. Input use

6. Inputs used in rice production

Input usage (unit as appropriate)	Modern varieties (summer)			Modern varieties (second crop)			Traditional varieties (usually in summer)		
	Total area (ld)	Total quantity	Unit price (Nu)	Total area (ld)	Total quantity	Unit price (Nu)	Total area (ld)	Total quantity	Unit price (Nu)
Inorganic fertilizer 1. Urea (per bag)									
2. Suphala (per bag)									
Herbicide (per bag)									
Pesticide (per bottle)									
Farm machinery (hire and fuel cost)									
Seed cost									
Other expenses									

D. Agricultural production, income sources, and general conditions

7(a). Questions for rice-surplus farmers only

Rice variety/rice product	Production (dre.)	Sales[a]			Payment / loan (dre.)	Milled rice requirement for the year (dre.)	Stored for seed (dre.)
		Quantity (dre.)	Price (Nu/dre.)	Value (Nu)			
1.							
2.							
3.							
Total							

7 (b). Questions for rice-deficit farmers only

For how many months did you not have rice? ________________ (please indicate the number of months).

Total production (dre.)	Purchased			Borrowed (dre.)	What other crop do you substitute for rice?
	Quantity (dre.)	Price (Nu/dre.)	Value (Nu)		

[a]Please specify: rice, milled rice, zaow (puffed rice), sip (rice made into alcohol), etc.; any rice products sold.

8. Annual household cash income

Sources	Value of the total products sold for the agricultural year
Rice and rice products[a]	
Other crops[a] (wheat, mustard, maize, etc.)	
Vegetables and fruits[a] (chili, tomatoes, apples, etc.)	
Livestock production[a] (milk, butter, cheese, animals, etc.)	
Off-farm employment[b] (hired labor for farm work)	
Nonfarm employment[b] (work in town, service provider, road construction)	
Remittances[b]	
Nontimber forest products	
Others (specify)	

[a]Products sold.
[b]If paid monthly or yearly, please record and indicate. Off-farm employment refers to paid activities related to agricultural work on another's farm, e.g., hired labor to care for animals, land preparation, etc.
Nonfarm employment refers to paid activities outside the farming sector, e.g., road construction, transportation services, tourism industry, etc.

9. Over the past 5–8 years, what changes have occurred in your household?

Factor	Increased	Decreased	Remained constant	Briefly discuss why and how these changes occurred
Rice production				
Self-sufficiency in rice				
Overall income				
Home improvement				
Pilgrimage				
Children's health				
Livestock numbers				
Farm machinery ownership				
New knowledge of farming practices				
Others				

E. Access to farming information

10. Where do you get most of your information on agricultural production systems?

Factor	Own experience	Relatives/neighbors	Extension officers	Demonstration trials/field day/training	Radio/TV/newspaper	Others (name)
Agricultural production						
New varieties						
Land preparation						
Chemical fertilizer						
MV planting time						
Rice pest control						
Weed control						
Farm machinery						
Marketing information						
Others						

Some sources of information could be
- *Own experience*
- *Other family members*
- *Neighbors/other farmers*
- *RNR-RCs through demonstration trials, exhibitions, and training*
- *Other NGO/extension workers*
- *Radio/television/newspaper/other media*
- *Others (specify)*

Appendix 3. Rice area, production, and other statistics for surveyed dzongkhags.

Dzongkhag (district)	Area (ha)	Production (t)	Yield (t ha^{-1})	Rice sold (% of total)	Food grain shortage	
					% of households	Months
Paro	1,269	3,083	2.43	2.7	59.8	2.7
Thimphu	690	2,151	3.11	2.3	58.9	2.9
Punakha	1,971	6,274	3.18	2.5	47.3	1.5
Trashigang	941	2,440	2.59	1.8	44.0	1.3
Wangdue	1,467	4,024	2.74	1.6	55.4	1.7
Samtse	2,889	4,650	1.61	0.2	84.8	2.9
Sarpang	2,839	5,830	2.05	0.6	61.8	2.7
Nationally[a]	19,395	44,298	2.28	1.2	56.1	1.7

[a] These seven dzongkhags make up 62% and 64% of the national area and production, respectively.
Source: MAO (2001).

Appendix 4. Name of dzongkhags, geogs, and villages included in the imapct assessment survey, 2002.

Dzongkhags (districts)	Geogs (blocks)	Name of villages
Paro	Doga	Chubar, Dhushar, Lechu, Luthroe, Jabjay and Pusha
	Shapa	Ddingkha
	Wangchang	Changkar
	Dopshari	Jangsa, Ramna, Ruchukha, and Shari
	Lungnyi	Bondey, Lungnyi, Jewphu, Gebjana, Getana, Woochu, and Zdakha
Punakha	Kabji	Wokuna and Sirigang
	Chubu	Gangkhalo and Jawakha
	Zomi	Gubji and Khawazara
Samtse	Chengmari	Bimtar, Garigmo, Katari, Kothari, and Masey
	Samste	Buduney, Chalikoop, and Manchetar
	Biru	Birutar, Khotitar, and Lamatar
	Nainital	Botey, Bhaungaon, Bitchgoan, Bowngoan, Raigaon, Newargaon, and Thakurigaon
Sarpang	Chusegang	Village names not listed on the worksheets
	Umling	
	Gaylephug	
	Sarpangtar	
Thimphu	Mewang	Kdrapchu, Sigay, and Tsaphu
	Genye	Bama, Bechumo, Cthanka, Dupgi, Gacarmo, Ggokha, and Yangoe
Trashigang	Radi	Chena, Dekling, Langtal, Pangthang, Radhi, Radi Pangthang, Pakaling, Tanglamani, Tshatsi, and Zonla
	Phongme	Bumtang, Gazeray, Lakhang, Lemp, Monangkhar, and Tongleng
	Bartsham	Braimang, Jongdung, Hingong Ugdama, Manchang, Muktangkhar, Sekhar, Yangkhar, and Zongthang
	Shongphu	Changme, Khaling, and Shongphu
Wangdue	Nisho	Chebakha and Lakhokha
	Tetsho	Bajothang, Thangu, and Rinchengang
	Gasewom	Changkha, Hetshokha, and Pasakha

Appendix 5. Names and institutional affiliation of the interviewed personnel.

