

The concept and implementation of precision farming and rice integrated crop management systems for sustainable production in the twenty-first century

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Agricultural production systems, including rice systems, have been very successful in increasing productivity and efficiency, thanks to genetic improvement, agrochemical practices, irrigation and farm machinery. However, the world population continues to grow steadily, while the resources for agricultural production diminish. Moreover, the economic pressure resulting from World Trade Organization (WTO) negotiations and increasing environmental degradation are threatening sustainable production in the twenty-first century. There have, therefore, been considerable efforts to develop innovative approaches for sustainable crop production.

In several countries in the developed world, the precision farming system (PFS) has emerged since the early 1990s in various forms, depending on the knowledge and technology available. PFS is implemented in combination with advanced information technology and full agricultural mechanization. Electronic information technology is used to collect, process and analyse multi-source data for decision-making (Sonka, Bauer and Cherry, 1997). The declining prices of agricultural products in recent years, coupled with the increase in production costs, have favoured the application of PFS in many developed countries. The importance of precision agriculture in the near future is further attested by the interest shown by NASA (National Aeronautics and Space Administration).

In many developing countries, however, there is no specific PFS programme – there is a shortage of capital, knowledge and technologies. Nevertheless, improved agricultural management is practised, exploiting available means and resources to increase agricultural productivity and production. In rice production systems, for example,

farmers in developing countries use their own experience as well as recommendations from research and extension services to undertake activities in seed selection, land preparation, crop management, irrigation and harvest. The recently developed rice integrated crop management systems, which may be adapted to the social and economic conditions, are promising for effective input use, increased productivity and improved farm profits.

THE PRECISION FARMING SYSTEM CONCEPT

PFS is based on the recognition of spatial and temporal variability in crop production. Variability is accounted for in farm management with the aim of increasing productivity and reducing environmental risks. In developed countries, farms are often large (sometimes 1 000 ha or more) and comprise several fields. The spatial variability in large farms, therefore, has two components: within-field variability and between-field variability.

The precision farming system within a field is also referred to as site-specific crop management (SSCM). According to the Second International Conference on Site-Specific Management for Agricultural Systems, held in Minneapolis, Minnesota, in March 1994,

SSCM refers to a developing agricultural management system that promotes variable management practices within a field according to site or soil conditions.

(National Research Council, 1997)

However, according to Batte and VanBuren (1999), SSCM is not a single technology, but an integration of technologies permitting:

- collection of data on an appropriate scale at a suitable time;
- interpretation and analysis of data to support a range of management decisions; and
- implementation of a management response on an appropriate scale and at a suitable time.

In a study of PFS in developed countries, Segarra (2002) highlights the following advantages to farmers:

- Overall yield increase. The precise selection of crop varieties, the application of exact types and doses of fertilizers, pesticides and herbicides, and appropriate irrigation meet the demands of crops for optimum growth and development. This leads to yield increase, especially in areas or fields where uniform crop management practices were traditionally practised.
- Efficiency improvement. Advanced technologies, including machinery, tools and information, help farmers to increase the efficiency of labour, land and time in farming. In the United States, a mere 2 hours are sufficient to grow 1 ha of wheat or maize.
- Reduced production costs. The application of exact quantities at the appropriate time reduces the cost of agrochemical inputs in crop production (Swinton and Lowenberg-DeBoer, 1998). In addition, the overall high yield reduces the cost per unit of output.
- Better decision-making in agricultural management. Agricultural machinery, equipment and tools help farmers acquire accurate information, which is processed and analysed for appropriate decision-making – in land preparation, seeding, fertilizer, pesticide and herbicide application, irrigation and drainage, and post-production activities.
- Reduced environmental impact. The timely application of agrochemicals at an accurate rate avoids excessive residue in soils and water and thus reduces environmental pollution.
- Accumulation of farmers' knowledge for better management with time. All PFS field activities produce valuable field and management information and the data are stored in tools and computers. Farmers can thus accumulate knowledge about their farms and production systems to achieve better management.

PRECISION FARMING SYSTEM IN THE DEVELOPED WORLD

Farmers in developed countries typically own large farms (10-1 000 ha or more) and crop production systems are highly mechanized in most cases. Large farms may comprise several fields in differing conditions. Even within a relatively small field (≤ 30 ha), the degree of pest infestation, disease infection and weed competition may differ from one area to another.

In conventional agriculture, although a soil map of the region may exist, farmers still tend to practise the same crop management throughout their fields; crop varieties, land preparation, fertilizers, pesticides and herbicides are uniformly applied in spite of variation. Optimum growth and development are thus not achieved; furthermore, there is inefficient use of inputs and labour. The availability of information technology since the 1980s provides farmers with new tools and approaches to characterize the nature and extent of variation in the fields, enabling them to develop the most appropriate management strategy for a specific location, increasing the efficiency of input application.

NEW TOOLS AND EQUIPMENT

In addition to mechanization, other tools and equipment are used in PFS in developed countries.

Global positioning system (GPS)

GPS is a navigation system based on a network of satellites that helps users to record positional information (latitude, longitude and elevation) with an accuracy of between 100 and 0.01 m (Lang, 1992). GPS allows farmers to locate the exact position of field features, such as soil type, pest occurrence, weed invasion, water holes, boundaries and obstructions. There is an automatic controlling system, with light or sound guiding panel (DGPS), antenna and receiver. GPS satellites broadcast signals that allow GPS receivers to calculate their position. In many developed countries, GPS is commonly used as a navigator to guide drivers to a specific location. GPS provides the same precise guidance for field operations. The system allows farmers to reliably identify field locations so that inputs (seeds, fertilizers, pesticides, herbicides and irrigation water) can be applied to an individual field, based on performance criteria and previous input applications (Batte and VanBuren, 1999). Perry (2005) highlights the specific advantages of GPS in farm operations:

- Farm machines are guided along a track hundreds of metres long making only centimetre-scale deviations.
- Rows are not forgotten and overlaps are not made.
- The number of rows can be counted during work.
- Tools and equipment can be operated in the same way from year to year.
- It is possible to work at night or in dirt with precision.
- The system is not affected by wind.
- An additional recorder can store field information to be used in making a map.

Sensor technologies

Various technologies – electromagnetic, conductivity, photo-electricity, ultrasound – are used to measure humidity, vegetation, temperature, vapour, air etc. Remote-sensing data are used to: distinguish crop species; locate stress conditions; discover pests and weeds; and monitor drought, soil and plant conditions. Sensors enable the collection of immense quantities of data without laboratory analysis. The specific uses of sensor technologies in farm operations are as follows:

- Sense soil characteristics: texture, structure, physical character, humidity, nutrient level and presence of clay (Chen *et al.*, 1997).
- Sense colours to understand conditions relating to: plant population, water shortage and plant nutrients.
- Monitor yield: crop yield and crop humidity.
- Variable-rate system: to monitor the migration of fertilizers and discover weed invasion.

