Background Paper No.2
Rice Productivity Improvement in Myanmar[1]

by

Glenn Denning, Kye Baroang, Tun Min Sandar,
and other MDRI and MSU colleagues

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EXECUTIVE SUMMARY

Rice productivity in Myanmar has stagnated in comparison with other rice producers in the region. Once the world's largest rice exporter, Myanmar is now a relatively minor player exporting an average 631,000 metric tons (MT) annually over the past four years. However, the nation's export potential remains high because of abundant land and water resources, recent indications of progressive policy reforms, increased agricultural investment, and constructive international engagement. Growing global demand for rice, increasing public and private investment in infrastructure, and the potential for significant yield increases, all point to a strong return on investments to improve rice productivity in the country.

At the farm level, there are nine areas of intervention where new practices and supportive policies would likely raise productivity and improve competitiveness: seed selection, land preparation, crop establishment, water management, soil fertility management, pest management, harvesting and threshing, drying and storage, and crop rotation. Additionally, improvements in farm-level productivity are more likely to be sustained if the farm surpluses are processed, transported, and marketed in ways that attract higher prices in domestic and international markets.

We recommend a two-pronged strategy to transform rice productivity: a short-game and a long-game[2]. The short-game includes three initiatives for immediate action and impact within one to three years, even with current policies and capacity limitations:

- Understanding the resource base: improving knowledge of production, climate and soils to enable better planning, execution and evaluation of public and private investments;
- Documenting ways to improve farm-level productivity: producing a comprehensive, multi-media Myanmar Rice Manual as a resource for research, extension, and education; and
- Demonstrating Change: Establishing Special Productivity Improvement Zones (SPIZs) in areas of low productivity, high potential and good market access.

The second prong of our proposed strategy is long-term institutional transformation. We propose targeting universities, research institutions and the extension service as follows:

- University Development Outreach Corps (UDOC): recruiting, training, deploying, and supporting 200 university graduates per year for two-year placements in rural locations throughout Myanmar;
- Myanmar Rice Research and Development Center: providing a critical mass and focus for market-oriented innovation in rice production systems using 21st century science and technology; and
- Transformative Extension Service: establishing a service-oriented institution with a mission of rural transformation through improved training, mobility, and connectivity.

Work on both short-game and long-game initiatives can and should begin simultaneously and immediately. Myanmar is well positioned to apply and adapt innovative and successful approaches from other countries and regions. This *second mover* advantage offers a low risk, high return opportunity to place Myanmar as a powerhouse of rice productivity and trade, with important lessons and spillover impacts to other important agricultural commodities.

[2] Terminology adopted for the diagnostic mission. Short game refers to investments that can be made immediately without major policy reforms or capacity improvements. Long game investments require more fundamental and often longer-term effort.

CONTENTS

LIST OF TABLES

TABLE **PAGE**

LIST OF FIGURES

FIGURE **PAGE**

ACRONYMS

APIPNM	Asia-pacific Network on Integrated Plant Nutrient Management
AWD	Alternate Wetting and Drying
BPH	brown planthopper
CARDI	Cambodian Agricultural Research and Development Institute
CGSD	Center on Globalization and Sustainable Development
FAO	UN Food and Agriculture Organization
FAS	Foreign Agricultural Service
FFS	Farmer Field School
GMOs	genetically modified organisms
ha	hectare
HYVs	High Yielding Varieties
ICT	Information and Communication Technologies
IDE	Institute of Developing Economies
IFAD	International Fund for Agricultural Development
IRI	International Research Institute for Climate and Society
IPM	integrated pest management
IRRI	International Rice Research Institute
IT	Information Technology
K	potassium
LIFT	Livelihoods and Food Security Trust Fund
LMY	Local Marketing Years
Long game	Investments that require more fundamental and often longer-term effort
MAB	Marker assisted backcrossing
MDRI	Myanmar Resources Development Institute
MOAI	Ministry of Agriculture and Irrigation
MODIS	Moderate Resolution Imaging Spectroradiometer
MRRDC	Myanmar Rice Research and Development Center
MT	metric tons
MVs	modern varieties
N	Nitrogen
P	phosphorus
SAR	Synthetic Aperture Radar
Short game	Investments that can be made immediately without major policy reforms or capacity improvements
SIPA	School of International and Public Affairs
SPIZs	Special Productivity Improvement Zones
SSNM	site-specific nutrient management
U.S.	United States of America
UDOC	University Development Outreach Corps
USDA	United States Department of Agriculture

1. INTRODUCTION

Rice production is central to the economy and food security of Myanmar. Between 1900 and 1940, Myanmar exported 2 to 3 million MT rice annually, up to 70% of national production (Win 1991). In the early 1960s, annual exports were in the range 1.3 to 1.7 million MT (United States Department of Agriculture (USDA) data from World Rice Statistics[3]). In recent years, exports have dropped below 1 million MT per annum (USDA), as population growth has outpaced productivity improvement. Myanmar's role in international trade has now diminished to that of a relatively minor player, exporting an annual average of 631,000 MT over the past four years, according to USDA estimates. In contrast, Vietnam has risen from being a net importer of rice in the 1980s to exporting over 7 million MT in 2012. [4]

A comprehensive description and historical perspective of rice production in Myanmar from colonial times to the late 1980s is found in Win (1991). Another descriptive and historical overview of the rice sector is provided by a University of Arkansas team (Young, Cramer, and Wailes 1998). The latter report also provided an economic assessment and highlighted prospects for the rice sector at that time. These two papers provided valuable background for this rapid diagnostic assessment.

With growing world demand, a large area favorable for rice growing, and opportunities for productivity improvement across the whole value chain, Myanmar has the potential to regain its status as a leading rice exporter. Economic liberalization[5], sector policy reforms, and greater openness to innovation and international cooperation present encouraging signals for the rice sector and for the agriculture sector as a whole. A recent statement from the Myanmar Rice Federation suggested an export target of 3 million MT is achievable by 2017[6]. The challenge now is to work at improving productivity at three critical segments of the rice value chain:

- Improving farm-level productivity;
- Improving off-farm processing and handling; and
- Improving export market competitiveness.

For the best results, all three spheres of improvement need to occur simultaneously. Greatest impact will be realized if these spheres of improvement converge. In this paper, we will focus mainly on farm-level productivity, including post-harvest handling and processing that occurs on or near the farm. Simply put, how can Myanmar's rice farmers produce rice more efficiently using their abundant natural resources (land, water, sunshine, genetic resources) while drawing on their labor, knowledge and ingenuity?

The paper will comprise three parts. First, we provide a short overview of rice production in Myanmar, outlining some of the more widespread constraints and their likely impacts on productivity. Second, we will address potential opportunities for improving farm-level productivity and profitability, drawing on research in Myanmar and neighboring countries.

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[3] World Rice Statistics is a database collated and managed by IRRI; it draws on production and export statistics from USDA and FAO. Information for most parameters is available from 1960 to the most recent year of available data. See: http://ricestat.irri.org:8080/wrs2/entrypoint.htm

[4] See: http://oryzamarket.com/Rice-News/17040.html

[5] The rationale and impacts of liberalizations of the rice market (1987 and 2003) are well described by Okamoto (2005).

[6] Ye Min Aung, secretary- general of the Myanmar Rice Federation, quoted by Bloomberg on Oct 29, 2012. http://www.bloomberg.com/news/2012-10-28/myanmar-seeks-to-regain-top-spot-in-rice-exports-southeast-asia.html

Third, we will argue for strategic investments in the short- and long-term that will raise productivity and help position Myanmar to produce more rice, more sustainably and more competitively than at present. At the outset, we accept that improvements in farm-level productivity are more likely to be sustained if the farm surpluses are processed, transported, and marketed in ways that attract higher prices in the domestic and international markets. Higher prices provide an incentive for producers to invest their labor and capital to achieve higher farm-level productivity. Another background paper in this series will examine those post-production opportunities. Productivity improvements are more likely within a supportive monetary and fiscal policy environment, which is largely outside the scope of this paper[7].

[7] See Dapice et al. (2011) for a discussion on the impact of exchange rates on Myanmar's export competitiveness.

2. ESTABLISHING A BASELINE: CURRENT STATUS OF RICE PRODUCTION IN MYANMAR

It is a daunting task to assess the current status of rice production in Myanmar. There are serious inconsistencies in the available data and, depending on which statistics are used, vastly divergent diagnoses can be reached. Underpinning a realistic assessment of the current status and potential are several basic questions:

- How much rice is currently grown?
- What is the yield level and aggregate production?
- What is the population of Myanmar?
- How much rice is consumed domestically? and
- How much is available for export?

More nuanced analyses would examine temporal and spatial variation in production. In addition, ideally, there would be a body of peer-reviewed research that might suggest the likely responses to different kinds of technical and policy interventions. There were serious limitations in obtaining reliable information in all of these respects. Yet, with the benefit of numerous interviews, field visits, and access to a limited number of published and unpublished reports, we aim to establish a profile of the sector that would undoubtedly be strengthened by further research.