Department of Research and Development Services
- Dr. Pema Choephyel, Director
- Mr. G.B. Chettri, Joint Director for Research
- Mr. Dorji Dradhul, Joint Director for Extension

Planning and Marketing Division
- Mr. Choni Dhendup, Office Head

Natural Resources Training Institute (Lobesa)
- Mr. Dorji Wangchuk, Director
- Mr. Jamba Gryeltshem, Head, Faculty of Agriculture
- Mr. Tulsi Gurung, Lecturer, Faculty of Agriculture

European Union
- Mr. Harry Franks, Co-Director, ESP Project
- Mr. Euclid D'Souza, Extension and Training Specialist

Helvetas/SDC
- Mr. Erwin Koenig, Resident Coordinator
- Mr. Sonam Pelijore, Programme Officer
- Mr. Samuel B. Moser, Co-Director at the Natural Resources Training Institute

International Rice Research Institute (IRRI)
- Mr. Julian Lapitan, IPMO Manager
- Dr. Glen Gregorio, Affiliate Scientist

Punakha Dzongkhag Office
- Mr. Deo Kumar Sharma (Kabiya)
- Mr. Tandin Tshewang (Talo)
- Mr. Glyeltshen
- Mr. Sonam Dorji (Toewang)
- Mr. Suraj Khawas
- Mr. Jambay Ngyen (Gmma)
- Mr. Glaylong (Dzomi)

RNR-RC Jakar
- Mr. Kinzang Wangdi, Program Director
- Dr. Walter Roder, Joint Program Director

RNR-RC Bajo
- Mr. Sangay Duba, Program Director
- Mr. Mahesh Ghimire, Senior Research Scientist

Appendix 6. Names and institutional affiliation of enumerators.

RNR-RC Yusipang
- Mr. Kencho Dukpa
- Mr. P.L. Giri
- Mr. Pushpa Raj Gurung
- Mr. Karma Pelden
- Mr. D.B. Rana
- Mr. Rinchen
- Mr. Gyem Thinley

RNR-RC Bajo
- Mr. Karma
- Mr. Jigme Norbu
- Ms. Tanka Maya Pulami
- Mr. Kencho Wangdi

RNR-RC Jakar
- Mr. Cheku Dorji
- Mr. Wangda Drukpa
- Ms. Tshering Pem
- Ms. Rinchen Wangmo

RNR-RC Khangma
- Mr. N.B. Adhikari
- Mr. Phunstho
- Mr. L.N. Sharma

Appendix 7. Crossbred lines between traditional varieties and elite lines.

Cross designation	Parents	Lines/bulks (no.)
CARD20	Local Kaap/IR64	107
CARD21	Local Maap 1/IR64	235
CARD22	Ugey Maap/IR36	50
CARD24	Local Kaap/IR60	20
CARD25	Local Kaap/Selewah	27
CARD26	Ugey Maap2/IR36	94
CARD27	Ugey Maap3/IR36	34
CARD28	Local Maap/IR58	45
CARD29	Local Maap/IR56	40
IR56346	Wangdue Kaap(L)/BG90-2	175
IR56347	Wangdue Kaap(L)/CO25	140
IR56350	Wangdue Kaap(L)/IR24	214
IR56354	Wangdue Kaap(E)/CO25	226
IR56357	Wangdue Kaap(E)/IR24	187
IR56359	Wangdue Kaap(E)/IR52	135
IR58545	Bja Naab/B2982B-	22
IR58559	Bja Naab/BG94-1	53
IR58566	Bja Naab/China 1039	15
IR58567	Bja Naab/IR9202-	41
IR58568	Bja Naab/IR9758-	33
IR58569	Bja Naab/IR15636-	15
IR58570	Bja Naab/JKAU450-	26
IR58571	Bja Naab/RPKN2-	60
IR58606	Bja Naab/IR31386-	9
IR58615	Bja Naab/IR10041-	34
IR60016	Bja Naab/IR31868-	12
IR60018	Paro Maap/IR31868-	120
IR60019	Th. Dumbja/IR31868-	51
IR60020	Th. Maap/IR31868-	44
IR60021	Bja Maap/IR32429-	66
IR60023	Paro Maap/IR32429-	53
IR60025	Th. Dumbja/IR32429-	39
IR60026	Th. Maap/IR32429-	–
IR60035	Paro Maap/Milyang 54	30
IR60036	Th. Dumbja/M 54	65
IR60037	Th.Maap/M 54	85
IR60063	Bja Naab/85-3504	45
IR60068	Paro Maap/85-3504	37
IR60072	Th.Dumbja/85-3504	45
IR60073	Th. Maap/85-3504	138
IR61328	Bja Naab/IR41996-	274
IR61331	Paro Maap/IR41996-	293
IR61333	Th. Dumbja/IR41996-	191
IR61334	Th. Maap/IR41996-	177
IR61375	Th. Dumbja/Diamante Inia	40
IR61376	Th. Maap/Diamante Inia	9
IR61380	Paro Maap/N. Inia	45
IR61383	Th. Dumbja/N. Inia	40
IR61384	Th. Maap/N.Inia	20
IR61388	Bja Naab/Suweon 332	229
IR61390	Paro Maap/Suweon 332	229
IR61391	Kuchum/Vary Lava	4
IR61392	Paro Maap/Vary Lava	9
IR62448	Semtokha Maap2/IR43450-	65
IR62467	Attey/Suweon 358	149
IR62470	Punakha Maap/Suweon 358	154
IR62471	Semtokha Maap2/Suweon 358	–
IR62472	Sukhimey/Suweon 358	–
IR62473	Zakha/Suweon 358	99
IR62476	Semtokha Maap2/S 359	80
IR62478	Zakha/Suweon 359	55
IR62734	S 353//No.11/Th.Dumbja	48
IR62744	S 359//IR41996/Paro Maap	38
IR62745	S 359//IR41996/Th. Dumbja	84
IR62746	S 359//IR41996/Th. Maap	–

continued

BOX 1. continued

IR63332	Zakha/Akihikari	86
IR64237	Zakha/IR39739-	32
IR64429	Akihikari//Akihikari/Pun.Maap	–
IR64430	Akihikari//Akihikari/Sem.Maap	29
IR65222	Attey/Akihikari	–
IR65239	Attey/YR3825-	135
IR65892	No. 11/Chummro	37
IR66408	Chhumro/IR55259-	74
IR66412	Chummro/IR60060-	152
IR66068	YR3825//YR3825/Barket	86
IR68136	Barket/Kochum	7
IR68142	IR64/Zawa Bondey	7
IR68146	JP5/Gyembja	9
IR68147	JP5/Kochum	7
IR68149	JP5/Zuchein	8
Total		5,740

(Source: Ghimiray 1999)

Appendix 8. Fertilizer use recommendations.

(a). Traditional rice varieites.

Dzongkhags	N (kg ha^{-1})	P_2O_2 (kg ha^{-1})	K_2O (kg ha^{-1})
Thimphu	40–49	30–40	0
Paro	49–59	20–30	0–20
Wangdi	30–64	20–30	0
Punakha	30–64	20–30	0
Trongsa	40–49	20–30	0
Gaylegphug	40–49	30–40	0–20
Chirang	40–49	30–40	0–20
Other[a]	40–49	30–40	0–20

(b). Improved varieites

Dzongkhags	N (kg ha^{-1})	P_2O_2 (kg ha^{-1})	K_2O (kg ha^{-1})
Thimphu	49–79	30–49	0–20
Paro	59–79	30–40	0–20
Wangdi	49–79	30–49	0–20
Punakha	59–79	30–40	0–20
Gaylegphug	59–79	30–49	20–30
Chirang	69–89	40–59	0–20
Tashigang	49–69	40–59	0–20
Samchi	59–79	40–49	20–40
Other[a]	59–79	40–59	0–20

[a]The remaining northern dzongkhags where fertilizer trials had not yet been completed when these recommendations were made.
Source: Improved Rice Cultivation in Bhutan, booklet for commission agents and farmer leaders.