Geographic information system (GIS)

The use of GIS began in 1960. This system comprises hardware, software and procedures designed to support the compilation, storage, retrieval and analysis of feature attributes and location data to produce maps. GIS links information in one place so that it can be extrapolated when needed.

Computerized GIS maps are different from conventional maps and contain various layers of information (e.g. yield, soil survey maps, rainfall, crops, soil nutrient levels and pests). GIS helps convert digital information to a form that can be recognized and used. Digital images are analysed to produce a digital information map of the land use and vegetation cover. GIS is a kind of computerized map, but its real role is using statistics and spatial methods to analyse characters and

geography. Further information is extrapolated from the analysis (ESRI, 2002). A farming GIS database can provide information on: field topography, soil types, surface drainage, subsurface drainage, soil testing, irrigation, chemical application rates and crop yield. Once analysed, this information is used to understand the relationships between the various elements affecting a crop on a specific site (Trimble, 2005).

Variable-rate technologies (VRT)

Variable-rate technologies (VRT) are automatic and may be applied to numerous farming operations. VRT systems set the rate of delivery of farm inputs depending on the soil type noted in a soil map. Information extrapolated from the GIS can control processes, such as seeding, fertilizer and pesticide application, and herbicide selection and application, at a variable (appropriate) rate in the right place at the right time (Batte and VanBuren, 1999; NESPAL, 2005). VRT is perhaps the most widely used PFS technology in the United States (National Research Council, 1997).

Grain yield monitors for mapping

A monitor mounted on a combine continuously measures and records the flow of grain in the grain elevator. When linked with a GPS receiver, yield monitors can provide data for a yield map that helps farmers to determine the sound management of inputs, such as fertilizer, lime, seed, pesticides, tillage and irrigation (Davis, Massey and Massey, 2005).

Crop management

The precision farming system employs the innovations and technologies described above (Rickman *et al.*, 1999). Thanks to satellite data, farmers have a better understanding of the variation in soil conditions and topography that influence crop performance within the field. Farmers can, therefore, precisely manage production factors, such as seeds, fertilizers, pesticides, herbicides and water control, to increase yield and efficiency. In the United States, for example, the management scheme of typical PFS comprises the following practical steps (NESPAL, 2005):

1. Determine management zones to be applied with PFS.
2. Establish yield goals.
3. Carry out soil sampling and data interpretation.
4. Make decisions regarding management of land

preparation, varieties, fertilizers and other nutrients to achieve yield goals.

5. Establish maps to discover the pest population: insects, diseases and weeds, using an integrated pest management (IPM) approach.
6. Apply precision irrigation.
7. Apply logging and automated record keeping.
8. Monitor and establish yield maps, evaluate PFS response and identify strengths and weaknesses for future improvement.

The Australian Centre for Precision Agriculture (2005) is currently focusing on the application of PFS in crop production and its site-specific crop management includes five main processes:

1. Spatial referencing. Collecting data on the spatial variation in soil and crop features requires accurate position determination in the field, using GPS.
2. Differential action. In response to spatial variability, farming operations, such as sowing rate, fertilizer, pesticide and lime application, tillage and water use, can be varied in real time across a field. Variation in treatment corresponds to the mapped variation in the field attributes measured.
3. Soil and crop monitoring. Soil and crop attributes are monitored on a finite scale. When observations are targeted with GPS, they provide data on the spatial variability of the attributes within a field.
4. Spatial prediction and mapping. Values for soil and crop attributes are predicted for unsampled locations across a field. This enables detailed representation of the spatial variability within an entire field through the creation of a smoothed map.
5. Decision support. Knowledge about the effects of field variability on crop growth – and the suitable agronomic responses – can then be combined to formulate differential treatment strategies.

In summary, PFS – also referred to as site-specific farming – is made possible by the deployment of GPS to locate sites within the fields. A computer integrates the GIS application map and the GPS receiver information, which are sent to the controller on the VRT machine, which applies variable rates in farming operations.

Adoption of PFS in developed countries

In developed countries, farmers – including rice farmers – have gradually moved from conventional highly

mechanized agriculture to a high-tech precision farming system. Many farmers in the United States and Canada began using GPS with a yield monitor to produce a yield map for field improvement. Sales of yield monitors in the United States have been increasing by between 70 and 300 percent a year from 1993 to 1998 (Swinton and Lowenberg-DeBoer, 1998). Recently, PFS has focused on the variable application rates of NPK fertilizers, seeding and irrigation. The development and adoption of PFS in Europe is less advanced than in the United States and Canada, due to the relatively small size of farms in most European countries. In Japan, where the average farm size is small, not all researchers and managers believe that PFS can be deployed to increase economic returns, reduce production costs and energy inputs, and conserve the agricultural environment. However, Shibusawa (2002) reported that the concept of PFS could be implemented on small as well as large farms:

- Farm variability is a major issue and PFS is equipped to find appropriate solutions. Variability exists in three aspects: spatial, temporal and predictive.
- Variable-rate technology is used to adjust agricultural inputs (fertilizers, pesticides, herbicides, water use) for site-specific needs within fields. On small farms, inputs can be applied manually. Variable-rate technology improves yield by re-organizing technologies, plants and fields. Its application requires:
 - correct positioning in the field;
 - accurate information on the location; and
 - timely operations on the site concerned.
- Decision-support system is a computerized process offering farmers a series of choices with regard to trade-off problems, where conflicting demands must be taken into consideration, such as productivity and environment protection (Shibusawa, 2000). This approach helps farmers optimize the whole production system.

In the United States, rice farmers typically adopt all of the new technologies described (GPS, sensor technologies, GIS, VRT and yield monitors). The following field operations are performed by rice farmers in California:

- Land preparation. Laser-based tools provide productivity enhancements, especially for land-levelling and drainage. A tractor equipped with laser

equipment can level land with a difference of just a few centimetres and create terraces on slopes. Good land-levelling facilitates good seed germination, efficient application of agrochemicals and water distribution in the fields.

- Land preparation, planting and field care. These operations can be done using computerized machinery equipped with GPS and GIS; time is saved and soil and labour productivity improved. GPS and GIS also help work to be done in rows resulting in precision within a few centimetres.
- Crop establishment. GPS and GIS guide seeding so that exactly the right amount is distributed in each part of a field to achieve optimal plant establishment.
- Fertilizer application. GPS, GIS and VRT help farmers apply fertilizers on time, with the right amount for each soil type, thereby increasing yield.
- Pesticide and herbicide application. GPS, GIS and VRT guide farmers to use pesticides and herbicides only where needed, resulting in lower production costs and reduced environmental pollution.
- Irrigation. Machinery and tools equipped with GPS and GIS ensure appropriate irrigation and drainage at the right time in the right place, resulting in water savings and reduced investment costs.
- Harvest. Machinery and tools equipped with GPS, GIS and yield monitor help to harvest rice fast, safely and accurately, working also at night or in dirt; yield maps can be produced for future improvement.
- Post-harvest operations. Advanced machinery and equipment increase the efficiency of post-harvest operations, resulting in high-quality rice, head rice and milling yield, and lower grain losses in processing and storage.
- Management. A computer system can create and update information on soils, water, crops, insects, diseases and herbicides for improved future management.