The first challenge is to estimate the area planted to rice. There are two sets of widely quoted national statistics. The Ministry of Agriculture and Irrigation (MOAI) reported a national harvested rice area of over 8 million ha during the past four years[8]. These data are reported annually by UN Food and Agriculture Organization (FAO) and cited widely. The USDA presents a significantly different picture in estimating an average harvested rice area of 6.7 million ha over the past four years. There are further inconsistencies when it comes to yield per hectare and national production (yield x area). Over the past four years, the MOAI has estimated an average national yield of about four t/ha, leading to aggregate national production of 32-33 million tons of rough rice[9]. USDA estimates production to be about half this level.

The sharp differences derive from the respective methodologies used by MOAI and USDA. The MOAI aggregates reports submitted by MOAI monitors at the local government level. Historically, these provided the basis for central monitoring of production targets assigned to each level of administration. This is likely to have introduced incentives to overestimate performance. USDA uses a combination of remote sensing information, interviews with key informants (including rice millers), import and export data, and direct crop assessments to derive their estimates.

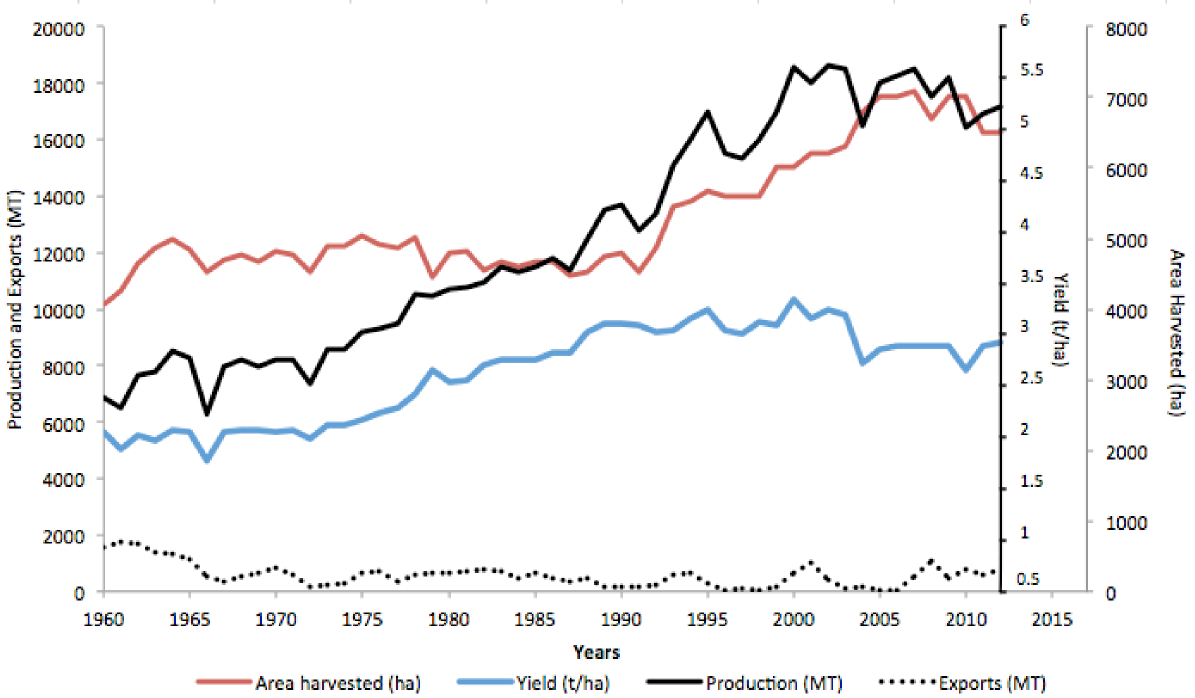
In an effort to establish a realistic working estimate of rice yield, we examined field surveys undertaken by international organizations including the International Rice Research Institute

[8] MOAI (2012).

[9] Rough rice is the same as the term *paddy*; it refers to unhulled rice. Throughout this paper, rice crop yields are quoted in terms of rough rice. Consumption and trade figures are normally quoted in terms of milled rice. A common standard for conversion, used by USDA, is that 100 kg rough rice yields 64 kg milled rice. In reality, the milling recovery of rice in Myanmar may be much lower, probably closer to 50%.

(IRRI)[10] and the Livelihoods and Food Security Trust Fund (LIFT)[11] over the past eight years (e.g., Garcia et al. unpublished; LIFT 2012). Farmer-reported monsoon rice crop yields were typically in the range of 1.8 to 2.8 MT/ha, while summer (dry season) rice crop yields were mostly in the range of 2.7 to 3.1 MT/ha. However, our interviews with farmers and key informants suggest that summer crop yields may be somewhat higher. Assuming the mid-point of each range, and assigning 5.7 million ha to the monsoon crop and 1 million ha to the summer crop[12], total rough rice production would be 16.0 million MT. If we take the upper yield estimates (2.8 and 3.1 MT/ha for monsoon and summer, respectively), the total production estimate is 19.1 million MT. Thus, the range of 16.0 to 19.1 million MT is broadly consistent with the USDA estimate of 17.1 million MT (average of the past four years). In the absence of more comprehensive independent data sets, we consider the USDA estimates for both rice area and production to be useful starting points for this diagnostic assessment. It is clear that yield has stagnated over the past 20 years, with overall production largely the function of increased harvested area (Figure 1)

Figure 1. Area, Production, Yield, and Exports of Rice in Myanmar, 1960 to 2012



Source: USDA data accessed from IRRI World Rice Statistics database 2013.
http://www.irri.org/index.php?option=com_k2&view=itemlist&task=category&id=744&Itemid=100346&lang=en

[10] IRRI is an international agricultural research center with headquarters in the Philippines. IRRI has worked on rice in Myanmar for more than 30 years through collaborative programs with the government.
[11] LIFT is a multi-donor trust fund established in Myanmar in 2009. Donors include Australia, Denmark, the European Union, the Netherlands, New Zealand, Sweden, Switzerland, the United Kingdom and the United States.
[12] The estimate of 1 million ha summer rice is based on the calendar of production that indicates that about 17% of the national tonnage is harvested between March and August, see: http://afsis.oae.go.th/x_sources/index.php?country=myanmar Assuming a total harvested area of 6.7 million ha, and equal yield in monsoon and summer, the total summer area would be 1.1 million ha. The likely higher yield of the summer crop, based on field estimates in Myanmar, would point to a lower summer crop area. IRRI is currently undertaking remote-sensing based research that will likely lead to better estimates of the monsoon and dry season areas.

Rice is consumed widely with national average per capita consumption of 160-208 kg[13]. This places Myanmar as one of the highest rice consumers in the world on a per capita basis. Consumers are sensitive to eating quality. When high yielding varieties IR8 was introduced to Myanmar in the 1960s, its grain quality was "unacceptable to the farmers" (Win 1991). Today in Myanmar, the price differential between traditional local varieties and modern IRRI-type varieties is large. *Paw San Yin*, a fragrant variety produced in the delta, can fetch double the price of higher yielding semi-dwarf types. Trading by individual varietal names has increased since the 1990s (Okamoto 2005).

The government continues to emphasize the importance of rice through investments in infrastructure and improving access to inputs. The MOAI has set a target of 5.2 MT/ha for paddy (MOAI 2012), which would effectively double the current USDA-estimated yield level of about 2.6 MT/ha.

Table 1. Rice Area Harvested, Production (Rough and Milled), and Exports (Local Marketing Years[14] 2009/10 to 2012/13)

	Unit	2009/10	2010/11	2011/12	2012/13	Mean (over 4 years)
Area Harvested	1000 HA	7,000	7,000	6,500	6,350	6,700
Production (rough rice)	1000 MT	18,191	16,450	16,900	16,797	17,085
Consumption and Residual (milled rice)	1000 MT	10,890	10,100	10,190	10,380	10,390
Export (milled rice)	1000 MT	445	778	700	600	631

Source: USDA FAS Circular Series FG 01-13, January 2013.[15]

[13] Using USDA estimates of production less exports. The range reflects the uncertainty on population (50 to 65 million people).

[14] Local Marketing Years (LMY)**:** LMY refers to the 12-month period at the onset of the main harvest, when the crop is marketed (i.e., consumed, traded, or stored).