Appendix 9(a). Recommended practices for rice production in the warm temperate zone (high altitude)

Areas

These recommendations are for high-altitude areas (1,600–2,600 m) that include Paro, Thimphu, and parts of Wangdue, Punakha, Tongsa, Lhuntshi, and Tashigang.

Varieties

No. 11
- Cold-tolerant, high-yielding, early maturing japonica rice
- About 90 cm tall and matures 135–145 days after sowing
- Short bold white grains with 66% milling (head rice) recovery
- Difficult to thresh
- Yields 5–7 t ha^{-1} under moderate management, but responds to fertilizer.

Local Maaps
- Cold-tolerant, tall stature, long growth duration, japonica types
- Medium-short red grains, preferred for eating
- Yields 2–3 t ha^{-1} under optimum management levels. Not responsive to higher levels of fertilizer.

Crop establishment

Nursery sowing
- Optimum sowing date: March or first week of April
- Seed rate: 50–60 kg ha^{-1}
- Use clean and healthy seeds.
- Seedlings can be raised using semidry or dry-bed methods (see leaflet on seedling production).

Field preparation

Land preparation is one important factor that influences rice yield. It provides good soil physical, chemical, and biological conditions for optimum growth.
- Two or three plowings are needed, followed by puddling and leveling.
- Plow thoroughly and then flood.
- Drain the water slightly and plow, rotovate, or harrow as needed and level the field.
- A final puddling and leveling may be required just before transplanting.
- Repair and maintenance of bunds and the incorporation of chemical fertilizers, if any, should be done before the final puddling.

Manure and fertilizer

Farmers routinely apply farmyard manure (FYM) to rice in the high-altitude areas. The rate of application varies widely from 5 to 20 t ha^{-1}. FYM contributes significantly to crop nutrition and soil conditions. It is desirable to encourage the use of FYM.

Our recommendation is to apply about 5–8 t ha^{-1} of FYM basally, and topdress with 35 kg N ha^{-1} 35–40 days after transplanting.

If adequate FYM is not available, apply 75-40-0 kg NPK ha^{-1}. Half the N and all the P should be applied as the basal dose. Topdress the remaining N 35–40 days after transplanting. For local varieties, limit N to 50 kg ha^{-1} to prevent lodging.

Transplanting

Transplanting time: mid-May to mid-June

The traditional random method can be used if
- Weed pressure is expected to be low.
- Butachlor will be used.
- Terraces are narrow and small.

Line planting should be done if weeding will be carried out with a rotary weeder.
- Use a rope to give a between-row spacing of 20 cm and within-row spacing of 15–20 cm.

A plant density of 25–35 per m^2 is optimum. Transplant local varieties at a closer spacing (15 x 15 cm), as they do not tiller well.

Weed control

Weeds are serious competitors of rice. They compete for water, nutrients, and sunlight and reduce grain yields.

Where weed pressure is low or moderate, two hand weedings 20 and 40 days after transplanting are sufficient. If hand weeding is to be done, plants should be closely spaced and the first weeding performed no later than 30 days after transplanting.

Where weed pressure is high, use line planting and rotary weeding. Two rotary weedings 20 and 40 days after planting are recommended. In areas where sochum is a severe problem, additional hand weedings may be required.

If there is little or no sochum but weed pressure is high, butachlor is a very effective alternative to rotary weeding. It is applied 3–6 days after transplanting at 30–40 kg ha^{-1} of 5% "Punch" granules.

If sochum is a major problem, it can be controlled by Sanbird applied at 25–35 kg ha^{-1} 4–6 days after transplanting. Alternatively, apply NC 311 at 25–30 kg ha^{-1}.

As weeding is laborious, and the use of herbicides is undesirable, there must be emphasis on indirect complementary weed control methods such as good land preparation, proper water management, and the use of weed-free seedbeds and seeds.

Water management

After transplanting, keep the water level low for 4–7 days until the seedlings recover. The water level should then be increased as the crop grows, ensuring adequate water from tillering to flowering.

If the water supply is limited, continuous flooding is not possible. In this case, irrigate at short intervals but do not let the field become excessively dry and crack. Flowering is the most critical stage when rice should not be exposed to moisture stress.

Drain water from the field 10–15 days before harvest to enhance ripening.

Plant protection

Insect pests and diseases are normally not a major problem in rice at high altitudes.

Harvest

Under normal conditions, harvesting begins from the first week of October. Harvest the crop when at least 85% of the upper portion of the panicles turns straw colored. Some leaves and stems may still be green at grain maturity, particularly for No. 11.

Local varieties shatter very easily; a timely harvest will minimize grain losses.

For further information, contact Mahesh Ghimiray, Field Crops Sector, RNR-RC Bajo.

Appendix 9(b). Recommended practices for rice production as a main crop in the dry and humid subtropical zones (medium altitude)

These recommendations are for medium-altitude (700–1,500 m) areas that include Wangdue, Punakha, parts of Trashigang-Monggar in the dry zone, and Tsirang, Dagana, and parts of Sarpang, Samtse, and Samdrup Jonkhar in the humid zone.

Varieties

IR64
- High-yielding tropical semidwarf variety
- Matures 145–150 days after sowing
- Grain quality similar to that of local white rice
- Milling recovery 65%
- Slender white grains
- Yields 5–7 t ha^{-1} under average conditions, but responds to higher fertilization

Milyang 54
- Japonica/indica cross that originally came from Korea
- About 95 cm tall and matures 140–145 days after sowing
- Slender white grains, good eating quality
- Higher yielding than IR64; yields 6–9 t ha^{-1} under moderate management
- Susceptible to sheath blight, particularly in high-rainfall humid areas

IR20913
- An advanced selection from the cross between Bhutanese (Paro) white rice and an IRRI line
- About 100 cm tall and matures 120–130 days after sowing
- Yields over 7.5 t ha^{-1} under good management
- Moderate cold tolerance at flowering and early maturity make it suitable for late planting as the main crop

Crop establishment

Nursery sowing
- Optimum sowing date: May in dry zone, June in humid zone
- Seed rate: 50–60 kg ha^{-1}
- Use clean and healthy seeds.
- Seedlings can be raised using wet- or semidry-bed methods (see seedling production leaflet).