Nevertheless, the adoption of PFS has been limited for various reasons:

- Gathering information for devising PFS strategies is expensive and time consuming.
- The benefits of PFS are not immediately apparent, gains are spread over a long period of time and it is difficult to estimate the costs and returns to users.
- Although diminishing, the costs of PFS technologies remain high for users.

The cost-effectiveness of PFS or site-specific farming is still in question, as the prices of high technology are high and farmers' skills are inadequate to handle large amounts of field data and information. Automation of the data-processing and interpretation processes, such as simulation models and decision-support systems, needs further improvement for friendly PFS implementation (Buick, 1997). Research on the profitability of PSF has revealed the following:

- Of the sites studied for VRT application of fertilizers, 57 percent produced greater profits for site-specific farming than for uniform rate technology (URT) (Swinton and Lowenberg-DeBoer, 1998).
- A study of nitrogen fertilization on Iowa corn revealed that the economic and environmental impact in moving from URT to VRT depended heavily on the yield variability in fields (Babcock, Bruce and Pautsch, 1998).
- A study of weed control with post-emergence herbicides concluded that weed patchiness was the most important factor influencing the profitability of VRT application of herbicides, as compared to URT application over the whole field (Oriade *et al.*, 1996).

These studies all focused on a single production parameter and conducted partial budgeting analysis to evaluate the profitability of PFS, ignoring the environmental, sustainability and informational issues (Ancev, Whelen and MacBratney, 2004).

As population density increases, together with food safety awareness and public concern for the environment, the precision farming system is viewed as increasingly viable. Since the concept of site-specific farming is appealing for both profitability and the environment, the widespread adoption of PFS will be realized in the near future. Cost will decrease over time as the technologies change and farmers' understanding of how to use them improves (Batte and VanBuren, 1999).

RICE INTEGRATED CROP MANAGEMENT – AN EXAMPLE OF PRECISION FARMING SYSTEM IN DEVELOPING COUNTRIES

In most of the developing world, Agricultural research and education institutes are familiar with the concept of PFS. However, the technologies and tools used in PFS in industrialized countries are beyond the reach of resource-

poor farmers in developing countries. Furthermore, not only have many developing countries in Asia and Africa made slow progress in agricultural mechanization, they are also less advanced in information technology and its everyday application. Researchers and extension workers in developing countries, therefore, have developed and disseminated the integrated crop management system to improve crop management and increase yield across fields.

Spatial and temporal variability is the key to PFS. In small farms, especially in Asia and Africa, the heterogeneity of agricultural land is not important in agricultural input management, and while a site-specific approach is relevant on large farms, it is essential on small farms. Nevertheless, managing variability in terms of the timing and amount needed for specific crop growth is essential for increasing farm productivity and profits. In rice production, for example, correct fertilizer application is the most important factor for determining the final yield of rice: it affects directly grain yield, and indirectly crop establishment, panicle and grain formation, and pest and weed occurrence. Use of a chlorophyll meter and leaf colour chart for field-specific N management (as tested by IRRI – International Rice Research institute – and national research centres) has helped farmers in nitrogen fertilizer application in a number of Asian developing countries (Siddiq, Rao and Prasad, 2001).

The improvement of crop management practices among small farmers in developing countries is often not an easy task. Crop management practices must be adjusted to crop varieties, environmental factors, knowledge and market forces. Input and output prices affect farmers' decisions with regard to the level of inputs to be applied, while employment opportunities influence the time spent by farmers in crop management. The improvement of farmers' management skills through the accumulation of data and information is an important aspect of PFS and it has been integrated into the development and dissemination of rice integrated crop management (RICM) in a number of developing countries.

The concept of the RICM system

Rice farmers carry out numerous cultural operations during the growing season. These activities, separately and collectively, impact all the phases of crop development and all the yield components that ultimately determine yield. Rice integrated crop management (RICM) systems are based on the understanding that

production limitations are closely linked (Clampett, Nguyen and Tran, 2002). For example, stronger seedlings from high quality seeds will not benefit yield if the crop is inadequately fertilized. Similarly, the crop cannot respond to improved fertility if it is competing with weeds or if insufficient water is supplied.

Historically, the concept of RiceCheck was presented by Mr J. Lacy, an Australian extension worker, at the first International Symposium on Temperate Rice – Achievements and Potential (Yanco, New South Wales, Australia, 21-24 February 1994) and at the FAO Expert Consultation on Technological Evolution and Impact for Sustainable Rice Production in Asia and The Pacific (Bangkok, Thailand, 29-31 October 1996). His presentations were greatly appreciated by participants.

In Australia, the RiceCheck system was developed in the mid-1980s for the management of irrigated rice production (Lacy *et al.*, 1993). The RiceCheck system is a framework for RICM and the evaluation of management results as a means to improve productivity and environmental outcomes. In this model, farmers are actively involved using discussion groups in a collaborative learning environment for improving management and yields (Clampett, Nguyen and Tran, 2002). With the application of the RiceCheck system, the average rice yield in Australia increased remarkably from 6 tonnes/ha in the mid-1980s to more than 8.5 tonnes/ha by the end of the 1990s.

The Expert Consultation on Yield Gap and Productivity Decline in Rice Production (Rome, 2000) recommended the development of RICM systems (similar to the Australian RiceCheck system) and their transfer through farmer field schools, in order to assist farmers in developing countries to narrow the yield gap in rice production and reduce rural poverty.

The development of RICM systems

The implementation of the recommendations of the Expert Consultation included collaboration between FAO and selected member countries in Asia and Latin America in a pilot test to develop and disseminate RICM systems for their possible implementation in other countries. In lowland rice production, researchers and extension officers generally provide recommendations regarding seed selection, land preparation, crop establishment, plant establishment, crop protection, nutrition management, water management, harvest management and post-harvest operations. However, the skills and knowledge in rice

crop management among farmers, extension officers and researchers in many developing countries have greatly improved since the Green Revolution in the 1970s. Therefore, the development of RICM systems must focus on areas of crop management with potentially immediate and significant impacts on yield and efficiency of input application. Discussions between FAO and collaborating countries suggested that there are five essential steps for the establishment of a comprehensive RICM system, based on the framework of the RiceCheck system (Tran and Nguyen, 2001):

- Identify key management areas. Study and prioritize all factors affecting the current rice yield gap and production in the selected (or target) location.
- Quantify good management practices (GMPs) of progressive farmers. Survey and analyse the rice production technology and practices of farmers to identify differences in each key management area.
- Review available technology and knowledge. Review current knowledge based on research results, practices and experiences of researchers, extension workers and farmers.
- Develop interim GMPs. Based on steps 1, 2 and 3, collate, in conjunction with researchers, extension workers and farmers.
- Evaluate GMPs. Test, demonstrate and monitor the developed RICM system with a farmer discussion group and train extension workers and farmers.