[15] See: http://usda01.library.cornell.edu/usda/fas/grain-market//2010s/2013/grain-market-01-11-2013.pdf

3. INVESTING IN RICE: THE CASE FOR IMPROVING PRODUCTIVITY

Working from the above assumptions, it is reasonable to conclude that there is considerable scope for productivity improvement in both the monsoon and summer season rice crops. While the absence of reliable statistics constrains a deep analysis of options, several factors suggest a high potential for improving rice productivity and the value of investing to achieve those productivity gains. These factors include:

a) Growth in Global Demand: Global rice demand continues to be driven by population growth and economic growth in Asia and Africa (IRRI 2010). Global rice demand is estimated to increase from 439 million MT in 2010 to 496 million MT in 2020 (a 13% increase), and further increase to 555 million MT by 2035 (a 26% increase over 2010 levels). Globally, farmers will need to produce an extra 8-10 million MT paddy each year to meet demand. With increasing pressure on land and water resources in neighboring countries, Myanmar, with an abundance of both resources, is well positioned to respond to market opportunities by increasing supply.
b) Improvements in Infrastructure: As Myanmar opens to increased public and private sector investment, infrastructure improvements can enhance the competitiveness of the country's rice. Investments in post-harvest technology can reduce field and household losses and improve milling recovery and grain quality. Better roads and supportive transport policies can reduce transaction costs of transporting the rice harvest to mills and markets.
c) Potential to Increase Yield: Rice yields are well below their potential in both monsoon and summer seasons. As indicated above, there is no compelling evidence at this time to question the USDA national yield estimate of 2.6 MT/ha. Indeed a range of estimates from independent field surveys and observations by the MSU team converge to support the USDA estimate as a reasonable approximation of national average yield. Assuming the USDA estimates for area and production, estimating the breakdown of monsoon and summer crops as 5.7 million and 1.0 million ha respectively, and deriving yields from surveys and key informants, we have adopted working estimates of 2.5 MT/ha for monsoon season and 3.2 MT/ha for the summer season. Experience from neighboring countries[16] would suggest that yield increases of 20% and 30% for the monsoon and summer seasons respectively are achievable within five to seven years (Table 2). Allowing for population-based consumption increases[17], no change in per capita consumption levels, and assuming no change in the area harvested, these increases would result in an additional 2.0-2.5 million MT milled rice for export each year. The question of how to achieve these increases is addressed later in this paper.

Growth in global demand and improvements in infrastructure will likely induce public and private investments aimed at improving productivity. Worldwide, farmers have been shown to produce more in response to market demand. The government's role will be to support farmers and the private sector through supportive policies and critical public goods like research and extension advice.

[16] Vietnam's nation average yield during 2010-2012 was 5.6 MT/ha.
[17] Assuming a population of 60 million, a population growth rate of 1%, consumption of 180 kg/person, and no major change in eating habits, Myanmar requires about an additional 100,000 MT rice annually.

Table 2. Estimates of Current and Projected Achievable Rice Yields in Monsoon and Summer Seasons

	Area (mil ha)	Current yield (MT/ha)	Projected achievable yield in 5-7 years[18] MT/ha
Monsoon season	5.7	2.5	3.0
Summer season	1.0	3.2	4.1
National average		2.6	3.2

Source: Senior Author

3.1. Rice Ecosystems

The major rice-producing regions of Myanmar are in the delta. Ayeyawady, Bago and Yangon regions make up almost half of the country's harvested rice area (MOAI 2011). Myanmar's major rice ecosystems[19] include rainfed lowland rice, irrigated lowland rice, deepwater rice and upland rice.

Rice is grown in Myanmar during the monsoon (June to November) and summer (December to May) seasons. There are two dominant rice production systems: rainfed lowland and irrigated lowland. During the monsoon season, Myanmar's rainfall in the delta and coastal region is sufficient for growing rice without supplemental irrigation from dams, river and stream diversions or groundwater. Where available, irrigation coupled with drainage structures, improves stability of production, and reduces the risks of flooding and stagnant water.

Large areas of the delta are subject to flooding ranging in duration from a few days to two or three months, presenting significant risks to farmers. Some areas, though declining in importance, are suitable for deepwater rice, a low yielding rice type that elongates to stay above the rising water. Other varieties, including a new variety carrying the Sub1 gene (Bailey-Serres et al. 2010), demonstrate adaptation to periods of total submergence[20], a potentially valuable trait as more frequent and prolonged submergence events may be a consequence of climate change.[21] Without the benefit of submergence tolerance, excessive flooding severely limits the scope for using improved high yielding varieties and crop management. Another relatively minor system involves transplanting of rice as floodwater recedes after the monsoon season, with subsequent irrigation from the receding water.

[18] Assumes 25% and 30% increase for monsoon and summer seasons respectively, and rounded to nearest 0.1 MT/ha.

[19] Using the classification developed by IRRI, rice is cultivated in four broad production ecosystems:
(i) irrigated: rice grown with good water control and flooded throughout the growing season
(ii) rainfed lowland: rice relying on the rainfall, with fields bundled to retain water, with a maximum of 10 consecutive days of water depth exceeding 100 cm
(iii) upland: rice grown without surface water, relying solely on the rainfall and
(iv) flood-prone: deepwater rice, grown in river areas, with no structured water control and water submergence in depth exceeding 100 cm for more than 10 days and up to five months.

[20] See time-lapse video of sub 1 performance with submergence: http://www.youtube.com/watch?v=DJsNwYX1Nc0&feature=youtube_gdata

[21] Baroang (2013) reviewed studies on projections associated with climate change. While there remains some uncertainty regarding the impact of climate change on Myanmar, Baroang concludes that the risk of flood-related disasters may rise with increases in more intense rainfall events and snowmelt. This effect may be exacerbated through rising sea levels. Additional information on climate risks to food security in Myanmar, see RIMES (2011)

In the dry zone, annual rainfall of 750-1,000 mm is generally inadequate to produce a rainfed rice crop except in low lying areas with a high water table. Rice grown in the dry zone can be productive when grown under irrigated conditions because of the increased hours of sunshine, especially during the summer season. Upland rice is grown in the hilly areas under a shifting cultivation known as *taungya*. Upland rice is direct seeded into moist soil with the first rains. As little as 200,000 ha of upland rice is planted in Myanmar, more than half of which is grown in Shan State. Fujisaka et al. (1992) described upland rice growing in rotation with potato and peanut in upland areas. Farmers reported using traditional varieties though some used fertilizer. As in most of Asia, upland rice has reduced in importance as productivity in lowland areas has increased and market access to the uplands has improved. These developments favor the adoption of higher value agricultural enterprises.

4. OPPORTUNITIES FOR IMPROVING AGRICULTURAL PRODUCTIVITY

For the purpose of this rapid diagnostic study, we focus on the predominant rainfed lowland and irrigated rice systems, representing about 90% of Myanmar's rice area. We do not address the deepwater and upland systems. Although these are locally important, there is a consensus that the scope for productivity improvement in both of these rice ecosystems is limited.

We have identified nine intervention areas in the rice production cycle where improvements in productivity and profitability can be achieved. Each of these intervention areas has relevance to both the rainfed lowland and irrigated rice systems.

1. Seed selection
2. Land preparation
3. Crop establishment
4. Water management
5. Soil fertility management
6. Pest management
7. Harvesting and threshing
8. Drying and storage
9. Crop rotation

4.1. Seed Selection

There are two components to seed selection: choice of variety and quality of seed. The choice of variety is made by farmers based on a combination of factors that include: (1) adaptation to the growing environment, (2) eating/cooking preferences of the consumers, (3) market preference/price, and (4) cost of seed. Modern rice varieties (also known as HYVs[22]) are variously reported to be used for 70-80% of the monsoon crop and for virtually all the summer crop. Garcia et al. (unpublished) reported adoption of modern varieties during the 2004 monsoon season at over 80%. We found that farmers often prefer local varieties during the monsoon season, especially in areas that are subject to flooding. This trend seems to have been strengthened by rising fertilizer prices over the past decade, which discourages farmers from using fertilizer where there is increased risk of flood or drought. Local varieties, such as *Paw San Yin*[23], are typically of higher eating quality and bring as much as double the price of the HYVs. HYVs are widely grown in the summer season because of their early maturity and the absence of flooding risk at that time of year. Nationwide, HYV adoption has been reported as 61%, with highest levels of adoption in the dry zone (FAO/WFP 2009).

[22] The term High Yielding Varieties (HYVs) is commonly used to describe varieties that have been bred for higher yield potential in more favorable rice-growing varieties. IR8 was the first and perhaps best known HYV. It was bred by IRRI and released and widely adopted in Asia in the late 1960s. Recognizing that such varieties did not always result in higher yields in all seasons and situations, the term modern varieties (MVs) has replaced HYVs in more recent literature. Modern varieties were introduced to Myanmar in 1967/8 (Herdt and Capule 1983).

[23] Paw San was judged the world's best rice at the World Rice Conference 2011 held in Ho Chi Minh, Vietnam. Paw San is a fragrant variety grown only in the monsoon season. It has the ability to elongate up to three times upon cooking. Variants of Paw San are grown in Ayeyarwady and Sagaing regions.

Important advances in plant breeding have the potential to revolutionize varietal improvement in Myanmar. Marker assisted backcrossing[24] (MAB) is a cost effective way to accomplish breeding program objectives, especially for important traits that must be quickly incorporated into existing popular varieties. MAB varieties also avoid the negative publicity surrounding genetically modified organisms (GMOs)[25]. Our discussions with IRRI scientists revealed that MAB approaches can assist Myanmar to develop a suite of new varieties with tolerance of stresses like submergence, drought, salinity, and some common pests and diseases. Through cooperation with IRRI's scientists, Myanmar researchers could use gene pyramiding[26] to develop *climate smart* varieties with multiple adaptation traits that are ready for farm use within three to four years. Experience suggests that well adapted varieties will spread rapidly through government production of seed, strategic field demonstrations, and seed exchange among farmers.