Field preparation

Land preparation is one important factor that influences rice yield. It provides good soil physical, chemical, and biological conditions for optimum growth.
- Two or three plowings are needed, followed by puddling and leveling.
- Irrigate the field before plowing, if dry.
- Plow thoroughly and then flood.
- Drain the water slightly and plow, rotovate, or harrow as needed.
- A final puddling and leveling may be required just before transplanting.

Repair and maintenance of bunds and the incorporation of chemical fertilizers, if any, should be done before the final puddling.

Manures and fertilizers

Farmers routinely apply FYM to rice in the medium-altitude areas, ranging from 5 to 20 t ha^{-1}. FYM contributes significantly to crop nutrition and soil conditions.

Our recommendation is to apply about 5–8 t ha^{-1} of FYM basally, and topdress with 35 kg N ha^{-1} 35–40 days after transplanting.

If adequate FYM is not available, apply 75-40-0 kg NPK ha^{-1}. Half the N and all the P should be applied as the basal dose. Topdress the remaining N 35–40 days after transplanting. For local varieties, limit N to 50 kg ha^{-1} to prevent lodging.

Sesbania aculeata (Dhaincha) can be grown for 6–8 weeks, then incorporated as green manure during land preparation. Sow Dhaincha at 50–60 kg ha^{-1} in April after harvesting wheat or mustard. Topdress 35 kg N ha^{-1} at panicle initiation for higher yields.

Transplanting

Transplanting time: June in dry zone, July in humid zone

The traditional random method can be used if
- Weed pressure is expected to be low.
- Butachlor will be used.
- Terraces are narrow and small.

Line planting should be done if weeding will be carried out with a rotary weeder.
- Use a rope to give a between-row spacing of 20 cm and within-row spacing of 15–20 cm.
- A plant density of 25–35 per m^2 is optimum.

Weed control

Where weed pressure is low or moderate, two hand weedings 20 and 40 days after transplanting are sufficient. Plants should be closely spaced and the first weeding done no later than 30 days after transplanting.

Where weed pressure is high, use line planting and rotary weeding. Two rotary weedings 20 and 40 days after planting are recommended.

If there is no or little sochum but weed pressure is high, butachlor is a very effective alternative to rotary weeding. It is applied 3–6 days after transplanting at 30–40 kg ha^{-1} of 5% "Punch" granules.

If sochum is a major problem, it can be controlled by Sanbird applied at 25–35 kg ha^{-1} 4–6 days after transplanting. Alternatively, apply NC 311 at 25–30 kg ha^{-1}.

As weeding is laborious, and the use of herbicides is undesirable, there must be emphasis on indirect complementary weed control methods such as good land preparation, proper water management, and the use of weed-free seedbeds and seeds.

Water management

After transplanting, keep the water level low for 4–7 days until the seedlings recover. The water level should then be increased as the crop grows.

If the water supply is limited, continuous flooding is not possible. In this case, irrigate at short intervals but do not let the field become excessively dry and crack. Flowering is the most critical stage when rice should not be exposed to moisture stress.

Drain water from the field 10–15 days before harvest to enhance ripening.

Plant protection

Insect pests and diseases are normally not a major problem in rice at medium altitudes.

Harvest

Under normal conditions, harvesting begins from the first week of October. Harvest the crop when at least 85% of the upper portion of the panicles turns straw colored. Some leaves and stems may still be green at grain maturity, particularly for improved varieties.

Local varieties shatter very easily; a timely harvest will minimize grain losses.

For further information, contact Mahesh Ghimiray, Field Crops Sector, RNR-RC Bajo.

Appendix 9(c). Recommended practices for rice production for the wet subtropical zone (low altitude)

These recommendations are made for the low-altitude (150–600 m) southern belt that includes Sarpang, Samtse, and Samdrupjonkhar for irrigated rice culture.

Varieties

BR 153
- BR 153 is a high-yielding, tropical semidwarf variety bred in Bangladesh.
- It is 100–110 cm tall and matures in 140–150 days.
- It has good resistance to diseases and pests and is tolerant of poor soils and poor management.
- It has slender white grains.
- Yields of 5–7 t ha^{-1} can be obtained under average management conditions.

BW 293
- BW 293 is a tropical, high-yielding variety developed in Sri Lanka.
- It is 75–85 cm tall and matures in 140–150 days from sowing.
- It has slender white grains with intermediate to high amylose content.
- It has a higher yield potential than BR 153 under similar input levels.

Crop establishment

Nursery sowing
- Optimum sowing date: June
- Seed rate: 50–60 kg ha^{-1}
- Use clean and healthy seeds.
- Seedlings can be raised using wet- or semidry-bed methods (see rice seedling production leaflet).

Field preparation

Land preparation is one important factor that influences rice yield. It provides good soil physical, chemical, and biological conditions for optimum plant growth.
- Two or three plowings are needed, followed by puddling and leveling.
- Irrigate the field before plowing, if dry.
- Plow thoroughly and then flood.
- Drain the water slightly and plow, rotovate, or harrow as needed to break clods, bury weeds, and puddle and level the field.
- A final puddling and leveling may be required just before transplanting.

Repair and maintenance of bunds and the incorporation of chemical fertilizers, if any, should be done before the final puddling.

Manures and fertilizers

FYM contributes significantly to crop nutrition and soil conditions. It is desirable to encourage the use of FYM.

Our recommendation is to apply about 5–8 t ha^{-1} of FYM basally, and topdress with 35 kg N ha^{-1} 35–40 days after transplanting.

If adequate FYM is not available, apply 80-40-30 kg NPK ha^{-1}. Half the N and all the P should be applied as the basal dose. Topdress the remaining N 35–40 days after transplanting. For local varieties, limit N to 50 kg ha^{-1} to prevent lodging.

Sesbania aculeata (Dhaincha) can be grown for 6–8 weeks and then incorporated as green manure during land preparation. Sow Dhaincha at 50–60 kg ha^{-1} in May. Topdress 35 kg N ha^{-1} at panicle initiation for higher yields.

Transplanting

Transplanting time: July.

The traditional random method can be used if
- Weed pressure is expected to be low.
- Butachlor will be used.
- Terraces are narrow and small.

Line planting should be done if weeding will be carried out with a rotary weeder.
- Use a rope to give a between-row spacing of 20 cm and within-row spacing of 15–20 cm.

A plant density of 25–35 per m^2 is optimum.

Weed control

Weeds are serious competitors with rice. They compete for water, nutrients, and sunlight and reduce grain yields.

Where weed pressure is low or moderate, two hand weedings 20 and 40 days after transplanting are sufficient. If hand weeding is to be done, plants should be closely spaced and the first weeding performed no later than 30 days after transplanting.

For weeds other than sochum, butachlor is very effective. It is applied 3–6 days after transplanting at 30–40 kg ha^{-1} of 5% "Punch" granules.