As expected, the RICM systems developed in different collaborating countries during the pilot tests varied considerably from one country to another (Table 1).

The performance of RICM systems

- Indonesia. ICM system evaluated in 31 districts in 24 provinces throughout the country.
- Philippines. PalayCheck system evaluated with irrigated rice farmers throughout the country.
- Thailand. Thai RiceCheck system tested on 200 farmers in Pathumtani, Prachinburi, Sakhon-Nakorn and Phitsanulok provinces in the Central Plain of the country.
- Viet Nam. “3 Increases, 3 Reductions” system developed and tested with farmers in Can Tho and Tien Giang provinces in the Mekong River Delta.
- Latin America. ICM systems tested with farmers in Rio Grande do Sul (Brazil) and in Calabozo and Portuguesa (Venezuela, Bolivarian Republic of).

The results of these pilot tests on the development and dissemination of RICM systems were very positive and encouraging. They formed a major part of the keynote address (p. 1-19). Similar results were also reported by FLAR (Latin American Fund for Irrigated Rice) in July 2006 (FLAR, 2006). Below are the summaries of the results of the pilot tests on the development and dissemination of RICM systems:

- Yield of irrigated rice generally increased with RICM systems. The increase was very high in Latin America, moderate in Thailand and low in Viet Nam. In Indonesia, variable yield increases were observed, with the exception of a single case of yield reduction. In the Philippines, rice yields were positively and closely correlated with the number of management areas in the RICM system that farmers were able to achieve.
- The application of RICM systems significantly reduced the cost of irrigated rice production in Thailand and Viet Nam. In Indonesia, production costs increased in some villages and decreased in others.
- The application of RICM systems increased the profits of irrigated rice production in all countries. The profit increase was significantly high in Brazil.
- The quality of milled grains was improved with the application of the RICM system in Viet Nam.

Transforming RICM systems for precision management in the twenty-first century

The pilot tests clearly demonstrate the ability of RICM systems to improve farmers’ skills in crop management for enhancing productivity and efficiency in irrigated rice production. RICM systems increase yield, reduce costs, increase profits and improve grain quality. RICM systems must aim to improve farmers’ knowledge, not only of crop production and protection, but of the conservation of natural resources. Therefore, for each area of management during the cropping season, the RICM systems should provide, as reference, input and output recommendations: “key checks”. The input recommendations must include the type and quantity of input to be applied, as well as the timing and method for input application, while the output recommendations must include the expected results of the input application in the area of crop management. A participatory approach involving farmers, researchers and extension workers should be applied in the development of the key checks

INTEGRATED SYSTEMS

SYSTÈMES INTÉGRÉS

SISTEMAS INTEGRADOS

TABLE 1
RICM systems in selected developing countries

Country	RICM system	Description of RICM system
Indonesia ^a	ICM	Six recommendations: Selection of rice varieties for high yield and seed Transplanting of young and healthy seedlings Incorporation of organic manure and basal fertilizer into soil and the use of leaf colour chart for nitrogen top-dressing Intermittent irrigation Frequent mechanical weeding Control of pests and diseases, based on a regular field observations and early warning system
Philippines ^b	PalayCheck	Eight recommendations: Use pure and high quality seeds of the best variety with at least 85% germination Level the field properly and achieve no high and low soil spots at initial flooding Sow the right amount of seeds following local planting and achieve at least 1 healthy seedling/hill at 10 days after transplanting Feed the rice plants with the right nutrients as needed; achieve at least 24 tillers/hill at panicle initiation Maintain appropriate water depth and achieve 3-5 cm water depth from early tillering to grain filling stage Apply appropriate pest management technology and ensure no significant yield loss from pests Harvest crop at the right maturity stage, i.e. 1/5 of panicle or 4-5 grains at the base of the primary panicle are in hard dough stage Thresh, clean and dry immediately before storing in clean sacks in order to achieve Premium grade 1 for paddy
Thailand ^c	Thai RiceCheck	Nine management areas: Seed selection and use Land preparation Crop establishment Nutrient management Insect pest and disease management Weed management Water management Rouging/purification of crop stand for seed production Harvest management
Viet Nam ^d	3 Increases, 3 Reductions	Five recommendations: Select new high-yielding varieties having pest resistance and high grain quality for export Apply in-row seeding with IRR1 drum seeders Apply fertilizers based on soil nutrient status and leaf colour chart to estimate the N rate for top-dressing Application of IPM Harvest in time to ensure good grain quality and reduce post harvest losses
Brazil ^e	ICM	Six strategic management practices: Planting date Seeding density Pesticide-treated seeds Balanced nutrition and in quantity for high yield Early weed control Appropriate irrigation water management.
Venezuela ^e	ICM	Six recommendations: Date of planting that permits to receive maximum solar radiation during the reproductive phase N fertilizer management for high efficiency Early weed control Improved irrigation water management Use of insecticide-treated seeds to control pest outbreaks Low planting density to reduce foliar disease and cost for treated seeds.

Sources:

^a Woodhead, 2003; Abdulrachman, Las and Yuliardi, 2005.

^b Redona, Castro and Llanto, 2004; Cruz *et al.*, 2005.

^c Clampett, 2003; Kunnoot, 2005.

^d Pham, Trinh and Tran, 2005.

^e Pulver and Carmona, 2005.

in the context of group discussions. Also, the key checks should be revised each year on the basis of new results from research and new experiences gained from application in the previous year.

This requires substantial improvement to the system of collection and dissemination of information on rice, its production factors, and its technologies as well as modification of the extension systems in many countries. Progressive farmers should be trained to use computers so that they can record rice-field data to be processed and analysed for improved crop management. On a regional basis, recommendations under RISM systems are very generalized, failing to take account of the inherent variability of lands and assuming average weather. It is, therefore, recommended, in the information technology age, that agricultural administrators and researchers consider using modern PFS technologies (e.g. GPS, GIS and yield maps) in developed countries, so that they may formulate recommendations for specific locations; detect pest occurrence, drought and flash flood spots; and design appropriate management. It is also recommended that they play a coordinating role in the implementation of these new and costly technologies for a regional development plan.

CONCLUSION

The precision farming system is an innovative approach for responding to the diminishing resources, economic pressure and increased environmental degradation in agriculture. Although there are economic concerns about the use of high technological tools in agriculture, PFS, or site-specific management, is a fast-developing field in developed countries. This system has helped an increasing number of farmers in developed countries to use more effectively farm inputs, such as fertilizers, insecticides, fungicides, herbicides and irrigation water, in order to achieve increased productivity, efficiency, profits and environmental protection. The cost-benefits of PFS are under investigation, while the system is being fine-tuned for wide adoption.

