IRRI DISCUSSION PAPER SERIES NO. 30

Increasing the Impact of Engineering in Agricultural and Rural Development

M.A. Bell, D. Dawe, M.B. Douthwaite, Editors

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INTERNATIONAL RICE RESEARCH INSTITUTE

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Contents

Foreword

Rice is now the staple food for nearly two and a half billion people. Although the rice research community has been successful to date in helping provide this staple food to expanding populations, challenges lie ahead. More rice must be produced on less land, and with less water and labor and inputs that can harm the environment. The use of rice is also changing with urbanization. Furthermore, rice farming must not be left to the elderly and the women but should be an attractive and profitable enterprise for the young farmers of tomorrow. The population that depends on rice will surpass four billion within our grandchildren's lifetime. For IRRI, the task is especially challenging: to spearhead a "green-green revolution" in rice—to continuously increase grain supplies and enhance their quality, protect the natural resource base, and provide a worthwhile enterprise for the next generation of farmers.

Engineering is a critical component for helping to meet the challenges facing increased rice production. In the early years of the Green Revolution, engineering made many technical contributions to reduce drudgery and help increase labor productivity. In these changing times, however, the role of engineering, particularly in public-sector research, has to change. The opportunity is for contributing to an integrated system from field preparation all the way through the chain to end users. It was with this potential role of engineers in rice systems in mind that IRRI sponsored the think tank covered in this publication.

Kenneth S. Fischer
Deputy Director General for Research
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Acknowledgments

As coordinator of the think tank, I particularly want to acknowledge the efforts of Glenn Denning and Derek Sutton, who helped make this conference so productive. I also thank Ellen Sunaz (administrative assistant of AED) and other AED staff for their logistical support, and the participants who so enriched the exercise. Finally, I thank Bill Hardy for his excellent editorial efforts.

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Increasing the impact of engineering in agricultural and rural development[1]

Terms of reference

Background

Funding for international and developed-country agricultural engineering (AE) has declined markedly in recent years, which might seem strange given the involvement of engineering in so many production and postproduction activities. As a result, the International Rice Research Institute (IRRI), among other concerned research groups, has been reviewing how best to reorient the discipline to increase its impact. Although the international AE sector has been in decline, public-sector AE in developing-country national programs is either unchanged or growing. Thus, AE staffing in national programs—at least in the short term—looks promising. Despite this trend, however, it appears that a review of the approach to AE internationally will also identify opportunities to increase and ensure continued impact nationally. To brainstorm about AE issues, this think tank brought together a group of public- and private-sector specialists from around the world.

Several issues led to developing the think tank: What is the role of the public and private sectors? (What can the private sector handle best? What can the public sector do best?) Does AE really not make an impact or is it more a lack of public awareness of impact? Irrespective of historical impact, what is needed to increase the present and future impact of the discipline?

Objectives

The objectives of the think tank were to

1. Identify opportunities to increase incomes and rice production in Asia.
2. Identify how AE can best contribute to the activities identified in point 1 (i.e., define a strategic approach to AE research & development).
3. Clarify the roles of the private and public (international and national) sectors in AE.
4. Identify how best to introduce changes needed in the approach to AE.

Thus, the think tank was structured around four main questions:

1. What should AE do (in response to trends in national economies, etc.)?
2. How should AE be done (i.e., what is the best approach to increasing impact through the discipline)?
3. What are the relative roles of the national public sector, international public sector, and private sector (and others)?
4. What next (i.e., how do we implement recommended changes?)?

Panel members

National program projects

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[1] Report prepared by M.A. Bell, with special assistance from D. Sutton, J. Rickman, W. Chancellor, L. Clarke, and G. Singh.

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Summarized think tank report

Trends, limitations, and opportunities

One of every three people on Earth depends on rice for more than half of their daily caloric intake. Ninety percent of the world's rice is grown and consumed in Asia, where more than half the world's people live, and about two-thirds of the world's poor live. Rice is also an important staple in some countries in Latin America and Africa.

Rice surpluses and low prices in recent years have given an impression that the world's food production problems are solved. But population pressure (especially in rice-growing countries) is intense: about 80–85 million additional people must be fed each year. The world's annual unmilled rice production must increase by approximately 35–40% from today's 562 million tons to keep up with population growth and income-induced demand for food between now and the year 2020.

From 1965 to 1996, total rice production more than doubled. More than three-fourths of this increase came from higher yields, while nearly one-fourth was the result of increased area

* ADB–Asian Development Bank, AED–Agricultural Engineering Division, AGSE–Agricultural Support Services, Agricultural Engineering Branch, AIT–Asian Institute of Technology, AMA–Agricultural Mechanization in Asia, Africa and Latin America, CIAP–Cambodia-IRRI-Australia Project, DDGR–deputy director general for research, DFID–Division for International Development, EO–External Operations, FAO–Food and Agriculture Organization of the United Nations, ICAR–Indian Council of Agricultural Research, IDRC–International Development Research Centre, NAPHIRE–National Post-harvest Research, SSD–Social Sciences Division, UAF–University of Agriculture and Forestry, UC–University of California.

harvested (because of a combination of increased cropping intensity, new land brought into cultivation, and a shift of land from other crops to rice). Much of the yield increase can be traced to the introduction of modern rice varieties and to the increased use of fertilizer, irrigation water, and other inputs.

In the future, increasingly rapid rural to urban population movement, increased industrialization, increased urban incomes, increased cropping intensity, and labor's unwillingness to undertake arduous tasks under unpleasant conditions will mean growing scarcity of land, water, and labor for rice production. Furthermore, farmers will also have to increase production without harming the environment. As incomes increase, diet diversification and demand for higher-quality rice and rice by-products will be increasingly important. Rice farming is increasingly under pressure to become more attractive and competitive in order to keep people on the land to produce the food needed to feed rural and urban consumers.

To meet the growing demand, rice production in Asia must increase significantly in the face of less labor, less land, and less water, along with greater concern for the environment. Rice quality and diet diversification will be increasingly important. Profitability of the rice system has to be increased.

Meeting the need

All disciplines have a role in increasing the volume, quality, and efficiency of rice production. Engineering can contribute at virtually every point along the production to consumption chain, both in its own right and also by complementing the research of other disciplines (Table 1). For example, increasing pressure on land, water, and labor availability requires innovative farm power and machinery systems. Improved and therefore more expensive seeds require more efficient and precise seeding devices. Reduced environmental impact requires more efficient application equipment for agrochemicals.

Engineering also has tremendous potential to improve the quality of life by increasing the viability and profitability of production, postproduction, and other rural and urban enterprises, and by enhancing labor productivity, reducing drudgery, improving welfare, and designing appropriate health and safety interventions. Engineering can also contribute to increased output by reducing pre- and postproduction losses through enhanced harvesting, handling, and processing as well as enabling more timely operations. Effective implementation of engineering in agricultural and rural development will provide people with choices (i.e., options among various tools and technologies to enhance human physical and intellectual capacity and to guide and assist people in making the most appropriate choice among those options).

Environmental concerns call for technologies to be developed to prevent or reverse the negative effects of agriculture and industrialization. In particular, diminishing soil and water resources can be more effectively managed through better engineering interventions to reduce erosion and contamination (pollution) and maintain adequate water quality for urban as well as rural uses.

Engineering along with other disciplines all have a role in achieving the needed increase in rice production. Engineering can contribute at almost every point along the production to consumption chain. Engineering has both a direct and indirect role (by increasing the impact of other disciplines).

Table 1. Engineering activities involved in agricultural production and research and interaction with other disciplines.[a]

Activities	Agronomy, physiology, and agro-ecology	Soil and water sciences	Plant breeding, genetics, and biochemistry	Entomology and plant pathology	Social sciences
Land forming (leveling, bund forming, roads, irrigation and drainage channels)	X	X			
Land preparation (primary/secondary tillage/puddling)	X	X		X	
Weed control (manual, chemical application techniques)	X				
Chemical application and safety (application technology)	X			X	
Seeding (machines/ techniques)	X		X		
Water management (catchments, supplies, drainage systems)	X	X			
Harvesting (cutting, gathering, threshing, transporting)			X	X	
Postharvest (crop drying, storage, handling)			X	X	
Food processing (hammer milling, pelleting, wafers)					X
Instrumentation/calibration (quality control /monitoring/ recording)	X	X	X	X	
Design and construction (machines, buildings)	X	X	X	X	

[a]An "X" indicates a primary opportunity for engineering to enhance the work of the other discipline. To some extent, engineering can probably enhance the work of all disciplines in each of these areas.

Paradigm shift—increasing impact

Engineering, perhaps more than other disciplines, has the potential to contribute to a wide range of options to help increase production and productivity and reduce poverty. All too often, however, the discipline has missed opportunities by working in isolation or interpreting its role too narrowly (e.g., as solely hardware[2] design and development).

By adopting a systems approach and integrating its efforts to work within a multidisciplinary environment, engineering can have a direct impact through research and development (R&D) as well as an indirect impact by being a catalyst for increasing the impact of other disciplines. By adopting a demand-led systems approach that considers all the stakeholders involved in the production to consumption chain, intervention points can be better identified and targeted, and R&D can be better focused to achieve outputs appropriate to each target group. Combined with a problem-solving orientation rather than a technology focus, hardware development becomes a tool and not the end in itself. Such an approach will be new to some in

[2] Hardware refers to machinery and equipment.

the discipline, but not to all. Already, some engineers, especially in developed countries, have identified the need to adopt some form of systems approach.

To capture the opportunities that a systems approach offers (including public-private sector alliances) will require engineers to work more closely with target groups in a more multidisciplinary environment. As such, it may be necessary to develop or tap into a wider set of skills (such as economics, operations research, ergonomics, business management, agronomy, etc.). Problem solving, not technology generation, must be the focus.

Maximizing the impact of engineering will require an interdisciplinary participatory systems approach.

Public-private[3] synergy

Engineering has a tremendous opportunity to take advantage of the synergy offered by public- and private-sector collaboration. By taking advantage of each sector's comparative advantage, strategic alliances will lead to increased efficiency and impact. For example, a better-focused public sector excels in policy understanding, engineering principles, market opportunity, information supply, needs assessment, and prioritization. Furthermore, it brings a long-term view to ensure that critical factors such as environmental issues are considered. The public sector also often houses the knowledge for improved hardware and business management that the private sector needs. Finally, the public sector can provide consumer protection and an unbiased assessment of market opportunities and forces that can help users make better informed choices. The public sector also has a role in developing a suitable policy environment to allow the private sector to develop efficiently.

The private sector in turn excels in innovation, distribution, and delivering products to consumers. An area where the public and private sectors are critically interdependent is in R&D to adapt existing technology to local needs, and in so doing provide farmers with the technology choice that is so often lacking. The public sector needs to be involved because the private sector often lacks resources and is reluctant or too weak to invest sufficiently in R&D, and may lack access to or understanding of new technology. In addition, the profit motive that both drives and constrains the private sector may result in a lack of strategic R&D on medium- and long-term constraints facing the system.

By developing public-private sector alliances, a number of mutual benefits emerge, including improved avenues for impact, access to target groups, improved efficiency of hardware development, improved efficiency of software (management) development, access to expertise, credibility, access to resources (e.g., land, equipment for testing), development of a suitable policy environment, and quality control. These benefits will combine to improve the access of end users to improved options and management.

Strategic alliances between a well-focused public and private sector will maximize each sector's comparative advantages to increase the efficiency of R&D.

[3] Although we use "public" and "private" sectors, we are aware that it may be clearer to some people as "government" and "nongovernment" or "commercial."

Implications for international engineering institutes

NARS will increasingly come under the budgetary pressures already faced by international institutes. The need to show impact will become stronger both nationally and internationally. The international sector, through institutions such as IRRI, has a number of roles to play in increasing impact both directly and indirectly, though the role will of course change based on the relative strengths of the public and private sectors in different regions. In general, the international sector can best help NARS by creating an enabling policy, operational, and professional environment (strategy and policy). It should also act as an advocate, facilitator, or catalyst in developing and promoting the role of engineering in agricultural and rural development (awareness). It should provide a regional or global focal point for the collection and dissemination of information, networking and a discussion forum, coordination of technical assistance (information and networking), and training opportunities and promotion of investment in better R&D methodologies (education and training).

Work programs should be implemented within a systems approach—enabling better R&D prioritization and implementation (helping NARS avoid the hardware trap where hardware is the output and not one of the tools to overcome the problem), plus identifying, developing, and promoting ways for the public and private sectors to work together better (R&D). The most critical contribution initially will likely be assistance in developing a systems approach. Because the public and private sectors differ throughout the region, the role of the international and national public sector must be dynamic. Although the private sector is growing tremendously, free-market forces still need some guidance (including at times policy elimination) to ensure effective development.

The roles of international agricultural engineering institutes in strategy and policy, education and training, R&D, and information networking must be dynamic. Initially, their most important role is likely to be in the development and dissemination of more effective systems R&D methodologies.

Next steps

The think tank brought together interested parties from around the world to identify key components for a more focused and effective engineering discipline. The output confirmed the approach already begun at IRRI (i.e., applying integrated multidisciplinary activities guided by a systems approach—a greater focus on application than design). IRRI will have a key role to play with other groups to implement this paradigm shift. IRRI will work with institutes such as AIT, ACIAR, DFID, and FAO to instigate change. PhilRice and others have already expressed their intent to draw on the outcomes of this think tank to better focus their efforts in engineering. We must take this opportunity to ensure that the engineering contribution better meets the numerous needs of all stakeholders. Too often, engineering has been the odd partner; it is now time to integrate engineering into multidisciplinary teams. At the same time that we are asking other disciplines to embrace engineering, however, the primary responsibility lies with engineers to adopt new approaches, demonstrate application of a wider set of skills, work in multidisciplinary settings (where we seek to first understand before being understood), and focus to solve problems.

In addition to awareness activities, IRRI will continue to develop a systems approach to use in Bangladesh, the Philippines, and other countries—similar to the one already begun successfully in Cambodia. We must act to capture key points and then apply and promote them.

Key recommendations (for IRRI)

Awareness program

1. Continue to reorient the role and function of engineering within the institute and the region.
2. Promote a systems R&D approach that is participatory and interdisciplinary. Promote "private-public partnerships" as an integral part of systems R&D.

Policy and strategy

1. Help develop R&D priorities and policies conducive to effective private- and public-sector development.
2. Help NARS to improve prioritization and avoid R&D methodology pitfalls, thereby improving the efficiency of activities and helping to not "reinvent the wheel."

Training and education

1. Help NARS develop their R&D capability through training and education, noting that some NARS already have this capacity.

Information and networking

1. IRRI should act as a facilitator in the region—especially in the areas of information transfer, networking, and promotion of "improved" research methodologies.
2. Act as rice systems technology information centers—possess knowledge of all globally available technologies that are not always known locally.
3. Link NARS to international advanced research institutes.

Research and development

1. Develop systems R&D methodologies including comprehensive decision support systems.
   a. Use a systems approach—a comprehensive understanding of the rice production to consumption continuum—to identify points of intervention with high impact. Issues such as a lack of institutional policies, credit facilities, etc., must be considered.
   b. Use an interdisciplinary approach in which AE is integrated with other disciplines to obtain an improved understanding of the problems and thus generate more appropriate solutions.
   c. Promote participatory R&D with the key players and stakeholders (including manufacturers, government organizations (GOs) & nongovernment organizations (NGOs), farmers, consumers, etc.) to provide the best solutions and meet real needs.
   d. Develop, where appropriate, "private-public partnerships" as an integral part of systems R&D (potential problems exist in areas such as intellectual property rights, such as the private sector's tendency toward monopoly versus the international public sector's desire to distribute products or technologies virtually free to all possible clients).
   e. Limit direct involvement in machinery design and development to cases in which an alternate supply cannot be identified.
2. Generate basic data that NARS don't have the capacity to produce but that are needed for applied research.

IRRI's response to key recommendations for international public-sector activities in engineering

Table 2 shows IRRI's response to the various recommendations, including some actions planned and comments. Recommendations were made under five broad areas: awareness program, policy and strategy, training and education, information and networking, and R&D.

Table 2. Responses to key recommendations for international public-sector activities in engineering.

Recommendation	Action planned	Comments
1. Awareness program		
Continue to reorient the role and function of engineering within the institute and the region and promote a systems R&D approach that is participatory and interdisciplinary; promote "private-public partnerships" as an integral part of systems R&D.	Publish in various fora, e.g., combine with FAO and AIT to promote at 1998 Asian Association of Agricultural Engineers conference.	IRRI agrees that the "new" approach must be promoted.
2. Policy and strategy		
Develop and influence strategies for improved technology flow, including development and maintenance of standards (must have feedback to governments and other concerned agencies); help develop policies conducive to effective private- and public-sector development.	Improve links with FAO.	Policy is often more of a constraint than technology availability. Policy needs to consider other socio-economic circumstances (need to interact more strongly with FAO & IRRI's Social Sciences Division, etc.).
Help develop R&D priorities; assist in prioritizing regional problems, constraints, and needs—identification, description, and understanding; target needs based on regional differences and socioeconomic conditions; help NARS avoid past mistakes in R&D methodology and identify training/education needs.	Begin data collection for initial evaluation of regional country issues and needs.	Most countries follow a similar path to rural development. We can help countries learn from history and obtain knowledge from other sources.
3. Training and education		
Help NARS develop their R&D capability through training and education (some NARS already have the capacity); develop new training methods/materials (e.g., traditional, "new" systems approaches, "new" technology).	1. Develop rice-quality management course upon request from Vietnam and Malaysia. 2. Need to document systems approach to be used in Bangladesh.	IRRI needs to develop stronger links with other institutes with knowledge on systems analysis (e.g., Wageningen Agricultural University?).

Table continued

Table 2 continued.

Recommendation (continued)	Action planned	Comments
4. Information and networking		
The IRRI AE Division should act as an information center for rice technology—possess knowledge of already developed technologies that are not always available locally; develop databases on available technology—noting choices and management requirements for different scales of production (tap existing sources of innovation); link to other sources (e.g., information on technology and systems for regional adaptation, complex technologies).	Database development is under way, will consist of technology options and management considerations. Links with FAO database	
IRRI should act as a facilitator in the region, especially in the areas of information transfer, networking, and promotion of "improved" research methodology; this should include networking, virtual centers (information technology), discussion and debate fora; facilitate partnerships; link NARS to advanced international research institutes.	IRRI should act as a facilitator for NARS in the region. Continue postharvest e-mail conference. Cohost 1998 Philippine Society of Agricultural Engineers Conference. Strengthen links to FAO, ACIAR, and advanced research institutes, etc. Promote improved research approaches.	Will present think tank outcomes on the participatory systems approach. Should we develop an e-mail conference on rice production?
5. R&D		
Develop and implement improved R&D methodologies (e.g., multidisciplinary participatory systems approach) that include comprehensive decision support systems.	Bangladesh study—new project will include engineering activities based on a participatory systems approach (postproduction opportunities will be the initial primary focus). Develop collaborative program on decision support systems with UC Davis.	Cambodia work highlights the effectiveness of a participatory systems approach. Staffing levels and present focus limit potential contribution and need to be developed.
Apply R&D to a wider scope of rural engineering (include use of existing technology adaptation and transfer).	Highlight engineering work in Cambodia. Work on crop establishment and land leveling.	

Table contunued

Table 2 continued.

Recommendation (continued)	Action planned	Comments
5. R&D (continued)		
Develop models for prototype public-private linkages: assist and support private sector; promote enterprise creation and development (manufacturing, operation, support services, advice/guidance, invention).	Continue current private-sector linkages: Spectra Precision, Rainbird, Briggs & Stratton, Massey Ferguson, etc.	Need to integrate better in IRRI consortia meetings. Need to integrate with other disciplines. Need to seek funds and collaboration to pursue work on Dry-seeding domains Soil texture x crop establishment interactions Mobility: simple system for soil mobility assessment; effects of soil, water, and management Direct involvement in machinery design and development should be limited, and conducted only when alternate supply cannot be identified.
Provide expert consultancy		Has been an ongoing role.
Provide instrumentation and information systems to facilitate research.		
Generate basic data that NARS don't have the capacity to produce but that are needed for applied research.	Conduct volcanic cube storage experiment. Refine data on low-cost dryer.	
Limit direct involvement to R&D not covered by other partners.		Any design and development work would only be considered when other sources cannot fill the gap.

Detailed output of think tank

Three papers were presented to help focus discussion and five case studies of successful technology development highlighted the characteristics of successful R&D programs and noted the relative roles of the private and public sectors in the R&D process. Two additional articles were distributed for reference. All of these follow this chapter.

Responses to opportunities and trends

Rice production in Asia must increase in the face of several constraints (e.g., less water, land, labor) and growing concern about the environment. Engineering has many opportunities to contribute to this task by integrating with other disciplines. Although some people may view engineering as only machinery development, its potential is really much broader. Table 3 lists some of these opportunities and intervention points.

To overcome the key constraints and increase incomes, there are various opportunities for applying engineering depending on the target group and zone (e.g., precision land leveling to reduce weeds, improve water management, etc.). But the appropriate response cannot be made in generalities; it first depends on identifying and quantifying the problem. Priorities will therefore change according to the target zone and group. Once the needs assessment in the target zone or group is done, then the appropriate options can be considered to overcome the problem. We need to consider what technology is already available and the socioeconomic circumstances.

Although the general application of engineering to agriculture and rural development is obvious, the need for engineering can perhaps best be strengthened through its potential contribution to information, labor and energy, and power/output relations. In addition, the efforts of others will be multiplied through the success of engineering. For example, the following equation (provided by W. Chancellor) demonstrates that all disciplines, including engineering, can contribute to improved food production.

Human resource inputs/unit food produced = land required/crop produced x crop produced/unit food produced x human resource inputs/land required

W. Chancellor has explained this equation. In some impoverished countries, most people are required just to provide food for everyone. This means that few human resources are available for other things valued in advanced civilizations such as medical care, art, and education. If we can make food production more efficient (reducing the amount of human resources needed to produce food) then people will be able to devote more resources to things that will improve their standard of living. This reduction in the people needed to produce food can be accomplished by the interaction of a number of technologies in the systems with which we work.

Reducing the land required to produce a given amount of crop is the province of agronomists, engineers, and soil scientists as well as plant breeders. Reducing the amount of crop required to produce a given amount of food is the province of postharvest experts (including engineers) and food technologists. Reducing the number of people needed to work a given amount of land (i.e., labor productivity) is within the province of agricultural engineers.

Table 3. Opportunities and intervention points for agricultural engineering.

Trends	Bottleneck	Response: Approach	Response: Macro interventions	Response: R&D opportunities	Conclusions
Increased global consumption Demand for higher quality Decreased rural labor availability and increased labor costs Decreased water availability Environmental degradation Competing uses for land	Understanding needs and opportunities Institutional policies/economics Lack of power, rural infrastructure, and support systems Lack of public- and private-sector partnerships Increasing complexity of technology Lack of credit and finance	Systems analysis Inter-disciplinary approaches Participatory approaches with farmers and manufac turers Capacity building (industrial extension) Improved public-private partnerships Knowledge brokers to gather and exchange information	Policy and institutional change Infrastructure improvements Rural industry promotion Credit requirements defined	Improve reliability of mechanical devices Improve measurement system Increase application of information technology Reduce drudgery Improve safety Identify innovative R&D methods (e.g., public-private partnerships)	Target R&D (e.g., niche markets such as small low-income farmers) Emphasize policies/ extension/ information Also need local adaptation capacity

The equation shows that an advance made in any one of the above three terms (land productivity, food production efficiency, and labor productivity) increases the impact and importance of advances in the other two terms. This shows that all of us can benefit from appreciating, understanding, and contributing to the other disciplines as well as to the discipline in which we as individuals may be working. This means that people who pit crop scientists against agricultural engineers (for example) in budgeting or allocations do not understand the overall picture. This equation also implies that if persons in one or two of the disciplines think that work in the remaining area is not important, they jeopardize the effectiveness of their own work.

Increasing impact—partnerships and systems

Impact will be increased if an effective delivery mechanism exists to deliver engineering technology and systems to end users. This can be done through *public- and private-sector partnerships.*

Impact will also be increased through effective assessments of problems, opportunities, and needs. This is best achieved through a *systems analysis.* A systems approach will require consideration of the entire production to consumption chain and a wider set of skills (e.g., economics, optimal operations research, ergonomics, business management, production/agronomy, etc.). Engineering has to evolve to be able to increase production, improve quality, reduce costs, reduce environmental impact, and ensure sustainability.

A systems approach captures the problem of a moving target because it is in touch with the market and is therefore demand-led and responds to needs. There will be increased impact (i.e., success) through a systems approach because:

- a major need will be met,
- an end user will have been effectively targeted,
- work is visible because those involved are active with the beneficiary, and
- work is interdisciplinary.

Table 4 shows some specific activities under a systems approach in agricultural engineering.

Activities of the international public sector[4]

The assumption is that the capacity of some NARS has increased; therefore, IRRI's role may change. Although technology hardware often exists, it may not be locally available or known. Therefore, information sharing is an important role. The international public sector has a role in promoting safety and quality standards and identifying appropriate options to ensure adequate choices for consumers and rice production and postproduction systems. Table 5 shows a summary of potential international public-sector activities.

If mechanization is essential and is growing despite a diminishing international public sector, what's the problem (i.e., why is an international public sector needed for engineering?)? The answer is that mechanization is only one aspect of labor-saving technology. Because technology is becoming more complex, improved policies and information flow provide

Table 4. Systems approach in agricultural engineering.

Systems approach	Activities
Needs assessment (defining true needs versus wants)	Identify target groups and their problems (quantify demand) Use participatory research—consider objectives of target group and other key players in the "chain" (e.g., public, private, end users, manufacturers, sales persons, etc.)
Engineering R&D	Identify and integrate role of private sector (entrepreneurs, manufacturers, farmers, sales persons) Integrate with other R&D disciplines Evaluate potential technologies in economic as well as physical terms Develop systems to offer choices to target groups Consider technology from similar environments (before designing) Demonstrate and train (e.g., skill enhancement for manufacturers/farmers/contractors; research methodology for national R&D programs) Develop quality assurance/standards (especially for the private sector) Consider ergonomics/people factors (assess safety) Generate, share, and exchange information
Discipline strengthening	Raise awareness of impact and contributions (governments, donors)
Other considerations	Develop mechanization strategy given global trends Make use of emerging tools (especially information technology)

[4] Many activities are common to both the national and international public sectors.

Table 5. Potential activities of the international public sector in engineering.

Theme	Paradigm shifts	Activities
Policy and strategy	Target engineering options Foster a healthy mechanization subsector Facilitate development of a conducive policy environment	Carry out awareness campaigns Help identify priorities Analyze policy (with feedback to governments and other concerned agencies) Conduct policy studies (must have NARS participation/support)
Training and education	Strengthen national R&D capacity (education) Introduce and promote participatory R&D approaches	Assess training/education needs Develop new training methods/materials Promote Internet connections and use Link NARS to advanced international institutes Develop and demonstrate curriculum on systems approach
Information and networking	Capture advances in information technology Coordinate networks	Identify innovations Create awareness Develop databases on available technology—choices and management requirements Identify information sources Act as center for generating choices on available technology (hardware and software) Develop Web links for virtual networks/centers for information exchange Develop decision support systems
R&D	Implement systems/interdisciplinary approach Identify/develop new R&D paradigm and methodologies (e.g., participatory approach)	Apply R&D to a wider scope of rural engineering Identify and implement a systems approach (help NARS avoid pitfalls) Develop basic designs/test data as requested by NARS/private sector Undertake R&D on advanced technology Link rice engineers with rice researchers worldwide
Public-private linkages	Partnership = collaborative alliances	(See Table 7)

opportunities to save money and increase the efficiency of change. So the role here is clearly not design and development. The gap is growing between technology advances and technology on offer through the private sector and choices are lacking for end users. In addition, although there is a strong case for public-sector funding of AE R&D work, this does not mean it all has to be done in the public sector. The international public sector for agricultural engineering has a broader role to play than just mechanization. Table 6 is a partial logical framework analysis for the international sector.

Role clarification: public-private links and roles

Private- and public-sector partnerships are one goal for improved impact. The factors to consider in who takes the lead for various activities will depend on aspects such as risk, alternate supply, potential profit (versus public good), strength of sector, source of expertise, and comparative advantage (Table 7).

Private-sector strength varies by region and country, and thus the relative roles and type of support required by the private sector and national public sector are constantly changing. The most appropriate role of the international public sector therefore varies. For example, at one end of the development spectrum with a weak public and private sector, the role will be more inclusive. As technology becomes more complex, however, the public sector in more highly developed NARS will often need to provide more complex assistance to the private sector—assistance that NARS may seek from the international public sector (e.g., India now needs to send public-sector engineers overseas to gain "improved" understanding and knowledge to provide the required services to the private sector).