As weeding is laborious, and the use of herbicides is undesirable, there must be emphasis on indirect complementary weed control methods such as good land preparation, proper water management, and the use of weed-free seedbeds and seeds.

Water management

After transplanting, keep the water level low for 4–7 days until the seedlings recover. The water level should then be increased as the crop grows to ensure adequate water from tillering to flowering.

If the water supply is limited, continuous flooding is not possible. In this case, irrigate at short intervals but do not let the field become excessively dry and crack. Flowering is the most critical stage when rice should not be exposed to moisture stress.

Drain water from the field 10–15 days before harvest to enhance ripening.

Plant protection

Insect pests and diseases are a major concern because of high temperature and humidity. The integrated pest management approach is recommended, which involves varietal resistance, cultural and biological control methods, and the use of pesticides as needed.

Harvest

Under normal conditions, harvesting begins from the first week of October. Harvest the crop when at least 85% of the upper portion of the panicles turns straw colored. Some leaves and stems may still be green at grain maturity, particularly for improved varieties.

Local varieties shatter very easily; a timely harvest will minimize grain losses.

For further information, contact Mahesh Ghimiray, Field Crops Sector, RNR-RC Bajo.

Appendix 10(a). Recommended practices for crop intensification: rice double cropping in the dry subtropical zone (medium altitude)

These recommendations are made for the medium-altitude areas (up to 1,500 m), particularly in the Wangdue-Punakha valley and Trashigang-Monggar.

First crop

Varieties

No. 11
- Cold-tolerant, high-yielding, early maturing, japonica rice.
- It has good seedling cold tolerance; however, symptoms such as yellowing of leaves and stunting may occur under very low temperature.
- It is about 90 cm in height and matures in 160 days from sowing.
- It has a yield potential of more than 7 t ha^{-1} under good management but it is difficult to thresh.

Barket
- Cold-tolerant, high-yielding, early maturing, japonica rice.
- It has good seedling cold tolerance and produces vigorous seedlings under a polytunnel nursery.
- It is 90–95 cm in height and matures in about 155 days.
- It is very easy to thresh, unlike No. 11.
- It has a yield potential of more than 6.2 t ha^{-1} under good management.

Crop establishment

- The first crop can be established by either transplanting or direct seeding.

Transplanting
- The first week of February is the recommended time to sow the nursery.
- Use a seed rate of 62–74 kg ha^{-1}.
- Raise seedlings using a polytunnel nursery bed.
- Raise seedlings in a polytunnel nursery (see leaflet on rice seedling production).

Time of transplanting
- The ideal transplanting time is the second week of March.
- The method of transplanting, either in line or randomly, should be decided depending upon the weed control method to be adopted and labor availability.

Direct seeding
Direct seeding greatly reduces the labor cost in establishing a rice crop. A direct-seeded rice crop also matures about a week earlier than a transplanted crop. However, the general requirements for successful direct seeding are a good rice variety, good land preparation, good weed control, and good water supply and management. Direct seeding can be done in two ways:

Dry furrow seeding
- Land preparation should be done in dry soil to obtain a well-pulverized seedbed as in a dry-bed nursery.
- Open up furrows 2–3 cm deep and 20–30 cm apart.
- Drop unsoaked seeds evenly or place 4–8 seeds at a distance of 10–15 cm along the furrow.
- After sowing, cover the seeds lightly with fine soil.
- Irrigate the field lightly after sowing. Do not keep standing water in the field as excess water deprives the seeds of oxygen and they eventually die. Keep the field moist until the seeds germinate.
- Keep the field saturated till seedlings attain a height of about 10 cm. Increase the water level gradually.
- Use a seed rate of 99–123 kg ha^{-1}.
- Optimum sowing time is the first half (1–15) of March.

Wet broadcast seeding
- Prepare the land as for any transplanted rice crop. However, the field should be properly leveled for efficient drainage.
- After final land preparation, allow the mud to settle overnight to avoid sinking of seed. Keep the water level at the minimum.
- Broadcast pregerminated seeds (soaked for 24 hours and incubated for 36–48 h) evenly. Walk backward while seeding and avoid making too many mud depressions that collect water and rot the seed.
- Keep the water level as low as possible till the seeds secure roots and emerge (after 2–5 days, but they may take longer if the temperature is low). Then, increase the water level gradually as seedlings grow in height.
- Use a seeding rate of 70–90 kg ha^{-1}.
- The first half of March is the optimum seeding time.
- Weed control is the biggest challenge of this method. Butachlor is not suitable as it suppresses emergence and arrests seedling growth at early stages. However, Sanbird and NC 311 can be successfully applied 5–7 days after seeding without affecting rice growth.

Other activities such as field preparation, manures and fertilizers, and weed control are similar to those of a normal crop of rice.

Second crop

Variety

IR20913
- It is an advanced selection from the cross between Bhutanese white rice and an IRRI line.
- It is about 100 cm tall and matures in about 130–140 days from sowing.
- It has a yield potential of more than 7 t ha^{-1} under average to good management conditions.
- It has moderate cold tolerance at seedling and flowering stages and is also good for late planting of the normal-season crop.

Crop establishment

Nursery sowing: 15 June-30 June
Seed rate: 49–62 kg ha^{-1}
Nursery raising: Seed selection as for the first crop. Seedlings could be raised by either wet-bed or semidry-bed methods.

Transplanting
Time of transplanting: 15 July-30 July
Transplant 20–30-day-old seedlings using 2–3 seedlings $hill^{-1}$.
Maintain closer spacing as recommended for the first crop.
Other practices are similar to those for a normal rice crop.

For further information, contact Mahesh Ghimiray, Field Crops Sector, RNR-RC, Bajo

Appendix 10(b). Mustard cultivation in the wetland production system.

Variety

Type 9 or T9

- Early maturing variety of Indian origin.
- Matures in 90–100 days.
- Semispreading growth habit, grows to a height of 100–110 cm.
- Seeds are medium in size, brownish black in color, and contain 40–42% oil.
- Yield of 0.75–1.0 t ha^{-1} under good management conditions.
- Recommended for medium-altitude valleys (<1,900 m) and low-altitude foothills.

M27

- Early maturing variety of Indian origin.
- Matures in 85–95 days.
- Semispreading type growing to a height of 85–90 cm.
- Seeds are medium in size and contain 43–45% oil.
- Yield of 0.5–1.0 t ha^{-1} under good management conditions.
- Recommended for medium-altitude valleys (<1,900 m) and low-altitude foothills.

BSA

- Late-maturing variety of Pakistani origin.
- Matures in 150–160 days.
- Grows to a height of 115–125 cm.
- Yield of 1.0–2.0 t ha^{-1} under good management conditions.
- Recommended up to an altitude of 2,300 m and for rice- and maize-based systems.