Owing to limited resources and the prevailing small farm size, agricultural production systems in developing countries have employed the PFS concept differently. In developing countries, PFS is an integrated crop management system that enables farmers to close the yield gap between fields and research stations – still very large in many countries. For rice production systems in developing countries, the recent pilot tests conducted by FAO and a

number of member countries had demonstrated the potential of RISM systems for precision farming. In order to keep pace with modern agriculture in developed countries, developing countries must enter the information age, moving from the present model of traditional agriculture to mechanized agriculture, in order to improve land and labour efficiency and productivity, before they are in a position to reach precision farming system at a high level.

REFERENCES

- Abdulrachman, S., Las, I. & Yuliardi, I.** 2005. Development and dissemination of integrated crop management for productive and efficient rice production in Indonesia. Paper presented at Consultation Workshop on Rice Integrated Crop Management Systems - Rice Check Methodology for Food Security, Livelihood Improvement and Environmental Conservation, Ho Chi Minh, Viet Nam, 28 Feb. - 2 Mar. 2005.
- Ancev, T., Whelen, B. & MacBratney, A.** 2004. On the economics of precision agriculture: technical, information and environmental aspects. Paper presented at the 2004 Annual Meeting of the Australian Agricultural and Resource Economics Society.
- Australian Centre for Precision Agriculture.** 2005. *Five main processes for a site-specific management system*, University of Sydney (available at www.usyd.edu.au/su/agric/acpa/pag.htm).
- Babcock, Bruce, A. & Pautsch, G.R.** 1998. Moving from uniform to variable fertilizer rates on Iowa Corn: Effects on rate and returns. *J. Agric. & Resource Econ.*, 23(2): 385-400.
- Batte, M.T. & VanBuren, F.N.** 1999. Precision farming – Factor influencing productivity. Paper presented at the Northern Ohio Crops Day meeting, Wood County, Ohio, 21 Jan. 1999.
- Buick, R.D.** 1997. Precision agriculture: an integration of information technology with farming. *Proc. 50th New Zealand Plant Production Conference*, 1997, p. 176-184.
- Chen, F., Kissel, D.E., Clark, R., West, L.T., Rickman, D., Luval, J. & Adkin, W.** 1997. *Determining surface soil clay concentration at a field scale for precision agriculture*, University of Georgia, GHCC-NASA at Huntsville.
- Clampett, W.** 2003. *Report of the consultancy mission for project TCP/THA/0167 – Training on Integrated Crop Management Technologies for Production of Good Quality Rice Seed*. Mission report, June 2003.

- Clampett, W., Nguyen, N.V. & Tran, D.V.** 2002. The development and use of integrated crop management for rice production. *Proc. 20th Session of the International Rice Commission*, Bangkok, Thailand, 23-26 July 2004, p. 135-144. FAO, Rome.
- Cruz, R.T., Llanto, G.P., Castro A.P., Barroga, K.E.T., Bordey, F.H., Redona, E.D. & Sebastian, L.S.** 2005. PalayCheck: The Philippines' Rice Integrated Crop Management System. Paper presented at a Consultation Workshop on Rice Integrated Crop Management Systems – Rice Check Methodology for Food Security, Livelihood Improvement and Environmental Conservation, Ho Chi Minh, Viet Nam, 28 Feb. - 2 Mar. 2005.
- Davis, G., Massey, R. & Massey, R.** 2005. *Precision agriculture: An introduction* (available at www.muextension.missouri.edu/explore/envqual/wq0450.htm).
- ESRI.** 2002. *Geography matters*. ESRI, White Paper, Sept. 2002, New York.
- FLAR (Latin American Fund for Irrigated Rice).** 2006 *Diffusion y adopcion temperana de practicas de manejo del cultivo arroz riego para altos rendimientos en Venezuela*. FLAR/CIAT. 72 pp.
- Kunnoot, L.** 2005. Development and dissemination of Thai RiceCheck: Results and recommendations. Paper presented at a Consultation Workshop on Rice Integrated Crop Management Systems – Rice Check Methodology for Food Security, Livelihood Improvement and Environmental Conservation, Ho Chi Minh, Viet Nam, 28 Feb. - 2 Mar. 2005.
- Lacy J, Clampett, W.S., Lewin, L., Reinke, R., Batten, G., Williams, R., Beale, P., McCaffery, D., Lattimore, M., Schipp, A., Salvestro, R. & Nagy, J.** 1993. *1993 Ricecheck recommendations*. Australia, NSW Agriculture and Rice Research and Development Committee. 16 pp.
- Lang, L.** 1992. GPS+GIS+remote sensing: An overview. *Earth Observation Mag.*, April: 23-26.
- National Research Council.** 1997. *Precision agriculture in the 21st century: Geospatial and information technologies in crop management*. Washington, National Academy Press. 149 pp.
- NESPAL.** 2005. *Benefits of precision agriculture* (slides, available at www.nespal.cpes.peachnet.edu/PrecAg/).
- Oriade, Caleb, A., King, R.P., Forcella, F. & Jeffreu, G.** 1996. A bioeconomic analysis of site-specific management for weed control. *Review of Agric. Econ.*, 18: 523-535.
- Perry, C.** 2005. *GPS guidance – Going beyond the hype!* (slides). University of Georgia, Precision AG Team (available at [www.nespal.cpes.peachnet.edu/PrecAg/GPS/Guidance files](http://www.nespal.cpes.peachnet.edu/PrecAg/GPS/Guidance%20files)).
- Pham, S.T., Trinh, Q.K. & Tran, D.V.** 2005. Integrated Crop Management for Intensive Irrigated Rice in the Mekong Delta of Vietnam: Case studies in Can Tho and Tien Giang provinces. Paper presented at a Consultation Workshop on Rice Integrated Crop Management Systems – Rice Check Methodology for Food Security, Livelihood Improvement and Environmental Conservation, Ho Chi Minh, Viet Nam, 28 Feb. - 2 Mar. 2005.
- Pulver, E. & Carmona, L.** 2005. *Bridging the yield gap in irrigated rice in Venezuela and Rio Grande do Sul, Brazil*. Annual Report of the CFC Project, July 2004 - July 2005.
- Redona, E.D., Castro, A.P. & Llanto, G.P.** 2004. *Rice integrated crop management: Towards a RiceCheck System in the Philippines*. The Philippines, PhilRice.
- Rickman, D., Luvall, J.C., Shaw, J., Mask, P., Kissel, D. & Sullivan, D.** 1999. *Precision agriculture: Changing the face of farming*. Geotimes feature article (available at www.ghcc.msfc.nasa.gov/precisionag/).
- Segarra, E.** 2002. *Precision agriculture initiative for Texas high plains*. Annual Comprehensive Report. Lubbock, Texas, Texas A&M University Research and Extension Center.
- Shibusawa, S.** 2002. Precision farming approaches to small-farm agriculture. *Agro-Chemicals Report*, 2(4): 13-20.
- Shibusawa, S.** 2000. Precision farming approaches for model and control. In *Proc. 14th Memorial CIGR World Congress*, Tsukuba, Japan, 28 Nov. - 1 Dec. 2000, p. 133-141.
- Siddiq, E.A., Rao, K.V. & Prasad, A.S.R.** 2001. Yield and factor productivity trends in intensive rice production systems in India. In *Proc. FAO Expert Consultation on Yield Gap and Productivity Decline in Rice Production*, Rome, 5-7 Sept. 2000, p. 267-344. Rome, FAO.
- Sonka, S.T., Bauer, M.E. & Cherry, E.J.** 1997. *Precision agriculture in the 21st century: Geospatial and information technologies in crop management*. Executive Summary, p. 168. National Academies Press (available at stills.nap.edu/catalog/5491.html).
- Swinton, S.M. & Lowenberg-DeBoer, J.** 1998. *Profitability of site-specific farming*. Site-Specific Management Guidelines, SSMG-3, Potash and Phosphate Institute.
- Tran, D.V. & Nguyen, N.V.** 2001. Understanding yield gap and productivity decline under intensive rice-based cropping systems. In *Proc. FAO Expert Consultation on Yield Gap and Productivity Decline in Rice Production*, Rome, 5-7 Sept. 2000, p. 13-37. Rome, FAO.