Public- and private-sector linkages

The issue of how to best facilitate public- and private-sector collaboration is but one of the factors involved in increasing the impact of engineering. Because this is a relatively new area, however, some additional thoughts on how this can best be developed follow in Table 8.

Table 6. Partial logical framework analysis.

International sector	Verifiable indicators	Assumptions	Risks
Goal: More and better rice that is more economically available and more profitable and environmentally sound to produce.			
Purpose: To enhance rice production and food systems through optimized, appropriate, and integrated engineering inputs and systems.			
Outputs: Engineering technologies and systems for people to have choices for enhancing rice production and use (e.g., improve quality and add value).			
*Themes**:			
Problem/constraint/needs identification, description, and understanding (targeting needs based on regional differences and socioeconomic conditions); tap innovative sources/new concepts			
R&D (in broad sense—including use of existing technology, adaptation, and transfer)			
Knowledge hub—information/knowledge delivery/exchange/dissemination from dynamic contemporary database—linked to other sources (e.g., information on technology and systems for regional adaptation, complex technologies)			
Networks and virtual centers (information technology), discussion and debate fora, facilitate partnerships			
Training and education on traditional and systems approaches and emerging technologies			
Expert consultancy			
Develop and influence policies, strategies, and standards (awareness program)			
Assist and support private sector—promote enterprise creation and development (manufacturing, operation, support services, advice/guidance, invention)			
Information systems and instrumentation to facilitate research			
Inputs:			
Money			
Data and technology			
Synergies (partnerships)			
People (knowledge, skills)			

* Extent of activity will depend on target and problem identification/needs assessment.

Table 7. Relative strengths, characteristics, and synergies of the public and private sectors.

Sector	Observations
Public	Primary focus is on technology development Takes a longer-term view (e.g., environmental considerations) Works better when linked to end users Often houses understanding of software for improved hardware management (needed by the private sector) Can provide consumer protection Needs public-sector structure conducive to promoting motivation
Private	Focused on profit (this both drives and constrains—short-term profit may not always be the best option for the system) Generally has a short term and relatively narrow focus Strength in hardware delivery to users Cannot always deliver as in developed countries (e.g., choice and expertise may be limited) Innovative Expertise not always available
Public- and private-sector synergies from partnership	Improved avenue for impact Increased access to target groups Improved efficiency of hardware development Improved efficiency of software development Consultancy available on needed expertise areas Increase opportunities and credibility Increased access to resources (e.g., land, equipment for testing, expertise) Improved policy environment is developed Quality control Improved market needs assessment

Table 8. Issues and concerns in forging public- and private-sector partnerships.

Constraints to linkages	Why have a link?	What results from linkages?	How can you facilitate linkages?
Insufficient incentive for public sector (e.g., evaluation system for public R&D) Public activities—may be policy-led, not need-led Lack of appreciation of private-sector interests and time line Conflict of interest Lack of modalities Inability to select innovative partners	Increase returns to public-sector investment Commercial opportunities identified by private sector More focused R&D Greater accountability—need to show impact. Published papers are not enough Private sector generally has a more effective delivery system	Setting of standards Activities private sector cannot afford (e.g., small scale in less developed countries) Link R&D design with manufacturing Definition of products Design assistance Risk investment Access to new technology Production engineering technology High-tech equipment available Business planning Materials technology Consultancy Skills training Enterprise development Source of supply Expert systems	R&D public-private companies Joint ventures Consultancy Design transfer to manufacturer Training to end users Network of industrial experts (worldwide) Secondment between private and public sectors Develop modalities Contract research (between private and public sectors) Field days, demonstrations, etc. Put private sector on boards of public institutes Public sector can recruit from private sector Direct intervention and assistance Develop incentives for commercialization

Developments in the Asian rice economy: challenges for mechanization and use

M.A. Bell and D. Dawe*

This paper outlines trends in rice production systems in Asia, highlighting the growing problems of land, water, and labor scarcity. Associated with these trends is the need to increase rural incomes, reduce poverty, and at the same time address growing concerns about the environment. By examining these problems and needs in rice production and postproduction, potential stakeholders can be identified. Roles and approaches in rice research for these stakeholders can then be developed and clarified to better address the needs of Asian rice production systems. This paper seeks to discuss future roles for agricultural engineering in international agricultural research institutions, and what organizational changes will be necessary to realize those roles. As we move into a more knowledge-intensive environment, where knowledge is substituted for increasing levels of inputs, we should consider how different stakeholders can best integrate their efforts to more effectively communicate knowledge to farmers.

Background and trends in the rice-growing environment

Where is rice produced?

Global rice production is dominated by the irrigated systems of Asia (Tables 1 and 2). Production by ecosystem is approximately 75% in irrigated areas, 18% in rainfed lowlands, 4% in upland areas, and 3% in flood-prone areas. The rainfed lowlands are of particular interest as many farmers in this ecosystem are poor. Thailand, India, the United States, Vietnam, and Pakistan are presently the largest rice exporters, in roughly that order (Table 3).

In the post–Green Revolution period, rice production in Asia has continued to grow. But the rate of growth has declined steadily in recent years because of a slowdown in yield growth and a virtual end to growth in new area available for production. The trend in the growth of average rice yields in Asia was 2.1% annum^{-1} from 1967 to 1981, 1.8% from 1982 to 1989, and only 1.0% from 1990 to 1996. The trend in the growth of land area planted to rice was only 0.4% annum^{-1} from 1990 to 1996, with most of that growth coming from Vietnam and Myanmar.

Future trends in the Asian rice economy: (1) more consumption and a shift toward higher-quality rice

Economic development and population growth are the prime factors driving change in Asia (Fig. 1). The world population is presently rising at a rate of approximately 84 million people yr^{-1}. Much of this growth is in Asia, and many of these people will be poor and depend primarily on rice consumption for survival (Greenland 1997; FAOSTAT Database). As a result, rice demand is expected to increase by approximately 40–60% over the period 1993–2020 (Pinstrup-Andersen et al 1997, Pingali et al 1997). This equates to an increase in production of approximately 5–7 million t of milled rice yr^{-1}, which is equivalent to adding around 2–3 million ha of new land yr^{-1} (at current average yield levels)—land that is not available. Production increases will therefore have to come primarily from reduced postproduction losses and increased yields ha^{-1}.

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Table 1. Distribution of rice crop area by ecosystem and production and yield (rough rice) for different Asian countries, Africa, and Latin America (countries listed by ranked rice area).

Country	Total rice area (000 ha)	1997 production (000 t)	1993 rough rice yield (t ha^{-1})	Distribution of rice area (%)			
				Irrigated	Rainfed lowland	Flood-prone	Upland
World	150,783	571,742	3.8	53 (79,915)[a]	27 (40,711)	8 (12,063)	12 (18,094)
Asia	134,839	522,050	3.9	55 (74,161)	29 (39,103)	8 (10,787)	8 (10,787)
India	42,800	121,512	2.8	45	33	7	15
China	31,348	196,971	6.3	93	5		2
Indonesia	11,600	51,000	4.4	72	7	10	11
Bangladesh	10,000	27,903	2.8	22	47	23	8
Thailand	9,175	20,700	2.3	7	86	7	1
Vietnam	7,021	26,397	3.8	53	28	11	8
Myanmar	6,600	21,200	3.2	18	52	24	6
Philippines	4,035	11,669	2.9	61	35	2	2
Pakistan	2,232	6,430	2.9	100			
Japan	2,100	13,000	6.2	99			1
Cambodia	1,950	3,390	1.7	8	48	42	2
Nepal	1,511	3,711	2.5	23	66	8	3
Korea, Rep.	1,045	6,593	6.3	91	8		1
Malaysia	660	2,065	3.1	66	21	1	12
Sri Lanka	660	2,610	4.0	37	53	3	7
Korea, DPR	600	2,300	3.8	67	20		13
Lao PDR	554	1,414	2.6	2	61		37
Other Asia	948	3,185	3.4				
Latin America	6,161	20,137	3.3	33 (2,033)	7 (246)	2 (123)	59 (3,635)
Africa	7,513	15,861	2.1	17 (1,277)	21 (1,578)	20 (1,503)	42 (3,155)
Other							
USA	1,141	8,137	7.1	100			
Italy	245	1,424	5.8				
Australia	155	1,407	9.1	100			
Others	729	2,727	3.7				

[a]Area—000 ha in parentheses.
Data source: Area, production, yield: FAOStat. Distribution of rice area: Huke and Huke (1997) for all Asia except Japan. IRRI 1995a for Japan, world, Latin America, Africa, other.

As consumption rises, there will also be a shift toward diet diversification and greater demand for higher-quality rice, such as aromatic rice (Wailes et al 1995, IRRI 1997). In some cases, there are production trade-offs between producing higher-quality rice and increasing production. For example, aromatic rice is nearly always lower-yielding. Thus, any attempt at profit maximization at the farm level through shifts to produce this lower-yielding, higher-quality rice will make keeping up with the growth in demand even more difficult. Other quality improvements might result in less of a trade-off with high yields. For example, achieving higher milling percentages and reducing postproduction losses through improvements in postproduction systems will actually increase yields—albeit at the country level rather than at the farm level.

Table 2. Ecosystem classification.

Ecosystem	Slope	Water control	Rice establishment	Soil aeration/other
Irrigated	Level bunded fields	Good water control, shallow flooded	Transplanted or direct seeded in puddled or plowed dry soil	Anaerobic soil during crop growth
Rainfed lowland	Level to slightly sloping bunded fields	Noncontinuous flooding of variable depth and duration, submergence not exceeding 50 cm for more than 10 consecutive days	Transplanted in puddled soil or direct seeded on puddled or plowed dry soil	Alternating aerobic and anaerobic soil of variable frequency and duration
Upland	Level to deeply sloping fields	Rarely flooded	Direct seeded on plowed dry soil or dibbled in wet nonpuddled soil	Aerobic soils
Deepwater/ flood-prone	Level to slightly sloping or depressed fields	>10 consecutive days of medium to very deep water (50 to >300 cm) during crop growth	Transplanted in puddled soil or direct seeded on plowed dry soil	Aerobic to anaerobic soil; soil salinity or toxicity in tidal areas

Source: Greenland 1997.

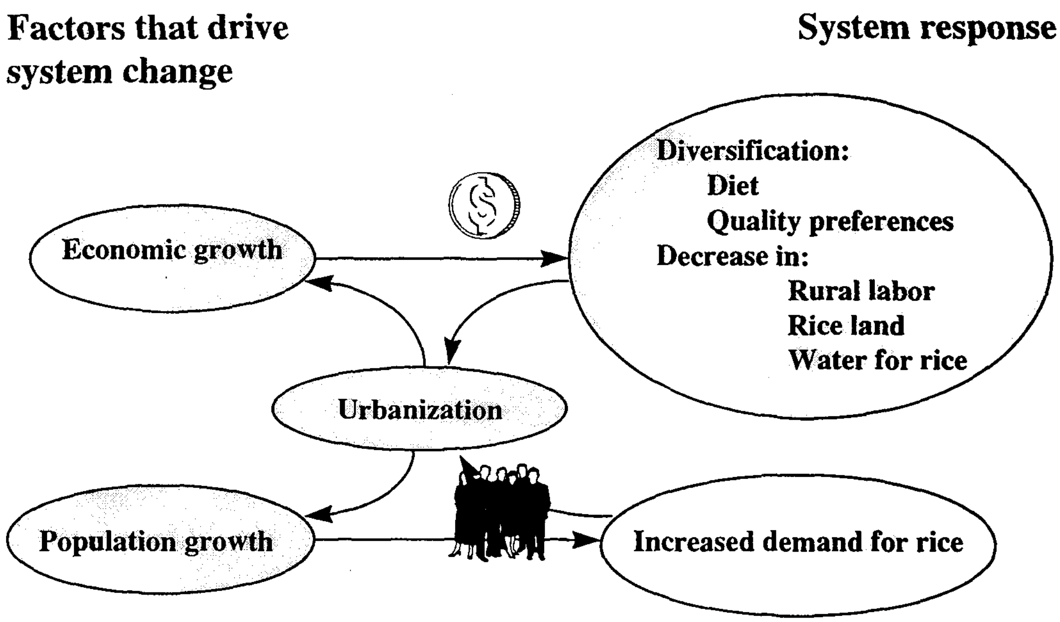

Fig. 1. Factors that drive system change and system response.

Table 3. Principal exporting countries, 1995.

Area	Rice exports in millions of metric t	% share of total world exports
World	23.3	100
Thailand	6.2	27
India	5.5	24
USA	3.1	13
Vietnam	2.3	10
Pakistan	1.9	8

Source: FAOStat 1998.

Future trends in the Asian rice economy: (2) less labor, water, and land, and degradation of the natural resource base

The needed increase in rice production will have to be achieved with less labor, less water, less land, and greater concern about the environment (Naylor 1996, IRRI 1997) (Fig. 1 and Table 4).

Labor. At present, except for countries such as Japan and Korea, most Asian countries have more rural workers ha^{-1} than ever before. But this is almost certain to change in the near future as population growth slows and as rural labor is drawn away from the farm because of increased urbanization and industrialization. In addition, the fact that the level of rural workers ha^{-1} has not yet declined in many countries does not mean that labor available for rice production is still abundant. For example, diversification out of rice and into higher-value agricultural products (e.g., fruits and vegetables) leaves less labor available for rice cultivation. Also, many workers in rural areas now work only part time in agricultural pursuits, preferring to devote more time to other, more lucrative, employment in manufacturing and services. These phenomena are reflected in rising rural wages in many Asian countries. Thus, although average arable land area per worker is much lower in Asia than in highly mechanized countries such as Australia and the United States, rising wages will force farmers in Asia to search for labor-saving technologies.

Water. Rice farmers will be forced to improve water-use efficiency in the coming years. Around 80% of the water in Asia is now used for agriculture and, of this, around 90% is used for rice. Rice is thus the dominant user of water in most of Asia. But demand for water by industrial and municipal users is growing rapidly. At the same time, the scope for increasing water supplies by constructing new irrigation systems is relatively limited. Much of the land most suited for irrigation has already been developed, so that constructing new systems is likely to be very expensive. Also, concern is increasing about the environmental consequences of large-scale irrigation projects. It is therefore unlikely that new supplies will be able to entirely offset the increase in industrial and municipal demand. Because the economic value of water use is typically much higher in manufacturing than in rice, water supplies available for rice will probably decrease.

Land. As with labor and water, land for rice production will also be in increasingly short supply in the 21st century. Land around urban areas, much of it irrigated, is being turned over to housing and industry, thus requiring the opening up of new land or increases in cropping intensity on old land. Growth in rice area harvested, however, has been diminishing throughout most of Asia over the past two decades. Rice area harvested in Asia increased from 118 million ha in 1977 to 120 million ha in 1996, an average increase of less than 0.1% yr^{-1}, except for Vietnam and Myanmar, where growth has been greater.

Table 4. Factors affecting the future of rice farming in Asia.

Factor	System response options
Increased population	Increase rice demand and production
Less labor	Increase mechanization
Less land	Increase production efficiency
Less water	Increase water-use efficiency
Increased off-farm incomes	Increase demand for higher-quality rice and rice products
	Diversify system (e.g., fruits & vegetables)
	Increase profitability of farming (increase resource-use efficiency) (increase value added)
Environmental concerns	Increase resource-use efficiency

Environment. Water quality and quantity will increasingly become an issue in the years ahead. Intensification of rice production over the past 30 yr has caused environmental problems such as salinization and waterlogging of land, contamination of water supplies by pesticides and fertilizers, and degradation of soil quality. As awareness grows, such issues will be increasingly handled through public opinion and political channels. The long-term effects of these problems on production are not always completely understood, but some of them are likely to present serious constraints to increasing production in the 21st century.

Because of the reduced availability of labor, land, and water for rice production in the 21st century, it will be important to generate new technologies and improve farmer knowledge if rice production is to keep pace with the growth in demand. If new technologies and germplasm are not forthcoming, prices will rise. These higher prices will adversely affect millions of poor rice consumers, many of whom live in urban areas.

Labor, land, and water will be the major factors limiting rice production in the future.

Country differences

The level of economic development and the rate of economic growth are the prime factors that drive wage levels and the use of resources such as water and land. Because different countries in the region are at different stages of economic development and are growing at different rates, the changes outlined previously will obviously occur at different rates throughout the region. By grouping Asian countries according to income level, nature of the food production system, and the extent of adoption of labor-saving technologies, it becomes easier to target the likely needs of each country (Tables 5, 6, and 7).

Technology change patterns

As labor, land, and water become scarcer and as input prices rise, farm profits will face increased pressure. If farms are to remain profitable and stay in production, changes in farm management need to occur. These changes tend to occur in three stages (Pingali et al 1997), namely:

1. Land intensification—move to increased cropping intensity.
2. Labor substitution—move to labor-saving mechanical and chemical technologies.
3. An increase in knowledge and management intensity—where better knowledge and management (timing and method) increase returns per unit input.

Table 5. Economic and rice production environments and stage of commercialization.

Country	Subsistence	Semicommercial	Commercial
Group 1. High income, self-reliant			
Japan			X
Taiwan			X
Korea, Rep.		X	X
Malaysia		X	X
Group 2. Excess rice production capacity			
Thailand	X	X	
Laos PDR	X		
Cambodia	X		
Myanmar	X		
Group 3. Risk of food insecurity			
Sri Lanka	X	X	
Bangladesh	X	X	
China	X	X	
India	X	X	
Indonesia	X	X	
Pakistan	X	X	
Philippines	X	X	
Vietnam	X	X	
Nepal	X		

Source: Hossain 1996, Pingali et al 1997.

Table 6. Characteristics of food production systems with increasing commercialization.

Level of market orientation	Farmer's objective	Sources of inputs	Product mix	Household income sources
Subsistence	Food self-sufficiency	Household generated (nontraded)	Wide range	Predominantly agricultural
Semi-commercial	Surplus generation	Mix of traded and nontraded inputs	Moderately specialized	Agricultural and nonagricultural
Commercial	Profit maximization	Predominantly traded inputs	Highly specialized	Predominantly nonagricultural

Source: Pingali et al 1997.

Almost all of the changes that are occurring in Asia in response to the changing environment (Fig. 2) reduce labor requirements. When labor-saving technologies are undertaken in response to rising wages, they pose little problem for most of the labor force because there will be an abundant choice of alternative jobs in such situations. On the other hand, if these technologies are promoted or adopted in a stagnant economy, the consequences for labor may be much more serious (although also possible is the failure of any mechanization program under such conditions). Therefore, the implications of policy and new technologies for local labor markets will continue to be an important research topic.

Research prioritization and the role of agricultural engineering

Prioritization of rice research must consider future trends in rice production as well as the particular needs of individual countries (Tables 5 and 7). The research focus will thus be different in different countries and ecosystems (Table 8). In general, though, the main priorities will be:

Table 7. Arable ha tractor^{-1}, adoption of herbicides and direct seeding, and pesticide use ha^{-1} for different countries. (Countries are listed by level of tractor mechanization within economic groupings.)

Country	Arable ha tractor^{-1} [a]	Herbicide use[b]	Direct seeding[b]	Pesticide use[c] (US$ ha^{-1})
Group 1. High income, self-reliant				
Japan	2	>100% herbicide	<0.5% (mech. transpl.)	775.80
Korea, Rep.	23	75–100%	10% (mech. transpl.)[d]	361.90
Malaysia	47	?	>60%	
Taiwan	?	>90%	Very little (mech. transpl.)	>57.10
Group 2. Excess rice production capacity				
Thailand	146	80% in direct seeded 10% in transplanted	30–40%	5.50
Myanmar	795		>50% in dry season	3.20
Lao PDR	983	Very little	?	
Cambodia	2,798	Very little	?	
Group 3. Risk of food insecurity				
Sri Lanka	28	Common[e]	>80%[e]	
Pakistan	73	?	Very little[f]	
China	130	30–40%	5–10%	9.50
India	132	Limited in northeast and south	30%[g]	4.90
		Popular in other areas	30%[g]	
Indonesia	308	>25%	<5%	9.50
Philippines	480	>50%	>30% in dry season	8.00
Nepal	505	Very limited	<10%[f]	
Vietnam	1,595			5.90
Mekong Delta		Widely used	>94%[h]	
North		Limited	20%[i]	
Bangladesh	1,783	Hand weeding	Transplanting	2.10
Bhutan	Few tractors	Hand weeding	Transplanting	

[a] Data from FAO (1996)—these figures make no allowance for differences in hp.
[b] Data from Naylor (1996)—obviously these figures can change dramatically.
[c] Herbicide, insecticide, and fungicide data from Wood Mackenzie Consultants Ltd., London.
[d] Data from Lim et al (1991) and J.K. Kim (pers. commun.).
[e] Data from Pathinayake et al (1991).
[f] Estimates from P. Hobbs (pers. commun.).
[g] Mostly in rainfed upland and some deepwater environments (R.K. Singh, pers. commun.).
[h] Mekong Delta produces >50% rice.
[i] Estimates from T. Tuong (pers. commun.).

1. Labor. Increase the application of labor-saving technologies. The trend in adoption of labor-saving technologies (Khan 1996) generally follows this order:
   a. Pumps for water management, mechanization of land preparation and leveling, mechanization of transport and hauling, portable threshers for harvest, small mills for milling.
   b. Direct seeding as a method of crop establishment, spray applications for pest control, substitution of chemicals for hand weeding.
   c. Combine harvesters.
2. Water. Increase water-use efficiency—economic reforms to increase the value placed on water, institutional reforms to improve management of water resources, water-saving irrigation technologies (e.g., improved leveling, intermittent irrigation).

Production

Land preparation

Animal & 2-wheel tractor (puddling) ⇒ 4-wheel tractor,
reduced tillage,
precision leveling

Germplasm

Current germplasm/traditional varieties ⇒ germplasm with improved:
nutrient use efficiency,
yield potential,
stress tolerance,
grain quality

Poor seed ⇒ certified/clean seed

Crop establishment

Manual transplanting ⇒ direct seeding,
mechanized transplanting

Water management

Flood irrigation ⇒ reduced irrigation (precision leveling)

Pest control

Manual weed control ⇒ fixed herbicide spray regime,
integrated weed management (incl. herbicides)

Spray insects on sight ⇒ calendar spray applications,
integrated pest management

Nutrient management

Manure applications ⇒ blanket nutrient management,
site-specific nutrient management

Postproduction

Harvesting

Manual harvesting cut & haul ⇒ combine harvesting

Threshing

Manual threshing/animal treading ⇒ portable threshers,
combine harvesting

Handling and storage

Bag handling & storage ⇒ bulk handling & storage

Drying

Sun drying ⇒ commercial drying

Milling

Small mills ⇒ commercial mills

Byproduct use

Byproduct waste ⇒ Byproduct use—adding value

System changes

Monoculture ⇒ diversified systems

Small farms/fields ⇒ larger farms/fields

Government extension services ⇒ contract supply & extension services

Subsistence or local market ⇒ commercial market,
specialized quality rice & products markets
(adding value)

Lack of concern for the environment ⇒ public & legislative environmental concern

Fig. 2. System and component technology changes expected in rice production systems.

Table 8. Research priorities for countries at different levels of economic and food security.

Group	Research and development needs and goals
Group 1. High income, self-reliant	Increase labor productivity
	Increase input-use efficiency
Per capita rice consumption is declining	Increase protection of the environment (improve/reduce chemical use)
High costs of production	Do maintenance breeding—varietal resistance to pests and diseases
	Improve grain quality
	Increase yield potential
Group 2. Excess rice production capacity	Develop world markets
	Develop rural infrastructure
	Improve grain quality
	Develop labor-saving technologies
	Reduce chemical use
Group 3. Risk of food insecurity	Attain food security
Scarce land, low income	Diversify cropping
Limited off-farm employment options	Increase labor productivity
High population growth (2%)	Maintain the natural resource base
High poverty levels	Reduce existing yield gap in rainfed areas
	Increase yield potential for irrigated areas

Source: Hossain 1996.

3. Land. Increase land productivity—improved germplasm, hybrid rice, improved crop management.
4. Environment. Improve protection of the environment and improve input-use efficiency (e.g., precision farming, decision support systems).
5. Quality. Improve rice quality—postproduction systems, breeding for better taste and aroma.

For each constraint, we need to identify the intervention opportunities and the types of appropriate technology intervention (we define technology as hardware and/or software). Often, the technology options exist (although they are not necessarily known or available to researchers and farmers). For example, tables similar to that of Rijk (1986) (Table 9) outlining various technology trends can be readily constructed to complement the levels of system sophistication identified in Figure 1. Although technology often exists, however, there are problems of:

- Identifying the priority problems and appropriate interventions for each system.
- Identifying who should implement the appropriate interventions.
  - If appropriate technologies do not exist:
    - Who can best intervene?
  - If appropriate technologies exist:
    - Who will match technologies (hardware and software) for the different systems?
    - Who can best transfer the technologies?
    - Who will assist with the efficient implementation of a technology?
- Identifying the best linkages between the different groups to ensure efficient system change.

Table 9. Levels of mechanization technology for different operations.

Function or operation	Level of mechanization technology[a]		
	Hand tool	Draft animal	Mechanical power
Land clearing	Brush hook, hand saw, motor chain saw	Buffalo and elephant for skidding and loading	Track-type tractor for clearing, skidders for log transport
Land development	Spade, hoe, basket, wheelbarrow	Earth scoop, leveling scraper, bund former	Wheel tractor, track-type dozer, motor scraper, excavator
Land preparation	Hoe, spade	Wooden plow, steel plow, spike harrow, disk harrow	Single-axle tractor, power tiller, two-axle tractor with various implements
Planting or seeding	Seed distribution by hand, plant stick, jabber, row marker, hand-pushed seeder	Furrow opener, marker wheel for dibbling, seed drill, seed-cum-fertilizer drill	Tractor seed drill, seeding with aircraft
Transplanting	Hand-operated paddy transplanter		Motorized paddy transplanter
Harvesting	Finger-held knife, sickle, scythe, threshing table, pedal thresher	Peanut lifter, cutter-bar mower, reaper, reaper-binder, treading (threshing)	Power reaper, power reaper-binder, power thresher, combine harvester
Crop husbandry	Hoe, weeding hoe, hand sprayer, water can, irrigation scoop	Wooden interrow weeder, walking-type tool carrier, riding-type tool carrier, spraying machine, Persian water wheel	Interrow weeder, motor knapsack sprayer, tractor boom sprayer, spraying with aircraft, diesel or electric irrigation pumps
On-farm processing	Mortar and pestle, flour-grinding stone, hand-operated paddy husker	Animal-powered sugarcane crusher, power gear for driving processing machinery	Single-pass rice mill, rubber-roll rice mill, hammer mill
Crop storage	Sun-drying, bag storage		Artificial drying, bulk storage, elevator, fork lift
Handling	Carrying, wheelbarrow, push cart		
Rural transport	Porter, push cart, rickshaw	Sled, pack harness, bullock cart	Power tiller with trailer, two-axle tractor with trailer, truck

[a] Within each operation, the level of sophistication increases vertically.
Source: Rijk 1986.

Identifying the important technologies will obviously be a key step. Furthermore, the role of agricultural engineering in identifying, adapting, testing, (possibly) developing, and extending will vary by country and technology. Before we speculate about the role of agricultural engineering in the future, it is therefore important to consider the key constraints to future rice production and how agricultural engineering might help to relieve those constraints.

Generating technologies to reduce poverty, increase farm incomes, and protect the environment

The production of new "technologies" will not be possible without the generation of intermediate products such as knowledge and improved research methods. If all goes well, these intermediate products will lead to final products and ultimately to the achievement of system goals. This process involves various key players at different steps along the way (see Fig. 3).