PT 30

- Medium-maturing variety from India.
- Matures in 120–130 days.
- Grows to a height of 75–90 cm.
- Yield of 0.75–1.0 t ha^{-1} under good management conditions.
- Recommended up to an altitude of 2,000 m and for rice- and maize-based systems.

Climate

The best yields are generally obtained when early plant establishment and growth occur under slightly warmer temperatures, with flowering and seed filling taking place at cooler temperatures.

Soils

Type 9 mustard can be grown under a wide range of soil conditions varying from sandy loam to clay loam. It thrives best on light loam soils. It neither tolerates waterlogging conditions nor does well on heavy soils. A soil with neutral pH is ideal for growth and development.

Field preparation

Irrigate 7–10 days before sowing to ensure good germination and early seedling vigor.

Plow deeply once, followed by a second and possibly third plowing using a local plow. Planking can be used after each plowing to prepare the seedbed.

Seeds and sowing

Selection of seed: Use healthy seeds of a recommended variety. Treat the seeds with Thiram at 2 g kg^{-1} seed to protect seedlings from diseases such as root rot and wilt.
Seed rate: 7.5–10 kg ha^{-1}.
Sowing time: October-November. An earlier sown crop would likely produce higher yields. If sowing is delayed, there is a danger of aphid attack.
Method of sowing: Broadcast seeds uniformly in a well-pulverized field. Light planking should be used to cover the seeds. Seed depth of 2–3 cm is optimal.
Spacing: For line sowing, use a spacing of 30 cm between rows and 5–10 cm within rows.

Manure and fertilizers

Apply 2.5–5 t ha^{-1} of FYM as a basal dose, then, 35 days after sowing, topdress with 50 kg ha^{-1} nitrogen.

If adequate FYM is not available, apply chemical fertilizers at 100-50-0 kg NPK ha^{-1}. Half the N and all the P should be applied as a basal dose. The remaining N should be topdressed 35 days after sowing.

After-care

Thin the mustard 15–20 days after sowing to give a plant-to-plant spacing of 5–10 cm. Intercultural operations should, if possible, be done 20–25 days after sowing to remove weeds and conserve moisture.

Irrigation

Two irrigations are usually sufficient:
First irrigation: at flowering stage, 20–25 days after sowing.
Second irrigation: at fruiting/podding stage, 50–55 days after sowing.

Plant protection

Mustard aphid

This aphid is the most destructive pest of mustard. It is pale green, soft-bodied, and 1–2 mm long. Adults and nymphs suck cell sap from various plant parts, thus affecting seed yield and oil content considerably.
Control:

- Early sowing—first fortnight of October.
- Removal of early-infected plant parts.
- Spray Malathion 50 EC at 1 mL L^{-1} of water.

Mustard sawfly

Adults are orange-yellow wasps with smoky wings and a black head and legs. Larvae are yellowish green or dark green with five lateral stripes. They appear in the early stages of the crop in October or November. The larvae make irregular holes in the leaves.
Control: spray Malathion 50 EC at 1 mL L^{-1} of water.

Alternaria blight

Small light brown circular spots appear on the cotyledon leaves, turning black in the advanced stage. Small circular brown or blackish spots appear on leaves, increase in size, and multiply rapidly, forming dark brown concentric rings.
Control: Spray the crop with dithane M-45 weekly. Use 2 kg of fungicide suspended in 1,000 L of water per hectare.

White rust

Small, white raised pustules appear on the leaves, stems, inflorescence, and floral parts. These pustules coalesce to form large patches.
Control:

- Apron SD-35 (Ridomil) 0.2% as seed dressing delays the primary infection.
- Spray dithane M-45 at 1.5 kg ha^{-1} at 15-day intervals.

Club root
Plants become stunted with pale green or yellowish leaves. Small to large spindle- or spherical-shaped knots or clubs appear on the main or lateral roots.
Control:
- Long-term crop rotation.
- Use resistant varieties.

Harvesting and threshing

Harvest when 75% of the pods turn yellowish. To minimize shattering losses, harvest in the morning when the pods are slightly damp with dew. Stack the mustard in bundles to dry it in the sun for a few days, and then thresh manually. For safe storage, clean the seed and dry it in the sun to reduce the moisture content to less than 8%.

For further information, contact Mahesh Ghimiray, Field Crops Sector, RNR-RC Bajo.

Appendix 11. Recommended practices for rice ratooning.

In areas where adequate water is available after the first crop season, rice ratooning could be practiced as an alternative to raising the second crop in rice double cropping. The ratoon crop matures earlier and requires less labor and water inputs. Water-use efficiency is high. Early maturing, high-yielding first-crop varieties such as No. 11 and Barket are suitable for ratooning.

The success of a good ratoon crop depends on the care with which the first crop is cultivated in the growing season. Agronomic practices for the first crop determine the success of ratooning and grain yields of ratoonable varieties. Variations in soil, water, light, and temperature influence ratooning ability. Tiller development is highly influenced by the carbohydrates that remain in the stubbles and roots after harvest and the level of nitrogen in the soil. Varieties with thick culms/stems store more carbohydrates and are more suitable for ratooning.

Agronomic practices

Time of harvest
The best time to harvest the main crop for raising a good ratoon crop is when its culms or stems are still green. Stalks should be cut before the main crop is fully mature and dried up so that the stems are physiologically viable for ratoon tillering.

Spacing
The effect of spacing on grain yield of the main and ratoon crops is different from one variety to another. In general, the optimum spacing for good ratoon yield is 20 x 20 cm.

Cutting height
Interactions between varieties and cutting height exist; some varieties tiller better when cut high, whereas others produce better tillers when cut at lower levels. For short-statured varieties such as No. 11 and Barket, a cutting height of 15–20 cm is optimum. Further reducing the cutting height increases the number of missing hills in the ratoon crop.

Water management
Excess flooding immediately after the main crop harvest can cause rotting of stubbles and can retard tiller formation. Keep the field drained but moist for about 10 days after harvest to promote sprouting and tillering. Thereafter, irrigate the field as in the main crop.

Fertilizer management
Studies on fertilizer requirements show that a ratoon crop needs nitrogen at the rate of 75% of the main crop. P and K are usually adequate and do not respond upon application. For the Wangdi-Punakha valley, topdress N at 50 kg ha^{-1} 20–30 days after harvesting the main crop.

Weed control
Weed intensity in a ratoon crop depends very much on the control measures applied to the main crop. A thorough handweeding should be carried out 20–30 days after harvesting of the main crop during the time of topdressing.

Harvesting

Harvest the ratoon crop when more than 80% of the grains are mature and turn straw-colored.

Yield

On average, ratoon rice can give a yield roughly equivalent to 40% of that of the main crop, with a 40% reduction in crop duration.

For further information, contact Mahesh Ghimiray, Field Crops Sector, RNR-RC Bajo.

Appendix 12. Recommended practices for direct seeding of rice.