Trimble. 2005. *Precision agriculture* (available at www.trimble.com).

Woodhead, T. 2003. *Back to office report*. FAO consultancy mission to Indonesia in February 2003.

Définition et mise en œuvre de l'agriculture de précision et des pratiques de gestion intégrée des cultures rizicoles en vue d'une production durable au vingt et unième siècle

L'approche des technologies agricoles de précision varie entre les pays développés et les pays en développement. Dans les pays développés, les agriculteurs utilisent des technologies avancées, y compris les technologies de l'information, pour mieux gérer les intrants agricoles à petite échelle (superficie plus réduite que le champ). Un système d'aménagement localisé peut être réalisé pour améliorer la productivité et l'efficacité et pour réduire les effets sur l'environnement. Il repose sur l'association de cinq technologies: système de géopositionnement par satellite (GPS), télécaptateur, système d'information géographique (SIG), technologie à taux variable (TTV) et contrôle des rendements.

Les techniques agricoles de précision, relativement récentes, sont progressivement adoptées aux États-Unis d'Amérique, en Europe et en Australie. Le rapport coûts/avantages n'est pas encore bien défini, mais le

système a été adopté dans nombre de grandes exploitations qui pratiquent des cultures à valeur élevée. Les capacités du système ainsi que la collecte et la gestion d'informations doivent être encore améliorées.

Dans les pays en développement, les agriculteurs peuvent recourir aux technologies de précision en utilisant leurs propres moyens et leurs propres connaissances pour accroître les revenus économiques et réduire les risques pour l'environnement, à partir des recommandations des vulgarisateurs. Ils sont encouragés à utiliser un système de gestion intégrée des cultures – similaire au RiceCheck australien – pour réduire les différences de rendement ainsi que la pauvreté rurale. Un système de gestion intégrée des cultures est un outil de production qui aide les agriculteurs à utiliser les quantités nécessaires d'intrants agricoles au moment voulu, ce qui permet de réduire les coûts de production et d'augmenter les bénéfices. Le

morcellement des terres est très fréquent dans la production de riz en Asie et en Afrique; de ce fait il y a peu de variation d'un champ à l'autre et le système d'aménagement localisé dans le cadre de la gestion intégrée des cultures n'est pas fondamental pour les petits agriculteurs qui ne disposent souvent que de quelques hectares par famille.

Cela dit, sur une base régionale, les administrateurs et les chercheurs agricoles devraient envisager d'utiliser les technologies modernes de précision (coordonnées GPS, indications géographiques et cartes de rendement): pour mieux cibler les recommandations destinées à des endroits précis dans la région; pour déceler des attaques de ravageurs, les zones de sécheresse et les endroits à risque d'inondations soudaines; ainsi que pour la gestion appropriée des ressources. Il est important que les petits agriculteurs puissent bénéficier des technologies modernes de l'information.

El concepto y aplicación de la agricultura de precisión y el sistema integrado de gestión de cultivos de arroz para la producción sostenible en el siglo XXI

La interpretación de la agricultura de precisión varía entre los países desarrollados y los países en desarrollo. Los agricultores de los países desarrollados se benefician de tecnologías avanzadas, como por ejemplo las tecnologías de la información para gestionar mejor los insumos agrícolas en menor escala que el campo en su totalidad. Para mejorar la productividad y la eficacia y reducir los efectos ambientales puede llevarse a cabo la ordenación específica para cada lugar, que se basa en la incorporación de cinco tecnologías: sistema de posicionamiento global (GPS), sensor a distancia, sistema de información geográfica (GIS), tecnología de aplicación variable de insumos (VRT) y seguimiento del rendimiento.

La agricultura de precisión es relativamente nueva y se está adoptando poco a poco en los Estados Unidos de América, Europa y Australia. Aunque sigue poniéndose en duda la relación entre costos y

beneficios, muchas explotaciones a gran escala con cultivos de alto valor ya han adoptado el sistema. Es necesario seguir mejorando las técnicas del sistema y la recopilación y gestión de la información.

En los países en desarrollo, los agricultores pueden aplicar el sistema de agricultura de precisión utilizando sus propios medios y conocimientos para aumentar las ganancias económicas y reducir los riesgos ambientales, basándose en las recomendaciones de los trabajadores de extensión. Se les alienta a utilizar el sistema integrado de gestión de cultivos, parecido al sistema RiceCheck australiano, para reducir las brechas de rendimientos, así como la pobreza rural. El sistema integrado de gestión de cultivos es un instrumento de producción integrada, que ayuda a los pequeños agricultores a aplicar insumos agrícolas en las cantidades adecuadas y en el momento oportuno, reduciendo así los costos de producción y mejorando los

beneficios. La fragmentación de las tierras es muy común en la producción del arroz en Asia y África, por lo que apenas hay variabilidad en el campo y el enfoque específico para cada lugar del marco del sistema integrado de gestión de cultivos no resulta indispensable para los pequeños agricultores que no suelen tener más de unas pocas hectáreas por familia.

Sin embargo, a nivel regional, los administradores e investigadores agrícolas deberían tener en consideración la utilización de tecnologías modernas de agricultura de precisión, como por ejemplo GPS, GIS y mapas de rendimiento, a fin de formular de manera más acertada recomendaciones relativas a lugares específicos en la región, detectar la presencia de plagas, sequía y puntos de crecidas repentinas, y gestionar de forma adecuada los recursos. Es importante que los pequeños agricultores obtengan los beneficios de la era de las tecnologías de la información.