Another prospect worth considering in Myanmar is Golden Rice[27]. This rice type contains high levels of β-carotene in the grain and has the potential to reduce the incidence of vitamin A deficiency which can cause blindness and death. The body converts β-carotene to vitamin A. According to published research (Tang et al. 2009), daily consumption of about a cup (or around 150 g uncooked weight) – could supply 50% of the Recommended Daily Allowance of vitamin A for an adult. Golden rice can only be produced through genetic modification (i.e., Golden Rice is a GMO) as there are no known rice varieties with high β-carotene. Having gone through strenuous evaluation for human and environmental safety, Golden Rice is now being field tested in the Philippines and Bangladesh. The variety is inbred and, therefore, will be reusable by farmers from year to year. The paucity of reliable data on nutritional deficiencies in the country makes it difficult at this time to determine the potential impact. However, considering the high per capita consumption of rice, promotion of Golden Rice is a low cost approach that has the potential to reduce vitamin A deficiency where other approaches have failed. By adding this trait to well adapted varieties, Golden Rice can simultaneously improve productivity and improve nutrition.

The MOAI has actively promoted the use of hybrid rice in recent years in cooperation with Chinese technicians. The MOAI reported hybrid seed production during the 2011 summer season on over 300 ha using Par-le-thwe variety. We observed this variety near maturity at the privately owned Gold Delta Company farm in Danubyu Township in November 2012. Production appeared to be comparable with the non-hybrid crop at about 4.5- 5 MT/ha. However, we were informed that a higher rate of fertilizer was used on the hybrid crop as compared with the neighboring non-hybrid. After consulting with many Myanmar and international rice agronomists and breeders, we could not find much support for the promotion of hybrid rice at this time. Chinese hybrid varieties are not well adapted to Myanmar's conditions. Hybrid seeds are costly to produce. Moreover, grain quality is poor, resulting in a low market price. All of these factors suggest caution in promoting hybrid rice on a wide scale without more thorough agronomic and economic assessment.

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[24] MAB is a modern plant breeding method that uses DNA markers, rather than visual screening, to improve breeding efficiency and speed up the development of new varieties.
[25] GMOs for our purposes refers to rice varieties that have been genetically engineered to include genes from other species of plant, animal, or microorganism.
[26] Gene pyramiding is an application of MAB that enables the efficient inclusion of multiple desirable traits into a single variety. This is extremely difficult to achieve through conventional breeding approaches.
[27] See details on Golden Rice:
http://www.irri.org/index.php?option=com_k2&view=itemlist&layout=category&task=category&id=764&Itemid=100533&lang=en

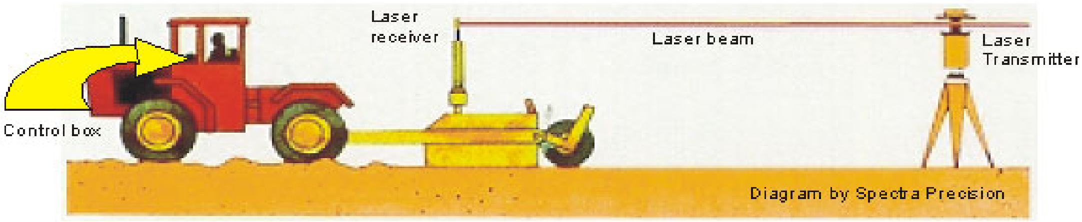
Most of Myanmar's rice farmers use their own seed from year to year. There is a national seed certification system in Myanmar. The government advocates the use of high-yielding certified seeds. However, the private seed sector is poorly developed. Although the production of hybrid rice seed is actively promoted by the MOAI, the broader impact of government seed distribution systems was not clear and requires further study. Field observations in the delta and in the dry zone suggest good scope for improving the uniformity of seed, which may increase yields by 5-20% as well as improve grain quality and market acceptability. A well-managed public sector seed system is essential for non-hybrid rice varieties. Once well adapted named varieties are made available to farmers, the seed can be readily multiplied and distributed through informal farmer-to-farmer mechanisms. A nation-wide varietal evaluation system must be linked to seed production and distribution programs.

4.2. Land Preparation

Lowland rice fields in Myanmar were traditionally plowed with cattle or water buffalo, the latter being more common in lower flood-prone landscape positions. Two wheel tractors, most imported from China, are increasing in importance. For most rice-growing areas, two-wheel tractors currently appear to be the best solution for reducing the land preparation time and enabling a short-turnaround between crops. We noted this to be critical for early establishment of the summer rice crop on the Shwebo Irrigation Scheme following closure of the main canals for maintenance during November and December. Likewise, in rainfed rice fields of the delta, farmers seek a short-turnaround time after rice harvest before establishing black gram (*Vigna mungo*) and other high-value post-monsoon crops grown mainly on residual moisture.

Four-wheel tractors are less common, but are used where fields are large. In some locations, the government runs tractor stations, renting out services to farmers. This is also practiced in consolidated farm areas managed by the Specialized Rice Companies. The main challenge in using four-wheel tractors is restricted field access and maneuverability within fields. Complementing the use of four-wheel tractors, attempts have been made by the MOAI and IRRI to introduce laser leveling as a means of improving land preparation and crop establishment (Figure 2). Laser leveling systems are commonly used in Australia, Japan, and the United States, and have been introduced in Cambodia, India, Vietnam, Thailand, Philippines, and China. Laser leveling achieves a more level field which, in turn, results in a more even distribution of water and more uniform germination of seeds, more effective weed control, and higher yields. Reductions in seed, fertilizer, and fuel use have been reported. Laser leveling was introduced by IRRI in 2006 for demonstration purposes. It has not been widely used to date.

Figure 2. Schematic Representation of Laser Leveling



Source: IRRI. http://www.knowledgebank.irri.org/rkb/benefits-of-laser-leveling.html

The high cost of equipment, the need for skilled operators, and the irregularity of field shapes all constrain adoption. However, there is scope for laser leveling as part of a broader initiative to consolidate rice fields for operational efficiency. With relatively large fields and reported labor shortages in rural areas, it is likely that mechanization of tillage will grow rapidly in Myanmar.

4.3. Crop Establishment

In Myanmar, rice is usually established through transplanting or direct wet seeding. Transplanting is the most common method for monsoon crop establishment, giving the rice plant a competitive advantage over weeds. For the transplanting method, rice seedlings grown in a nursery are pulled and transplanted into puddled and leveled fields 15 to 70 days after seeding. This operation can be done manually or using a machine. Manual transplanting is well suited to situations where the land is uneven, the water level is variable, and labor costs are low. We observed no cases of machine transplanting, although this practice, widely used in Japan, South Korea, and China, is showing potential in South and Southeast Asia as the labor cost of manual transplanting rises. Mechanized transplanting methods should be explored in Myanmar drawing on regional experience.

In Myanmar, wet seeding is more common for the summer rice crop. This is because of the lower likelihood of submergence and related mortality of young seedlings. Wet seeding involves the sowing of pre-germinated seeds onto a puddled soil. The seed may be broadcast by hand or less commonly using a seeder. For best results, a level field surface is required, and herbicide is used to control weeds. The drum seeder was widely distributed in Myanmar through LIFT and implementing partners with mixed results (Barca et al. 2012). While having the potential to save seed and reduce labor costs, adoption rates remain low. Farmers reported that drum seeders consumed more time than direct broadcasting, and required a greater investment in hand weeding. According to the LIFT evaluation report, maintenance of the drum seeders was also identified as a constraint to adoption on a sustained basis[28].

4.4. Water Management

Myanmar has extensive water resources available for irrigated agriculture, including for rice farming. Surface water from the Ayeyarwady and Sittoung River Basins has been developed for rice irrigation over the past century. Naing (2005) reports high potential for groundwater development in the Ayeyarwady River Basin. The area of rice under irrigation is unclear. As shown in Table 2, if we only consider dry season irrigation, we estimate that at least 15% of the planted rice area is irrigated. By taking into account wet season supplemental irrigation, the area for irrigated rice is likely to be 25-30% of the total planted area. However, more research is needed to determine the extent and reliability of existing irrigation systems. Deployment of modern remote sensing tools can assist this research (see Section 5).

Optimal water management requires that rice grows in a saturated soil for most of the growing season. Surface water is not required except for its utility in suppressing weeds. In most settings in Myanmar and elsewhere in South and Southeast Asia, farmers seek to maximize water flow to their fields to reduce the yield-reducing effects of water deficit. In irrigated rice, farmers are concerned about their access to adequate water from canals.

[28] For further details including farmer comments, see Barca et al. (2012).

Competition for water is common during the dry season, especially where there is limited regulation and an absence of cooperative water management. We saw little evidence of water user groups in Myanmar. However, they have been shown elsewhere to foster participation in and ownership of change processes that are designed to improve water resources management.[29] According to the International Fund for Agricultural Development (IFAD undated), "(c)urrent research on water-related rural institutions and organizations finds that *there is no single 'right' type of institution or organization, there is no one recipe*". With this in mind, Myanmar would benefit from testing and evaluating alternative models for participatory water resources management.

In low lying fields, there are risks of submergence and stagnant water, both of which can sharply reduce yields. Salt water intrusion affects rice in the delta, and is more serious in the summer crop season. Around 3% of the country's rice is affected by salinity.