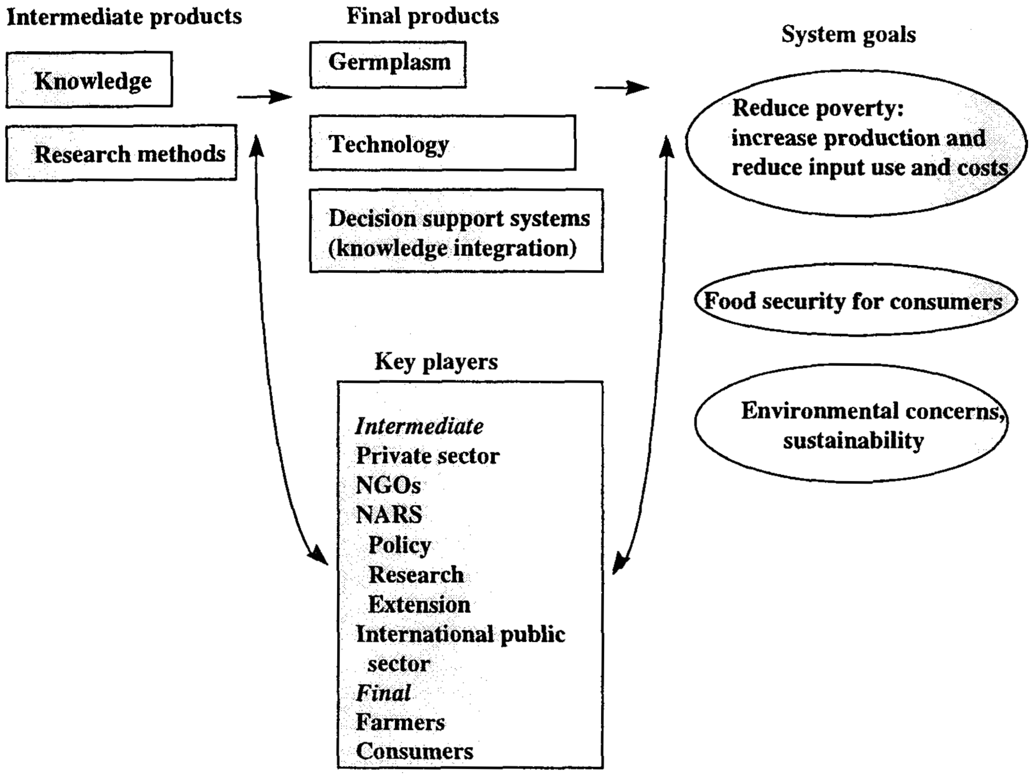

Fig. 3. Road map for impact: primary products, key players, and system goals.

Meeting the ultimate system goals will depend on two critical factors: (1) setting appropriate priorities for the most important problems and technologies, and (2) devising research and development agendas that involve the key stakeholders in the technology generation and dissemination feedback loop. These two factors are not separate steps; indeed, they must be linked. If priorities are set correctly and the technologies are generated in a manner that takes into account the needs of the key stakeholders (e.g., Tables 10 and 11), success at reaching the system goals is more likely to be achieved. Different technologies will sometimes have conflicting effects on different system goals, and these need to be reconciled and taken into account in the priority-setting process. For example, an increased use of herbicides will relieve the constraint of reduced labor availability and help to increase production, but it may adversely affect the environment and the sustainability of rice production.

Defining the appropriate role for each stakeholder at each stage of the process is admittedly a difficult task, and is one of the goals of this conference. The appropriate role for each player is not a question that can be answered in the abstract; it will depend on comparative advantages, and on the technologies that need to be developed. Therefore, before attempting to assess the most appropriate roles for the various key players, it is probably best to attempt to set priorities for the generation of future technologies. Once this is done, then the other questions can be asked. For example, What are the relative roles of the public sector (international and national) and the private sector? To what extent are they, or should they be, competing and/or cooperative? To what extent are lessons from the history of agricultural engineering relevant? What impact will the reduced availability of donor funding have? These are some of the questions that we hope to address during the conference.

Table 10. Expected outputs/needs of different stakeholders in production systems.

Stakeholder	Expected outputs/needs
Rice farmers	1. Available mechanized technology options, competitive with current practices 2. Available and affordable spare parts 3. Land tenure assurance 4. Credit and finance—realistic, available, and affordable 5. Guaranteed farm-gate prices. 6. Sensible subsidies and price support if implemented
Contractors	1. Available mechanized technology options, competitive with current practices 2. Available and affordable spare parts 3. Credit and finance— realistic, available, and affordable 4. Sensible subsidies and price support if implemented
Farmer-based cooperative enterprises	1. Better management skills 2. System designs and procedures, technical and financial
Machinery importer/ distributor/ dealer	1. Credit and finance—realistic, available, and affordable 2. Technical and financial assistance and advice 3. Understanding of farmer needs and potential markets
Manufacturers	1. Favorable domestic economy and policy to promote local and/or foreign investment 2. Credit and finance—realistic, available, and affordable 3. Lower cost of raw material—steel products 4. Hardware designs/jigs and templates 5. Marketing assistance 6. Technical assistance and advice (especially for smaller-scale manufacturers) 7. Well-defined market needs
Extension engineers	1. Information bulletins 2. Training on technologies 3. "Basket" of technology options to meet farmers' needs
Researchers	1. Security in funding 2. More experience in commercial processing and business operations 3. More training on research instrumentation
Consumers	1. Graded and packaged rice at reasonable prices 2. More consistent quality for varietal brands 3. More choices 4. Longer shelf life of rice products 5. Fewer contaminants
Policymakers	1. More economic information 2. Better understanding of the workings of industry to develop appropriate policy

Source: Clarke 1997.

Table 11. Expected outputs/needs of different stakeholders in postproduction systems.

Stakeholder	Expected outputs/needs
Rice farmers	1. Mechanized harvesting technology, competitive with current practices 2. Guaranteed farm-gate prices 3. Premium prices for good-quality harvest 4. Threshing and transport services to remove burden from farmers, particularly during periods of inclement weather
Rice-processing businessmen	1. Local options for upgrading processing plants (specifically choice of drying plants with the capacity to dry the volumes purchased during the rainy season, with the cost of drying competitive with sun drying) 2. Hardware and software for producing better-quality rice products 3. Technology for using rice hull as a source of energy for drying, even powering the rice mill, that is convenient to operate 4. Milling technology that gives better total and head rice recoveries 5. Standardized varieties in terms of physical and biochemical properties 6. Bulk handling technology for lower handling costs 7. Cost-effective pest control technology
Extension engineers	1. Information bulletins 2. Training on technologies
Manufacturers	1. Lower cost of raw material—steel products 2. Hardware designs 3. Marketing assistance 4. Jigs and templates
Farmer-based cooperative enterprises	1. Better management skills 2. System designs and procedures, technical and financial
Consumers	1. Graded and packaged rice at reasonable prices 2. More consistent quality for varietal brands 3. More choices 4. Longer shelf life of rice products 5. Fewer contaminants
Researchers	1. More experience in commercial processing and business operations 2. More training on research instrumentation
Policymakers	1. More economic information 2. Better understanding of the workings of industry

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Agricultural mechanization: a history of research at IRRI and changes in Asia

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Some of the earliest formal engineering efforts on behalf of Asian agriculture were those concerned with irrigation, drainage, and water supply development. Governments or other large organizations of involved parties sponsored most of these efforts. These land and water development activities were so site-specific that much of the engineering had to take place locally.

The development/adoption, use, and maintenance of engineering-based technology by the private sector appeared in the early days on the Asian scene in the form of systems for the milling of grains and processing of plantation or export crops such as sugar, Manila hemp, cotton, etc. Much of the engineering of these processing technologies had been imported, but their installation, maintenance, and operation required on-site engineering activities.

A pattern similar to that of the engineering of land and water development technologies applied to the development of the transportation infrastructure, which served all economic sectors, but which was one of the essentials of the structural transformation associated with modernized, high-productivity agriculture. The engineering of the mobile transport equipment that operated within this infrastructure, however, followed a pattern similar to that of the crop-processing technologies. Thus, formal engineering inputs to Asian agriculture were introduced in connection with well-developed public- and private-sector organizations.

For hundreds of years earlier, informal development of "traditional" technologies had been going on in Asia. This dealt with not only water handling, transportation, and crop processing but also farm field operations. It has been primarily within the past 50 years that formal engineering has found its way into this latter technical arena. The pathways for this infusion have involved both imported technology and local technology development and have involved both the public and private sectors. Furthermore, these formally engineered technologies have interfaced with, and operated side-by-side with, traditional technologies. The resulting milieu in which formal engineering activities engaged with agricultural mechanization in Asia in the early 1960s was a scene with many individual initiatives. The great complexities of such a situation implied that any engineering inputs advanced had little chance of finding their way into mass on-farm use unless they happened to match exactly the on-farm operational requirements and the technical capabilities of the manufacturer, distributor, and sales/service organization. Both the technical and economic aspects, from all points of view, needed to be satisfied by the engineering designs put forward.

Agricultural mechanization research at IRRI

The Agricultural Engineering Department (AED) of IRRI was initially (1960) concerned with the development and maintenance of research facilities for the Institute and with the field operations required. Once this work had been completed and institutionalized, attention was turned to

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research aimed at understanding the constraints and potentials associated with the application of low-cost inanimate energy to rice-farming operations on wet soils. Key information on energy requirements and energy form equivalents was developed. Much work was also done on traction problems on flooded rice soils. In 1965, a grant was received from USAID for research on developing equipment to meet the needs of small-scale rice farmers. This started with extensive survey work to ascertain the economic circumstances of such farmers and the economic conditions that had to be satisfied by equipment that they might adopt.

As equipment design work began (1967), the economic analyses and information gathering focused to a greater extent on the economic potentials of various design alternatives and on the economics of manufacturing and using possible new designs. In support of the equipment design activities, engineering research was also conducted on determining the characteristics of rice plants, soils, and production processes such as water use and growth response to solar radiation. Also in support of the equipment design program, a machine evaluation program was started (later called testing and utilization). This activity aimed at evaluating the design prototypes developed and testing existing technologies to find out how they might be improved, or to find technological features that might be of use in the equipment design work.

The period from 1967 to 1976 saw intensive activity in the equipment design area. As some potentially valuable designs began to become available, the economics research turned more toward understanding the conditions and processes involved in the adoption and use of these designs by small-scale farmers and the comparative changes that such adoption might entail. Basic information was developed on losses associated with traditional practices, how rice is allocated and used in farmers' households, and traditional rice storage and handling methods.

Table 1 lists (in approximate chronological order) the items for which designs were developed and carried through the prototype testing stage. Table 2 lists parallel research on gaining basic engineering knowledge and information, as well as fundamental economic understandings. In addition to these two basic areas of research, a great deal of work was done in various forms (e.g., trials with ..., tests of ..., comparisons of ... with ..., effects of ..., survey findings about ..., performance of ..., development of ...). Most of these activities aimed at gaining understandings valuable in supporting many of the research activities on machine development and rice system characterization. Nevertheless, many of the findings from the "trials with ..., etc." studies had not been generally known previously, and the distribution of these findings was of value to other engineers and economists. Table 3 provides information on the subject-matter distribution for published reports of AED work at IRRI.

In the early 1970s, a new category of activity called "industrial extension" was started. Even though the equipment designs developed involved major efforts to have all machine components of a type that could either be made by existing local manufacturing technologies or be acquired at competitive cost in local markets, small-scale manufacturers were generally reluctant to be the first to build a new product. IRRI industrial extension engineers working with these manufacturers were able to overcome this reluctance and assist in making sure that the manufactured products were of good quality. The good notices received by this industrial extension program from all quarters were the basis for expanding this activity to other rice-growing countries. These engineers extended IRRI equipment designs and assisted local manufacturers in other countries in the manufacture of complementary items and in the modification and adaptation of IRRI designs to local needs. The countries participating were Bangladesh, India, Indonesia, Myanmar, Pakistan, the Philippines, Sri Lanka, and Thailand.

Table 1. Equipment designs developed through the prototype stage.

1. Cone thresher
2. Rotary wetland tiller for large tractors
3. Tractor PTO[a]-driven thresher
4. Drum (hold-on) thresher
5. Table thresher
6. Tractor PTO-driven push-type tiller-puddler
7. Traction aid auxiliary wheels
8. Power weeder
9. Anhydrous ammonia applicator (2-wheel)
10. Rice stripper-harvester
11. Rotary harrow for small tractors
12. Row seeder for lowland rice
13. Rotary screen winnower
14. Differential slip cage-wheel tiller
15. Heated sand dryer
16. Flame-type conducted-heat dryer
17. Accelerated dryer for sorghum
18. Rice hull furnace
19. Multipurpose tool carrier
20. Convection dryer
21. Manual grain cleaner
22. Thresher for Taiwan
23. Row seeder for pregerminated rice
24. Upland row seeder
25. Extendible strake lug wheel
26. Manual submersible pump
27. Individual row hopper-seeder
28. 4–6 hp tiller
29. Low-lift bellows pump
30. Laboratory centrifugal huller
31. Axial-flow thresher
32. 8–14 hp tiller
33. Herbicide applicator (wiper)
34. Batch-type dryer
35. Steel huller rice mill improvements
36. Low-lift irrigation pump
37. Moisture tester
38. Power grain cleaner
39. Reciprocating grain cleaner
40. Steering clutches for 5–7 hp tiller
41. 15–20 hp four-wheel tractor
42. Deep-placement liquid fertilizer injector
43. Deep-placement granular applicator
44. Jet pump attachment
45. Vertical axis windmill
46. Solar collector for grain dryer
47. Single-pass rice miller
48. Tubular pump
49. Self-propelled cart/thresher
50. Parboiling machine
51. Diaphragm pump
52. Batch dryer burner
53. Twin-bed batch dryer
54. Spot injector for granular fertilizer
55. Steam engine (gas engine conversion)

Table continued

Table 1 continued.

56.	Portable thresher
57.	Portable grain cleaner
58.	Rice transplanter
59.	Piston pump for windmill
60.	Combine harvester attachment for power tiller
61.	Rotating bowl rice mill
62.	Multicrop upland seeder
63.	Producer gas generator
64.	Load-sensing tool carrier
65.	Axial-flow pump
66.	Rotary tiller for 6–8 hp tractor
67.	10-row liquid injector
68.	Wetland paddy seeder
69.	Inclined-plate planter
70.	Dryer-burner safety valve
71.	Head-feed thresher
72.	Half-ton batch dryer
73.	Floating rototiller modification
74.	Foot-powered pump (piston)
75.	Solar tunnel dryer
76.	Rotary drum dryer (coconut husk-fired)
77.	Vortex wind machine (warehouse ventilator)
78.	Rat barrier
79.	Snail-egg clapper
80.	Cono puddler
81.	Peristaltic pump
82.	12-row transplanter
83.	Small sprayer
84.	Tube-well drilling rig
85.	Closed transfer system sprayer
86.	Mini-boom sprayer
87.	Spinning brush applicator
88.	Cono weeder
89.	Star-wheel reaper
90.	Rice husk stove (2)
91.	Test-tube miller
92.	Rice stripper (British patent teeth)
93.	Biomass chopper
94.	Air-stream seed cleaner
95.	Agricultural waste furnace
96.	Warehouse dryer
97.	Two-furrow plow
98.	Root crop chipper
99.	Axial-flow drying fan
100.	Rolling injection planter
101.	Motorcycle PTO
102.	Volcanic ash removal auger

"PTO = power takeoff.

In the late 1970s, there was concern in some circles in developed countries that the mechanization of agriculture in developing countries would lead to social disruption in those countries with regard to employment, income distribution, and even agricultural production. To address this concern, the economics section of the IRRI AED undertook a special research project funded by USAID on "The Consequences of Small Farm Mechanization on Rural Employment, Incomes, and Production in Selected Countries of Asia." The study involved four research sites in

Table 2. Institutional research projects.

1. Data on evapotranspiration, seepage, and percolation
2. Soil tillage depth effects on rice
3. Physical properties of the rice plant and kernel
4. Actual farmers' field scheduling and distribution of operations
5. Energy requirements for rice farm operations
6. Rice soil trafficability—cone index variations over time
7. Power requirements for rotary tillage of wetland
8. Torque measurement dynamometer for tractor PTO[a]
9. Dynamometer to measure 6-component soil forces on tillage tools
10. Threshing cylinder type characteristics
11. Design parameters for horizontal oscillating screens
12. Tractor rolling resistance in wetland conditions
13. Effects of stubble treatment on ratoon rice
14. Performance of cage wheels and other traction aids
15. Dynamic analysis of rotary tillage
16. Breaking dormancy of seed (chemicals, heat)
17. Design parameters for rotary screens
18. Accelerated conduction drying of rice
19. Rice-milling characteristics
20. Centrifugal rice-milling methods
21. Forces on lugged wheels
22. Solar-drying methods
23. Rice straw fuel properties
24. Partial-drying process characteristics
25. Compacted soil pan studies
26. Dryer fan performance characteristics
27. Rice hull char properties
28. Sun-drying process characteristics
29. Human energy measurements in wetland tillage
30. Water-use efficiency characteristics
31. Pump test flowmeter
32. Rice growth response to solar energy
33. Water buffalo energy input/output characteristics
34. Instrumented pulley for power measurement
35. Flooded rice soil physical properties
36. Economic demand for tractors
37. Economic effects of farm size
38. Rice field grain losses
39. Home consumption and marketable surplus of rice
40. Farm-level rice storage characteristics
41. Postproduction grain losses
42. Employment statistics and dynamics for rice farm communities
43. Economics and costs of manufacturing IRRI machines
44. Grain dryer value analysis
45. Economics of tiller, thresher, and reaper use
46. Income distribution statistics and dynamics for rice farm communities

[a]PTO = power takeoff.

three countries and assembled data from 1,300 farm and landless households over a two-year cropping period. Also undertaken were a large number of special case studies. The sites were in West Java and South Sulawesi in Indonesia, Suphanburi in Thailand, and Central Luzon in the Philippines.

With the advent of the 1973 oil embargo, attention was focused on fossil fuel consumption not only for the sorts of technology with which the AED was working but also for

Table 3. Subject-matter distribution for 394 publications of the IRRI Agricultural Engineering Division (1963-96).

Subject matter	Publications (no.)
Field operations, machinery, and implements	125
Irrigation and irrigation equipment	24
Tillage	27
Fertilization	24
Planting	30
Pest control	15
Weeding	5
Postproduction operations	130
Harvesting and threshing	41
Rice milling and processing	38
Drying	44
Biomass use	7
Machine testing and evaluation	7
Mechanization in agriculture and economic development	63
Economics of mechanization	69
Mechanization, income, and employment	39
Comparative economic studies of rice production and processing	17
Economic aspects of machinery manufacturing and marketing	13

the fertilizer manufacture and water management control technologies that served as key inputs to the yield-increasing developments of the central IRRI research program. Consequently, agricultural engineering research at IRRI began to include studies on methods to apply fertilizers in a more effective manner and on the use of rice husks and rice straw as energy resources to replace fossil fuels in cooking, drying, parboiling, and milling.

Chemical control of rice pests has for some time been considered as part of a modern production methodology. In recent years, data have begun to appear on the large numbers of farm workers in Asia who suffer from the toxic effects caused by these pesticides. Agricultural engineering research at IRRI therefore includes work on both safer ways to use pesticides and nonchemical methods of pest control.

Nominally, equipment design and the economics of mechanization programs at IRRI have been the focus of the work in the AED. The unique facilities at IRRI, the concentration of highly capable engineers and scientists, the abundance of authoritative published information, and the large number of development ideas, projects, and prototypes associated with the AED, however, have made IRRI an important center for agricultural engineering information exchange in Asia. Many visiting engineers and scientists from around the world have been part of the AED's activities.

Agricultural engineering and rice farm mechanization conferences at IRRI have had sufficient resources to bring together numbers of experienced researchers that were large enough to ensure many valuable information exchanges. These exchanges have been backed up by publication and documentation programs that have extended these exchanges far beyond the individuals involved. Thus, IRRI has served the agricultural engineering field in Asia as a communication center. In addition to this communication function, the AED has had an educational role. Nearly 100 postgraduate students from universities throughout the world have worked with IRRI AED personnel and facilities to do their thesis research. The AED has also done cooperative research with other organizations such as the U.S. Department of Agriculture National Soil Dynamics Laboratory, the Chinese Academy of Agricultural Mechanization Sciences, the Philippine Ministry of Agriculture, and the U.N. Regional Network for Agricultural Machinery.

The activities of the IRRI AED have, probably more than those of any other IRRI department, been funded on a special-project-by-special-project basis. This has caused staffing and research program planning to be of a somewhat different nature than for other IRRI departments. This may have caused the program of agricultural engineering to be considered as "adjunct to" or "less integrated with" overall IRRI objectives and work than may have been the case for other departments. At various times, efforts have been made to change this situation, but the weight of precedent and the wishes of donors have impeded such change.

Mechanization developments in Asian agriculture

When agricultural mechanization research began at IRRI in 1962, almost all Asian food-grain production used animal and human power. Since that time:

1. Japanese, Taiwanese, and South Korean agriculture has become essentially fully mechanized, using first small-scale equipment and now machines of increasing size.
2. The rice-growing area of northwestern Malaysia has experienced a major outflux of young rural people to industrialized centers, with fields now being tilled by large tractors and harvested by large combines owned by farmers' associations or by private contractors.
3. India has become the country manufacturing the greatest number of four-wheel tractors of any country in the world and it has more than one million in operation.
4. Factories in the People's Republic of China have for several years been manufacturing about one million two-wheel tractors per year, many of which carry out transport duties in nonagricultural seasons.
5. A locally designed two-wheel tractor has become popular in Thailand, with annual production on the order of 50,000.
6. The IRRI axial-flow thresher extended to Thailand by the IRRI industrial liaison program has been enlarged by local manufacturers and is now used extensively. Some manufacturers have further developed the thresher into a self-propelled combine that is increasing in popularity.
7. A locally designed axial-flow pump has become popular in Thailand and is widely used. It is powered by the engine of the local two-wheel tractor. A similar pump has become common in Vietnam.
8. Used four-wheel tractors from Europe (50–70 hp) and from Japan (15–30 hp) have become available in Asia at low prices.
9. Large tractors for tillage and tractor-mounted reapers for harvest are being used extensively in Pakistan.
10. The IRRI axial-flow thresher has become widely used in the Philippines.
11. Diesel- and electric-powered pumps in Indian agriculture now number about 12 million.
12. Most of the wheat in India not harvested by combines is threshed by diesel- or electric-powered threshers.
13. All maize produced in Thailand is shelled by locally made power-driven shellers.

14. Intermediate-scale rice mills have taken over (from hand pounding) the majority of rice processing in Indonesia.

The above list could be extended with many similar citations. But many fields in Asia are still operated with animal and human power, and many more use this energy source for some operations, whereas tillage and threshing are mechanized. Thus, the environment in which formal engineering activities may engage with agricultural mechanization in Asia is now composed of a traditional sector, a modernized sector, and a third sector that involves potentials and problems that will become apparent in the near future.

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Increasing the impact of engineering in agricultural mechanization: some thoughts from the profession

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In this paper, we present and assess the results of a survey of the views of key people on the past, present, and future of public-sector agricultural engineering in developing countries. The survey found a general consensus that there was a need for agricultural engineers in international and national research and development (R&D) units to look at the methodological approach used for research, development, and transfer. Respondents believed that future funding could best be secured and enlarged by adopting an R&D protocol that placed agricultural engineers within a multidisciplinary team working closely with the private sector. The team would provide not only innovative prototype designs but also a whole package of other inputs to help manufacturers successfully commercialize the new technology, and help end-users learn how to use it. In addition, agricultural engineers should clarify the roles of the public versus private sector, clarify priorities, and communicate success stories more effectively. Most respondents thought that there had been a serious decline in funding for agricultural engineering in some areas because public-sector agricultural engineering has had, or has been perceived to have had, little impact in farmers' fields. One reason suggested was that these R&D units often have little contact with commercial companies and end-users and, as a result, have not been able to develop technologies that meet real needs. Agricultural engineers working for the public sector in developed countries, who have also faced serious declines in their profession, have for some time realized that their survival depends on close links to the private sector. They have had to learn new skills and to work within multidisciplinary teams. In developing countries, a very limited number of R&D units have been working closely with the private sector. This paper concludes that understanding why more R&D units have not adopted this multidisciplinary R&D approach, and then working to remove constraints, is critical for the future of public-sector agricultural engineering in developing countries.

Since 1984, staffing levels of the Agricultural Engineering Division (AED) at the International Rice Research Institute (IRRI) have fallen from nine internationally recruited engineers to two, and from 17 nationally recruited engineers to five. For some time, we have been concerned about the reason for the decline and what can be done to reverse it. We have corresponded with a number of key people in agricultural engineering and other disciplines, and have received a wealth of informed feedback. We believe this feedback will be of value to other agricultural engineers who also want to reverse, or avoid, the decline. The major part of this paper reports the responses to an e-mail survey, which asked the following questions:

- Have other agricultural engineering R&D units experienced declines similar to that at IRRI?
- What have been the causes of the declines?
- Does the public sector have a legitimate role in trying to develop machines for small-farm agriculture?
- What can be done to reverse the decline?

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- Amir Kahn, Consultant, ATDP/IFDC project in Bangladesh and former head of AED, IRRI.
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- Kamil Okyay Sindir, Department of Agricultural Machinery, Ege University, Ismir, Turkey.
- Bill Stout, Professor of Agricultural Engineering and President of CIGR, Texas A&M University, USA.
- Derek Sutton, Chief Advisor to DFID's Renewable Natural Resources Research Strategy, Silsoe Research Institute, Silsoe, England.
- Brendan Williams, Consultant, Pathway Precision Farming/Agri-Technologies, Victoria, Australia.

Extent of the decline

The decline in public-sector agricultural engineering goes beyond IRRI and the small-farm sector, and seems particularly prevalent in developed countries. For example, according to Williams, "...agricultural engineering in Australia has seen a massive decline...since 1984," bigger than declines in other agricultural disciplines over the same period. From the United States, Butts said that retiring engineers at the National Peanut Research Laboratory are not necessarily being replaced, in spite of having research programs tuned to industry's and donors' requirements. Stout (referring to agricultural engineering institutes) said in an article he wrote in September 1997 for *Resource*, "Just about every agricultural research and education program that I have visited around the world has had recent budget cuts." Friedrich says that student enrollment in agricultural engineering is down.

The decline in agricultural engineering, however, does not seem to have yet affected national agricultural research systems (NARS) in developing and newly industrialized countries. De Padua believes that the numbers of agricultural engineers employed by the public sector in Thailand, Indonesia, and the Philippines have increased since 1984, as have numbers of students enrolling in agricultural engineering.

Chancellor points out that the decline in IRRI's AED may not be representative because the Division was originally conceived without a research mandate to design and maintain IRRI's own equipment. Since then, AED's research has been more dependent than other IRRI divisions on direct donor funding. Rijk agrees that the IRRI AED is different, because IRRI, like other international research centers, was set up to overcome R&D problems in NARS.

Reasons for the decline

Seven of the 17 respondents said that lack of impact was the main cause of the decline. Clarke said that in his involvement with agricultural engineering over 29 years, he has visited government- and university-run R&D workshops in most of the 30 countries he has been to: "In these workshops, it is common to see rows of prototypes that have been 'developed.' But one virtually never sees any of these prototypes in commercial production and in common use in agriculture. The returns to investment in this R&D appear to be very low or nonexistent." Rijk said that he had taken hundreds of slides of prototype equipment at R&D centers, but had hardly ever taken a picture of the same piece of equipment operating in a commercial environment. Conze said that the decline was because there were no examples anywhere in the world where the public sector had successfully developed smallholder machines. But de Padua pointed out that in some cases NARS engineering R&D has been "cutting edge" and commercially successful. He mentioned the development of the fluidized-bed dryer at the King Mongkut's Institute of Technology Thonburi (KMITT) in Thailand as one of a number of examples. Even with such successes, however, de Padua concluded that NARS R&D has generally had less impact than it might have had because of an R&D protocol that lacks links with target beneficiaries and the private sector.

Williams thought that the decline of the profession in Australia was in part due to both poor performance and a failure of agricultural engineers to publicize and promote their activities. Conze and Friedrich thought that agricultural engineers in Germany have suffered from a failure to communicate the importance of the profession. Conze suggested that a contributing factor is that agricultural economists, who have been more successful in communicating, have failed to acknowledge mechanization as an important production factor. Stout (1997), in his *Resource* article, also pinpointed failure to communicate effectively as one reason for the decline, and Borlagdan agreed with Stout that all agricultural engineers should promote their work more vigorously through publishing and the popular media.

Balasubramanian and Chancellor both said that the perception that small-farm mechanization was labor-displacing and hence socially undesirable contributed to the decline in the past, but was less of an issue now. Chancellor said he believed the main reason for the decline is that many people do not see the contribution of agricultural engineering to the general development process. He pointed out that advances in civilization occur when people are released from agriculture to do other things. People are released by technological change that increases yields, makes farm work more efficient, and reduces crop loss. Mechanization is a component, often a key component, of this process.

Is there a legitimate role for public-sector agricultural engineering?

We occasionally hear the comment at IRRI that the private sector can meet agricultural engineering needs, and therefore the public sector is perhaps obsolete. We asked our key respondents for their opinion on the validity of this view and how prevalent they thought it was. Chancellor said that he had heard virtually no one argue that developing machines for smallholder agriculture in developing countries should be left completely to the private sector. Conze, on the other hand, believed that some people did take the view that public-sector R&D should not be funded because R&D units had been completely unsuccessful in developing equipment that was subsequently adopted by farmers—unless the prototype had been given to the private sector right after the research stage. But he did see agricultural engineering as having a crucial role to play in CIS countries (former USSR), where a lack of appropriate equipment is the single most important reason for crop failures and falling agricultural output.