The system of rice intensification: using alternative cultural practices to increase rice production and profitability from existing yield potentials

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Although the system of rice intensification (SRI) is controversial in some circles (SurrIDGE, 2004), it is gaining acceptance and beginning to spread around the rice-growing world. Age-old cultural practices, such as transplanting rather mature seedlings densely in paddies that are kept continuously inundated, are demonstrable constraints to productivity; the increased application of synthetic fertilizers and agrochemicals is not economically viable for many farmers and it is also environmentally undesirable and unsustainable.

At the International Rice Conference convened by FAO for the International Year of Rice in 2004, IRRI's former director-general, Dr Ronald Cantrell, gave the following objectives for the rice sector to enable it to better meet the needs of both people and countries in the twenty-first century (Cantrell and Hettel, 2004):

- Increased land productivity
- Greater water productivity
- Accessibility for the poor
- Environmental friendliness
- Increased pest and disease resistance
- Increased tolerance of abiotic stresses
- Higher rice quality
- Increased profitability

These eight goals can be advanced through the use of insights and methods that have been synthesized into what is now called the system of rice intensification (SRI).

Until 6 years ago, this system was known and practised only in Madagascar, the country where it was developed over 20 years ago (Laulanié, 1993). Today, its benefits have been demonstrated in at least 24 countries in Asia, Africa and Latin America, for example:

- In Cambodia, only 28 farmers were willing to try the new methods in 2000 when the NGO (non-

governmental organization), Cambodian Center for Study and Development in Agriculture (CEDAC), first presented SRI to dozens of villages. By 2005, the number of SRI users had reached between 40 000 and 50 000 (MAFF, 2005). The Government of Cambodia has made SRI a key part of the agricultural sector strategy in its national development plan for 2006-10.

- In India, Andhra Pradesh state, where the first on-farm comparison trials were made in 2003, results across all 22 districts demonstrated a yield advantage of 2.5 tonnes/ha over best farmer practices. Within 3 years, the area under SRI in the state had reached more than 40 000 ha (ANGRAU, 2006). The Government of India has recommended the new methods to Indian rice farmers "wherever feasible" (press release, 31 May 2005).
- In eastern Indonesia, with the intervention of a management team from the consulting firm, Nippon Koei, farmers did 1 849 on-farm trials between 2003 and 2005 over a total area of 1 363 ha. Average SRI yields were 84 percent higher than current best farmer practices and used about 40 percent less water (Sato, 2006). With fertilizer use reduced by 50 percent, farmers' overall production costs were lowered by 25 percent; their net income from rice production could, therefore, increase fivefold.
- In Africa and Latin America, SRI has been slower to spread, but its advantages have nevertheless been seen in no fewer than ten countries outside Asia. For example, a farmers' cooperative in northwest Zambia – where rice yields are less than half the world average and where food aid is often needed – applied SRI in the last season and achieved rice yields of 6.144 tonnes/ha (dried weight) (Ngimbu,

2006). In Madagascar, over 200 000 farmers are currently using SRI methods, with yields as high as 17 tonnes/ha (the Hon. Harison E. Randriarimanana, Minister of Agriculture, Livestock and Fisheries, personal comment, 31 March 2006).

Since SRI productivity is driven more by biological agents and endogenous soil processes (enhanced by alternative management practices) than by external inputs, there is considerable variation in results, from place to place and year to year. Success cannot always be guaranteed – any more than with other agricultural methods. Nevertheless, the accumulating evidence of SRI's positive effects should make the system of interest to farmers, researchers and policy-makers alike.

THE NEED FOR A PARADIGM SHIFT

The Green Revolution was successful in increasing rice and other grain production in the latter part of the twentieth century, but momentum was lost during the last decade. The Green Revolution paradigm was based on two complementary strategies:

- Change the genetic potential of crop plants, in particular making crops more responsive to the application of fertilizer and other exogenous inputs.
- Increase the application of such inputs – utilizing water, fertilizer and insecticides and other biocides to obtain higher yields.

These efforts resulted in greater production in many countries around the world. The success was achieved, however, at a cost – environmental as well as economic. Of particular concern is the heavy dependence on inorganic N for raising rice output. In China, for example, over-application of N fertilizers has become a serious problem, with farmers responding to diminishing returns by applying larger and larger quantities of N fertilizer. Forty years ago, application of 1 kg of N could yield 15 to 20 kg of additional rice. Now a mere extra 5 kg of rice are obtained from the addition of 1 kg of N (Peng *et al.*, 2004), and this figure is still decreasing. In places where N fertilizer application rates now exceed 500 kg/ha per year, nitrate levels in the groundwater are reaching 300 ppm of dissolved nitrate (S. Peng, personal communication, citing studies by Jerry Hatfield, United States Department of Agriculture [USDA]). According to the United States Environmental Protection Agency, 50 ppm is the highest level deemed acceptable in drinking

water supplies, and even 10 ppm can cause serious health problems for newborns. Thus, the use – and especially the overuse – of N fertilizer needs to be curtailed in many areas.

Cassman *et al.* (1998) estimated that, given the declining marginal productivity of N fertilizer, to achieve the 60 percent increase in rice production that the world needs by 2030, it will be necessary to triple N fertilizer applications. This is likely to be unacceptable environmentally and unfeasible economically. Moreover, such increases in fertilizer use would have adverse impacts on soil and water quality and would increase greenhouse gas emissions from rice paddies if continuously flooded (Liesack, Schnell and Revsbach, 2000). It is, therefore, essential to explore ways of mobilizing more of the N that plants need through cheaper and ecologically more benign biological processes.

The land and water resources for rice production are diminishing. In Asia, the increase in urbanization and industrialization has reduced the water for agricultural production in general and for rice production in particular (Barker *et al.*, 1999). Elsewhere – for example, in Australia, Egypt, Portugal and Spain – inadequate water supply is the main factor limiting the cultivation of rice (Nguyen and Ferrero, 2006). In some of the most intensively-cropped areas in China and India, where groundwater is used for irrigation, water tables have been falling at a rate of 1 m per year or more. Darwin *et al.* (2005) estimated that the amount of land for rice, maize, sugar cane and rubber in tropical areas would decline by 18 to 51 percent in the next century as a consequence of global warming. Thus, productivity gains from the remaining land and water resources are increasingly urgent.

Global rice production in 2005 was just sufficient to meet the world demand for rice, and it is projected that production in 2006 will satisfy effective demand (Calpe, 2006). This does not take into consideration, however, the more than 850 million people suffering from hunger and malnutrition associated with poverty. Given the continuing growth of the world population, the need for global production is projected at 771 million tonnes by 2030, and there will be a smaller resource base (FAO, 2003). Sustainable increases in rice production are a key element in meeting Millennium Development Goal 1, to reduce hunger and poverty in the world. Reducing the agricultural demand for irrigation water (in particular, for rice) is crucial for sustainable production in the future.

Helping plants develop better root systems is a biological strategy for addressing water scarcity; it is less costly than other solutions which continue to increase the water supplied for rice production.