Alternate Wetting and Drying (AWD)[30] is a water-saving technology that irrigated rice farmers can apply to reduce their water use. With AWD, the field is alternately flooded and non-flooded. The number of days of non-flooded soil in AWD between irrigations can vary from 1 day to more than 10 days. The moisture content of fields is determined through field water tubes. Based on the level of water in these tubes, farmers can determine when to irrigate. This method works only where farmers have direct access to and control of water delivery, e.g., through groundwater. The method is widely adopted in China. While improving water use efficiency, yield reductions are common (Bouman et al. 2007). Overall, AWD may find a useful niche in rice growing areas with reliable pump access to groundwater and surface water bodies.

Overall, the best option for water management is to expand access to irrigation, coupled with investments in drainage. The Shwebo Irrigation Scheme, drawing on water from the Thapanzeik Dam and Kabo Weir, appear to have the necessary infrastructure to support productive irrigated agriculture. The team was informed of plans to extend the command area of the Scheme through a new canal on the western side of the Mu River. Improvements in water use efficiency would likely be achieved through: (1) farmer organization through water user groups, (2) improved extension support, (3) infrastructure to support storage, processing and marketing, (4) improved rice varieties and associated agronomic management practices, and (5) crop diversification to high value (non-rice) crops during the summer season.

Groundwater has high potential for development in the Ayeyarwady Delta. However, groundwater represents only 10% of total consumption and is currently used mainly for domestic consumption (Figure 3). However, further development of groundwater should be coupled with careful assessment and monitoring of the risk of high arsenic content, which has been reported at dangerous levels in some parts of the Delta (Tun 2003; Mukherjee et al. 2006).

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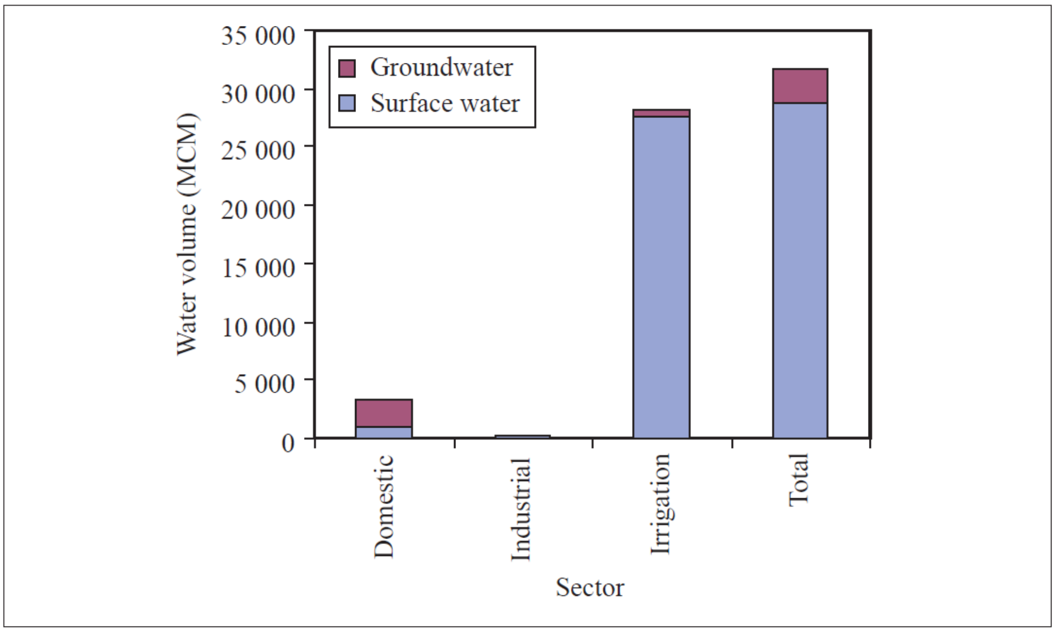
[29] See IFAD: http://www.ifad.org/english/water/innowat/topic/groups.htm
[30] See http://www.knowledgebank.irri.org/rkb/water-management-fact-sheet/saving-water-alternate-wetting-drying-awd.html?tmpl=component&page=

Figure 3. Water Consumption by Sector and Source in Myanmar 2001



Source: Naing et al. 2008.

4.5. Soil Fertility Management

Overall, the rice soils of Myanmar appear relatively fertile[31]. Alluvial and swampy soils dominate in the delta, while vertisols[32] are more important in the irrigated rice lands of the dry zone. Information on current fertilizer use by farmers is limited.

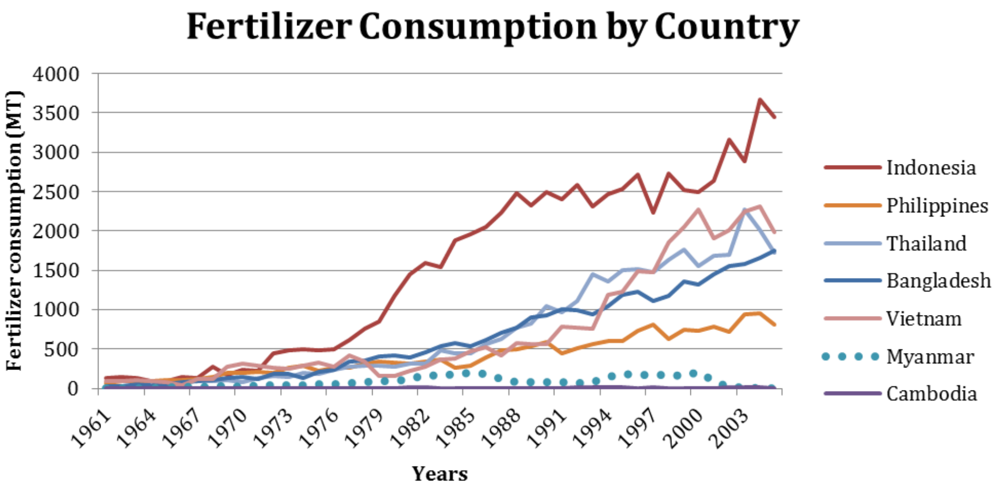
However, based on published surveys and farmer interviews, it appears that fertilizer use on rice is common, though farmers apply at relatively low levels. Nitrogen (N) fertilizer as urea is often applied during the dry season, while little phosphorus (P) or potassium (K) is used in either season. In most locations we visited, fertilizer was reported by farmers as being available. However, the high cost and low rice price constrain its use. Fertilizer consumption in Myanmar has declined sharply over the past few years and lags behind its regional neighbors (Figure 4).

The LIFT baseline survey reported that, during the monsoon season, 63% of rice farmers interviewed in the delta/coastal zone and 76% in the dry zone applied inorganic fertilizer (Table 3). Corresponding adoption rates in the dry season were higher. Similar trends were observed with organic fertilizer.

[31] Asia-pacific network on Integrated Plant Nutrient Management (APIPNM) http://www.apipnm.org/swlwpnr/reports/y_ta/z_mm/mmtx221.htm

[32] Vertisols are clayey soils that have deep, wide cracks for some time during the year. They shrink as they dry and swell as they become moist. According to FAO, although their high natural fertility and positive response to management make vertisols attractive for agriculture, some of their other properties impose critical limitations on low-input agriculture. Vertisols are suitable for rice production. They are relatively easy to puddle and retain water well. For further information: http://www.fao.org/Wairdocs/ILRI/x5493E/x5493e05.htm

Figure 4. Total Fertilizer Consumption from Chemical Sources ('000 MT)



Source: IRRI World Rice Statistics
http://www.irri.org/index.php?option=com_k2&view=itemlist&task=category&id=744&Itemid=100346&lang=en

Garcia et al. (unpublished) reported low fertilizer application rates from more detailed surveys conducted in 2004 in Nyaungdon Township of Ayeyarwady Division. They found, that during the monsoon season, 54% of farmers applied urea, usually as a single application, at an average rate of 59 kg/ha (equivalent to 27 kg N/ha). For the summer crop, 100% of farmers applied urea, more often as a split application, at an average rate of 86 kg/ha (40 kg N/ha). Both of these rates are low by South and Southeast Asian standards. Low rates of farmyard manure were often applied in addition to urea during the monsoon season, but less commonly in the summer season. The rates and practices reported by Garcia et al. (unpublished) from 2004 were consistent with information from our farmer interviews in November 2012.

Research undertaken by IRRI has demonstrated good responses to fertilizer during the summer season[33]. During the 2005-6 summer season, site-specific nutrient management (SSNM[34]) was evaluated and demonstrated in collaboration with the Myanmar Agriculture Service (MAS) in 72 on-farm trials in six townships (Kyaiklatt, Myaung Mya, Letpandan, Pyay, Shwe Bo, and Taikkyi) in four of the major rice-growing divisions in Myanmar. Results from the omission plot trials showed that N was the most limiting nutrient at the sites. Both P and K were deficient in most sites, but to a lesser degree. The yield increase from N application ranged from 0.7 to 2.7 t/ha, while P response ranged from 0.3 to 1.8 t/ha, and K response ranged from 0.3 to 1.6 t/ha.

Table 3. Use of Inorganic Fertilizer (% Farmers Reporting Use) by Rice Farmers

Zone	Monsoon season	Summer season
Delta/coastal	63	93
Dry	76	100

Source; LIFT Baseline Survey Results 2012.