Gummert, Harris, Borlagdan, and Sindir all said that there must be a role for the public sector because manufacturers supplying the small-farm sector in developing countries are too weak to invest sufficiently in R&D. Interestingly, this may also be true to some extent in the United States. Butts said that companies in the U.S. manufacturing equipment for producing, harvesting, and curing peanuts are generally small, with very limited R&D resources. Gummert said that the public sector has a vital role to play in making available, to the private sector, technologies that have been successfully applied in other parts of the world. He pointed out that, without the public sector playing this role in the past, axial-flow threshing, stripper harvesting, and in-store drying would not have been applied in the tropics. Sindir said that manufacturers in developing countries, if they had no R&D support, simply copied imported machines rather than developing something more appropriate. Williams said that agricultural engineering in Australia has suffered from having a weak manufacturing base from which to work. This is because Australia imports most of its agricultural equipment from the U.S.

Clarke, Rijk, and Friedrich thought that the public sector would have a role *only* if it profoundly changed the way it works.

Reasons for lack of impact

- Balasubramanian gave the following reasons for the lack of impact of agricultural engineering:
- A lack of "breakthroughs"—most agricultural engineers tinker with machines that came from somewhere else, making minor improvements.
- "Improvements" are made without considering farmers' real needs for mechanical technologies.
- The machines that reach end-users are of poor quality because of inadequate interaction between the public sector and manufacturers.
- The public sector fails to ensure that end-users are adequately trained in machine operation and maintenance, and in making simple repairs.
- The public sector gives little or no assistance to manufacturers to modify and improve machines on the basis of feedback from early adopters.

The idea that the successful introduction and adoption of a new technology requires more from the public sector than just the provision of a prototype is shared by Clarke, Rijk, and Friedrich. Clarke pointed out that "the development of prototypes outside of the environment in which they will have to be mass-produced and marketed fulfills only a part of the process of the commercialization of a product." He believes that the failure of the public sector to assist with the whole process of commercialization (and by implication the failure of the private sector to manage without this assistance) is the reason for the negligible number of public-sector prototypes that make it into commercial production and hence farmers' fields.

Borlagdan, who has worked in the Philippines agricultural engineering sector, found that the link with industry was almost nonexistent. He observed that R&D units were driven more by the prospect of government funding for a project than the needs of industry and farmers. Rijk and

Conze agreed with this perspective, saying that NARS R&D units were driven more by political considerations than real need.

Chancellor was more positive about the impact of public-sector agricultural engineering. About 15 years ago, he prepared a list of 26 mechanization "success stories" in Asia. Seven of them had a direct linkage to public-sector R&D. In many of the other cases, he found that "public-sector R&D first produced alternative approaches, which were not chosen by industry. Via this seemingly unsuccessful work, the field of alternatives was narrowed to the extent that industrial ventures could proceed with a reduced probability of failure. Thus, some credit was due to public-sector efforts, though the linkage between the adopted technology and the institutional work was not immediately obvious." Gummert noted six more-recent successful technologies that have been developed or adapted by the public sector in close collaboration with manufacturers.

Gummert believed that part of the problem is that, although donors are increasingly funding projects aimed at system and capacity building, impact is still being assessed in traditional terms—numbers of machines adopted in farmers' fields. This is because it is easy to count machines, but harder to measure the extent and impact of capacity building. Also, he pointed out that most development projects run for, at most, nine years—three project phases of three years each. Projects need to demonstrate quick results to get the second phase funded, and this requirement often hinders the development of a sound approach.

Muhtar thought that agricultural engineering had suffered because agricultural engineers were perceived to work as "lone rangers," outside the rest of the research system. This criticism is consistent with other comments suggesting that public-sector agricultural engineering lacks a problem-solving orientation. Instead, it emphasizes technology (= machine) generation. Thus, the finished R&D product is a machine that sits in a showroom, rather than a problem solved. This has led to criticism of the profession as a group of "tinkerers."

When comparing agricultural engineering with other disciplines, Keatinge noted that agronomy had not done any better than agricultural engineering in achieving impact in farmers' fields. He said, "There are a substantial number of agronomic prototype technologies 'on the shelf,' but the failures are less obvious than prototype machines. Likewise, in plant breeding, to get one widely adapted variety, you have to release really quite a number and then be lucky. It is just that breeders have a continuous technology delivery pipeline set up and funded, which makes it easier for them to ride out the periods with lack of success." Williams agreed, saying that, in an Australian context, "We have plant breeding programs with 20 times the budget (of agricultural engineering R&D units) that have not displaced the one main variety that has been with us for 20 to 30 years.... The breeding programs have never been cut back because they do a great job of selling themselves."

How to reverse the decline

In his paper in *Resource*, Stout (1997) throws down the gauntlet to engineers to promote their work as much as possible. Chancellor indicated that engineers should try to communicate the "big picture" of agricultural engineering's contributions to civilization. Sutton believed that the role of agricultural engineering in development was somewhat confused, as were the relative merits of public- and private-sector involvement in the development process. He suggested that agricultural engineers needed to develop clearer messages and define priorities more distinctly and credibly.

Nearly all the respondents said that public-sector engineers should work much more closely, and much earlier in a project cycle, with the private sector. Friedrich said that they should be involved right from the conception of an idea. Clarke said, "Traditional government and university workshops should cease doing actual engineering work in their own isolated environments. They should develop a core of experts (and not just engineers) that can be put into companies to provide a package of assistance when and where required." Balasubramanian said that the public sector should work with a select set of manufacturers, providing them with innovative designs, assistance in quality control, and a bundle of machine "software" including operator manuals and training videos. A package suggested by Clarke is designed around the individual needs of the company and may contain all the elements needed to successfully develop and market the product, including "identifying the product (market studies), identifying investment requirements to make the product, assisting with production engineering and cash flow, helping to identify and prepare commercial credit packages, developing the supply chain, and assisting with any other factor affecting the development of the product and the market."

Rijk said that IRRI's industrial extension program had probably been the most successful agricultural engineering program in developing countries, an outcome that supported Clarke's strategy of providing support to companies. (The IRRI industrial extension program began informally in the early 1970s, and received $3.6 million in USAID funding from 1980 to 1986, when the money stopped.) Stout agreed that IRRI's approach—help to develop the private sector and provide prototype technology—was correct. Rijk, on the other hand, had doubts on the cost-effectiveness of bilateral projects providing this support through the NARS, which are driven by national political considerations and not real need. He recommended that donors consider direct delivery of technical assistance to the private sector.

Gummert said that in a country such as Indonesia it was not feasible for a bilateral project to completely bypass the public sector because it is impossible to give field demonstrations of new equipment without involving the local government. He pointed out that there were advantages in working with government in terms of sustainability and extending industrial assistance programs and new technologies over more of the country.

Friedrich said that German research institutes were increasingly seeking to develop expertise in particular areas, making a name for themselves and attracting commercial companies keen to buy research from them. He suggested that this might be a model for developing countries to follow as well. The development of the fluidized-bed dryer and combine harvester in Thailand demonstrates that Thailand, which has a relatively well-developed agricultural machinery industry, is moving along this path.

Conclusions

The level of consensus in the responses to our survey surprised us. True, there are also some important differences in opinion, but this perhaps points to the confusion in understanding the role of agricultural engineering in development that one respondent highlighted.

Most respondents thought there had been a serious decline in international agricultural engineering for development and in public-sector agricultural engineering in developed countries since the early 1980s. The decline had been greater than that in other disciplines. But agricultural engineering in developing and newly industrialized countries may actually have increased during the period.

Most respondents thought there was a legitimate role for the profession, especially in providing support to commercial companies that supply the small-farm sector. A smaller number said that support was needed because these companies, even in the peanut sector in the U.S., are too small to be able to invest much in R&D.

Most of those surveyed believed that the decline in agricultural engineering had occurred because traditional R&D units in government agencies and the universities have had little or no contact with commercial companies and end-users. As a result, they have developed machines that have not met real needs. Even if a prototype has met a real need, R&D units have provided little more than the hardware, and companies have not had the capacity to successfully commercialize it.

There was a consensus that reversing the decline in the profession depends on achieving greater impact, and publicizing that impact far more effectively, particularly to policymakers. There was also a call for engineers to clarify and communicate the roles and priorities of agricultural engineering.

Respondents generally agreed that, to achieve greater impact, agricultural engineers need to provide not only innovative designs but also a whole package of other inputs, tailor-made for select companies, that might include everything needed to successfully commercialize the product—in other words, industrial extension or liaison. Three of our survey group said that IRRI had successfully done this from the early 1970s to 1986. In 1985, a review of the agricultural engineering components in the CGIAR system identified IRRI's industrial extension program as the key to its success (NIAE 1985). The most successful technology to emerge from this program, which several respondents mentioned, was the axial-flow thresher, which has now been successfully commercialized in at least 10 Asian countries.

Two important questions emerge. First, if IRRI was doing the right thing in the 1970s and 1980s, and this was identified as early as 1985, why then did it stop its industrial extension program? We suspect that one reason is simply that the inclusion of "extension" in the project title led people to see it as extension work and not as an R&D approach that integrated stakeholders in the process. Extension in CGIAR circles tends to be understood as spreading the message about a new technology that has already been tried and tested, and hence the responsibility of the NARS, not IRRI. The second question is: Why have the NARS not generally adopted the approach? Three respondents suggested an answer—the NARS may be working to fulfill political objectives and not the real needs of manufacturers and farmers. There was a significant difference in opinion about the implications of this. One respondent believed that bilateral projects should bypass the NARS and target assistance directly to the private sector. Another said that working with the NARS was crucial for sustainability and wider application of bilateral projects, and the approaches they might develop. A third respondent gave examples where the NARS have successfully worked with manufacturers and end-users to produce commercially successful new technology.

There was some debate about whether low adoption rates for new equipment technology demonstrate that agricultural engineering has failed. Adoption rates for new machines may not be an adequate indicator of success for projects aimed at capacity building or strategic research, for example. It is easy to count machines in the field, but some of the important effects of capacity building occur in the longer term and are much harder to quantify. For example, how do we quantify contributions to improvements in production or postproduction efficiencies through the provision of knowledge leading to improved management of existing machinery or adoption of more suitable alternative technology available "off-the-shelf"? There was also some debate as to what rates of adoption constituted success. Two respondents made the point that agricultural engineering had been no less successful in getting new technologies into farmers' fields than disciplines such as agronomy or plant breeding. A low success rate seems to be inherent in developing new technologies—it is estimated that only 2% of U.S. patents have the potential of becoming major innovations, which suggests that invention has an inherently low success rate (Mongavero and Shane 1982). Failure of machinery R&D programs is more evident because the research products are more visible than seed or a fertilizer recommendation.

Visibility of low adoption rates is certainly an issue. Two respondents gave the large numbers of unadopted prototypes they have seen in R&D units as their measure of failure, and we suspect that many policymakers use the same sort of measure. But there was some debate whether unadopted technologies have zero impact on technology change. One respondent suggested that he had found in a survey that unadopted technologies served to reduce the field of alternatives for the private sector. The same point is made in the technology change literature. According to Mokyr (1990), "Failed inventions are dispensable ex post, but in an ex ante sense all major and minor inventors operated in complete uncertainty about whether their projects would succeed, and thus all were part and parcel of technological creativity." This assumes, however, that the inventors have some links to adoption pathways and are not operating in isolation.

Further questions raised

A. We believe that an important finding from this survey is that the approach agricultural engineering needs to adopt to achieve greater impact has been known and used since the 1970s, but has not been taken up to any great extent. We therefore need to identify and tackle the constraints to the adoption of this approach. To promote further debate in this area, we pose some further questions:
   - What constrains NARS R&D units from working more closely with the private sector? Do national political considerations mean that NARS R&D programs are inherently unsuitable to working effectively with the private sector?
   - Because the main business of most NARS is plant breeding, where the private sector is not a major stakeholder in the adoption pathway, has this constrained NARS R&D units from working closely with the private sector? Can the constraints to adopting an improved R&D approach be overcome? If so, how?

B. The survey reveals that the public sector has a legitimate role in supporting the agricultural machinery sector when it too weak to carry out the R&D required to meet farmers' needs.
   - Are there other legitimate roles for public-sector agricultural engineering?
   - How do the roles change as a country develops?

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Production and use of tractors in India

G. Singh*

The Indian tractor industry, comparatively young by world standards, has grown at a phenomenal pace during the past 35 years. By 1996, the industry had produced more than 224,000 units and had emerged as one of the world's leading producers of four-wheel tractors. This achievement reflects the dynamism of the tractor manufacturers and the pragmatic policies adopted by the government of India to enable the country to meet the growing demand for tractors by Indian farmers. Average annual sales of tractors in India have doubled each decade for the past five decades. Assuming that a tractor lasts for 15 years and a power tiller lasts for 10 years, the number of tractors and power tillers in different states was computed. In 1996, Punjab, the state with the highest wheat yields, had 80 tractors per 1,000 ha, followed by two neighboring states in the north, Haryana, with 59 tractors per 1,000 ha, and Uttar Pradesh, with 22 tractors per 1,000 ha. In contrast, the predominantly rice-growing states with high yields had many fewer tractors—Andhra Pradesh had only 6 per 1,000 ha. Tractor sales are much higher in the northern states where wheat is grown because tractors are more suitable for the dryland preparation for wheat than for land preparation for rice, which is usually carried out in flooded and soft field conditions. Rice fields also tend to be small and bordered by earth mounds for water control, which makes the operation of larger four-wheel tractors difficult. Most power tillers, which are smaller and more suitable for wetland preparation, have been sold in the rice-growing states of southern and eastern India, such as West Bengal, Tamil Nadu, Karnataka, Assam, Kerala, and Andhra Pradesh.

Four-wheel tractors were first used in India in significant numbers for land reclamation. In 1947, the Central Tractor Organization and a few State Tractor Organizations were set up. From 1947 to 1959, about 1 million ha of land were reclaimed. This created demand for tractors to cultivate the reclaimed areas. The number of tractors in use was estimated to be 8,635 in 1951, 20,000 in 1955, and 37,000 in 1960. The annual demand for tractors was met entirely through imports.

When planned economic development of the country began in 1951, the tractor industry was included in the "Core Sector," which indicated its strategic importance. Its growth and development policies were therefore reviewed in each successive National Plan. The farm equipment industry, like other industries, had to follow the legislation enacted under the Industrial Development and Regulation Act of 1951. The main features of this act were:

1. The reservation of certain sectors of core and heavy industry for the government, i.e., steel, heavy engineering, machine tools, aircraft, etc.
2. The reservation of certain classes of items exclusively for manufacture by the private small-scale sector.
3. The requirement to obtain an industrial license from the government for manufacturing any new product when the capital investment in land and buildings required to set up manufacturing exceeded Rs. 1 million.

Companies that required an industrial license, and that had foreign collaborators, had to supply the following information:

- Details on the capabilities of the collaborator and the terms of collaboration.

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- Details on any down payments and royalties.
- Details on the extent of financial participation.

The intention of these requirements was to ensure Indian control of management.

Domestic industry was protected by a ban on imports on products for which local manufacturing capability could meet demand, and by import tariffs when local manufacturing could not fully meet demand. As industrialization progressed, the capital investment level below which a license was not required was increased from Rs. 10 million to Rs. 30 million and then to Rs. 50 million. From 1992 to 1996, the requirement for licenses in most industries was dropped. Development councils for various sectors of industry were set up nationally to advise the government on ways to promote industry. The growth of the farm equipment industry in India has to be viewed in the light of this scenario.

Tractor industry: 1960-70

The development of the tractor industry in the 1960s was dictated by a government policy to promote mechanization of agriculture by encouraging the local manufacture of tractors, and at the same time protecting the interest of farmers by making tractors available to them at reasonable prices. The first local tractor manufacturer began in 1959. Table 1 lists the early manufacturers, their foreign collaborators, and the year they began manufacturing. In the first few years of local production, capacity lagged behind demand, which was increasing sharply. With the expectation that demand would continue to increase, the government issued more industrial licenses to manufacture tractors and allowed the importation of tractors to continue. Although the price of tractors imported from East European countries was lower than that of locally manufactured ones, the government did not believe that the imports were harming the domestic industry because there was an acute shortfall in supply. To increase the demand for locally fabricated components, the government raised the duty on imported components to 40%. To protect farmers, the government imposed price controls on locally manufactured tractors in 1967. In 1968, to further increase local production, the government liberalized the licensing of tractor manufacturers and encouraged other entrepreneurs to begin manufacturing. By October 1974, the supply situation had eased, and the government relaxed price controls on locally manufactured tractors.

Tractor industry: 1970-80

The government's decision in 1968 to encourage new entrepreneurs to begin manufacturing tractors, and the sudden upsurge in demand because of the Green Revolution, led to a flood of requests for new collaboration with foreign companies. Of the six manufacturers that were established in the 1970s (Table 1), Kirloskar Tractors, Harsha Tractors, and Pittie Tractors did not survive. The collaboration of Escorts Tractors Ltd. with Ford ended in the early 1990s.

Emphasis on the local production of tractors continued from 1970 to 1980, with the government fully supporting existing and new manufacturers. At the same time, farmers received additional credit to buy tractors, and the credit market was liberalized. New entrepreneurs were allowed to import both assembled tractors and tractors in complete knockdown (CKD) form until 1973. The oil crisis in 1973, and the resulting economic crisis, led the government to ban imports of assembled tractors, except for specific World Bank projects, and to ban the importation of CKD kits by new entrepreneurs. Stagnant demand after 1973, and the proliferation of manufacturers, made the market intensely competitive. The market began to recover around 1977 as a result of a government directive to commercial banks to set up agricultural development

Table 1. Manufacturers, their collaborators, and the year when production began.

Manufacturer	Collaborator	Year
Eicher Tractors Ltd.	Gebr, Eicher Tractorenfabrik, West Germany	1959
Tractors and Bulldozers Ltd./Gujarat Tractors Ltd.	Motokov-Praha, Czechoslovakia	1963
Tractor and Farm Equipment Ltd.	Massey Ferguson, UK	1961
Escorts Ltd.	Moloimport Warazawa Zaklady Mechaniczne Ursus, Poland	1964
International Tractor Co. of India Ltd./ Mahindra & Mahindra Ltd.	International Harvesters, UK	1965
Escorts Tractors Ltd./Escorts Ltd. (Farmtrac Division)	Ford, UK	1971
Hindustan Machine Tools Ltd. (Central Sector PSU)	Motokov-Praha, Czechoslovakia	1971
Kirloskar Tractors Ltd.[a]	Klochner-Humboldt Deutz, Germany	1974
Punjab Tractors Ltd. (State Sector)	CMERI, India	1974
Pittie Tractors Ltd.[a]	Own know-how	1974
Harsha Tractors Ltd.[a]	Motoimport, Russia	1975
Auto Tractors Ltd.[a]	British Leyland, UK	1981
Pratap Steel Rolling Mills Ltd./ Haryana Tractors Ltd.[a]	Own know-how	1983
VST Tillers & Tractors Ltd.	Mitsubishi, Japan	1983
United Auto Tractors Ltd.[a]	Uzina Tractorul, Romania	1986
Asian Tractors Ltd.[a]	Own know-how	1989
International Tractors Ltd.	Own know-how	1996
Bajaj Tempo Ltd.	Own know-how	1997
Braham Steyr Tractors Ltd.	Case-Steyr Landmaschinen-Technnik, Austria	[b]
Greaves Ltd.	Same Deutz-Fahr, Italy	[b]
New Holland Tractor (India) Pvt. Ltd.	New Holland Tractors, Italy	[b]

[a] Currently not in production.
[b] Product under test and evaluation.

branches to increase rural lending, and the provision of additional funds to commercial banks from the National Bank for Agriculture and Rural Development. Several bumper harvests led to the expansion of irrigation facilities. The production of tractors surpassed 62,000 by 1979 (Figure 1).

Tractor industry: 1980-90

The expansion of the tractor market from 1977, and the anticipation of growing demand, led to the establishment of five more tractor manufacturers between 1980 and 1990 (Table 1). Only one of these, VST Tillers & Tractors Ltd., remains in business. Manufacturers established before 1980

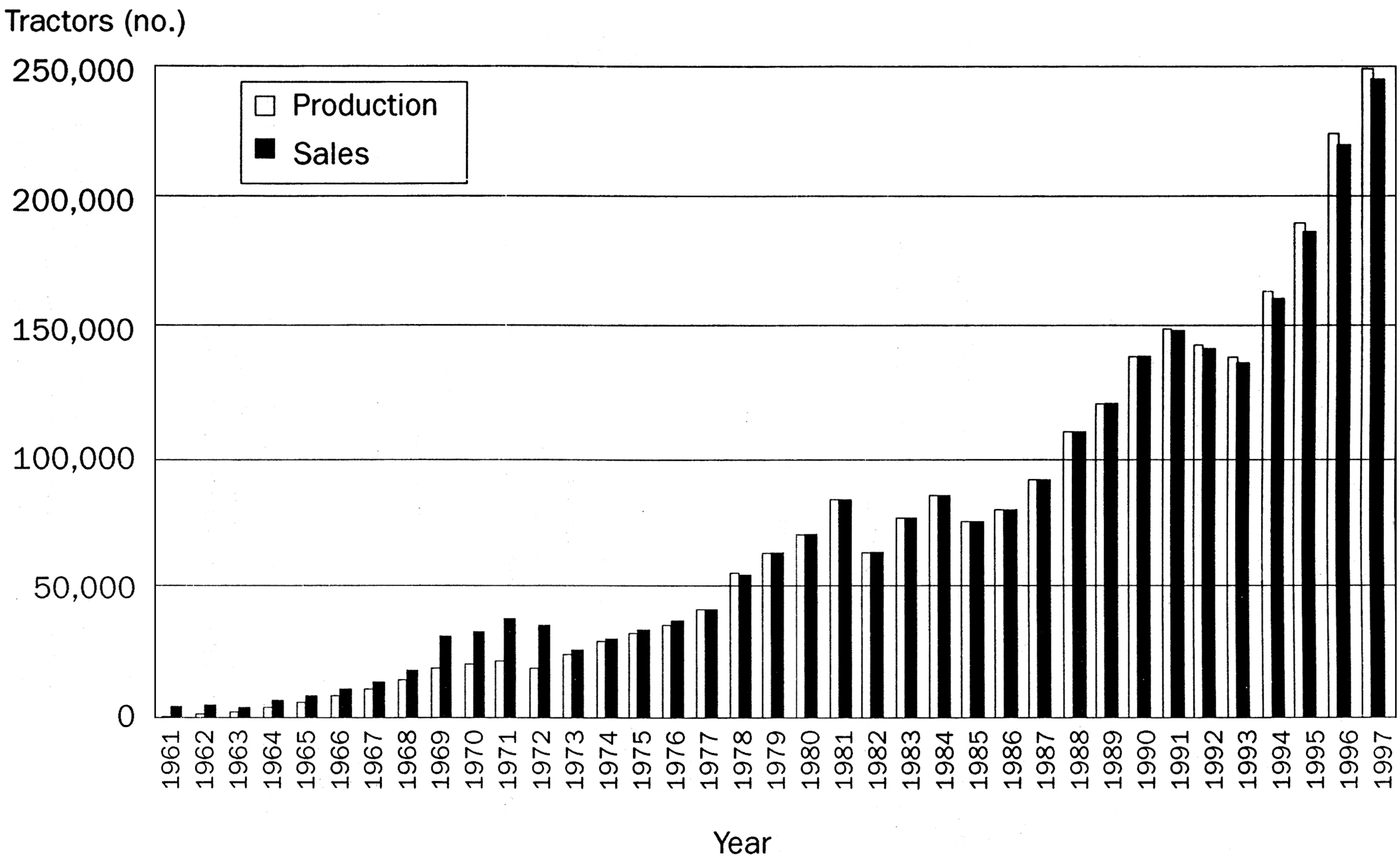

Fig. 1. Production and sales of tractors in India.

had achieved completely indigenous production and were able to increase output during the period. The manufacturers also consolidated their positions and concentrated on improving product quality by upgrading production technology. Working groups in the Ministry of Industry and the Ministry of Agriculture recommended improving tractor fuel efficiency by fixing norms for specific fuel consumption; reducing noise, vibration levels, and emission levels; and increasing ergonomic and safety aspects. The industry grew well from 1980 to 1990 and production surpassed 120,000 tractors by 1989. A net importer of tractors in the 1950s and 1960s, India became a net exporter through sales to Africa.

To make tractors available to small farmers, the government removed the production tax (excise duty) on tractors of 12 drawbar horsepower or less. This tax exemption was subsequently extended to tractors fitted with engines not exceeding 1,800 cc capacity.

Tractor industry: 1990-97

The Indian tractor industry has changed a great deal from the 1960s, when manufacturers needed protection from foreign competition, to now, when they compete in the international market. The tractor market in India is now much more liberal in that local manufacturers, as of 1992, no longer need government approval or an industrial license. Foreign companies can now also manufacture locally themselves, although government approval is required. Imports of assembled tractors, however, are only possible with a government import license. Credit facilities for farmers to buy tractors, which were established in the 1980s, have continued and been increased with additional funding. Table 1 shows the new manufacturers that have begun manufacturing, or are expected to begin soon.

The production of tractors surpassed 220,000 units in 1996, and is estimated to rise to about 300,000 by the year 2000. With the entry of European tractor manufacturers into India, technology and sophistication are expected to improve further in the near future.

Present status of tractor industry

The tractor-manufacturing industry is now well established in India. Of the 18 manufacturers who have set up since 1959, seven have achieved respectable levels of production (Table 2). There are now only two manufacturers of power tillers (Table 3).

All seven tractor manufacturers have developed in-house capability to sustain themselves and expand. Component manufacturers are also well established and the industry no longer depends on imported parts. Recent collaboration with foreign firms is likely to further boost the capabilities of Indian tractor manufacturers. Of the seven that have been successful, six were set up with foreign collaboration, which indicates the importance of foreign technical know-how, particularly when starting manufacturing.

The growth in annual tractor sales has been accompanied by a significant increase in the number of models produced of varying size to meet the diverse needs of farmers. There are now more than 40 models of tractor manufactured in India, ranging in power (measured at the power take-off—PTO—shaft) from 11 kW to 50 kW. Table 4 provides technical details of the tractor models produced in India. The increase in the power range reflects the diversity of the market, which is made up of large, medium, and small farmers, and entrepreneurs who provide custom-hire services.

Table 2. Sale of tractors by make, 1996.

State	Eicher	TAFE	M&M	GTL	PTL	Ford (Esc.)	Escorts	HMT	VST	Subtotal
Andhra Pradesh	947	2,515	7,416	53	1,579	289	582	961	4	14,346
Assam	0	142	125	12	8	2	35	24	9	357
Bihar	586	1,240	1,659	12	1,138	205	1,454	1,654	2	7,950
Gujarat	647	5,642	5,417	197	2,820	1,548	2,047	1,243	112	19,673
Goa	0	0	0	0	0	0	0	0	2	2
Haryana	5,214	1,882	3,168	0	2,884	3,309	4,364	969	0	21,790
Himachal Pradesh	0	0	55	0	0	0	0	216	0	271
Jammu & Kashmir	0	0	130	0	128	80	87	19	0	444
Karnataka	17	3,383	3,360	160	618	590	683	2,407	26	11,244
Kerala	0	136	574	18	104	47	49	1	1	930
Madhya Pradesh	2,500	2,744	4,467	239	4,754	1,160	4,069	3,249	1	23,183
Maharashtra	107	3,654	6,042	361	2,097	1,812	2,646	1,406	140	18,265
Manipur	0	67		0	0	0	0	0	0	67
Orissa	0	663	868	4	236	57	275	286	2	2,391
Punjab	2,709	3,153	5,490	38	5,251	4,422	4,055	1,966	0	27,084
Rajasthan	1,679	7,261	4,587	46	2,216	2,370	2,696	794	0	21,649
Tamil Nadu	32	4,705	4,143	126	520	583	675	876	5	11,665
Uttar Pradesh	6,209	4,468	7,188	31	8,001	1,235	11,132	2,435	3	40,702
West Bengal	0	175	845	19	286	1	307	369	11	2,013
Other States	0	0	0	0	0	0	0	0	0	0
Union Territories	156	0	38	3	394	6	12	0	2	611
Exports & others	0	1,755	1,803	15	0	149	28	143	0	3,893
Total	20,803	43,585	57,375	1,334	33,034	17,865	35,196	19,018	320	228,530

Table 3. Sale of power tillers by make, 1996.