Direct seeding markedly lowers the labor cost in establishing a rice crop. Under ideal conditions, similar high yields can be obtained with direct-seeded and transplanted crops. A direct-seeded rice crop also matures about a week earlier than a transplanted crop. However, the general requirements for successful direct seeding are a good rice variety, good land preparation, good weed control, and good water supply and management.

Varieties

Any short-statured, early-to-medium-maturing varieties are suitable for direct seeding. All of the so-far recommended improved varieties can be successfully direct-seeded. However, IR20913, IR64, No. 11, Barket, and BR153 are particularly suitable. Tall local varieties such as Zakha, Attey, and Maaps are not suitable as they lodge severely at maturity.

Crop establishment

One of the most common methods for direct seeding is wet broadcast seeding.

Wet broadcast seeding

Prepare the land as for a transplanted rice crop. It is particularly important that the field should be properly leveled for efficient drainage.

After final land preparation, allow the mud to settle overnight to avoid sinking of the seed. Keep the water level to a minimum.

Broadcast pregerminated seeds (soaked for 24 hours and incubated for 36–48 h) evenly. Walk backward while seeding and avoid making too many mud depressions that collect water and rot the seed.

Keep the water level as low as possible till the seeds secure roots and emerge. This should take 2–5 days, but may be longer if the temperature is low. Then increase the water level gradually as seedlings grow in height.

Seed rate

Use a seed rate of 70–90 kg ha^{-1}.

Seeding time

Depending on the cropping season, variety, and growing area, direct seeding should be done 15–20 days prior to the recommended transplanting time.

Weed control

Weed control is the biggest challenge in a direct-seeded crop. Good land preparation, proper water management, and optimum plant stand help in reducing weed pressure to a large extent. Keep the field weed-free by hand weeding. The number of weedings depends on the weed pressure in any particular locality or cropping season. Butachlor is not suitable as it suppresses emergence and arrests seedling growth at early stages. If available, Sanbird and NC 311 can be applied 5–7 days after seeding without affecting rice growth.

Other cultural practices

Other cultural practices are the same as in a transplanted crop.

For further information, contact Mahesh Ghimiray, Field Crops Sector, RNR-RC Bajo.

Appendix 13. Wetland and dryland area in the survey, 2002.

Altitude	Wetland	Dryland (ha)	Total	% of land		
				Wetland	Dryland	Total
High	87.5	27.5	115.0	76.1	23.9	100.0
Medium	68.0	16.1	84.1	80.8	19.2	100.0
Low	79.5	36.8	116.3	68.4	31.6	100.0
Total	235.0	80.4	315.4	74.5	25.5	100.0

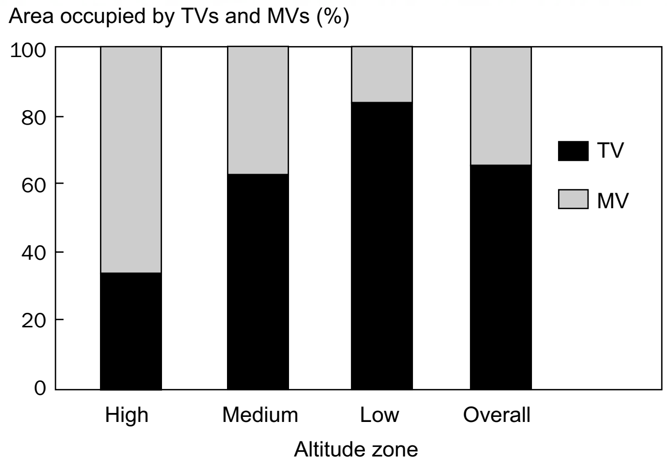
Source: Impact assessment survey, 2002.

Appendix 14. Households adopting different groups of rice varieties, 2002.

Households adopting	Number of households				% of households			
	High	Medium	Low	Overall	High	Medium	Low	Overall
TVs only	24	34	41	99	22.9	41.5	68.3	40.1
TVs and MVs	33	34	12	79	31.4	41.5	20.0	32.0
MVs only	48	14	7	69	45.7	17.0	11.7	27.9
All households	105	82	60	247	100.0	100.0	100.0	100.0

Source: Impact assessment survey, 2002.

Appendix 15. Wetland rice area under different rice varieties,



Appendix 16. Area under each modern rice variety, 2002.

(a). IMV group.

Altitude	% of IMVs planted	
	IR64	IR20913
High	24.4	75.6
Low	100.0	0.0
Medium	93.6	6.4
Total	92.5	7.5

(b). OMV group.

Altitude	% of OMVs planted				
	Khamgma Maap	No. 12	Khumal 3	BR 154	Unidentified MVs
High	77.3	17.2	0.0	0.0	5.5
Low	0.0	0.0	0.0	69.4	30.6
Medium	14.2	53.6	19.7	0.0	12.5
Total	61.7	15.8	0.8	11.6	10.0

(c). BMV group.

Altitude	% of BMVs planted		
	Bajo Kaap 1 & 2	Bajo Maap 1 & 2	Yusi Ray Maap
High	34.0	40.9	25.2
Medium	44.4	55.6	0.0
Total	41.5	51.4	7.1

Source: Impact assessment survey, 2002.

Appendix 17. Yields for different groups of rice varieties, 2002.

Altitude	Yield level (t ha^{-1})				
	BMVs[a]	IMVs	OMVs	MVs	TVs
High	4.1	3.5	3.2	3.3	3.2
Medium	4.7	4.4	3.4	4.3	3.1
Low	na	3.5	2.6	2.7	1.6
Overall	4.4	4.3	3.2	3.6	2.8

[a]na = not applicable.
Source: Impact assessment survey, 2002.

Appendix 18. Yields for each modern rice variety, 2002.

(a). IMV group.

Altitude	Yield (t ha^{-1})	
	IR64	IR20913
High	2.5	3.8
Medium	4.4	4.0
Low	3.5	na[a]
Overall	4.3	4.0

[a]na = not applicable.

(b). OMV group.

Altitude	Yield (t ha^{-1})				
	No. 11	Khamgma Maap	BR 153	Khumal 2	Unidentified MV[a]
High	3.8	3.1	na	na	3.1
Medium	3.6	3.7	na	1.9	3.6
Low	na[b]	na	2.5	na	3.0
Overall	3.8	3.1	2.5	1.9	3.2

[a]Average yield of varieties not identified individually.
[b]na = not applicable.

(c). BMV group.

Altitude	Yield (t ha^{-1})		
	Bajo Maap 1 & 2	Bajo Kaap 1 & 2	Yusi Ray Maap
High	3.6	4.5	3.4
Medium	4.2	5.1	na
Overall	4.1	4.8	3.4

Source: Impact assessment survey, 2002.

Appendix 19. Cost of production for different groups of rice varieties, 2002.