[33] International Plant Nutrition Institute (IPNI) Research Database
http://www.ipni.net/far/farguide.nsf/$webindex/article=633A2F14852571340011E078034161E0?opendocument
[34] Buresh, Witt, and Pampolino (undated) define SSNM as "a plant-based approach for managing the nutrient needs of rice in intensive production systems. It provides principles and tools for 'feeding' rice with nutrients as and when needed to achieve high yields while optimizing use of nutrients from indigenous sources."

Low fertilizer use on rice and modest yield levels suggest moderate to high responses to increased fertilizer use in Myanmar. SSNM improves nutrient use efficiency and matches fertilizer use and crop needs based on a target yield. SSNM is a sound approach and deserves attention by extension services in Myanmar. As connectivity improves in rural areas, SSNM approaches can be transmitted to farmers through IT-based tools such as Nutrient Manager for Rice[35] a computer-based decision support tool developed by IRRI that enables rapid access to fertilizer guidelines for specific rice fields.

4.6. Pest Management

There are a large number of insects that feed on the rice crop. Morris and Waterhouse (2001) documented 29 species of insects and crabs that feed on rice in Myanmar. Of those, nine species were considered significant (Annex Table 1). Naing et al. (2008) reported a low incidence of pests and diseases in the main rice growing areas of upper and lower Myanmar. The most commonly found rice pests were stem borer (*Scirpophaga incertulas*), rice gall midge (*Orseolia oryzae*), Jassid (*Nephotettix apicalis*), and rice ear bug (*Leptocorisa* spp.). Only rice gall midge was reported causing a large yield reduction in a particularly heavy rainfall year. Naing et al. (2008) reported sheath blight as the main rice disease in terms of incidence in fields surveyed. Overall, they concluded that grain yield losses due to diseases and pests were for the most part insignificant. These results were consistent with our observations and interviews in November 2012.

Despite the apparent low level of damage by insect, there has been a recent sharp increase in the use of pesticides in Myanmar (Barrion et al. 2011). This has raised concerns of misuse and related negative environmental and health impacts. In addition, there is clear evidence from several countries in Southeast Asia that inappropriate use of pesticide can lead to worsening of pest problems, most notably planthoppers[36]. In our interviews with farmers, pesticides were widely used; however, farmers were uniformly unclear about their efficacy and risk. Farmers relied heavily on agro-dealers for advice on pesticide use.

Recent research by Aung et al. (2012)[37] reported farmers using a narrow range of insecticides in Myanmar. Most commonly used pesticides were organophosphates and organochlorines, particularly dimethoate, phenthoate and endosulfan, all of which are banned or under restricted use in most countries. The study showed that farmers had strong beliefs favoring the spraying of insecticides. Without regulation and sound extension advice, Myanmar's rice farmers are likely to experience the disastrous effects of crop damage caused by the brown planthopper (BPH), as experienced in Thailand, Indonesia, and China over the past three decades. BPH resurgence is associated with the killing of natural BPH enemies through inappropriate use of pesticides. An additional concern associated with increasing pesticide use is the impact on fish grown in or adjacent to rice paddies.

Ecologically-based approaches to pest management have been developed and deployed in several countries of Southeast Asia. The concept of ecological engineering was introduced to Myanmar through a training workshop in 2011(Win 2011)[38]. These approaches point to

[35] IRRI: http://webapps.irri.org/nm/phbeta/about.php
[36] See FAO synthesis of the evidence supporting this argument: Rice IPM in Asia: ecological principles underlying the farmer field school (FFS). http://www.fao.org/docrep/005/ac834e/ac834e08.htm#TopOfPage
[37] http://ricehoppers.net/2012/10/baseline-myanmar-rice-farmers-insecticide-use-low-but-their-beliefs-favor-spraying/
[38] http://ricehoppers.net/2011/07/myanmar-initiates-ecological-engineering-for-rice-production/

pesticide use as a weapon of last resort. Indeed, Dr. K.L. Heong, one of the pioneers of integrated pest management (IPM) and ecological engineering, is adamant that Myanmar farmers are much better off not using any insecticides at all (Heong personal communication). Heong is concerned that even with formal registration of pesticides, there needs to be licensing and advertising restrictions, coupled with training and awareness programs, in order to avoid overuse. Vietnam has made good progress in this area. Based on our mission, farmers remain far from convinced. They continue to see pesticides as part of *modern* rice farming and see this practice as a necessary insurance measure against yield loss.

Naing et al. (2008) also reported on weed control practices in rice. Hand-weeding was most commonly observed. Overall, farmers in all regions expressed only very basic knowledge about chemical weed control methods. We have no data on the trends in herbicide use. However, with rising labor costs and increasing use of direct seeding in place of transplanting, it is likely that herbicide use will increase.

4.7. Harvesting and Threshing

Rice is generally harvested manually using family and/or hired labor, the balance of which depends on farm size. We observed one combine harvester (a Kubota) operating efficiently at the Gold Delta Company farm in Danubyu Township. As the name suggests, a combine harvester combines the harvesting and threshing operations. Based on published and unpublished surveys and our interviews, mechanization of harvesting in Myanmar is rare. Martin Gummert, IRRI agricultural engineer with many years of experience in Myanmar and elsewhere in Asia, has observed a rapid adoption of combine harvesting in most Southeast Asian countries (Gummert personal communication). This trend is driven by the high labor cost and grain losses associated with traditional manual harvesting methods. Gummert cited the case of Cambodia where there were no combine harvesters in 2007 and manual harvesting cost $120/ha. By 2012, there were over 2,000 combine harvesters in Cambodia servicing farms for $100-120/ha, compared with manual harvesting which had risen to $180/ha. Gummert also reported rapid uptake of combine harvesting in Vietnam. It is highly probably that this same development will be observed in Myanmar as the country seeks to intensify farming and improve grain quality for export.

After harvesting, farmers usually stack their stalks un-threshed on the paddy field bunds. This practice is undertaken to focus labor on land preparation to enable a quick turnaround to either a second rice crop or a post-rice pulse crop such as green gram. Early crop establishment is associated with higher yield, and pulses attract a much higher price than rice. The downsides of stacking on bunds are losses through rat damage and shattering, and deterioration in grain quality, especially if there are rain showers.

Threshing is done traditionally through trampling by cattle. However, mechanical threshing is increasing in importance. Gummert believes that this combination of hand harvesting and mechanical threshing is the intermediate step to combine harvesting in response to higher wage rates. However, it is reasonable to anticipate widespread use of combine harvesters in Myanmar over the coming five to ten years. Mechanized harvesting and threshing will likely reduce the losses associated with an extended period of field stacking.

4.8. Drying and Storage

Farmers normally sun-dry their grain on any available space, including on roads. The latter practice leads to uneven grain drying which, in turn, results in a higher proportion of broken grains and lower quality of the final product. Stones and other impurities further reduce quality. Martin Gummert reports that efforts to introduce farm-level driers have failed everywhere in Southeast Asia. The basic reason is that farmers are unable to obtain a price premium for well dried grain. Gummert believes that the practical solution lies further along the value chain at the site of rice milling and trading. He cites a successful model whereby farmers have their grain dried for a fee to a service provider, thus leveraging economies of scale and eliminating the need for farmers to purchase individual driers.

IRRI introduced a modified flat-bed dryer using a rice husk furnace to Myanmar in 2007. The technology originated at IRRI, but was modified in Vietnam, where there are now more than 7,000 dryers in the Mekong Delta. According to Gummert (personal communication), there are now around 120 dryers of the original Vietnamese design and another estimated 200 copies. Members of the mission observed rice-hull fueled driers in action in Shwebo. The fans of these driers are mostly powered by diesel generators which are more cost-effective and reliable than using grid-sourced electricity. These driers appear relatively easy to construct, operate and maintain, and are already being manufactured in Myanmar by manufacturers trained in Vietnam with support from IRRI.

Farmers store unhulled rice for both grain and seed. Rice for consumption and later sale is normally stored unhulled rather than as milled rice, as the husk provides some protection against insects and helps prevent quality deterioration. Grain and seed is stored on-farm in jute bags and traditional storage granaries, baskets, drums, and other containers. Storage losses and reduced germination can occur through excessive moisture and infestation of insects and rodents.

A new system of hermetic storage developed by IRRI has shown promise[39]. At the farm level, unhulled rice can be stored in sealed plastic bags. This method controls the moisture content of the grain. Respiration by the grain and insects inside the storage container consumes oxygen and produces carbon dioxide. Oxygen levels are reduced from 21% to less than 10% within a short period. Below 5% oxygen, insects are killed and the viability of seed retained. Hermetic storage does not work with milled rice because of the lack of biological activity. A national distributor for hermetic storage systems was recently appointed so the systems should soon be available in Myanmar (Gummert personal communication).

4.9. Crop Rotation

Aside from jute, little else can be grown in low lying delta areas during the monsoon season. Rice is well suited to flooded fields, as long as the plants are not submerged for more than a few days[40]. In some areas during the 1990s, the government promoted double cropping of rice during the monsoon season as a way of boosting production. However, farmers found it difficult to harvest and dry the first crop at that point in the monsoon season (usually in

[39] http://www.knowledgebank.irri.org/rkb/grain-storage-systems/hermetic-storage-systems.html
[40] The exception being the deployment of varieties with the sub-1 gene that enables the rice crop to survive submergence for up to 21 days in clear water and 10 days in turbid water.