State	VST	KAMCO	Subtotal
Andhra Pradesh	321	5	326
Arunachal Pradesh	0	0	0
Assam	367	530	897
Bihar	24	27	51
Gujarat	193	24	217
Goa	318	12	330
Haryana	0	0	0
Himachal Pradesh	0	0	0
Jammu & Kashmir	0	0	0
Karnataka	1,661	30	1,691
Kerala	428	151	579
Madhya Pradesh	66	7	73
Maharashtra	360	74	434
Manipur	0	190	190
Meghalaya	0	60	60
Mizoram	0	0	0
Nagaland	20	0	20
Orissa	81	127	208
Punjab	0	0	0
Rajasthan	0	0	0
Tamil Nadu	905	622	1,527
Sikkim	0	0	0
Tripura	0	267	267
Uttar Pradesh	6	10	16
West Bengal	494	2,570	3,064
Union Territories	91	6	97
Subtotal	5,335	4,712	10,047
Exports	0	3	3
Total	5,335	4,715	10,050

Use of tractors and power tillers

Figure 1 shows the annual production and sales of tractors, including imports and exports. The average annual sales of tractors have approximately doubled each decade for the past five decades. We expect that in the year 2000 tractor sales in India will be around 300,000 units.

Table 5 shows the density of tractors and power tillers as calculated from the annual sales in each state (Tables 6 and 7), and from the assumption that a tractor lasts for 15 years and a power tiller for 10. Table 5 shows that in 1996, Punjab, the state with highest wheat yields, also had the highest tractor density—80 per 1,000 ha—followed by the neighboring states of Haryana (59 per 1,000 ha) and Uttar Pradesh (22 per 1,000 ha). In contrast, the predominantly rice-growing states with high yields had much lower tractor densities—Andhra Pradesh had only 6 per 1,000 ha. Tractor sales are much higher in the northern states, where wheat is grown, because tractors are more suitable for the dryland preparation for wheat than for land preparation for rice, which is usually carried out in flooded and soft field conditions. Rice fields also tend to be small and bordered by earth mounds for water control, which makes the operation of larger four-wheel tractors difficult. Most power tillers, which are smaller and more suitable for wetland preparation, have been sold in the rice-growing states of southern and eastern India, such as West Bengal, Tamil Nadu, Karnataka, Assam, Kerala, and Andhra Pradesh.

Table 4. Model, power range, and indicative prices of tractors.

Model	Engine		Max. power at PTO[a] -kW	SFC[b] at max. power ($g\ kWh^{-1}$)	Weight in kg PTO-kW^{-1}	Price[c] Rs PTO-kW^{-1}
	No. of cylinders	Capacity (cm^3)				
Mahindra 225 DI	2	1,261	12.0	271	143	14,890
Mahindra 265 DI	3	1,788	22.8	249	76	8,590
Mahindra B-275 DI	3	1,892	23.3	256	75	9,150
Mahindra 365 DI	3	1,810	21.9	255	79	9,310
Mahindra 475 DI	4	2,384	29.0	238	61	7,950
Mahindra 575 DI	4	2,523	31.2	233	60	9,950
Swaraj 724 FE	2	1,728	16.0	259	108	10,660
Swaraj 735 FE	3	2,592	25.1	250	73	8,400
Swaraj 855	3	3,308	33.9	257	57	7,850
Escorts 325 M	2	1,795	16.6	288	100	10,780
Escorts 335 M	2	1,960	20.9	250	84	9,520
Escorts 355 M	3	3,120	33.2	339	55	7,380
Escorts 340 M	3	2,727	29.6	245	63	7,600
Farmtrac 50	3	2,868	31.0	297	59	9,090
Farmtrac 60	3	3,147	33.3	253	59	8,970
TAFE 25 DI	2	1,670	17.7	269	90	9,960
TAFE 30 DI	3	1,788	25.1	258	66	8,490
TAFE 1035 DI	3	2,365	24.9	243	66	8,780
TAFE 245	3	2,500	30.5	256	58	8,400
Eicher 241 NC	1	1,557	15.1	262	110	10,870
Eicher 242 NC	1	1,558	14.1	267	115	11,830
Eicher 312	2	1,790	20.3	259	85	8,920
Eicher 364 NC	2	1,963	22.9	272	76	8,980
HMT 2522 Edi	2	1,560	16.1	266	102	11,070
HMT 3522	3	2,340	22.5	254	84	9,250
HMT 4511	3	2,698	30.5	274	70	8,100
HMT 5911	4	3,456	37.2	264	64	8,300
Hindustan G 312	2	1,798	18.7	271	91	7,120
Hindustan G 453 DI	3	2,697	32.3	290	62	7,520
Hindustan Super G-614	4	4,160	39.2	285	69	7,830
Hindustan G 614	4	4,667	48.9	277	56	7,400
Mitsubishi MT 180 D	3	900	11.6	351	59	14,000
Sonalika International	3	2,400	24.5	255	73	8,870
Tempo OX 45	4	2,596	29.0	254	66	8,840

[a] PTO = power takeoff.
[b] SFC = specific fuel consumption.
[c] Prices subject to change.

Table 5. Tractor and power tiller density (units per 1,000 ha).

State	Agricultural land area (000 ha)	Power tiller (10 yr) No. 1987-96	Density (no. 1,000 ha^{-1})	Rank	Tractor (15 yr) No. 1982-96	Density (no. 1,000 ha^{-1})	Rank
Andhra Pradesh	14,460	3,652	0.3	13	91,901	6.4	9
Arunachal Pradesh	350	1	0.0		3	0.0	
Assam	3,205	6,955	2.2	6	5,991	1.9	18
Bihar	10,743	1,277	0.1	16	64,966	6.0	10
Gujarat	10,292	1,961	0.2	14	129,087	12.5	5
Goa	67	818	12.2	1	126	1.9	17
Haryana	3,711	19	0.0		219,247	59.1	2
Himachal Pradesh	1,010	11	0.0		1,844	1.8	19
Jammu & Kashmir	1,014	83	0.1	18	3,321	3.3	14
Kamataka	12,321	9,867	0.8	10	65,301	5.3	11
Kerala	1,796	5,455	3.0	5	7,417	4.1	13
Madhya Pradesh	22,111	388	0.0		165,627	7.5	7
Maharashtra	20,925	3,405	0.2	15	98,636	4.7	12
Manipur	175	1,219	7.0	2	285	1.6	20
Meghalaya	302	495	1.6	9	7	0.0	
Mizoram	84	44	0.5	11	2	0.0	
Nagaland	968	93	0.1	17	45	0.0	
Orissa	5,296	1,763	0.3	12	10,480	2.0	16
Punjab	4,033	19	0.0		320,598	79.5	1
Rajasthan	20,971	33	0.0		154,555	7.4	8
Sikkim	111	0	0.0		0	0.0	
Tamil Nadu	7,474	13,024	1.7	8	76,318	10.2	6
Tripura	308	2,056	6.7	3	20	0.1	
Uttar Pradesh	17,986	265	0.0		396,502	22.0	4
West Bengal	5,656	19,918	3.5	4	13,938	2.5	15
Union Territories	140	293	2.1	7	5,217	37.3	3
Total	165,509	73,114	0.4		1,831,434	11.1	

Table 6. Annual tractor sales by state, 1980-96.

State	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996
Andhra Predesh	2,240	2,886	3,003	3,981	6,341	4,061	3,573	2,773	3,410	4,616	6,404	8,055	7,473	5,918	7,333	10,888	14,072
Arunachal Pradesh	0	0	0	0	0	0	0	0	0	0	0	1	0	0	2	0	0
Assam	164	165	157	413	550	358	606	296	970	406	330	303	221	257	355	428	341
Bihar	1,720	1,829	1,059	1,536	2,576	3,512	4,716	6,602	5,546	4,955	6,781	4,179	3,677	2,910	3,708	5,312	7,897
Gujarat	4,179	4,784	4,088	6,540	6,698	3,872	5,022	4,078	5,197	6,259	7,460	9,271	9,913	10,042	13,966	17,388	19,293
Goa	0	0	0	0	0	0	20	10	11	4	3	35	13	11	3	12	4
Haryana	9,342	11,122	8,582	9,641	9,814	9,115	11,196	11,397	14,129	15,186	17,269	17,269	20,676	16,714	17,585	18,950	21,724
Himachal Pradesh	66	176	112	80	134	85	141	102	0	145	155	89	65	169	108	188	271
Jammu & Kashmir	194	162	106	92	57	68	92	71	63	139	251	407	348	408	401	367	451
Karnataka	1,002	1,404	1,619	2,153	3,342	2,092	1,955	1,946	2,851	3,283	3,408	5,252	6,255	5,192	6,196	8,671	11,086
Kerala	226	213	246	508	443	341	318	350	323	244	379	440	645	590	646	1,024	920
Madhya Pradesh	3,269	3,548	2,767	4,521	6,160	4,966	6,207	7,281	10,620	9,733	10,267	13,876	10,547	11,443	21,175	23,069	22,995
Maharashtra	3,900	4,605	2,926	3,123	3,135	5,504	3,486	3,454	4,684	5,391	7,538	7,354	5,074	6,929	9,847	12,143	18,048
Manipur	13	5	5	10	5	6	0	0	0	42	42	28	15	4	0	73	55
Meghalaya	5	0	0	0	0	7	0	0	0	0	0	0	0	0	0	0	0
Mizoram	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0
Nagaland	0	0	0	0	0	0	0	0	0	0	0	0	0	41	0	4	0
Orissa	300	374	159	243	274	206	288	280	353	421	735	842	681	919	1,106	1,623	2,350
Punjab	20,427	21,511	18,785	19,461	14,689	13,761	18,876	19,008	18,835	21,660	22,146	23,786	26,518	26,094	25,123	25,027	26,829
Rajasthan	3,616	3,670	4,415	5,564	6,114	6,162	7,110	7,595	8,995	8,755	10,295	14,659	13,451	11,137	12,390	16,854	21,059
Sikkim	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tamil Nadu	1,136	1,399	1,652	1,579	3,097	2,792	3,273	2,772	3,070	3,214	5,043	5,324	6,215	6,988	8,736	11,380	11,183
Tripura	1	7	0	0	0	0	0	0	0	0	1	0	0	1	18	0	0
Uttar Pradesh	12,673	18,646	12,525	14,158	15,933	18,135	17,312	20,776	23,874	30,821	39,352	37,416	30,352	30,723	31,717	32,996	40,412
West Bengal	269	326	100	227	452	815	452	885	1,178	1,332	1,382	1,166	823	700	984	1,442	2,000
Union Territories	452	708	649	1,443	320	1,172	316	77	65	74	132	221	214	82	402	36	14
Subtotal	65,194	77,540	62,955	75,273	80,134	77,030	84,959	89,753	104,174	116,680	139,373	149,973	143,176	137,272	161,803	187,875	221,004
Exports	0	0	0	0	0	0	0	113	368	650	458	583	1,174	1,498	3,038	3,454	3,719
Total	65,194	77,540	62,955	75,273	80,134	77,030	84,959	89,866	104,542	117,330	139,831	150,556	144,350	138,770	164,841	191,329	224,723

Table 7. Annual sales of power tillers by state, 1980-96.

State	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996
Andhra Predesh	83	45	74	177	304	102	60	46	126	249	290	486	671	502	531	425	326
Arunachal Pradesh	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Assam	24	98	99	152	0	266	380	416	522	462	528	695	149	489	801	1,996	897
Bihar	31	63	58	20	69	9	161	153	191	267	133	126	121	107	46	82	51
Gujarat	12	10	26	42	26	50	29	35	95	281	155	240	247	333	247	111	217
Goa	0	0	0	0	0	17	3	2	22	57	14	11	20	52	95	215	330
Haryana	0	0	0	0	0	0	0	0	0	0	1	1	0	9	1	7	0
Himachal Pradesh	0	0	0	0	0	0	0	0	0	0	0	2	0	0	5	1	3
Jammu & Kashmir	0	1	5	0	0	18	19	10	48	4	1	18	0	2	0	0	0
Karnataka	1,529	1,598	1,231	1,805	2,551	475	416	298	685	518	452	788	924	1,349	1,318	1,844	1,691
Kerala	199	162	151	175	285	51	267	228	234	350	484	457	526	1,237	700	670	569
Madhya Pradesh	1	1	2	1	15	0	0	2	0	17	32	74	15	87	34	54	73
Maharashtra	58	5	30	20	25	115	104	91	173	282	356	300	648	436	335	350	434
Manipur	0	0	34	36	20	0	47	90	122	241	120	140	66	44	85	121	190
Meghalaya	16	20	30	0	20	0	20	20	50	50	40	40	20	85	70	60	60
Mizoram	0	0	0	0	0	0	0	0	0	0	0	0	24	5	15	0	0
Nagaland	0	0	1	0	0	0	0	0	0	0	16	12	28	5	7	0	25
Orissa	0	0	2	3	5	0	5	110	126	121	276	308	187	157	118	152	208
Punjab	0	0	0	0	0	0	0	0	0	0	1	0	0	17	0	1	0
Rajasthan	1	11	0	0	5	0	0	0	0	4	15	8	0	5	0	1	0
Sikkim	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tamil Nadu	67	36	60	108	214	1,059	940	478	665	639	990	1,085	2,615	1,939	1,506	1,580	1,527
Tripura	74	20	22	10	42	0	165	265	86	190	182	274	189	190	200	213	267
Uttar Pradesh	11	67	0	12	1	1	2	0	6	28	40	66	6	74	16	13	16
West Bengal	174	486	270	294	354	318	794	934	1,565	1,647	1,968	2,314	2,137	2,213	1,895	2,181	3,064
Union Territories	0	0	0	0	0	0	10	15	10	13	17	23	27	16	33	42	97
Subtotal	2,280	2,623	2,095	2,855	3,936	2,481	3,422	3,193	4,726	5,420	6,112	7,468	8,620	9,353	8,058	10,119	10,045
Exports	53	59	140	107	184	21	0	0	0	10	11	60	22	96	294	256	3
Total	2,333	2,682	2,235	2,962	4,120	2,502	3,422	3,193	4,726	5,430	6,123	7,528	8,642	9,449	8,352	10,375	10,048

IRRI–Spectra Precision collaborative development of a precision wet-leveling system

L. Gustafsson and J. McNamara*

This paper describes the formation of a collaborative relationship between the International Rice Research Institute (IRRI) and Spectra Precision and the development of a precision wet-leveling system for rice.

The first meeting

In March 1996, Spectra Precision regional managers Peter Rod and Joe McNamara contacted IRRI and asked to visit its experiment station. Mark Bell, head of the IRRI experiment station, gave a tour and showed the laser systems installed on Mitsubishi bulldozers. A meeting followed with discussions on what the rest of the world was doing with lasers and how Bell could better apply the systems IRRI owned. Bell also explained IRRI's role in the region and suggested Spectra contact IRRI agricultural engineer Joe Rickman in Cambodia to discuss his ongoing project. Bell said that Rickman was part of a team helping to rebuild the Cambodian rice sector, had experience with lasers in Australia, and was keen on precision land leveling. Phone numbers were exchanged and everyone agreed to keep in touch.

Cambodia

McNamara's initial contact with Rickman was exciting. Rickman explained what he was trying to do in Cambodia with such enthusiasm that McNamara wanted to go there as soon as possible. I tempered McNamara's enthusiasm with discussions of the potential Cambodia really presented to our company. This minor setback did not stop McNamara from wanting to work with Rickman; it only slowed him down.

Contact between McNamara and Rickman continued for more than nine months to work out details on the proper implement and how to build it for land leveling. This also gave McNamara time to convince me that we were getting in on the ground floor of "something big."

In January 1997, McNamara went to Cambodia to do the long-awaited demonstration of the precision land-leveling system. Rickman had designed and built the only box scraper McNamara knew of, which could be towed by a drawbar or attached to a three-point hitch. The installation went well, but there was no time to do a field trial before McNamara left for another country.

After long discussions with Rickman, it became clear that he was keen to retain the laser system in Cambodia. Rickman laid out a plan to train his people over the next 30 days by leveling fields around Phnom Penh. Once his people were trained, he was going to include the system in a field day planned for March. He explained the obvious benefits to Spectra of keeping this system in Cambodia and invited me to that field day.

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The grand plan

Following McNamara's visit to Cambodia and equipped with ideas from Rickman, McNamara presented a business plan to me for agricultural development in Asia. The plan involved donating one complete system to Rickman in Cambodia and one system to Bell in the Philippines. In return, Spectra could conduct training courses on precision land leveling in the north at IRRI and in the south in Cambodia. McNamara sold the plan to me as a strategic alliance between IRRI and Spectra where both would benefit. I agreed with the plan and decided to attend the field day Rickman had scheduled.

The first training course was scheduled for May in Cambodia and, after this, we would begin implementing the IRRI donation and training courses. We were able to arrange for six participants from Malaysia, Thailand, and Indonesia to attend the first course in Cambodia. As the date neared, however, the participants began to cancel one by one because of political unrest in the country. Then, in July, a coup d'etat brought the Cambodian part of the "grand plan" to a halt.

With complete confidence that Rickman would be able to continue the work on leveling in Cambodia, we began working out the details for the donation to IRRI.

Discovery of the precision wet-leveling system

IRRI already had three or four bulldozers equipped with laser systems and Bell and McNamara decided that the automation of a tractor would be more appropriate for the Asia-Pacific region.

For several months before our visit, Bell kept mentioning the need to look at wet leveling using our laser system. McNamara's thought was, "if you have my land-leveling system, you will not need to wet-level any more." McNamara really did not understand why Bell was pushing wet leveling when we were having great success in Thailand, Myanmar, and Korea with dryland leveling.

In September, an engineer and McNamara flew to the Philippines to begin the installation. Eugene Castro from the IRRI Agricultural Engineering Division built a scraper using plans supplied by Rickman. After the installation, Castro began testing the system in dry fields around IRRI. McNamara made two visits to work with Castro on the set-up and use of the system for dry leveling. Because of the wet field conditions, however, Castro was seeing mixed results and often had to wait a week or two to level a field.

On McNamara's third visit, a puddler had been attached to the tractor and was being tested in flooded fields (Fig. 1). He was asked to review how the system was being used on flooded fields and to make recommendations to improve the results. McNamara made minor adjustments to the hydraulic system and gave tips on set-up.

Bell suggested that a slope be put into the laser to see if the system could be used to improve field drainage. A slope of 0.05% was dialed into the laser and the tractor was sent to the field. Twenty minutes later, the 25 x 100-m field had been leveled and the water began to run to the end of the field. That was when both Bell and McNamara realized that we might have a system for wet leveling.

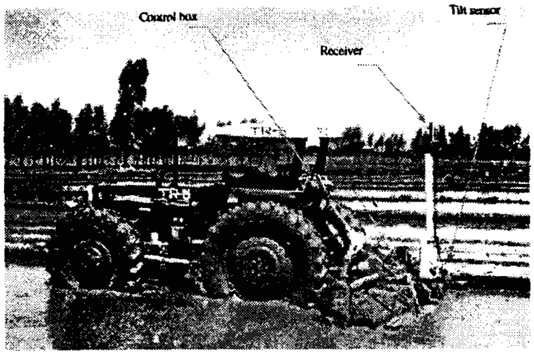

Fig.1. Laser system for wet-leveling.

Despite this early optimism, however, Bell's field crew listed a dozen reasons why the system would not work on production fields and why it would slow the field preparation time. Rather than argue, they decided to try the system on a field that had been recently harvested, plowed, and flooded.

They moved to the field and set up the laser with 0.05% slope across the field and began the test. This time the tractor had to puddle the field three times to achieve a smooth level surface. Members of the group were beginning to exhibit that "I told you so" look. They tried a second field with similar results, and Bell and McNamara were becoming a little concerned.

One of the supervisors then suggested leveling the field with 0% slope first and turning the soil to slurry before leveling with a slope. The tractor entered a new field and in one pass turned the field to slurry. The field was then smoothly leveled using 0.05% slope.

Bell called together the field crew to review the tests. It became clear that one-third of the group believed that the system could help achieve a process of plow, puddle, and plant, but the rest believed they should continue with the current process of plow, puddle with a dozer, level with hand tractors, and plant. Testing of the system continued.

About two or three weeks later, McNamara received an e-mail from Bell stating that the field crew had "fallen in love" with the new system and wanted to move the laser systems from the existing bulldozers to the tractors. In January 1998, we sent an engineer to IRRI to supervise the installation of another system on a tractor.

Current situation

Several countries have shown great interest in precision wet leveling. Korea, Japan, Uganda, Pakistan, Indonesia, and others have been in touch. One area of concern with the wet-leveling system, however, is the complex nature of the installation. A new installation kit must be designed for each tractor model used in the market. Spectra Precision has the expertise to design these systems, but the cost and time required make this approach cost-prohibitive.

During the early part of 1998, we have been designing the "Laser-Link" as a solution to this problem. The Laser-Link is an adapter that mounts between the tractor's three-point hitch and the implement. The Laser-Link is equipped with lift and tilt cylinders and allows the laser system to use remote hydraulic ports to drive the system. The precision wet-leveling system will now be able to work with any tractor and any implement using a single installation kit.

In February 1998, the first Laser-Link was built and tested on-site at IRRI. Over the next several months, the Laser-Link will be field-tested at various locations throughout the region and refined.

Conclusions

In closing, Joe McNamara asked me to say, "Mark Bell, his staff, and others had a vision two years ago that there had to be a way to improve wet leveling and thus increase rice production in Asia. A commercial manufacturer like us would not have had the mental fortitude or commercial desire if left on our own to pursue such a task. IRRI's noncommercial desire led to a clear, open, and honest communication of needs and their hard work helped us *jointly* develop the precision wet-leveling system and Laser-Link. These systems can be used worldwide (including the United States) and can be manufactured on a nonexclusive basis. Finally, this collaborative effort has proven, almost by accident, that the public and private sector can combine their expertise to quickly develop commercially viable products that target specific regional needs."

The Thai combine: a case study of equipment development in Thailand

S. Krishnasreni and T. Kiatwat*

Rapid industrialization in Thailand has led to acute farm labor shortages, rising labor costs, and upward pressure on the overall costs of agricultural production. As a result, agricultural machinery that helps farmers solve these problems has become a critically important input in modern Thai agriculture. An example is the locally manufactured rice combine harvester, which has been rapidly adopted since the early 1990s. The development and diffusion of the machine is an excellent example of public- and private-sector collaboration. The government sector provided technical assistance to manufacturers in the form of consultancy on various aspects of the equipment's design, fabrication, and operation. The government sector has also helped produce a handbook covering operation, repair, and maintenance, and trained manufacturers' personnel to train owners. To help improve quality, the Thai Industrial Standards Institute has recently established quality standards for rice combine harvesters. Taken together, these inputs have contributed, and continue to contribute, to the evolution of a reliable locally manufactured rice combine harvester adapted to meet the needs of Thai farmers and field conditions.

An overview of farm machinery in Thailand

Thailand is one of the world's largest suppliers of agricultural produce. About 63% of the total population of 57 million lives in rural areas, and most earn their living by farming. The country's total land area is about 514,000 km^2 (51.4 million ha), of which 41% is in agricultural production. Of the total of 17.5 million ha of cultivated land, approximately 14 million ha are rainfed. Rice is the most important crop and covers about 60% of cultivated land; maize is the second most important, covering about 10%. Other crops grown are rubber, cassava, sugarcane, mungbean, soybean, kenaf, groundnut, and fruits. Table 1 shows areas, level of production, and prices of major crops.

Agriculture's contribution to the gross domestic product (GDP) of the country has been declining. From 1974 to 1994, GDP declined from 25% to 11% (Table 2). But agriculture will continue to play an important role in Thailand's development by providing food security and helping to maintain social structure and cohesion.

The rapid expansion of the nonagricultural sectors, which often offer better prospects and higher wages than agriculture, has caused the rate of migration of labor out of rural areas to increase every year. The agricultural labor force is currently shrinking at about 1% yr^{-1} (Table 3). Therefore, the agricultural labor shortage, which is already acute in many areas, will become more so, particularly in the Central Plain, with its close proximity to Bangkok. Farm mechanization, and its effective use, will play an increasingly important role in increasing labor productivity, and hence reducing the labor shortage.

Status of agricultural mechanization

The contraction of the agricultural labor force by more than 50% in the past 20 years has already made agricultural machinery a vital input in Thai agriculture. But the level of agricultural

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Table 1. Planted area, production, and farm-gate prices of main crops in Thailand.

Commodities	1992-93			1993-94			1994-95		
	Area[a]	Prod.[b]	Price[c]	Area	Prod.	Price	Area	Prod.	Price
Rice	9,672	19,917	3,268	9,480	18,447	3,496	9,708	21,111	3,704
Maize	1,351	3,672	2,730	1,337	3,328	2,810	1,412	3,965	2,940
Cassava	1,456	20,203	600	1,410	19,091	570	1,322	18,164	1,150
Sugarcane	1,002	39,827	350	857	37,823	490	942	50,597	435
Mungbean	384	261	9,190	343	231	9,190	62	256	9,720
Sorghum	186	250	2,230	175	208	2,290	177	228	2,730
Soybean	367	480	7,670	416	513	8,060	436	528	7,820
Groundnut	104	137	7,790	96	136	8,650	104	150	9,070

[a]Area x 1,000 ha.
[b]Production x 1,000 ha.
[c]Price = Baht t^{-1}.
Source: Agricultural Statistics of Thailand, crop year 1994-95, Office of Agricultural Economics.

Table 2. Percentage of gross domestic production during previous national economic and social development plans.

Sector	3rd plan 1972-76	4th plan 1977-81	5th plan 1982-86	6th plan 1987-91	7th plan 1992-94
Agriculture	25.1	21.4	9.0	14.9	10.9
Nonagriculture	74.9	78.6	81.0	85.1	89.0

Source: Office of Agricultural Economics, Ministry of Agriculture and Cooperatives.

Table 3. Total population and percentage employed in agriculture from 1992 to 1996 and projected trend from 1997 to 1999.

Year	Population (x 1,000)				Labor Force (x 1,000)			
	Agric.	Nonagric.	Total	% in Agric.	Agric.	Nonagric.	Total	% in Agric.
7th plan								
1992	36,245	21,784	58,029	62.5	19,684	13,328	33,012	59.6
1993	36,540	22,143	58,683	62.3	19,833	13,546	33,379	59.4
1994	36,491	22,615	59,335	61.9	19,914	13,833	33,747	59.0
1995	36,855	23,130	59,985	61.4	19,969	14,146	34,115	58.5
1996	36,943	23,690	60,633	60.9	19,999	14,486	34,485	58.0
8th plan								
1997	37,008	24,270	61,278	60.4	20,016	14,839	34,855	57.4
1998	36,948	24,974	61,922	59.7	19,959	15,265	35,224	56.7
1999	36,783	25,780	62,563	58.8	19,843	15,753	35,596	57.5

Source: Agricultural Economics Research Division, Office of Agricultural Economics.

mechanization differs from region to region, depending on farm income (Table 4). The Central Plain region is the richest and most progressive farming area in the country. Here mechanization has progressed from power-intensive operations, such as land preparation, water pumping, and threshing, to control-intensive operations, such as harvesting, seeding, and weeding. This has led to the adoption of more sophisticated machines, such as combine harvesters, seed drills, and sprayers. The introduction of combine harvesting has also made the adoption of other equipment necessary, such as stationary balers to handle the straw, and grain dryers. The introduction of seed drills fitted to hand tractors has meant that farmers who own old-model single-axle two-wheel hand tractors have begun adopting newer hand tractors, which are easier to control. The old-model hand tractors do not have steering clutches to help turning, unlike newer models, and have only a single forward speed, whereas newer hand tractors have a gearbox giving forward and reverse speeds.

The size of some machines, as well as the number sold, has also increased. For example, the original axial-flow paddy thresher that became popular in the early 1980s had a 4-foot cylinder length, was powered by a 10-hp diesel engine, and had a capacity of about 1–1.5 t $hour^{-1}$. Recently, manufacturers have started producing a self-propelled thresher with an 8-foot cylinder length, fitted

Table 4. Land use, yield, water resources, farm size, and agricultural income by region (1991).