Inputs	High (Nu ha^{-1})		Medium (Nu ha^{-1})		Low (Nu ha^{-1})		All households (Nu ha^{-1})	
	TVs	MVs	TVs	MVs	TVs	MVs	TVs	MVs
Urea	517.5	462.6	649.8	709.6	21.9	0.0	396.4	390.7
Suphala	25.2	99.8	90.3	85.6	27.6	0.0	47.7	61.8
Herbicide	917.5	718.6	593.6	645.5	20.8	0.0	510.6	454.7
Pesticide	112.1	77.6	15.7	6.3	13.7	13.1	47.2	32.3
Seed cost	6.3	5.3	18.5	13.1	12.6	0.0	12.5	6.1
Farm machinery	113.8	194.8	196.5	150.5	16.9	417.2	109.1	254.2
Other inputs	0.0	98.7	42.4	26.3	13.5	292.0	18.6	139.0
Cost of all inputs	1,692.4	1,657.3	1,606.7	1,636.9	127.0	722.3	1,142.0	1,338.8

Source: Impact assessment survey, 2002.

Appendix 20. Average retail price (per kg) of milled rice, 2002.

Dzongkhag (district)	Red rice[a]	Round rice	Local white rice	Bhog white rice	S F white rice	Raw fine white rice	Common white rice
Tairang	19.04	*	23.10	*	*	*	*
Paro	31.38	*	30.50	35.38	12.65	12.68	10.00
Punakha	25.9	*	23.80	12.30	15.00	*	12.00
Lhuntse	28.08	*	26.67	26.37	15.33	13.78	9.75
Dagana	*	*	*	25.00	*	12.00	10.00
Mongar	20.00	*	23.50	24.05	22.36	12.99	11.56
S/Jongkhar	*	*	12.00	*	10.00	11.78	11.00
Thimphu	24.58	*	25.38	*	*	*	*
Gelephu	10.58	10.74	10.46	14.86	9.50	9.20	8.93
Tashigang	10.90	*	*	20.00	13.35	12.00	10.00
Samtse	10.97	*	11.57	20.52	9.29	*	8.35
Average	20.16	10.74	20.77	22.31	13.44	12.06	10.17

[a]* = not available.
Source: Planning Department, 2002.

Appendix 21. Farm-gate price of milled rice, 2002.[a]

Altitude	MV white[b]	MV red[c] (Nu kg^{-1})	TVs
High	25.5	24.4	19.3
Medium	18.9	20.4	17.7
Low	10.1	na	12.3
Overall	18.9	23.3	17.8

[a] The farm-gate price of rice is based on 129 households that reported selling rice by varieties. Forty-one households from the high-altitude zone, 81 households from medium altitude, and seven households from low altitude are represented. na = not applicable. [b]White rice MVs sold were IR64, IR20913, Bajo Kaap 1 & 2, BR 153, and unidentified MVs. [c]The red MVs sold were Bajo Maap 1 & 2 and Khangma Maap. The average price per kg of milled rice is Nu 19.97. The average paddy price per kg is Nu 11.98 (19.97 x 0.6, conversion rate of 60% from paddy to milled rice is used).
Source: Impact assessment survey, 2002.

Appendix 22. Household and wetland farm size among MV adopters, 2002.

Altitude	Family size		Wetland farm size	
	MV adopter	Nonadopter	MV adopter	Nonadopter
High	8.7	7.8	0.21	0.32
Medium	8.0	8.7	0.23	0.20
Low	7.4	7.4	0.79	0.67
Overall	8.2	7.9	0.34	0.29

Source: Impact assessment survey, 2002.

Appendix 23. Indications of changes in rural households in last 5–8 years, 2002.

Indicators	Households adopting		
	MVs only	TVs only	TVs & MVs
Self-sufficiency			
Increased	28.5	30.4	41.1
Decreased	22.2	63.9	13.9
Constant	24.4	61.0	14.6
Rice production			
Increased	30.0	29.4	40.6
Decreased	21.8	65.5	12.7
Constant	27.6	51.7	20.7
Overall income			
Increased	28.5	35.5	36.0
Decreased	4.2	83.3	12.5
Constant	38.5	46.2	15.4
Home improvement			
Increased	25.9	40.5	33.5
Decreased	0.0	66.7	33.3
Constant	25.5	44.7	29.8
Pilgrimage			
Increased	42.9	11.4	45.7
Decreased	15.4	76.9	7.7
Constant	29.0	53.2	17.7
Livestock			
Increased	28.1	36.8	35.1
Decreased	27.3	38.0	34.7
Constant	23.1	50.0	26.9
Farm machinery			
Increased	13.0	40.7	46.3
Decreased	0.0	100.0	0.0
Constant	9.6	58.5	31.9
Farm knowledge			
Increased	29.7	32.3	38.0
Decreased	0.0	50.0	50.0
Constant	13.5	63.5	23.1

Appendix 24. Increase in production and net returns from new rice technologies.

(a). Per hectare estimations

Altitude	Yield (t ha^{-1})		Yield difference (t ha^{-1})	MV adoption rate (%)	Difference in MVs over TVs (NU ha^{-1})		
	TVs	MVs			Gross returns	Cost	Net returns
High	3.2	3.3	0.1	66.2	590	–35	625
Medium	3.1	4.3	1.2	37.5	14,120	30	14,090
Low	1.6	2.8	1.1	16.7	13,330	595	12,734
Overall	2.8	3.6	0.8	34.9	9,294	197	9,097

(b). National-level estimations

Altitude	Total rice area (ha)[a]	Area occupied by MVs (ha)	Increase in production (t)	Net returns (000 Nu)
High	5,302	3,510	351	2,194
Medium	10,605	3,972	4,681	55,968
Low	10,605	1,771	1,970	22,549
Overall	26,512	9,252	6,824	80,711

[a] Total rice area based on the Cadastral survey.
Source: Impact assessment survey, 2002.

Appendix 25. Production with increased BMV adoption rates.[a]

BMV adoption rate	Area affected	Increase in production	
		BMVs over TVs	BMVs over OMVs
5	795	1,265	1,002
10	1,591	2,529	2,004
15	23,861	3,794	3,006
25	3,977	6,323	5,011
30	4,772	7,588	6,013

[a]Yield difference of 1.59 (t ha^{-1}) and 1.26 (t ha^{-1}) for BMVs over TVs and BMVs over OMVs, respectively, and the national rice area for the high- and medium-altitude zones (15,907 ha) is based on the Cadastral survey.
Source: Impact assessment survey, 2002.

Appendix 26. Difference in net returns for increased cost of production.

Production cost, MVs over TVs (%)	Net returns	
	Nu ha^{-1}	National (000)
17.2	9,187	85,005
30.0	9,002	83,294
50.2	8,774	81,184
75.1	8,487	78,529
100.1	8,202	75,892
149.9	7,633	70,627
200.1	7,060	65,325

Source: Impact assessment survey, 2002.