September/October) and this practice has been largely discontinued (Garcia et al. (unpublished).

For more than 20 years, farmers have been strongly encouraged by the government to intensify rice cropping through a summer rice crop. Recent policy changes have signaled opportunities to diversify production after harvesting the monsoon crop. Pulses, oilseeds, and vegetables are now widely grown in rainfed areas and where summer irrigation is insufficient for a second rice crop. In irrigated areas, early maturing pulses are sometimes grown between the monsoon and the summer seasons. The growing demand for livestock feed suggests there may be opportunities to expand production of yellow corn and soybean, both of which require much less water than rice. Soybean has the added value of breaking the cereal rotation with benefits to soil fertility and pest and disease management. We saw little evidence of soybean in the field[41], but see promise in exploring its yield and income potential.

[41] MOAI (2012) reports 169,000 ha soybean harvested in 2010-11 at an average yield of 1.53 MT/ha. We were unable to verify these data through interviews or field observations.

5. STRATEGIES FOR IMPROVING PRODUCTIVITY OF RICE SYSTEMS

In order to facilitate further development and wider adoption of innovations described above, we recommend a two-pronged strategy for improving rice system productivity: short-game and long-game. The short-game prong includes three opportunities for immediate action and impact within one to three years even in the absence of major policy reforms and capacity improvement.

5.1. Short-game Initiatives

5.1.1. Understanding the Resource Base: Production, Climate, and Soils

An improved understanding of the rice production environment will enhance the efficacy and efficiency of planning, implementation, and evaluation. As detailed earlier in this report, current rice statistics (area and yield) are inconsistent and unlikely to be an accurate reflection of reality. This can be remedied relatively quickly and cost-effectively using a combination of new and traditional methods.

We recommend that IRRI and national partners be supported to undertake a comprehensive assessment of rice productivity in the country. Rice areas and yield estimates can be determined through a combination of MODIS[42] and SARmap[43] data. These methods may also be used to differentiate rice growing ecosystems, thereby enabling better targeting of investments for extension and research. IRRI is working with SARmap in a consortium with SDC, GIZ, and Allianz. The consortium will use remote sensing technologies to map and observe rice growth in selected regions in Asia (Bangladesh, Cambodia, India, Indonesia, Philippines, Thailand, and Vietnam). We propose that this work be extended to Myanmar. These remote sensing methods will need to be complemented by field studies, including statistically sound crop cut protocols to improve production estimates.

Since climate patterns are highly variable within the country, and have significant impacts on rice production, we recommend greater effort to identify location-specific seasonal variability and historical trends. Expanding understanding of current and expected future climate conditions enables actors throughout the agriculture sector to better manage climate risks, both from extremes such as cyclones and from inter-annual variability. Integrating remote-sensing products and weather station data, even if currently limited, can help build this knowledge base and provide a foundation for improved climate forecast capability. For example, the Earth Institute’s International Research Institute for Climate and Society (IRI) can work with national partners to develop locally relevant downscaled seasonal forecasts from the institute’s suite of global and regional products[44].

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[42] MODIS (or Moderate Resolution Imaging Spectroradiometer) is a key instrument aboard the Terra (EOS AM) and Aqua (EOS PM) satellites. Terra MODIS and Aqua MODIS are viewing the entire Earth's surface every 1 to 2 days, acquiring data in 36 spectral bands, or groups of wavelengths. See: http://modis.gsfc.nasa.gov/about/

[43] SARmap is a Swiss company founded in 1998 as spin-off of the University of Zurich. SARmap provides remote sensing information and services. Synthetic Aperture Radar (SAR) interferometry technology systems provide weather independency, allowing penetration of cloud cover which is a constraint in making monsoon season assessments.

[44] The Earth Institute’s IRI has developed and applied a comprehensive range of forecasting tools that can be readily used to support agricultural planning in Myanmar. See: http://portal.iri.columbia.edu/portal/server.pt?open=512&objID=580&parentname=CommunityPage&parentid=3&mode=2&in_hi_userid=2&cached=true and http://iri.columbia.edu/asia/agriculture/india

Access to such information along with integrated decision support systems tailored to user needs and capacities can help stakeholders at all levels (e.g., farmers, private sector input suppliers, extension agents, and local and national government agencies) can improve planning and decision making across timescales. As examples, season-ahead climate information can inform varietal choice and contribute to a dynamic, climate-sensitive crop calendar. There is also a need to conduct downscaled climate change projections (particularly for near-term change over the coming two to three decades) to better assess possible impacts at a sub-national level and support planning for infrastructure, longer term crop variety needs and water resources management.

There is also an opportunity to develop accurate, up-to-date, and spatially referenced soil information to support agriculture in Myanmar. This coincides with developments in technologies that allow for accurate collection and prediction of soil properties. We propose an initiative to develop a practical, timely, and cost-effective soil health surveillance service to map soil conditions, set a baseline for monitoring changes, and provide options for improved soil and land management in Myanmar. This effort would be part of a wider global effort to digitally map the world's soil resources[45].

5.1.2. Documenting Ways to Improve Farm-Level Productivity and Profitability

To improve the productivity and profitability of Myanmar's rice systems, we recommend further identification and refinement of best practices in each of the dominant rice ecosystems as well as in other important farming systems (e.g., rainfed crops in the dry zone[46]). To this end, we recommend the development of a comprehensive and practical rice production manual for Myanmar. This manual would cover all nine intervention areas outlined above. The manual will draw on research and experience from Myanmar and other rice growing countries and serve as a valuable resource syllabus for training of students and professionals alike. The Myanmar Rice Manual will build from available literature and expert opinion. Workshops and regional field travel to neighboring countries is recommended to assemble the needed information. The manual would be accessible online, and make extensive use of video to communicate practical steps for improving productivity and profitability[47]. A range of training modules can be developed and tailored for different audiences. While a manual for rice is a high priority, we would also recommend a similar effort for non-rice crops and livestock.

5.1.3. Demonstrating Change: Special Productivity Improvement Zones (SPIZs)

With the right combination of technologies and supportive policies, Myanmar can achieve the productivity improvements described earlier in this paper. Yield improvements of 20% and 30% in monsoon and summer seasons respectively can be attained in five to seven years, just as they were in Vietnam as farmers became more efficiently connected to the domestic and international markets.

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[45] http://globalsoilmap.net/

[46] ICRISAT would be very well placed to lead this work in the dry zone.

[47] Digital Green, an NGO operating in India and Africa offers a potential model for developing and deploying video-based training materials in rural areas, even in the absence of internet access. See: http://www.digitalgreen.org/

Demonstrating change will be crucial in mobilizing support from the public and private sectors. To this end, we recommend the establishment of a Special Productivity Improvement Zones (SPIZs) where best practices across the value chain are applied. These SPIZs would be identified on the basis of productivity improvement potential and better market access. The latter provides a positive feedback loop to investments in productivity improvement. Complementary public and private investments would be undertaken within these SPIZs, including:

- Modern extension services: trained workers deploying information and communication technologies (ICT) approaches;
- Irrigation and drainage development and rehabilitation;
- Land consolidation with improved access and maneuverability for mechanization;
- Rural credit provision with provisions for crop insurance;
- Agro-dealer network support: training and finance;
- Telecom infrastructure: providing 3G access;
- Improved all weather roads and improved transport systems;
- Strategically-located post-harvest service centers (public-private partnerships); and
- Applied research services for field testing innovations.

Sustainable improvements in agricultural productivity for rice and other commodities require investment in key public institutions: universities, research institutions, and extension services.

The second prong of our proposed strategy is long-term institutional transformation that must be accompanied by policy reforms and major investment in human resource and institutional capacity. These interventions require political will to make and sustain fundamental and far-reaching changes in the agriculture sector.

5.2. Long-game Initiatives

5.2.1. Supporting Universities to Advance Agricultural Development in Myanmar: University Development Outreach Corps[48]

The universities of Myanmar have suffered from decades of underinvestment and isolation. Yet, these institutions provide the country's future leaders and change agents. We propose a radical scheme that would create a new cadre of professionals with the knowledge and skills to modernize agriculture and transform rural communities. We are calling this the University Development Outreach Corps (UDOC). Each year, graduates of Myanmar's agricultural universities would compete for places in a two-year field-oriented program that would deploy UDOCs in communities throughout the country. Akin to the U.S. Peace Corps or Teach for America, these early career professionals would receive initial training and orientation upon graduation, as well as at strategic times during the program. ICT approaches will be introduced to support acquisition and sharing of relevant science and technology. UDOCs would be paid a basic wage, and provided with appropriate transport and equipment.

We suggest that approximately 200 young professionals per year could enter the program, representing each of the important agro-ecological zones, and recruiting young professionals

[48] This program is by no means limited in scope to rice. However, given the importance of rice in Myanmar, we anticipate that a large proportion of the UDOCs would be deployed in rice growing areas.

who have cultural and language experience in those zones. Efforts would be made to ensure a good ethnic balance so that UDOCs could be deployed in their home regions. The program would aim for gender equality and, if necessary, provide incentives for women to be recruited. After successfully completing the program, UDOCs may then compete for scholarships for a master's program, again with objectives of appropriate ethnic and gender balance.