Detail	Region			
	North	Northeast	Central Plain	South
Land use for agriculture (ha)				
Paddy fields	2,431,515	6,075,654	2,004,924	577,986
Field crops	1,675,992	2,152,788	1,510,144	24,054
Fruit tree and tree crops	280,638	295,056	700,700	1,939,349
Vegetables and flowers	44,098	33,454	49,500	10,255
Grass land	21,465	63,171	19,924	8,529
Farm size (ha)	3.67	4.23	5.10	3.62
Water resources				
Average annual rainfall (mm)	1,101	1,428	1,431	2,472
Irrigated area (ha)	1,133,314	699,381	2,104,522	457,226
Paddy fields under water pumping project (ha)				
Wet season	59,929	51,364	57,992	6,808
Dry season	17,091	37,371	31,939	13,910
Yield of major crops (t ha^{-1})				
Rice (wet season)	2.56	1.70	2.73	2.03
Rice (dry season)	4.39	2.91	4.06	2.80
Maize	2.65	2.60	2.96	2.83
Sorghum	1.34	1.14	1.26	–
Sugarcane	51.69	56.58	50.40	–
Cassava	14.20	13.41	14.35	–
Mungbean	0.74	0.64	0.71	0.78
Soybean	1.36	1.33	1.61	1.70
Groundnut	1.38	1.48	1.61	1.08
Farm income (US$ $farm^{-1}$)	1,331	761	3,169	1,402

Source: Agricultural Statistics of Thailand, Crops 1992-93.

onto a farm truck, powered by a 90–130-hp engine, with a capacity of about 8–9 t $hour^{-1}$. These large paddy threshers are mainly owned by contractors, not individual farmers. The machines have been modified to be able to handle soybean and other cereal crops.

Manual harvesting has roughly the same labor requirement as manual threshing. But harvesting is more control-intensive than threshing and requires more sophisticated equipment. As a result, the mechanization of harvesting has occurred more slowly. Nevertheless, since the early 1990s, manufacturers in the Central Plain have been manufacturing and selling a locally designed rice combine harvester. But farmers also urgently need combine harvesters that can harvest other crops such as soybean, maize, and sugarcane. Unfortunately, locally adapted and proven machines have not been available; as a result, harvesting mechanization levels in these crops have fallen behind those of rice (Table 5). Imported machines have tended not to meet farmers' needs in the same way as locally produced ones. For example, more than 2,000 locally made rice combine harvesters have been sold compared with only 60 imported sugarcane harvesters.

The Agricultural Engineering Division (AED) of the Department of Agriculture, in collaboration with manufacturers, is working to fill this gap in farmers' choices by developing appropriate harvesters such as a soybean reaper, a maize picker, a maize combine harvester, and a tractor-mounted whole-stick sugarcane harvester.

In other regions, mechanization is rapidly following the pattern mapped out in the Central Plain with the adoption of power-intensive equipment such as hand tractors, water pumps, and threshers (Table 6).

Most agricultural equipment is manufactured in Thailand; only four-wheel tractors are always imported. Some manufacturers recondition and reassemble imported used tractors. About 75% of sprayers and 30–40% of water pumps are imported (Table 7). Some agricultural machines are exported (Table 8).

Public (government)-sector agricultural engineering has worked to promote mechanization in step with socioeconomic conditions and the country's National Development Plan. Besides AED, several universities are carrying out research and development (R&D) on agricultural mechanization: Kasetsart University in the Central Plain, Khon Kaen University in the northeast region, and Chiang Mai University in the north.

Table 5. Mechanization level in the production of some important crops.

Operation	Mechanization level by crop (% of cultivable area)			
	Rice	Maize	Sugarcane	Soybean
Plowing	90	95	100	80
Planting	5	80	75	70
Irrigating	50	30	40	50
Weeding (spraying)	75	75	70	80
Harvesting	20	5	15	5
Threshing	90	90	–	90
Drying	10	20	–	5

Source: Estimation undertaken by Agricultural Engineering Division, Department of Agriculture.

Table 6. Agricultural machinery and equipment in use from 1991 to 1994.

Year	Northeastern	Northern	Central Plain	Southern	Whole kingdom
Single-axle two-wheel tractors (5–12 hp)					
1991	97,788	367,110	256,840	132,541	854,279
1992	117,345	430,914	282,524	153,747	984,530
1993	140,813	505,807	310,776	178,346	1135,742
1994	168,975	593,717	341,854	206,880	1311,426
Tractors (22–75 hp)					
1991	9,958	18,833	33,874	2,345	65,010
1992	11,452	22,658	42,971	2,720	79,801
1993	13,170	27,260	54,511	3,155	98,096
1994	15,146	32,796	69,150	3,659	120,751
Water pumps					
1991	179,012	317,962	664,298	59,454	1,220,816
1992	205,380	356,848	757,631	67,670	1,387,529
1993	235,632	400,490	864,077	77,021	1,577,220
1994	270,340	449,469	985,479	87,665	1,792,953
Machine-operated sprayers					
1991	8,718	35,143	211,852	4,233	259,946
1992	10,804	39,781	231,892	4,931	287,408
1993	13,389	45,031	253,828	5,744	317,992
1994	16,593	50,974	277,838	6,691	352,096
Hand-operated sprayers					
1991	970,023	1,596,913	1,122,889	374,645	4,064,470
1992	1,241,453	1,966,295	1,347,466	510,253	5,065,467
1993	1,588,834	2,421,119	1,616,958	694,946	6,321,857
1994	2,033,418	2,981,148	1,940,349	946,492	7,901,407
Threshers					
1991	4,346	13,020	24,694	2,566	44,626
1992	4,781	14,922	27,262	2,672	49,637
1993	5,259	17,102	30,097	2,782	55,240
1994	5,786	19,600	33,227	2,897	61,510

Source: Agricultural Statistics of Thailand, crop year 1994-95.

Status of agricultural machinery manufacturing

The Thai agricultural machinery industry established itself around 1965 with the manufacture of a low-lift propeller water pump and hand tractors. The industry expanded rapidly in the 1970s. Manufacturers now produce a wide range of agricultural equipment, from simple implements, such as plows, to complicated machines, such as the rice combine harvester and large-capacity rice dryers. Table 9 shows that the most important types of farm equipment, in terms of numbers produced and numbers sold, remain machines that mechanize power-intensive operations such as land preparation, water pumping, and milling.

Thailand now has around 200 agricultural machinery manufacturers. These firms vary in size, from small workshops with a working area of about 50 m^2, employing 4–5 workers, to large manufacturers with a working area of more than 3,000 m^2 and employing 100 workers or more.

Table 7. Numbers and values of machines imported in 1993 and 1994.

Machinery and equipment	1993 Units	1993 Value (x $1,000)	1994 Units	1994 Value (x $1,000)
Tractors (2-wheel and 4-wheel)	15,496	166,825	55,519	213,327
Land preparation implements	193	100	168	161
Water pumps	787,859	133,331	875,135	165,051
Seeders	637	62	423	41
Broadcasters	349	382	377	304
Harvesters	714	4,270	512	6,757
Threshers	125	37	28	12
Balers	326	2,055	354	2,238
Sprayers	65,862	3,839	76,184	4,559
Miscellaneous	375,916	6,020	1,020,600	8,887

Source: Agricultural Statistics of Thailand, crop year 1994-95, Department of Customs.

Table 8. Numbers and value of agricultural machinery exported in 1993 and 1994.

Machinery and equipment	1993 Units	1993 Value (x $1,000)	1994 Units	1994 Value (x $1,000)
Tractors (2-wheel and 4-wheel)	6,221	5,052	22,714	6,849
Land preparation implements	87	81	120	42
Sprayers	900	8	2,005	10
Water pumps	62,686	9,080	79,139	11,484
Miscellaneous	6,580	2,072	10,461	2,224

Source: Agricultural Statistics of Thailand, crop year 1994-95, Department of Customs.

A survey carried out by AED and the Thailand Institute of Science and Technology Research in 1987, and updated in 1994 by AED, grouped manufacturers into three categories with reference to the number of workers employed: small—up to 10 employees—94 (46%); medium—more than 10 and up to 30 employees—72 (34%); and large—more than 30 employees—40 (20%).

Most manufacturers employ unskilled workers with only a primary school education. Only 30% of these workers have a formal technical qualification. Most firms use skilled workers to train unskilled ones. Progressive manufacturers release their workers to attend training courses organized by government agencies. Recently, a few manufacturers have begun employing professional engineers. Some firms pay for consultancy from private engineering companies. In general, most small and medium firms produce more products than larger manufacturers, who concentrate on one or two products only.

Most large and medium firms are located in the Central Plain. Recently, some of them have established branches in other regions. Most firms have equipment such as lathes, shapers, drills, power saws, electrical or gas welders, guillotines, small rollers, and air compressors. In addition, some of the large firms, especially hand-tractor factories, have large hydraulic presses, universal cutting machines, and milling machines. Some even have sophisticated machine tools such as

Table 9. Approximate annual production of agricultural machinery and equipment in 1994 and 1995.

Items	Production (no.)	Firms (no.)
Small diesel engines	100,000	3
Single-axle two-wheel tractors	70,000	30
Disc plows for power tillers	70,000	18
Disc plows for large tractors	7,000	15
Animal-drawn moldboard plows	80,000	10
Frame for animal-drawn plows	8,000	10
Water pumps	75,000	20
Paddy threshers	1,800	3
Other crop threshers	400	8
Maize shellers	400	8
Peanut shellers	10	1
Seed drills	3,000	15
Knapsack sprayers	70,000	3
Sugarcane planters	300	5
Rice mills	3,500	50
Small rotary movers	10,000	10
Trailers	8,000	10
Farm trucks	2,500	30
Rice combine harvesters	400	8
Reapers	100	3
Dryers	50	5

Source: Estimation from survey undertaken by Agricultural Engineering Division, Department of Agriculture.

computer numerical-controlled equipment and computer-aided drafting facilities. Basic operations such as foundry, gear cutting, forging, and heat treatment are normally obtained from other specialized firms. The materials most commonly used are mild steel, cast iron, and cast aluminum. Raw materials and specialized services are more readily available in Bangkok than in the regions, which is why most firms are located in or around Bangkok.

Three joint-venture companies produce 80% of the stationary engines used to power agricultural equipment. These firms have been building diesel engines for the domestic market since 1980. Annual production of stationary engines is now around 120,000 units.

Nearly all the machines manufactured in Thailand are modifications of an imported prototype or have originated from public R&D institutes. AED has contributed and continues to contribute a great deal to the development of new prototypes for local manufacturers.

Farmers' needs for more sophisticated, control-intensive machinery will increase in the future, as previously discussed. As experience has shown in Thailand, technologies developed in other countries may have the potential to meet many of these needs. But imported technology needs to be adapted to local conditions, production skills, and available raw materials. This adaptation work takes time, is expensive and risky, and is therefore a constraint to technology transfer between private companies and to the establishment of joint ventures. A role for the public sector might be to initiate and assist with the establishment of cooperation and transfer to private manufacturers when machines are suitable and have a high marketing potential.

AED is now helping a large manufacturer to identify and contact foreign partners for the importation or assembly of appropriate rice transplanters and maize combine harvesters. Companies in the Republic of Korea and Germany have been contacted and the initial terms of a contract are being considered by a Thai manufacturer. We hope that some agreement for cooperation will take place soon.

Extension of agricultural machinery

The extension of agricultural machinery in Thailand is mainly carried out by the public sector, although some large manufacturers/dealers do sometimes demonstrate new products. The main public-sector agencies responsible for extension are AED and the Farm Mechanization Sub-Division, Department of Agricultural Extension (DOAE).

The extension of agricultural machinery by the public sector has improved as agricultural mechanization has become increasingly important in Thailand. Before 1981, the training and visiting system was used, but suffered from a lack of subject matter specialists in farm mechanization at the provincial level. In 1981, however, the DOAE established the Farm Mechanization Promotion Center to support the Agricultural Mechanization Promotion Program provincially. There are now four DOAE Farm Mechanization Promotion Centers—Chainat in the Central Plain, Petchaburi in the west, Roi Et in the northeast, and Chiang Rai in the north.

AED's own early extension efforts suffered from a lack of explicit work plans and targets. Until 1984, AED attempted to promote mechanization nationwide, but lacked focus and continuity, which resulted in unsatisfactory results. After 1984, under the UNDP/FAO/THA Agricultural Machinery Production Project, AED changed its extension strategy from a nationwide basis to one concentrating on specially selected pilot areas. AED now has five Agricultural Machinery Training Centers, which have been built up not only to train but also to test, evaluate, and demonstrate newly developed equipment. Additional resources in the form of staff and equipment have been allocated to the Pathumtani (Central Plain), Nakornsawan (lower north), Chiang Mai (upper north), Khon Kaen (northeast), and Pattaluang (south) centers.

For industrial extension, AED staff frequently visit manufacturers to gather and exchange information. AED also has an annual budget for providing technical assistance to a minimum of five manufacturers per year.

The present bottleneck in agricultural mechanization extension activities is the lack of sufficiently competent extension officers in the provinces and districts. DOAE is tackling this shortcoming and has conducted several training courses for extension officers. But because most provincial and district officers are agricultural technology graduates, it is quite difficult to train them to be able to carry out mechanization extension activities efficiently. Notwithstanding this constraint, a more intensive training program for extension officers has been formulated by AED and DOAE, and it will be submitted for approval and implementation during the Eighth National Plan.

Development of a rice combine harvester in Thailand

Development of mechanical rice harvesters

The first mechanical rice harvesters introduced into Thailand fell into two categories—binders and reapers.

Binders. Japanese binders were introduced to Thai farmers in 1975. These machines cut the rice stalks and conveyed the cut plants to the side of the machine to form a bundle, which was then bound with string. Japanese binders have a harvesting capacity of about 0.05 ha $hour^{-1}$. This equipment has not gained popularity among farmers because the machine and its binding accessories were quite expensive, and the long straws of the harvested rice rendered its threshing efficiency low.

Reapers. Mametora, Chinese, and Japanese reapers were introduced in Thailand from 1978 to 1986.

The Mametora reaper, which has a harvesting capacity of 0.16 ha $hour^{-1}$, was imported and tested in Thailand through the Regional Network for Agricultural Machinery (RNAM) exchange program. The Mametora reaper could not compete with the Chinese reaper introduced a few years later.

The Chinese reaper was introduced in 1980-81. This machine cut the rice stalks, conveyed the plants to the side of the machine in a similar manner to the Japanese binder, but then let the crop fall in a windrow. Collecting and bundling of the windrow were usually done manually by a separate team. The machine had a capacity of about 0.3 ha $hour^{-1}$ and enjoyed some market success, selling about 1,000 units before disappearing. Its disappearance was attributed to the design not being well suited to Thai farm conditions, and the machine being too heavy to transport easily between farms.

Realizing the defects of the Chinese reaper, the Japanese company Kubota developed a lighter reaper for the Thai market, which was introduced in 1986-87. This 125-kg machine had a field capacity of 0.20–0.27 ha $hour^{-1}$. But it was not widely adopted mainly because of its high price and difficulties farmers experienced contracting manual labor to pick up and bundle the windrow.

Why imported rice combine harvesters have not been adopted in Thailand

Imported combine harvesters from Europe, the United States, and Japan were introduced into Thailand as early as 1979. But they were not adopted to any extent for the following reasons:

1. Most imported machines did not work efficiently under Thai field conditions, mainly because they were designed for large field sizes, whereas Thai fields were smaller. As a result, imported combines were often too big, heavy, and difficult to transport between fields and farms. Most imported machines were also not designed for, and did not work well in, the lodging varieties commonly grown in Thailand, and could not handle the large number of rice varieties grown together in close proximity.
2. The price of the machines was too high for farmers and farmer cooperatives to afford.
3. Most distributors did not provide after-sales service and spare parts.

Development and adoption of Thai rice combine harvesters

Realizing the shortcomings of imported combine harvesters, the Thais developed a combine harvester using the same design principles as used in imported combine harvesters, but modifying some parts to better suit local conditions. For example, the most popular design uses the IRRI-designed axial-flow thresher, which had already been adapted to local conditions as a stationary thresher. About eight rice combine harvester manufacturers now produce approximately 400 units per year. The selling price ranges from US$36,000 to $60,000 $unit^{-1}$ (1US$ = 25 Baht[1]). Best estimates put the number of combine harvesters sold since 1990 at 2,000.

The development and rapid adoption of the local combine harvester is largely a result of the acute labor shortages discussed earlier. Farmers found that hiring locally made rice combine harvesters to harvest and thresh costs US$75 ha^{-1} versus $120 ha^{-1} for hiring manual labor and using a mechanical thresher. Farmers have also found that mechanical harvesting has reduced grain loss from 7.8% for manual harvesting to less than 6% for mechanical harvesting.

To help local rice combine manufacturers improve the performance of their product, AED conducted a survey to find out the problems encountered by users of locally manufactured rice combine harvesters. They also evaluated some of these machines to make recommendations on how to correct their defects and improve their performance. This information will also be provided to decision-making bodies to help them formulate future government programs.

Description of the Thai combine harvester

Locally manufactured rice combine harvesters consist of eight major components: the prime mover, undercarriage, transmission and steering, and harvesting, feeding, threshing, cleaning, and output units. Figure 1 shows a typical Thai rice combine harvester.

Prime mover unit. Locally made rice combine harvesters usually employ a secondhand imported diesel engine of about 80–100 hp. Recently, with the encouragement and assistance of AED, large manufacturers have begun offering combine harvesters with new Perkins or Caterpillar engines.

Undercarriage unit. The undercarriage unit (Fig. 1) is patterned on a bulldozer. This unit has five major components: track, driving gear, idler, carrier roller, and track roller units.

The track unit consists of sprockets and chains. Wooden shoe tracks of 80 x 250 cm are normally used to reduce the equipment's weight and prevent it from sinking in wet fields. Some manufacturers use used sprockets and chains from a bulldozer whereas others fabricate these parts by themselves, or order them from local workshops. It was observed, however, that the quality of the locally made sprockets and chains is inferior because most metals used in fabricating them are not hardened. Recent models of some large manufacturers, however, use new imported sprockets and chains to increase durability and reliability.

A driving gear unit transmits the power from the final drive unit to the track unit. A secondhand driving gear of a bulldozer is normally used, although some large manufacturers have started using new imported driving gear units.

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[1] A pre-July 1997 exchange rate is used because rates have fluctuated wildly since then.

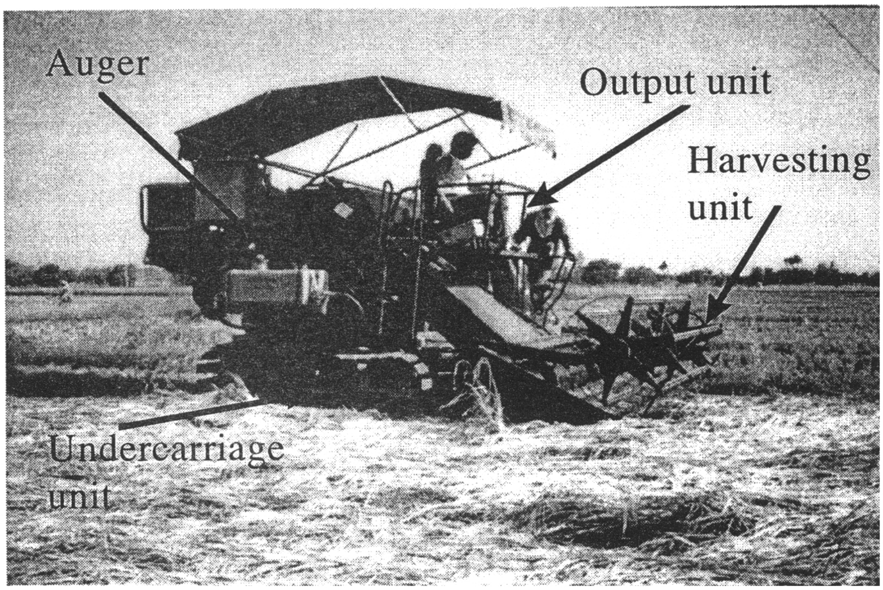

Fig. 1. A locally made rice combine harvester showing the undercarriage unit, the harvesting unit, and the output unit.

An idler unit consisting of support rollers guides the track chain. This part is usually fabricated by the manufacturers themselves.

The carrier roller unit normally consists of one or two rollers that are used to adjust the tension of the track chain.

The track roller unit usually has two or three rollers that are used to support the weight of the machine. Secondhand track rollers are usually used, which explains their normally short life span. Some large manufacturers, however, have begun using new imported track rollers.

Transmission and steering unit. This unit employs either a direct or a hydrostatic drive system. A direct-drive system is normally employed because of its lower cost. Some manufacturers use a secondhand truck gearbox, whereas others fabricate the gearbox.

Harvesting unit. A harvesting unit (Fig. 1) has three main parts: a cutter-bar, a reel, and a front auger. A 3-m-long John Deere cutter-bar is normally used, whereas the reel consists of a hexagonal skeleton frame with rotated fingers to convey the rice stalks to the front auger.

Feeding unit. The feeding unit conveys harvested rice stalks to the threshing unit. It consists of an auger that collects the cut rice plants from the harvesting unit, and in turn feeds a chain and slat conveyor.

Threshing unit. This unit is a locally made axial-flow rice thresher consisting of a cylindrical threshing drum and a spaced steel-rod concave housing.

Cleaning unit. The cleaning unit has a blower and an oscillating screen. This unit is normally built as an integral part of the axial-flow thresher.

Output unit. The output unit (Fig. 1) conveys threshed rice from the cleaning unit through an auger.

Collaboration between the government and private sector in developing and improving locally made rice combine harvesters

Most local rice combine harvester manufacturers employ 6 to 25 people and have simple workshop facilities consisting of lathes, electric and gas welders, power hacksaws, and other basic tools used in metal work. Heavy precision machinery used in the manufacturing of large machinery is not normally found and this is perhaps why most machine components produced in these workshops are of relatively inferior quality.

AED has conducted field surveys to evaluate the use and performance of the Thai rice combine harvesters. Field capacity was found to range from 0.42 to 0.9 ha $hour^{-1}$ and total grain loss was found to be less than 10%. Listed below are some of the problems commonly found with combine harvesters in the field.

1. The most serious problem found was frequent breakdown of the locally made chain and sprocket components in the undercarriage unit. Locally made sprockets and chains were generally weaker than their imported counterparts because they were not hardened. Some manufacturers have improved the durability of the undercarriage unit by using imported new sprockets and chains of reputable brands.
2. The prime mover unit was installed at the back of most machines, and low down, resulting in dirt and waste material from the threshing unit entering the engine. This problem was reduced by positioning the prime mover unit on top of the machine.
3. Secondhand or locally fabricated cutter-bars lacked durability. Replacing them with new parts of reputable brands greatly improved the durability of the cutter-bar.
4. Because most locally manufactured rice combines are patterned on imported combines, they are large and heavy, weighing up to 5.5 t. Therefore, a large trailer is required to move them. A truck carriage was designed to fit the combine harvester and make transport more convenient.
5. The machine has a single control for the threshing drum speed, feed rate, cutting speed, and traveling speed. To optimize machine performance, there should be a separate control for each; manufacturers are now developing this.
6. After-sale service, spare parts, and training are often lacking. Not all manufacturers provide a warranty on the combine, although some provide free machine repair for the first 32–48 ha of operation.
7. Safety and machine vibration are still being improved. Machine vibration is relatively high, especially when the machine is operating in a dry field.

Based on the above problems commonly found with the Thai combine harvesters, the government and private sector have collaborated in the following ways:

Machinery development. For development of the machines, the government sector provided much of the technical expertise, especially for designing, fabricating, and selecting materials, and for evaluating and optimizing machine operation. The private sector provided the materials and manpower to construct the machines. AED has frequently encouraged and worked with combine harvester manufacturers to improve the product in terms of design and quality, particularly by helping manufacturers to identify and see the effects of poor quality. As a result, some manufacturers have begun replacing secondhand or locally fabricated parts, including the engine, with new imported parts.

Operation and training handbooks. AED has also encouraged and helped manufacturers to provide handbooks with the equipment they produce. The handbooks cover the proper operation of the machine, repair and maintenance, and safety aspects. Handbooks also exist for hand tractors, seed drills, threshers, reapers, and mechanical dryers.

Training courses. AED runs two types of training courses, one designed for manufacturers and the other for farmers. The course for manufacturers trains the people in the company who will themselves train new owners in the operation, repair, and maintenance of the machine.

Quality. The quality of Thai agricultural equipment tends to be poor compared with machines built in developed countries because manufacturers compete almost solely on price, and most local manufacturers lack the technical skills to produce high-quality equipment. The use of quality standards is an important way to improve quality. Thailand has agricultural machinery standards as part of the Thai Industrial Standards (TIS) drawn up by the Thai Industrial Standards Institute (TISI). TISI has adapted agricultural machinery standards from several countries to Thai manufacturing and farm conditions. Standards for combine harvesters have recently been completed. Standards also exist for hand tractors, threshers, and hand-operated sprayers.

To obtain the standard certification, manufacturers can apply for an industrial standard certification through testing agencies nominated by TISI. The government provides credit in kind for farmers to buy machines with the quality standard certification through the Bank of Agriculture and Agricultural Cooperatives. National standards legislation also requires that machines sold to government agencies be TIS-certified. But these incentives have not yet led to many machines being certified. Most manufacturers claim that fulfilling the quality standards would add greatly to the cost of their machines, and this would restrict sales because most farmers do not see the benefit of this additional cost. Some large manufacturers, however, have applied some of the requirements of the national standards to their products, such as safety guards and warning signs to help prevent accidents.

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The SSR-1 dryer: a case study of equipment development in Vietnam

Phan Hieu Hien*

Development of the very low cost SRR-1 dryer is described from its start in 1995 up to the end of 1997, when farmers had adopted about 700 units. Tools for development and extension procedures for the dryer are discussed. Roles of the public and private sectors are analyzed as components of integrated development.

In less than three years, from 1995 to 1997, the SRR-1 dryer was developed and promoted throughout Vietnam, with about 700 units sold to farmers. It is now featured with other technologies as an effective means for solving the problem of drying rice harvested in the wet season. The importance of drying was reported in several conferences in Vietnam and abroad (Hien 1991, Hien et al 1996). Losses in quantity and quality caused by rain and wet harvested grain reportedly range from dozens to hundreds of millions of dollars each year.

The case study of the SRR-1 dryer and its rapid spread analyzes (1) development of the SRR-1 dryer, (2) roles of the public and private sector in its development, and (3) conditions contributing to its success.

Development of the SRR-1 dryer

The technical development and performance evaluation of the SRR-1 dryer have been reported elsewhere (Hien et al 1996, 1997). The following section summarizes the main points and describes the tools used for its development.

Description and specifications of SRR-1 dryer

The SRR-1 dryer (Fig. 1) has three components: an axial fan, an electric heater, and a bamboo-mat drying bin.

The drying bin has two concentric bamboo-mat cylinders of 0.4 m and 1.5 m diameter, and 1.1 m high. The bin can hold 1 t of rice.

The fan is driven by a 0.37-kW (0.5 hp), single-phase, 2,800-rpm electric motor. The fan is positioned on top of the inner bamboo-mat cylinder. At 300-Pa static pressure, the airflow is 0.4 $m^3 s^{-1}$.

The heater is a 1,000-Watt resistor from the electric stove; it is mounted beneath the lower rotor. Supplemental heat from the resistor is used selectively at night or during continuous rain. Alternatively, a coal stove can be used to save electrical energy; coal is refilled every 3 h.

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Drying capacity. Drying capacity for 1 t of paddy can be reduced from 26% moisture content (wet basis) to 14–14.5%. If with a resistor, drying time is 4 d, of which total "fan-on" time is 80–85 h, including "resistor-on" time of 14–25 h. Energy consumption for the fan is 30 kWh, for the resistor it is 14–25 kWh. If with a coal stove, drying time is 2 d, of which total "fan-on" time is 48 h, including coal-firing time of 40 h. The fan consumes 20 kWh of energy, the stove consumes 40 kg of coal.

Quality of dried paddy. The final moisture differential between various points is about 1% (using a resistor) or 2.5% (using a coal stove). Head rice recovery is higher by at least 2% compared with sun drying (much higher in adverse weather with continuous rain).

Storage capacity. After drying, paddy can be stored in the same bin (Fig. 2). Once a week during noon time (low air relative humidity), turn the fan on for 1-h ventilation. After 9 mo, the moisture content, head rice, and germination are maintained. Insect infestation and grain yellowing are minimized. Cooking quality is normal.

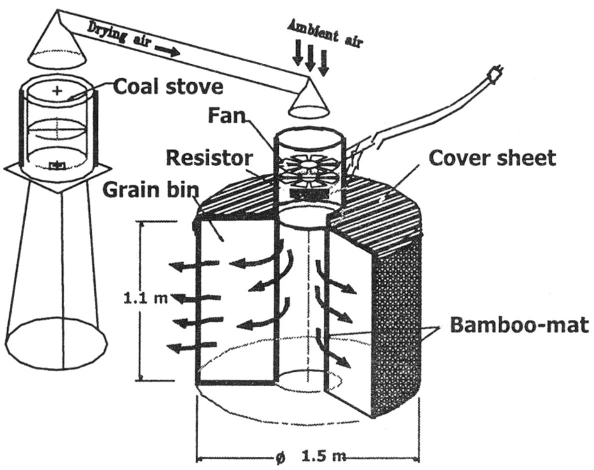

Fig. 1. Construction of SRR-1B dryer with coal stove.