We believe that such a program would be an appropriate focus for strategic capacity building efforts in the agriculture sector. International and bilateral partners including universities and CGIAR centers could engage this program through training programs. In 10 years, about 2,000 graduates of the program would provide the nucleus of strong national capacity in the agriculture sector. We anticipate that the UDOCs would retain important alumni-like connections and alliances that would extend years after completion of the program. Over time, UDOCs would likely fill important leadership roles in research and extension, as well as in the private sector.

5.2.2. Research Institutions: Myanmar Rice Research and Development Center

Innovation is the engine room for improving productivity and profitability of agriculture. Myanmar's relative isolation and limited research capacity caused long-term stagnation of rice research and development. In order to engage more effectively and to benefit from scientific and technical advances in rice research, Myanmar requires a strong national institution. This approach has been instrumental in advancing agriculture in all parts of the world. Countries such as China, India, Bangladesh, Thailand, Vietnam, Cambodia, and the Philippines all have strong national rice research and development institutions that ensure a critical mass of expertise and strong coordination and prioritization of activities with a national perspective. IRRI has played a pivotal role in helping design and develop these institutions.

We recommend the establishment of a Myanmar Rice Research and Development Center (MRRDC). We suggest that IRRI works with Myanmar rice scientists and administrators to review the strengths, limitations, and lessons from other national centers in the region. The MRRDC should be designed to fit the unique circumstances of Myanmar and the new approaches to 21st century research and development. These considerations would include understanding the diverse rice growing ecosystems of Myanmar; the critical importance of export markets, post-harvest management, and grain quality; availability of new IT-based tools for research and development; the rapid advances in rice genomics and rice varietal improvement; and modern approaches to precision farming. Despite limited donor support, IRRI has maintained low-level, but productive collaborative relationship with Myanmar's scientists for the past two decades. Based on our discussions with national researchers, this partnership has been appreciated but is insufficient. We recommend inviting IRRI to establish a long-term (10-15 year) partnership program in Myanmar to help establish and support implementation of the Center and its programs nationwide. IRRI is currently active in the delta region with a focus on stress tolerant varieties, improved agronomy, mechanization, and post-harvest technologies[49].

[49] See http://irri.org/index.php?option=com_k2&view=item&id=12396:asia's-next-rice-granary-myanmar?&lang=en

We recommend that a new expanded Myanmar-IRRI partnership[50] would focus on five priority areas:

- Characterization of the bio-physical and socio-economic environment;
- Varietal improvement with extensive varietal testing and breeding using MAB;
- Agronomic efficiency enhancement: improving soil and water management;
- Mechanizing operations to improve labor, power and land-use efficiency; and
- Capacity building to reinvigorate universities, research and extension institutions.

5.2.3. Transformative Extension Service: Rural Transformation through Training, Mobility, and Connectivity

The moribund state of agricultural extension in Myanmar requires a radical rather than incremental approach to institutional development. Farmers currently rely on an unregulated private sector and an underfunded MOAI Extension Department for advice on agriculture. The consequences are evident. Farmers are using outdated varieties while concurrently being asked to plant unproven hybrids; they are confused about how to handle insect and disease infestations; and they appear unaware of the basics of balanced plant nutrition. Rural transformation towards higher productivity and greater competitiveness cannot be achieved using 20th century approaches to knowledge and skill dissemination.

Myanmar's extension service has the potential to leapfrog developments by establishing an extension service that is participatory, community-focused, market-driven, and modern IT-powered[51]. The new extension service would use modular IT-based learning methods drawing on the Myanmar Rice Manual and equivalent manuals for other commodities. Extension professionals would advance through in-service training and competency testing. The UDOCs would inject enthusiasm and innovation into the service. These strategies will draw extensively on experience gained across South and Southeast Asia. Myanmar is well positioned to apply and adapt approaches based on experience elsewhere. This *second mover* advantage offers a low-risk, high return opportunity to place Myanmar as a powerhouse of rice productivity and trade with important lessons and spillover impacts to other important agricultural commodities.

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[50] Lessons could be learned from IRRI's successful long-term program in Cambodia that helped develop the Cambodian Agricultural Research and Development Institute (CARDI). See: http://www.cardi.org.kh/?page=detail&menu1=6&ctype=article&id=6&lg=en

[51] A good overview of ITC for agriculture approaches can be found at http://www.e-agriculture.org/sites/default/files/uploads/media/eAg_Sourcebook_4_Oct2012_0.pdf

Annex Table 1. Arthropod Pests of Rice in Myanmar

Pest	Order	Family	Myanmar common name	English common name	Rating
Brevennia rehi (Lindinger)	Hemiptera	Pseudococcidae	စပါးဖတ်ပိုး	rice mealybug	P
Chilo polychrysus (Meyrick)	Lepidoptera	Pyralidae	ဆစ်ပိုးခေါင်းနက်	darkheaded rice stemborer	+ +
Chilo suppressalis (Walker)	Lepidoptera	Pyralidae	ဆစ်ပိုးအကြား	striped rice borer	+ +
Cnaphalocrosis medinalis (Guenee)	Lepidoptera	Pyralidae	ရွက်ခေါက်/ကပ်ပိုး	rice leaffolder	+ +
Dicladispa armigera (Olivier)	Coleoptera	Chrysomelidae	ပိုးမလောင်းမီး	rice hispid	+ + +
Euscyrtus concinnus (de Hann)	Orthoptera	Gryllidae	နှံကောင်	cricket	+
Gryllotalpa orientalis Burmeister	Orthoptera	Gryllotalpidae	မြေခွေးပုရစ်	oriental mole cricket	+
Hypomeces squamosus (Fabricius)	Coleoptera	Curculionidae	ရွှေမှုန့်ကျိုင်း	gold dust weevil	P
Leptocorisa acuta (Thunberg)	Hemiptera	Alydidae	စပါးနံ့စုပ်ပိုး	rice earbug , paddybug	+ + +
Leptocorisa oratorius (Fabricius)	Hemiptera	Alydidae	စပါးနံ့စုပ်ပိုး	rice earbug , paddybug	+ + +
Melanitis ismene (Cramer)	Lepidoptera	Nymphalidae	စပါးရွက်လိပ်ပြာ	green horned caterpillar	P
Mythimna separata (Walker)	Lepidoptera	Noctuidae	နှံဖြတ်ပိုး	paddy armyworm	+ + +
Nephotettix virescens (Distant)	Hemiptera	Cicadellidae	ဖြုတ်စိမ်း	green leafhopper	+ +
Nezara viridula (Linnaeus)	Hemiptera	Pentatomidae	ပဲကျွဲပိုးစိမ်း	green vegetable bug	P
Nilaparvata lugens (Stal)	Hemiptera	Delphacidae	ဖြုတ်ညို	brown planthopper	+ +
Orseolia oryzae (Wood-mason)	Diptera	Cecidomyiidae	ကြက်သွန်နီမြိတ်ပိုး	rice gall midge	+ + +
Oxya hyla (Serville)	Orthoptera	Acrididae	နှံကောင်	rice field grasshopper	P
Paraponyx stagnalis Zeller	Lepidoptera	Pyralidae	ရွက်လိပ်ပိုး	rice caseworm, rice case bearer	+ + +
Parnara guttatus (Bremer and Grey)	Lepidoptera	Hesperiidae	စပါးရွက်ကပ်ပိုး	rice skipper	P
Pelopidas mathias (Fabricius)	Lepidoptera	Hesperiidae	စပါးရွက်ကပ်ပိုး	rice skipper	P
Potamon dayanum (Wood-mason)	Crustacea	Potamidae	လယ်ပုစွန်လုံး	land crab	+
Psalis pennatulata (Fabricius)	Lepidoptera	Lymantriidae	စပါးခူမွေးရှည်	hairy caterpillar	P
Recilia dorsalis (Motschulsky)	Hemiptera	Cicadellidae	ဖြုတ်ကြား	zigzag leafhopper	P
Scirpophaga incertulus (Walker)	Lepidoptera	Pyralidae	အဝါရောင်ဆစ်ပိုး	yellow rice stemborer	+ + +
Scotinophara sp.	Hemiptera	Pentatomidae	ကျွဲပိုးနက်	black rice bug	P
Sesamia inferens (Walker)	Lepidoptera	Noctuidae	ပန်းရောင်ဆစ်ပိုး	pink rice stemborer	+
Sogatella furcifera (Horvath)	Hemiptera	Delphacidae	ဖြုတ်ကျောဖြူ	white backed planthopper	+ + +
Spodoptera litura (Fabricius)	Lepidoptera	Noctuidae	ငမြှောင်ကောင်	rice cutworm, cluster caterpillar	+ + +
Spodoptera mauritia (Boisduval)	Lepidoptera	Noctuidae	ငမြှောင်ကောင်	rice armyworm	+ + +
Stenchaetothrips biformis (Bagnall)	Thysanoptera	Thripidae	လှေပိုး	rice thrips	P
Varuna litterata (Fabricius)	Crustacea	Grapsidae	ဖောင်စီးဂဏန်း	quasi-sea crab	+

Source: Morris and Waterhouse 2001.

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