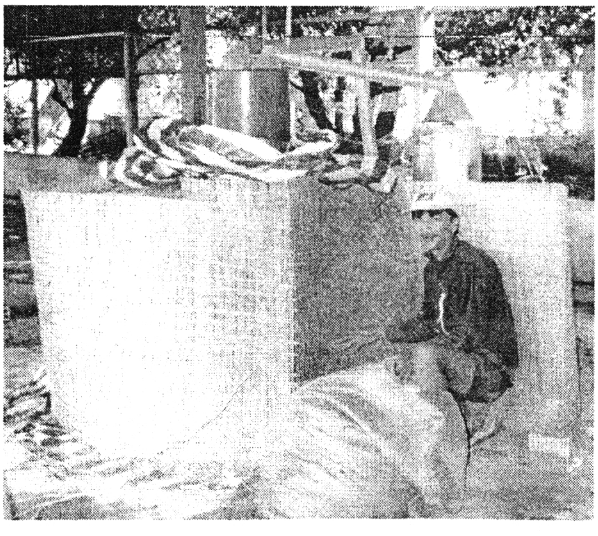

Fig. 2. Unloading the SRR-1 dryer.

History of SRR-1 dryer development

In April 1994, the project "*Postharvest Technologies for Rice in the Humid Tropics*" was started at the University of Agriculture and Forestry (UAF), Ho Chi Minh City, in cooperation with the International Rice Research Institute (IRRI) in the Philippines, and financially supported by the German Agency for Technical Cooperation (GTZ). The objective was to evaluate and introduce the technology called the "low-temperature in-bin drying and storage system (LTIBDS)" in Vietnam. The starting point was a 5-t LTIBDS dryer that had been tested intensively at IRRI (Muehlbauer et al 1992), based on a similar previous application in Korea (Kim et al 1989).

At UAF, we built a 6-t unit (Fig. 3), which was similar to the IRRI 5-t dryer, with only minor modifications. The primary objective was to verify the low-temperature drying process for the first time under Vietnamese conditions. Test results with this 6-t dryer confirmed that it was a technical success. But economically, its drying cost was too high to be accepted by farmers (Hien et al 1997). These technical and economic results were similar to those obtained by other project researchers in the Philippines and Indonesia.

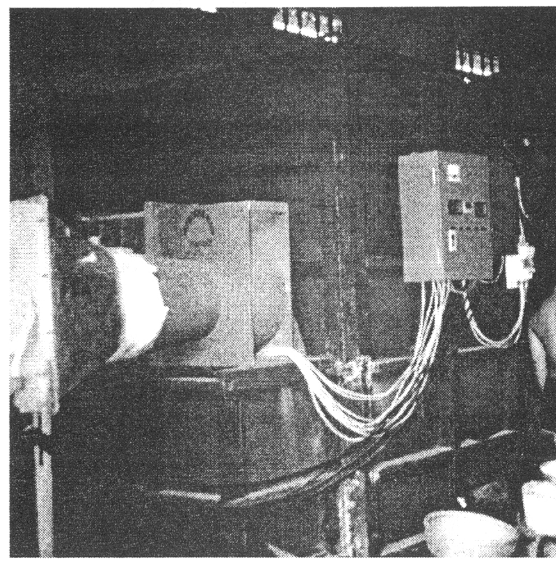

Fig. 3. The 6-t low-temperature dryer.

To reduce the drying cost, we went in two directions: scaling up to a 30-t dryer to realize economies of scale, and scaling down to a 1-t dryer, using low-cost materials and a simplified configuration. The 30-t dryer was technically successful also, but ecologically unsuitable (flood during harvest, etc.); it ended up as a 7-t flatbed dryer.

The 1-t model was designed in April 1995 and tested in July-August 1995. After drying four batches with good results, it was named the SRR-1, meaning "very low cost dryer–1 t" in Vietnamese. Although it was not released until the end of the 1995 wet-season harvest, 18 units were sold to farmers in Ho Chi Minh City and in districts of neighboring Long An Province. Records show sales of 50 units up to March 1996, 300 units at the end of 1996, and nearly 700 units at the end of 1997. Now, at a sales price of US$80 each, this is the cheapest mechanical dryer in Vietnam.

A promotion campaign was extended to the central and northern provinces in 1997. As of 1998, the SRR-1 dryer is on the list of postharvest equipment that will be promoted in the Danida-assisted "Postharvest and Rice-Processing Development Project in the Provinces of Can Tho, Soc Trang, and Thai Binh" from 1998 to 2001. This pilot project aims at increasing the quality and value of Vietnamese rice for export in these three provinces.

Abroad, with funding from the IRRI-CREMNET program, five SRR units were taken to Myanmar, Bangladesh, the Philippines, Indonesia, and India for testing (Fig. 4). All had good technical results. The fabrication technology was transferred to the cooperating agencies in these

Fig. 4. SRR-1 in demonstration to farmers in Bangladesh.

countries. The dryer was estimated to cost about US$100 in India and $200 in the Philippines. The Bangladesh Rice Research Institute fabricated 10 more units for promotion.

With appropriate consideration of the socioeconomic conditions, we believe that the SRR-1 dryer can be as successful in other countries as it has been in Vietnam.

A patent for the SRR-1 dryer (Number HI-0180 effective 28 June 1996) was issued in Vietnam to prevent imitators from claiming exclusive rights of use. The design is ready to be transferred to manufacturers by UAF without royalties. In 1996, the fabrication methodology was transferred to a mechanical cooperative workshop in Hue, 1,000 km from Ho Chi Minh City.

Development tools for SRR-1 dryers

Two main tools were used in developing the SRR dryer: a test duct for the fan and a spreadsheet for calculating the drying cost.

Test duct for fan. Thanks to the test duct (Fig. 5), the performance of the fan and furnace system was known prior to the actual drying tests. Using the psychrometric chart, drying time was estimated with sufficient accuracy. This preknowledge made us more confident in proceeding with the drying tests, usually with paddy borrowed from farmers.

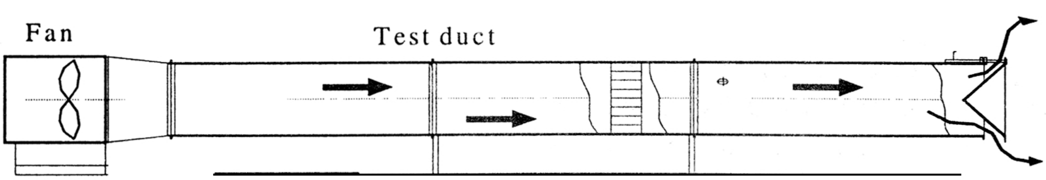

Fig. 5. Fan test duct.

The same procedure followed at UAF has been used in developing other dryers (flatbed, fluidized-bed, in-store dryers).

Spreadsheet for calculating drying cost. We used a one-page spreadsheet in Quattro or Excel. Cost data are entered in unprotected cells, and drying cost results in fractions of a second. Thus, by testing different assumed cost data, and keeping in mind a maximum acceptable cost to farmers, we arrived at the maximum investment dictated for the design, *before* the engineers started to design. In the case of the 1-t dryer, we specified a maximum of US$150. Two design configurations were tried in April 1995; the SRR-1 was the successful one.

Extension procedure for the SRR-1 dryer

The extension approach drew heavily on previous experience with flatbed dryers that indicated that users buy the dryer for their own business. If the first user obtains a profit with the dryer, then neighbors will also be interested in buying it. This extension method is a most effective and cheap approach, which was important because there were no subsidies for buying the dryer.

Thus, with support from the GTZ/ IRRI project, the extension procedure for farmers in the provinces was: upon request, we brought the dryer (by car or by motorbike) (Fig. 6) to the farmer's house, where we loaded and dried one batch for a few days. After drying this batch, if the farmer was satisfied, he paid 900,000 VN dong (approx. US$80) to own the dryer. If the farmer was not satisfied, we brought back the dryer.

So far, farmers have purchased practically all the dryers. By subsidizing the transportation and technical backstopping, the SRR dryer has been firmly anchored in farmers' land and minds. In one instance, we spent US$600 just to sell an $80 machine in Quang Ngai Province, 800 km from Ho Chi Minh City. This outlay was later compensated as farmers traveled the long distance to buy 25 more units. Two neighboring provinces then bought about 10 units.

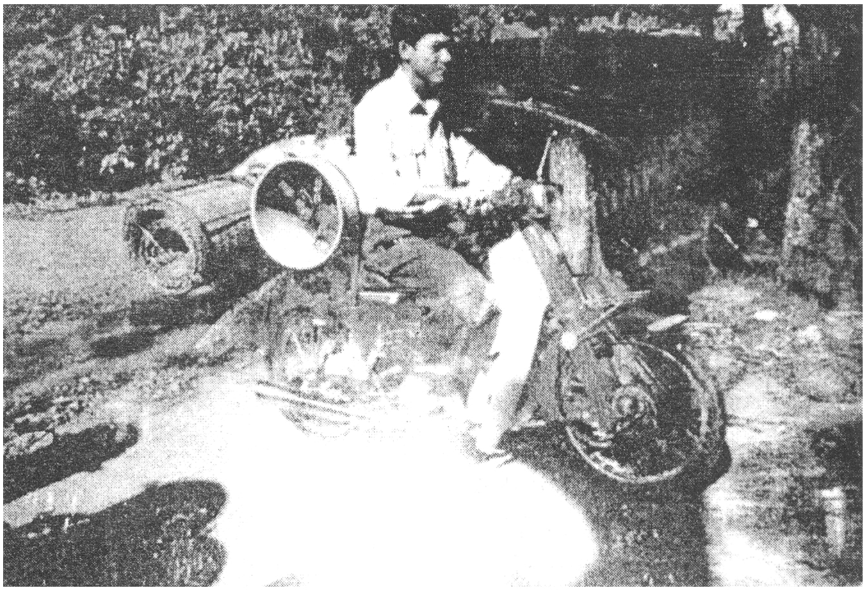

Fig. 6. Transportation of SRR-1 dryer by motorbike for 1-hour installation.

The SRR-1 dryer has been featured in newspapers and on radio and television (at no cost). We wrote the first article on the SRR-1 in September 1996 for *Popular Science* magazine in Ho Chi Minh City. This story resulted in a dozen farmers going to manufacturers. From then on, journalists were after more news about the dryer.

Abroad, several publications also mentioned the SRR-1 dryer; it was on the cover page of the Proceedings *Drying in Asia* published by the Australian Centre for International Agricultural Research (ACIAR) in 1996.

In Vietnam, the extension services of several provinces (Long An, Ho Chi Minh City, An Giang, Dong Thap), on their own initiative, have been active in promoting the SRR-1. The magnitude of the dryer investment and its mechanical simplicity made the extension work similar to promoting a new rice variety or a new cultural practice.

Roles of the public and private sector in development of the dryer

Public sector

For development of the SRR-1, the UAF, IRRI, and GTZ were the public-sector participants, with the following roles.

Development of prototypes. The actual cost of all the 6-t and 1-t prototype dryers was less than US$3,000, but the support base for their development was more than tenfold. This included support by GTZ for the equipment and allowances. The equipment was pooled with other equipment previously or concurrently acquired by other sister drying projects supported by the International Development Research Centre and ACIAR. Thanks to this support, we were able to develop a capable research staff of eight members, with testing equipment sufficient for local development. Without such a strong base, the development work would have been modest. No private-sector ventures take on that role without anticipating profits.

Extension of successful prototypes. UAF assumed the role of extension. We believe that manufacturers could never be good promoters of drying technology, especially in the case of small dryers, because too much time and cost are involved, and too little profit! *Extension, at least for drying, should be the work of the public sector.*

Thus, for the SRR-1 dryer, the test engineer and promoter of the first dryer were considered as important as the design engineer in providing feedback for modifications. Promotion of the SRR dryer occurred because it was profitable for farmers and not because it was the outcome of a foreign-assisted project.

Private sector

Private manufacturers. As soon as the first prototype showed the potential of being widely adopted, dryer fabrication was separated from research work. Le Van Ban, one of the research engineers, was accredited with the fabrication of dryers in his backyard shop. He has been totally responsible for customers and for the quality of his products. Of course, this went with some profit from the sales of dryers (estimated at about US$10 per dryer). A "private manufacturer" was thus established in the link and proved to be effective.

Private users. As in the case of the flatbed dryer, users from public agencies were not major promoters of the technology, although some were strikingly progressive. Rather, the main actors in promoting the dryer were users in the private sector. New machines, like new babies, need personal care.

Who should extend? Manufacturers or users?

In general, users of technology should have priority in receiving the extension. They are numerous and diverse. They represent *quantity.* The machine in their hands is just a means; any means needs training on its adaptation and efficient use, in other words, extension.

On the other hand, just a few *quality* manufacturers are enough, even just one in the start-up phase. The machine represents potential profit for them. If this is real profit, they will learn to make it with minimum external training or even none at all. Thus, for the SRR-1, we did not pay much attention to any "industrial extension." As long as there was a good prototype and a good number of users, the manufacturing sector would "automatically" be established.

Conditions contributing to the success of the SRR-1 dryer

The SRR-1 replicated the success enjoyed by other equipment in Vietnam, such as the axial-flow thresher and the flatbed dryer (Hien 1991a). Conditions contributing to their success have been partly discussed in the above sections and can be summarized by the following formula:

Local supply		Local demand
Total cost of machine use	$<$	Total profit gained (or loss avoided) by machine use

The total cost of use should include several items: reliability cost, opportunity cost, etc. The total profit should be based on current practices, not on theoretical or wishful thinking. For example, if the actual harvest is 1 month, then, in calculating depreciation cost, 30 days should be used. We should not say that maximum use and efficiency for a dryer should be calculated using 180 days. This might be the goal in the long run, but not the means for deciding which technology to adopt.

Conclusions

The SRR-1 dryer can be considered as a case of "integrated technical development," from design, prototype testing, and manufacturing to sales, monitoring, feedback, modifications, extension, and adoption. The public and private sectors complemented each other. The "nuts and bolts" approach, with due attention to simple economic considerations, resulted in a suitable small drying system. The field of agricultural engineering needs other products like the SRR-1 dryer that end up in the hands of farmers. Capable agricultural and mechanical engineers are needed for the design of appropriate machines; dedicated extensionists with necessary training are needed to teach farmers on the use of machines, and to develop new skills to provide feedback to designers and manufacturers.

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A systems approach to agricultural engineering in Cambodia

J.F. Rickman*

The agricultural engineering component of the Cambodia-IRRI-Australia Project (CIAP) is being implemented with the Cambodian Department of Agricultural Engineering (DAE) to help farmers sustain their rice crops through better land, water, and crop management.

In fulfilling this aim, leveling rice fields has been identified as one of the most important activities that all Cambodian farmers could adopt. A farming systems approach has been used to develop technologies for land leveling, land preparation, crop establishment, and water control. On-farm demonstrations have been widely used to demonstrate these technologies. A pump-testing facility has been developed to quantify the performance of both locally manufactured and imported irrigation pumps.

A training and machinery demonstration center has been developed for training courses, workshops, and farmer field days. Farm tillage and leveling equipment has been built and tested under local conditions.

Activities

Water management

Poor water control is a major constraint to rice production in Cambodia. Fields are often very uneven due to many years of poor plowing techniques and opportunities are often missed to prepare land and plant the crop. Uneven fields are also more prone to drought, take longer to shed floodwater, and are more difficult to manage.

Results indicate that

1. Farmers' fields vary by up to 20 cm in elevation within the field.
2. Back-blade or wet leveling reduces this to 4 cm and laser leveling to 2 cm.
3. Crop yields have been increased significantly by land leveling (28–50%).
4. Direct seeding has been used successfully and labor costs reduced.
5. Phosphate deficiencies occur in heavily "cut" areas but disappear in the second year.

Land preparation

Cambodian farmers have used four-wheel tractors widely since the 1960s. Local statistics indicate that at least 12% of Cambodia's rice fields are mechanically plowed and, during 1997, machinery dealers reported a large increase in demand for 60–80-hp tractors. These tractors are being used with three-disc and seven-disc plows. Poor plowing techniques and the inappropriate selection of equipment have contributed to a large number of very uneven and poorly prepared rice fields.

Results indicate that

1. Crop yields have increased 10–16% via more thorough land preparation.

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2. The four-wheel-tractor-based system gave the highest yields in crops that were grown both with and without fertilizer. The animal-based system yielded less than the four-wheel-tractor-based system in all trials.

Crop establishment

At present, 70% of Cambodian rice farmers transplant their crops. Transplanting rice is a very time-consuming and costly operation. Most farmers using this technique spend more than 30 person-days ha^{-1} in establishing their crops. By leveling and terracing fields, farmers have better water control within their fields and can therefore broadcast their crops, if desired.

Results indicate that

1. Crop yields of direct-seeded crops are not reduced relative to those of transplanted crops.
2. Plant establishment rates are often below 15%.
3. Broadcast crops lodge badly at the crown of the plant.

Fertilizer placement

Incorporating fertilizer in the top 10 cm of soil often requires an extra plowing and also increases the risk of losing fertilizer, especially in a direct-seeding situation.

Results indicate that there has been no significant yield difference when placing fertilizer on the surface, incorporating it in the top 10 cm of soil, or placing it deeper, at 20 cm.

Pump testing

A pump-testing facility was developed at the Department of Agricultural Engineering workshop for performance testing of local and imported pumps.

Results indicate that

1. Reducing pump speed significantly reduces pump capacity on low-lift pumps. At speeds below 1,000 rpm, the output for all of the low-lift pumps dropped to less than 15% of their total capacity.
2. Increasing the discharge height of a low-lift pump from 2 to 3 m decreased the average output by 42%. A similar test with medium-lift centrifugal pumps showed only a 12% reduction in capacity over the same change in discharge height.
3. Pump capacities can be increased 26% by moving the impeller inside the pump housing.

New farm equipment

New farm equipment has been developed as the need has arisen.

Developments to date involve the following:

1. Chisel plow. A three-point-linkage mounted tined plow was built and has been used successfully for land preparation.
2. Leveling bucket. A drag-type land-leveling bucket has been fabricated for use behind a 70-hp tractor.
3. Bund builder. A three-point-linkage mounted bund builder has been fabricated for use behind a 60–80-hp tractor.
4. Grain dryers. A two-bin grain dryer and a 1-t aerator were fabricated to complement grain drying on a drying pad.
5. Weir. A portable V-notch weir for measuring water flow was fabricated.

Training and demonstration center

Training is a critical component of the project to ensure sustainability by developing the capacity of local staff.

Results indicate that

1. Training courses have been conducted on land preparation, surveying technology, blacksmith techniques, and hammermill production for personnel from the Department of Agronomy, Department of Agricultural Engineering, European Union, Prek Leap Agricultural College, and private-sector machinery companies.
2. A new farm machinery workshop has been built at the Cambodian Agricultural Research and Development Institute research site.
3. Four students are presently doing postgraduate studies in New Zealand and Australia.

Time frame

The time frame, determined by the funding agency, is six years and, obviously, it could be argued that this is insufficient time for consolidating a program.

The first three years have focused on developing and extending technologies. The last three years of the project will be used to localize technology and involve other stakeholders such as contractors and other private-sector organizations.

Securing the future

Unless another donor is found after the CIAP ends, the DAE and Department of Agronomy will probably not have a budget to continue the work in agricultural engineering. CIAP has played a major role in the technology and capacity building of individuals locally and internationally.

Local engineers are being taught to obtain outside funding through consultancies and improved proposal writing. CIAP engineers want to learn about business management because they see that privatization may be the only way they can survive. Business opportunities do exist, especially in land preparation, water management, harvesting, and machine maintenance and, collectively, this group has expressed a desire to take up that challenge.

Roles of the private sector and government in formulating concepts and a methodology for an agricultural mechanization strategy[1]

L.J. Clarke*

Part I: Concepts and methodology

Introduction

Tools, implements, and powered machinery are essential for agriculture. It can be argued that they are one of the most important inputs. The term "*mechanization*" is generally used as an overall description of the application of these inputs. Three kinds of power are used to provide an energy source for these tools, machines, and equipment: manual power, animal draft, and motorized power.

The level, appropriate choice, and subsequent proper use of mechanization inputs in agriculture have a direct and significant effect on achievable levels of agricultural production, the profitability of farming, and the environment. In general, in a situation where the expansion of agricultural land is limited, the application of advanced tools and machines does not by itself lead to increased unit yields. But the full benefit of using many advanced crop husbandry inputs such as improved seed, fertilizer, and pesticides cannot be realized without the use of improved tools. Only under certain conditions, where production increases achieved by using other improved inputs have reached their limits, can improved tools and equipment by themselves lead to production increases, cost reductions, or improvements in the environmental sustainability of farming. In situations where land is not a constraint, increased farm power can lead to direct increases in production by simply increasing the land area or animal numbers that one person can handle.

In the past, misunderstood concepts and inappropriate selection and use of certain mechanization inputs (mainly tractors and heavy machinery) have, in many parts of the world, led to heavy financial losses and lower agricultural production as well as environmental degradation. Mechanization has often become a burden to the national budget and the farming community rather than being a productive input. This has been the case especially in centrally planned economies, where mechanization was heavily subsidized through the provision of government-planned and -operated machinery services. Similar models of government provision of services have been tried in many developing countries and have in every case failed.

The development of "appropriate" tools and equipment has also been a favorite subject for development assistance. But the activities of these projects generally took place in relative isolation in government and university departments and workshops and the resulting prototypes only occasionally found their way into commercial production and onto the market. In virtually every workshop in university departments of agricultural engineering is to be found a display of improved machines and hand tools that were never developed beyond the prototype stage.

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* Chief, Agricultural Engineering Branch, Agricultural Support Systems Division, FAO, Rome, Italy. This paper was presented at the International Commission of Agricultural Engineering Conference held in Morocco, January 1998.

[1] The views expressed in this paper do not necessarily reflect the official views of FAO or its member countries.

Further examples of misapplied mechanization inputs can be found in many technical cooperation projects, which were mostly planned and implemented with the best intentions but in an uncoordinated way and without due consideration of sustainability and economic aspects. It is an unfortunate fact that only a very few mechanization projects can claim to have been completely successful.

The role and place of mechanization

Despite its high cost and high profile, mechanization is still only an input like others such as fertilizer, seed, and crop protection chemicals, and it is one of a mix of management tools farmers have available to maximize production and profit. Therefore, in a free-market situation, it is inappropriate for governments to have an individual policy on mechanization except as a component contributing toward the realization of broader agricultural policy. To have a policy to "mechanize" would imply that the introduction and expansion of mechanization inputs is an end in itself, whereas it is only one of a mix of management tools that farmers use for the purpose of agricultural production. Government policies on privatization and the market, as well as other policies, will affect the way in which mechanization inputs are made available and will determine the effectiveness of the subsector. In a free-market economy, the amount and choice of mechanization inputs is demand-driven, whereas in a planned economy it is supply-driven. Mechanization should not be an end in itself; therefore, in a true free-choice situation, governments should refrain from making policies that will stipulate by which means or by how much agriculture will be mechanized. *The type and degree of mechanization should be decided by producers to best suit their business and their own particular circumstances, and the choice of suitable methods will therefore be just one of a number of choices that farmers have to make.* The decision on whether and how to mechanize is often a complicated mix of reasons, with economic reasons paramount.

Formulating an agricultural mechanization strategy

Within a general agricultural policy, governments develop strategies to achieve policy objectives. A strategy on mechanization should be just one of a number of strategies leading to the achievement of overall government policy. Agricultural Support Services, the Agricultural Engineering Branch (AGSE), began work several years ago in the field of formulating an agricultural mechanization strategy and studies have been carried out in several countries in Latin America, Africa, Asia, and Eastern Europe. Recently, with the changes occurring because of structural adjustment programs, the concepts of agricultural mechanization strategies have been further developed and adapted.

The philosophy behind the work of AGSE on an agricultural mechanization strategy is that national governments should provide the basic conditions for largely self-sustaining development of the agricultural subsector of mechanization within a policy of minimum direct intervention. The purpose of any interventions should be clearly identified and should fall within the objectives of the strategy. That does not mean, however, that agricultural mechanization can be neglected when formulating national policy. On the contrary, special attention should be paid to the effects that other policies have on the level and use of engineering inputs in agriculture.

All parties involved in formulating a strategy as well as those parties subsequently affected by it should be clear about its purpose. A strategy is basically a plan of how to move from one situation to a new situation. It is therefore fundamentally important that everybody is clear about what the new situation should be.

A typical formulation of agricultural mechanization strategy will contain several logical steps. The first step to be carried out is an overall analysis of the agricultural sector related to farm power inputs as well as an analysis of the existing national farm mechanization situation, including national inventories, domestic manufacturing and assembly (tools, implements, tractors, etc.), importation of farm tools and machinery, descriptions of farming systems in relation to the use of farm power, and their respective changes over time. This should lead to a statement of the *existing situation.*

Second, *policy issues* that affect farm mechanization are identified and problem areas and constraints are analyzed. This work is usually carried out in close cooperation with officials from the ministry of agriculture. Thus, awareness can be created of the effects of policy on agricultural mechanization and production.

Third, before formulating a strategy, it is important to define an (ideal) *future situation.* The resulting strategy will be the definition of the actions required to move from the existing situation to the future situation. This will generally be divided into defining the respective roles of the private and government sectors. The second part of this paper deals with this in more detail.

Finally, the strategy document should clearly define *follow-up activities* to assist policymakers and planners in carrying out the strategy. These activities usually consist of recommendations on policy adjustments to correct distortions in the subsector; investment plans to develop manufacturing, commercial companies, and farm mechanization; and a definition of government support activities required for the subsector.

For all the parties interested and involved in mechanization, there are several fundamental requirements for a thriving and sustainable subsector. The main groups of directly interested parties are (or should be) in the private sector and are farmers, retailers and wholesalers, manufacturers, and importers.

Virtually all mechanization inputs have to be paid for by farmers and all have to be purchased or replaced on a regular basis. "Regular" might mean every year for a hoe or it might mean every 10 years for a tractor. Also, farmers will often have a requirement for "service." This might mean something as simple as a nut and bolt or repair of a hoe or a spare handle, or it might mean an oil and filter change for a tractor. On a similar basis, retailers or small manufacturers (village shops or artisans) have to have access to supplies from wholesalers; large-scale manufacturers will need regular access to supplies and other inputs.

The fundamental requirement for a sustainable subsector is a strong linkage between these different parties and that all of them must be able to make a livelihood from their businesses.

If one of these parties is not making a livelihood, then the whole subsector will be adversely affected. In extreme cases, there will be a total collapse. This has happened, unfortunately, in a number of countries; in others, the subsector is barely functioning.

The main objective of defining a mechanization strategy is the establishment of conditions that will ensure the free and undistorted development and operation of these linkages and the definition of actions that will allow this to happen. The role of government is to define a suitable policy environment as well as provide support activities to create these conditions.

The existing situation

General agricultural situation. Generally speaking, the farmer level should be looked at first with a detailed analysis of the profitability of farming. If farmers are not making money from their cash crops, then they will have no surplus resources to purchase mechanization inputs. It is necessary to identify the major farming systems in each region of the country and the importance of farm mechanization in those systems. The final stage in the preliminary analysis of farming systems is to collate the available statistics and studies for each of the systems, indicating:

1. the number of farms in each system;
2. average farm size;
3. dominant crop/livestock production systems, including types of crops and method of production;
4. input use and production;
5. farm power and equipment use;
6. crop and livestock budgets;
7. average farm income; and
8. off- and nonfarm income.

This analysis should permit a preliminary identification of those systems where farm power is, or has the potential to be, important.

Supply chains. It is important that the existing *farm machinery and equipment supply chain* be thoroughly investigated, clearly understood, and analyzed. This will mean an in-depth collection of data about manufacturers, importers, artisanal activity, and national, regional, and local distribution and retail systems. The analysis will lead to an understanding of the constraints and problems faced by the different individuals, companies, and organizations engaged in these activities.

The farm machinery subsector varies substantially between countries. At one end of the spectrum are those countries with very few small- or medium-scale manufacturers, although they may have a significant number of local artisans and craftsmen. These countries rely mainly on imports to provide their farm tool, machinery, and equipment needs. In the middle of the spectrum are a group of countries that have a reasonable range of farm machinery available either from an indigenous small- or medium-scale manufacturing industry or from village artisans and craftsmen, or that are able to import those items they cannot manufacture. At the other extreme are countries that are self-sufficient in machinery manufacture and that may also be able to export a limited range of items.

Constraints in the supply chain should be identified as well as the reasons for their existence. If constraints exist, they will often arise because of one or more government policies. The identification and recognition of the effects of policy therefore form an important part of strategy formulation. Special attention should be given to government activities and interventions in the subsector, particularly both direct and indirect subsidies and their effects. Other government activities in areas such as training, education, extension, credit, and research and development, as well as any external interventions (projects, NGOs, bilateral gifts, etc.), should be identified. From this, a clear picture of the subsector and what affects it should emerge.

General economic situation. The collection of a selected number of *general indicators* of the status of a country's economy and its rate of development is also important. Typical data to be collected would be:

- Population
- Gross domestic product
- Wage rates
- Rural poverty
- Existing goals, objectives, and policies relating to mechanization
- Annual sectoral development plans
- Macroeconomic framework—planning rules and procedures, foreign exchange regulations, trade regulations, pricing regulations, taxes, levies, export and import regulations, quotas, tariffs, and estimates of domestic demand or consumption

Because most developing countries are predominantly agrarian societies, most national development goals and policies influence agricultural development and are thus likely to exert some effect on the subsector. A variety of documents should be requested at an early stage in the preliminary evaluation so that an evaluation of the impact of government policies can be made. In particular, it will be necessary to review the medium-term development plan and supporting documents.

In addition to the basic farming systems and the general economic situation, several related items should be examined whenever possible, such as gender and environmental issues.

Gender issues. Gender issues should be an important part of any study, particularly in connection with farming systems and postharvest processing. The analysis must include an initial breakdown of the major labor inputs on the basis of whether they are provided predominantly by male or female (or child) labor and whether the labor source is the farm family, exchange labor, or hired labor.

Environmental issues. Mechanization can have both positive and negative effects on the environment, although the negative ones tend to be most frequently highlighted. Positive effects include more timely field operations, which will allow farmers to avoid having to work in fields when conditions are poor; more efficient use of water, particularly in rice production; and better weed control. At the same time, mechanization must be recognized as having potentially negative environmental effects such as the extension of cropping into soils and climates that are not suited to the activity, adoption of land preparation technologies that are easy to implement but result in soil erosion, and promotion of the use of potentially hazardous chemicals for pest control. During the initial study, it will not be possible to consider all of the potential environmental issues, but those relating to specific types of mechanization should be identified, and possibilities for their amelioration considered.

Supporting institutions. The various institutions associated with the agricultural sector in general, and farm machinery and equipment in particular, should be identified. The types of institutions and likely available information involve:

- Credit—formal and informal credit sources for machinery manufacture, purchase, and use; credit terms, duration, and collateral requirements.
- Research and development institutions—agricultural universities; regional, national, and international centers. The type of information collected could include programs, staffing, facilities, budgets; crop and livestock conditions, practices, production performance, research; and agricultural engineering research, development, testing, and evaluation.

- Education and training programs—courses, student numbers, curricula, staff, facilities, student follow-up, budgets, and development plans.
- Agricultural and industrial extension—public- and private-sector activities, structure of systems, staff numbers and qualifications, contacts with farmers and manufacturers.
- Consumer protection—legislation regarding protection of consumers from illegal business practices, information dissemination, credit protection, etc.

Policy issues. A comprehensive review and evaluation of government policies that affect the subsector should be carried out. This will lead to an understanding of:

- what the government expects to achieve;
- how the government plans to go about it and the time frame for achievement;
- what and how national resources are to be mobilized and what mechanisms are to be adopted to promote their efficient allocation; and
- where, when, and how the government's policies influence agriculture in general and farm power supply in particular.

To achieve this effectively, current development policies will need to be analyzed. This will include laws, rules, and regulations that reflect those policies, particularly those that affect agricultural mechanization. There must also be an appreciation of the potential for encouraging changes in existing policies. The policy instruments that most frequently need to be considered are listed in the second part of this paper.

The future situation

As has been stated previously, the fundamental requirement for a sustainable subsector is a strong linkage between the different parties and that all of them must be able to make a livelihood from their businesses. For those involved in the private sector, an ideal future situation would consider the following:

Farmers need availability of the widest choice of appropriate farm tools, machinery, and equipment at affordable prices as well as access to spare parts and service to allow them to make the best choice for their own business; availability of credit to allow them to purchase these inputs; availability of information and advice to help them make the correct choice; legislation to protect them from commercial exploitation.

Retailers and wholesalers require a fair and competitive commercial environment in which to develop their businesses. This involves access to commercial credit for development and cash flow purposes, a stable market in which to sell their products, access to development assistance, and removal of any unfair competition from the area.

Manufacturers require access to a stable supply of raw materials at stable prices, credit for business development and cash flow, foreign exchange, good communications, a stable market, contacts with potential overseas partners/licensees, market information, assistance with product research and development and with production engineering, etc.

Importers require a fair and competitive commercial environment in which to develop their businesses. This includes access to foreign exchange at undistorted rates, foreign contacts, removal of any unfair competition from the area, marketing assistance, and access to credit for business development and cash flow.

Apart from a future picture of the private sector, other future situations must be specified:

Investment requirements—Farm tools, machinery, and equipment are essential inputs in the agricultural production process. By analyzing the current and past situation in the country, it should be possible to assess current and future investment in these inputs (e.g., farm tools, farm machinery) and whether the subsector is investing enough to ensure future agricultural production. This analysis can then be used to prepare investment plans and projects.

In addition, the *role of government* will need to be defined clearly. In general, the traditional role of government has been in the following areas: *policies that affect the subsector; research and development; testing; education, training, and extension; supply of information; mechanization departments—ministry of agriculture; consumer protection.* The second part of this paper deals with this in more detail.

Part 2: Roles of the private sector and the government

Introduction

In the first part, it is stated that:

> *"Mechanization should not be an end in itself; therefore, in a true free-choice situation, governments should refrain from making policies that will stipulate by which means or by how much agriculture will be mechanized;"* and *"The philosophy behind the work of AGSE on an agricultural mechanization strategy is that national governments should provide the basic conditions for largely self-sustaining development of the agricultural subsector of mechanization within a policy of minimum direct intervention."*

If the government does not decide on types and levels of mechanization and that the subsector should be largely self-sustaining, then one might reasonably ask, "What then *are* the respective roles of government and the private sector?" A generally held misconception, particularly among those who advocate structural adjustment programs and who generally have little understanding of the subsector and its importance, is that the government should adopt a "laissez-faire" attitude toward farm machinery, tools, and equipment. The belief is that this sector should be left totally to the private sector, and that the government should pull out of all activities concerned with manufacturing, importation, and retailing. In principle, this is correct; in reality, however, as soon as structural adjustment is implemented, seldom do entrepreneurs come forward quickly to fill the gap and, even if they do, the market can develop in a skewed manner. This is particularly so in situations where the government has been heavily involved in these activities and the private sector has been previously discouraged. Development of the private sector requires programs, incentives, and assistance. Therefore, the role of government needs to be defined clearly.

An important part of formulating a mechanization strategy is the definition of the two sectors: *the private sector and the government.*

Role of the private sector

As mentioned previously, the private sector usually has four main groups of interested parties: farmers, retailers and wholesalers, manufacturers, and importers.

In most free-market economies, each of these groups contains small to medium businesses[2]. The *linkages* among the four are essential to the successful and sustainable development of the subsector. A basic, fundamental requirement is that the "businesses" in each of these groups must be profitable. If farmers are not making money, they will not be able to purchase inputs; if retailers cannot sell items at a profit, they will not stock them, and, if manufacturers are not fabricating tools and machines at a price that farmers can afford, their business is unsustainable. This may appear to be a simple observation, but the absence of a thriving agricultural machine and tool manufacturing, importing, and retailing subsector can often be traced to the lack of profitability in one of these groups. In many countries, therefore, a major development goal must be creating linkages between each group and addressing issues that affect the profitability of one or more of these groups. The requirements of each group will differ.

Farmers[3]. A farmer or farm business should be able to freely choose the type, size, and extent of mechanization inputs from a range of those available on the market. Strategy should be aimed at *creating the conditions* whereby industry and commerce can provide this choice at competitive and undistorted prices and at physical distances that are within a farmer's reach. Apart from the obvious question of farm profitability, several issues and strategy components have a direct effect on a farmer's machinery investment decisions.

1. *Land tenure*—uncertainty of ownership leads to a lack of investment and commitment. Governments and other involved parties should cease speculating on what size and type of farm is most appropriate or economic. Emphasis should be given to creating conditions whereby any person, company, or group of individuals can create a farm business. It is also vitally important that farmers have title to their land so that collateral is available for borrowing.

2. *Credit and financing* should be available for all sizes and types of farm operation. Collateral requirements should be realistic and physical access to sources of credit should be made easy, but with the condition that the business plan and cash flow be realistic. This may mean establishing rural agricultural banks within easy reach of farming communities or promoting other community savings and credit schemes. The providers of credit should, ideally and if necessary, be in a position to help farmers formulate investment and business plans. If a high risk element exists (small farms, low collateral, marginal profitability, etc.), development agencies that might be prepared to take on high risks could be approached. This might apply in particular to marginal agricultural areas such as mountainous regions. In general, however, credit should not be made available exclusively for farm machinery nor should special conditions be created for the purchase of farm machinery only. A bias toward particular investments will result in distortions in the agricultural economy, particularly for rural labor.

3. *Credit for contractors and group users of farm machinery* should be made available under the same conditions as for farmers. Contractors can sometimes make a great contribution to agricultural production. They facilitate an efficient multifarm use of machinery and make available to farmers machines that they might not be able to afford individually. Cultural and other considerations will determine which contracting and multiuse

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[2] In this context, even the smallest farmers are considered to be a "business" in that they must purchase inputs and sell products, whatever the size of the transactions. Similarly, even the smallest blacksmith is regarded as a "business."

[3] "Farmer" in this context means a private individual, a company, or an association.

arrangements will develop. There are many forms of multifarm use of machinery. In its simplest form, this might mean an individual farmer doing work for his neighbors or a more formal group ownership of machines. Some countries have specialized contracting companies.

4. *Farmers' choice of machinery* is essential in a free agricultural economy. Notable in centrally planned economies were the restricted types and sizes of farm machinery available. Different farms require different types and sizes of machines. What is also usually forgotten is that individuals wish to make their own choice of what they invest in. One farmer may wish to purchase hand and animal draft equipment and rely on this for farming, another may wish to purchase a tractor for both his own use and to contract services for his neighbors. As long as both choices are viable, there is no reason why farmers should not be able to choose. Outside persons and agencies should avoid being prescriptive.

5. *Farm-gate prices* will influence farmers' purchasing decisions. Governments should be continually aware of the profitability of farming and how this affects investment in inputs.

6. *Subsidies and price supports* are common in many countries. If countries decide to use subsidies for farm machinery, then the purpose and time limitations of the subsidies should be clearly stated and understood. Capital subsidies for specific technologies (e.g., subsidies or preferential interest rates for tractors) should be avoided. The choice of a machine then remains under farmers' control and they are not influenced to purchase a particular type of machine or technology through financial incentives rather than for pure business reasons. Hastily applied and hastily removed subsidies distort markets for farm machinery and make financial planning by farmers, dealers, and manufacturers very difficult. Farmers and businesses above all wish for stability.

7. *Support for farmers' associations.* In many countries, farmers have associations that can provide services to their members and also lobby government on matters of interest. Governments should encourage this because it creates a means of dialogue; however, these associations should be created and organized by farmer initiative.

8. *Technical assistance* is required by farmers and the government. Farmers require assistance in all aspects of their activities—agricultural, financial, and planning. Governments require assistance to develop the above services, perhaps through individual ministries or through agricultural banks or other appropriate institutions.

Retailers, wholesalers, and importers. The existence of sales outlets that are within easy reach of farmers is essential to developing a successful and sustainable private farming system. Special attention should be given to creating conditions so that distributors and small dealers can develop. These commercial units may range from a small one-family shop in a village to a large national distributor for domestically produced and imported machinery. Any foreign or government assistance for financing farm machinery, tools, or equipment should be channeled through a distributor/dealer network and not directly through the government. Importers should, in principle, be allowed free access to markets. This will create a wider choice for farmers and create a situation in which the domestic manufacturing industry will be stimulated to produce high-quality and functionally advanced machinery and tools at competitive prices.

The main issues and strategy components are:

1. *Financing* is required for start-up capital, and to ensure cash flow and adequate inventory. Collateral requirements should be as flexible as possible to encourage small entrepreneurs to take risks in starting up small businesses. Development agencies may be able to assist in these business development programs.

2. *Technical and financial assistance*, particularly for smaller businesses, is required for planning, marketing, stock control, bookkeeping, and contracts, and for making contacts with potential suppliers and partners. Governments may need to set up special business development programs.

Manufacturers. Conditions should be created so that domestic manufacturing can develop. Market conditions, particularly the profitability of agriculture, will determine the extent and technical level of the industry. There needs to be an appraisal of domestic manufacturing potential and capabilities so that a realistic picture of a likely future industry can be formed. New companies will develop through joint ventures, foreign investment, or local investment. Governments should recognize this by creating conditions for positive developments. The most pressing needs are usually financing and credit, assistance in setting up joint ventures, and assistance in commercial aspects such as marketing, export, and business development.

Financing is required for start-up capital, and to ensure cash flow and adequate inventory. Collateral requirements should be as flexible as possible to encourage small entrepreneurs to take risks in starting up small businesses. Development agencies may be able to assist in these business development programs. Foreign exchange will be required on a regular and constant basis for importing raw materials.

Technical and financial assistance, particularly for smaller businesses, is required for planning, marketing, stock control, bookkeeping, and contracts, and for making contacts for the formation of joint ventures and manufacturing agreements. Governments may need to set up special manufacturing development programs.

Role of the government[4]

Development of the private sector requires programs, incentives, and assistance. The sort of assistance required by the private sector has already been broadly defined. The government should provide this assistance. The role of the government therefore needs to be defined clearly.

The following policy instruments most frequently need to be considered:

- Exchange rates.
- Agricultural input prices—direct market intervention to manipulate input prices, tariffs, and import restrictions, and input subsidies.
- Prices for agricultural products.
- Farm and nonfarm employment—employment and wages policy, migration.
- Land ownership and tenure.
- Agrarian institutions.
- Research on farm power—agricultural machinery, agricultural sustainability, transfer of farm power technology.
- Agricultural extension.

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[4] Much of this section has been taken from the draft "Guidelines for Agricultural Mechanization Strategy Formulation" prepared for AGSE by Mr. John Wicks. The subject is further elaborated in Annex I of that draft.

- Infrastructure—rural transport, marketing, and irrigation.
- Agricultural financial markets.
- Industry.
- Transport.

Policies relating to agriculture can be divided into two groups: those about which there is general agreement on the need for government intervention, and those about which disagreements remain (Timmer 1991[5]).

Policy areas about which it is generally agreed that some form of government intervention is desirable include (1) agricultural research, (2) larger-scale infrastructure investments (including irrigation), and (3) marketing infrastructure.

Agricultural research is considered an important and legitimate area for government intervention because of its "public good" characteristics. The case for government intervention is less clear, however, for research on large-scale agricultural machinery because of the involvement of private enterprise and the limited market. The agricultural marketing infrastructure also has strong "public good" characteristics, and is seldom confined to exclusive use for agricultural products and inputs. Policies on the agricultural marketing infrastructure are relevant to agricultural mechanization in that machinery and equipment can be used transport products from the farm and transport inputs to the farm.

Policy areas still subject to considerable disagreement are exchange rates, price interventions, land tenure, farmer organizations, agricultural extension, and marketing boards.

Governments have traditionally influenced exchange rates by fixing them at artificial levels or limiting their rate of adjustment, often creating artificial shortages of foreign currency. More recently, governments have been encouraged to relax foreign exchange regulations so that the market can fix the appropriate exchange rate.

Price interventions cover three main agricultural policy areas: input prices, product prices, and financing. The chief price intervention issue is subsidized interest rates in the agricultural credit market. Price interventions relating to agricultural mechanization depend on the benefits derived from correcting market distortions to better reflect the true values of agricultural output or input prices and equity gains from improving the welfare of the rural poor (e.g., greater employment opportunities for landless laborers).

The key issue for land tenure policy is how it can be used to improve both equity and efficiency. Land tenure policy can affect mechanization by influencing the ability of farmers to use certain types of agricultural machinery and equipment efficiently.

Agricultural extension has traditionally been considered a role of government. But it is now being recognized that many governments do not have the resources to provide free extension services to all farmers. While the solution in many developed countries has been to levy a charge, a more workable approach in developing countries may be to pass the extension role to the private sector, including nongovernment organizations.

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[5] Timmer, C.P. 1991. *The role of the state in agricultural development.* In: C.P. Timmer (ed.), Agriculture and the state: growth, employment, and poverty in developing countries. Ithaca, New York: Cornell University Press. p 1-28.

Other policy areas that are not specific to agriculture can have a substantial influence on the processes of agricultural machinery and equipment use, such as employment and wages, industry, and transport. Employment concerns are central to development objectives—levels of agricultural employment are influenced by the substitutability of machinery and equipment for labor in farm operations. Mechanical innovations stem primarily from the industrial sector; industry policy can influence profitability in the agricultural machinery and equipment industry. Transport policy is closely linked to marketing infrastructure policy.

Experience with conducting preliminary studies on strategy formulation indicates that the important issues relating to each policy area need to be discussed and clarified with the relevant government agencies. In light of the discussions, the list of issues may be revised. Once policies are understood, a draft position paper should be prepared and circulated to policymakers and analysts within government service, university departments, etc., for comment. Team members, and not just policy analysts, should make every effort to meet with these persons and discuss their detailed comments. A revised policy paper should then be prepared as part of the report and discussed in the workshop that terminates the preliminary evaluation.

Policy analysis should also consider the following factors.

1. *Research and development.* Although in general this is best carried out by the private sector because companies are in the best position to judge what is best for their own particular business, research and development (R&D) is expensive and requires skills and expertise that may not be affordable by developing businesses. Governments may therefore need to be involved in R&D. If so, however, this should be carried out in close cooperation with the private manufacturing sector to ensure that R&D is closely linked with the identification of markets and subsequent manufacture. Any R&D financed by government (or external agencies) should be channeled through private companies. Expertise required should be in the company itself. It is not appropriate for governments to run public-sector development workshops because these workshops tend to become isolated and have little connection to the private sector.

2. *Testing* of farm machinery is a controversial subject and is a topic that can itself be the subject of a workshop. In fact, AGSE has in the past year carried out two 5-day regional workshops on this important subject. The main issue is whether governments can run a testing program without preventing the free development of the private sector and restricting the choices that farmers should have available. AGSE has published two bulletins on this important subject[6].

3. *Education, training, and extension*[7]. Governments should develop an integrated and interlinked education, training, and extension program. The type and level of education and training will need to be geared toward the requirements of the agricultural manufacturing and production sectors.

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[6] Reference is made here to two AGSE bulletins dealing with this subject:
Bulletin 110—Testing and evaluation of agricultural machinery and equipment, 1994 (Eng., Sp.).
Bulletin 115—Selection, testing and evaluation of agricultural machines and equipment, 1995 (Eng., Fr., Sp.).

[7] See AGSE Bulletins:
88/1—Agricultural engineering in development: basic blacksmithing: a training manual, 1992 (Eng., Fr., Sp.); 88/2—Agricultural engineering in development: intermediate blacksmithing: a training manual, 1992 (Eng., Fr., Sp.) 88/3—Agricultural engineering in development: advanced blacksmithing: a training manual, 1992 (Eng., Fr.); 92—Agricultural engineering in development: human resource development training and education programmes, 1992 (Eng., Fr., Sp.).

4. *Mechanization departments–ministry of agriculture.* With the prevailing constraints to government spending, many governments' policies are to reduce the amount of national resources spent on the civil service and to remove from it all but the essential policy-making functions. Under such conditions, mechanization departments should be primarily responsible for advising the government on the formulation of mechanization policy, strategy, and programs for development of the overall sector as outlined above, as well as for collecting data and statistics and disseminating information. Once an overall strategy has been defined, governments can easily identify components for which resources are required and for which appropriate outside assistance is perhaps required.
5. *Consumer protection.* This area covers the introduction of laws and regulations that will protect consumers. This should include safety regulations, enforcement of contract law, introduction and enforcement of standards, consumer information services, publication of test reports, protection against unscrupulous commercial practices, consumer credit protection, etc.

Conclusions

It is important that governments identify a strategy for the farm mechanization subsector and agricultural engineering in general. The expected results of a study on an agricultural mechanization strategy are proposals on how the national government can help the private sector (1) meet demands from farmers and other consumers in the agricultural sector and (2) develop a sustainable system of manufacture, importation, retailing, and use. Every commercial unit involved in this chain will have to be profitable for the whole system to develop and flourish. This means that the strategy should have a positive impact on agricultural production and the economy and should not have a detrimental effect on the environment or be against other public interests. The strategy should clearly state the different roles of the government and the private sector. These might include issues related to areas of general public concern such as consumer protection, the environment, or safety, and other activities that have been identified as not being able to be left to free-market forces.

Introducing change: What next?

M.A. Bell*

"To remain the same when change is needed is to make a mistake." (Victor S.L. Tan)
"A man who has committed a mistake and doesn't correct it is committing another mistake." (Confucius)

Process of change

If change is required in the approach used for agricultural engineering (AE), then we must consider the process of change. Three steps are involved in change (from Egan 1988, Hussey 1995, Johns 1992):

1. Unfreezing—developing an awareness that the present scenario is inadequate, and thus there is a need to change.
2. Change—creating a preferred scenario; designing and implementing a plan that moves from the current to the preferred scenario.
3. Refreezing—making the new environment firm. If this is not done, people will drift back to the previous scenario. It is also an opportunity for assessing the effectiveness of the change to date and evaluating the need for further change.

Implementing change will involve:

1. Diagnosis—identifying problems and suggesting needed changes.
2. Resistance management—helping overcome resistance to change by gaining support for the change. If change is adequately identified as needed, then resistance to change can come from political interest and self-interest, low individual tolerance for change, misunderstanding, lack of trust, a different assessment of the situation, and/or a resistant organizational structure.
3. Evaluation and institutionalization—determining whether the change achieved the objectives, and whether the change is now considered adequate.

Change for agricultural engineering?

The question for us is, If others have changed (e.g., AE in the United States), do we automatically have to also change? I think we would all agree that "no." Instead, we need to change if we deem that there is a better scenario for AE.

During the past two days, we have looked at opportunities and approaches. We have heard how research, design, and development, when done in isolation, have resulted all too often in multiple prototypes sitting in public research and development (R&D) institutes—prototypes that never make it to the field. We need to learn from successes and failures of the past (e.g., Rijk 1990) and present to make the necessary adjustments to help both public- and private-sector engineering—both nationally and internationally—increase their impact. (My personal opinion is that there is an opportunity to improve—to look more at application and problem solving and have equipment development as one of our tools, not our focus.) The challenges and changes

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needed for the international public sector will likely differ from those for the national public sector. Target groups may vary, but there will probably be common elements in the approach.

In the preparation for this think tank (see paper by Douthwaite and Bell), it was apparent that a number of people, including some present at this meeting, felt the need for change in the discipline. But if the need for change is so clear to some, why is it not so clear to others? If change is required, what is the direction required and the steps needed to introduce it? Further, have we learned from the past? For example, a 1985 conference (IRRI 1986) led to the development of a series of recommendations on some related points (Table 1). Some points have clearly emerged as common in this think tank. Having "reidentified" some key points, we surely want to avoid further repetition of the call for change. We therefore need to focus our efforts on implementing that change.

In working toward change, the think tank has produced some much-needed outputs, including in particular:

1. Clarity in terms of a desired R&D strategy.
2. Clarity on the relative roles of public (national and international)-sector agricultural engineering and its interaction with the private sector.

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Table 1. Recommendations from IRRI (1986).

Recommendations for international institutes, programs, and donors

1. Place less effort on on-site adoption of mechanization and more on new areas such as upland mechanization of farming systems.
2. Identify problems and create methodologies for national programs to use—establish problem priorities, select interdisciplinary teams, schedule technology introduction, obtain institutional support, and develop appropriate national policies. International institutes should concentrate on developing machines that national programs cannot handle.
3. Counterbalance technologies developed through multinational firms, such as genetic engineering of crop varieties that requires manufactured inputs.
4. Continue to create methodologies, promote technology exchange, generate improved technology, create information data banks, standardize terminology, facilitate academic training, train trainers for national programs, and assure free flow of information.
5. Provide information to those who frame national policies by researching the implications of technology production, resource allocation, and economic impact of technologies.

Improve agricultural mechanization in Mid-Africa

1. Recognize needs of semiarid areas: better weed control; emphasis on hand tools, especially sprayers; use of animal power, especially donkeys; improvement of intercropping systems; improved water-harvesting methods; postharvest technology for drying and storing; processing feed for intensive animal production; erosion control; firewood plantation development; and small enterprise development.
2. Recognize needs of humid tropics: minimum or zero tillage to conserve soil and water and maintain fertility; agroforestry and fodder crops to forestall desertification; and postharvest processing, especially of root crops.
3. Improve preharvest operations by applying equipment innovations based on human and animal power that need little adaptive development, integrating them with soil and water management, and providing training and extension to manufacturers and farmers.
4. Improve postharvest operations, including solar crop drying and mechanical drying using alternate energy sources.
5. Improve primary processing of food for local market and feed for livestock, including cassava, gali, fermented soya, banana drink, and flour.
6. Improve agroindustries for processing and packaging based on local materials.
7. Provide the institutional framework by strengthening linkages between engineering R&D and farming systems programs and manufacturers, and between farmers and farming systems programs and manufacturers and their after-sales service.

Strengthen national institutions

1. Help strengthen national institutions with roles in research, development, and extension of agricultural mechanization; facilitate their work with inventors, manufacturers, and farmer associations; and help them formulate mechanization policies.
2. Strengthen linkages between international and national institutions.
3. Encourage basic research in international institutions and applied research in national institutes.
4. Continue the industrial extension program of IRRI as a successful model of technology dissemination in order to further strengthen national institutes and sustain national agricultural mechanization development.
5. Provide training, particularly on machinery design, and exchange experts between IRRI and national institutes.
6. Ensure appropriate mechanization technology through socioeconomic research.

Table 1 continued

Table 1 (continued).

Stimulate local innovations and manufacture of small farm equipment

1. Strengthen national technical, engineering, and industrial services and orient them to serve small and medium-size manufacturers.
2. Stimulate small-to-medium-scale entrepreneurship through improved national policies and liberal credits from industrial financial institutions.
3. Establish an integrated national program for upgrading capabilities of small-to-medium industries and entrepreneurs, with appropriate policies for technology, training, management, and manufacture.
4. Interlink international aid agency programs with cooperation between R&D institutions and manufacturers at national and regional levels.
5. Facilitate these objectives by IRRI's development of the model draft of the memorandum of understanding between R&D institutions and manufacturers; promotion of wetland and dryland equipment developed and manufactured by developing countries; expansion of its industry service program through collaboration with donor agencies and industrial organizations such as the United Nations International Development Organization, stressing local production and strengthening of national engineering technical services; development of pilot demonstration programs for national use, financed by international donors.

Improve marketing and accessibility of agricultural equipment for small farmers

1. Evaluate appropriateness of hand tools, small human- and animal-powered equipment, and power equipment.
2. Consider marketing alternatives for hand tools such as through local blacksmiths, in village markets and hardware stores, through mail order, and through cooperatives and farmer associations.
3. Strengthen distribution of small human- and animal-powered equipment by encouraging government and private organizations to train local manufacturers and users; encourage government to supervise quality control at the introductory stage; encourage private distributors to use commissions and bonuses to stimulate sales.
4. Facilitate marketing of power equipment by encouraging appropriate national mechanization policies for selection of equipment to be introduced, pricing, and imports; encouraging custom-hiring cooperatives and individual-hiring enterprises; encouraging government and banks to provide special credit for establishing such enterprises; and providing subsidies for equipment users, avoiding use of farmland as collateral.
5. Encourage IRRI to concentrate on defining priorities, restricting introduction of new equipment to a few selected manufacturers and dealers, allowing them to make a profit and thus improve quality and marketing; provide market research; and improve feedback from national adoption programs.

Identify characteristics of appropriate equipment for small farms

1. Identify characteristics of small farmers before selecting and designing equipment, assess farmers' needs and socioeconomic status, and facilitate interaction between engineers, other professionals, and users.
2. Identify farming/cropping systems of farmers, including constraints that mechanical interventions can alleviate.
3. Provide more attention to animal-powered equipment.
4. Consider physical stress on users and user safety.
5. Develop local power sources and match implement design to those sources. Use materials and fabrication techniques that produce energy-efficient equipment.
6. Introduce reliable equipment with a short payback period.
7. Develop machines for incorporating organic matter, improving soil properties, and reducing weed populations.
8. Design equipment that uses standardized parts and can be repaired and serviced at the village level.
9. Design simple machines, yet ones that can accept attachments for different operations.
10. Remember the basic design criteria: economically viable, technically feasible, and socially acceptable.