UNDERSTANDING THE SYSTEM OF RICE INTENSIFICATION

The system of rice intensification is a set of insights and principles applied through certain management practices that promote more productive phenotypes from existing genotypes of rice, whether improved or local varieties. This is accomplished by:

- inducing greater root growth; and
- nurturing more abundant and diverse populations of soil biota which provide many benefits for plants (Wardle, 2002).

Altering the management of rice plants' soil, water and nutrients is a low-cost way of enhancing plant root growth and the activity of soil organisms. Non-SRI practices can be detrimental in various ways:

- Flooding of rice plants has been practised for centuries, even millennia. It constrains growth, functioning and survival of the roots. Up to three-quarters of the rice roots degenerate by the start of the plant's reproductive period (Kar *et al.*, 1974).
- Crowding rice plants in dense hills or close spacing of hills results in the growth potential of the canopies and root systems being inhibited. The "edge effect" – i.e. the more vigorous and productive growth of widely-spaced plants – is thus limited to the borders of rice fields.
- Heavy application of fertilizers and agrochemicals can have adverse impacts on the soil biota, which provide numerous services to plants: N fixation, N cycling, P solubilization, protection against diseases and abiotic stresses, and induced systemic resistance, for example (Tan, Hurek and Reinhold-Hurek, 2002; Doebbelaere, Vanderleyden and Okon, 2003; Randriamiharisoa, Barison and Uphoff, 2006).

SRI methods create above-ground and below-ground environments that are more favourable for the rice plant's growth (Stoop, Uphoff and Kassam, 2002; Randriamiharisoa, Barison and Uphoff, 2006). SRI involves transplanting young seedlings (<15 days, preferably 8-12 days), singly (not in clumps), very

carefully and gently, with optimal wider spacing (starting at 25×25 cm and increasing whenever better soil fertility permits). Irrigated paddy soils are kept moist but are not continuously saturated, maintaining mostly aerobic soil conditions, either by daily applications of small amounts of water or by alternate wetting and drying. For best results, weed control is done with a rotary hoe several times during the vegetative growth phase before the canopy closes, aerating the soil as well as removing weeds. Organic fertilization (compost, manure, mulch etc.) is utilized to the greatest extent possible, although synthetic fertilizers can be used if insufficient biomass is available. Although SRI was developed for irrigated rice production, a new variant is rainfed SRI, where SRI concepts and methods are adapted to upland circumstances. Yields of 6 to 8 tonnes/ha have been reached with such adaptations in northern Myanmar, southern Philippines and eastern India (Kabir, 2006; Gasparillo *et al.*, 2003; Sinha and Talati, 2005).

RESULTS OF SRI EVALUATION

Researchers in different countries and from various institutions conclude, following years of analysis, that SRI methods offer multiple major benefits. Research has been extensive and the list below is far from exhaustive:

- **China:**
 - Tao, Wang and Min (2002), Zhu *et al.* (2002) and Zhu (2006) (China National Rice Research Institute)
 - Yuan (2002) (China National Hybrid Rice Research and Development Center)
 - Zheng *et al.* (2004) (Sichuan Academy of Agricultural Sciences)
 - Wang *et al.* (2002) (Nanjing Agricultural University in China)
- **Indonesia:**
 - Gani *et al.* (2002) (Indonesian Agency for Agricultural Research and Development)
- **India:**
 - Satyanarayana, Thiyayarajan and Uphoff (2006) (presenting data from more than 1 600 on-farm trials supervised by the agricultural universities in Andhra Pradesh and Tamil Nadu states)
 - Subbiah, Kumar and Bentur (2006) (Indian Council of Agricultural Research)

- **Japan:**

- Horie *et al.* (2005) (Kyoto University)

The scientific basis for acceptance of SRI methods is thus increasingly well understood, although research still remains to be done: SRI is a work in progress.

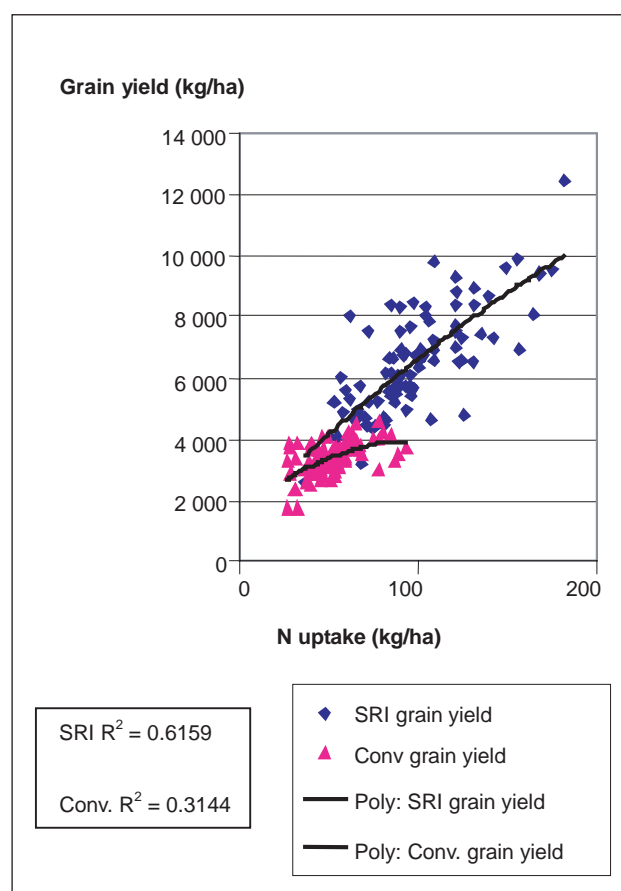
The results reported by the M.S. Swaminathan Research Foundation (Table 1) are reasonably representative of those obtained in farmers' fields using alternative methods. Trials showed SRI yielding between 7.5 and 9.75 tonnes/ha, compared to 4.056 tonnes/ha – a yield increase of between 87 and 144 percent. Taking into consideration the reduced cost of inputs and decrease in water consumption, the returns to farmers' resource investment was even greater.

Figure 1 shows how plants grown with SRI methods are better able to take up nutrients and convert them into grain yield. This relationship, as well as many others, was evaluated by Barison (2002) using the QUEFTS model (Janssen *et al.*, 1990). The analysis revealed how yield could double with SRI methods when the same farms and same farmers were involved. The same relationships were seen in the measurement of P and K.

The analysis of rice plant roots revealed that SRI plants have better and deeper root growth (Table 2). Although they have less root density in the top soil layer (0-5 cm below the surface) compared with rice plants grown using conventional methods, they have more root density in lower soil layers. Visual comparison of SRI and conventional rice plants growing under comparable soil conditions confirms what Barison measured.

Planting fewer and younger seedlings combined with a reduction in water applications may seem risky. On the contrary: when SRI methods are used as recommended, the result is positive, due in part to the larger, deeper root

FIGURE 1
Regression relationships between N uptake and grain yield for SRI and conventional methods



Source: Barison, 2002.

systems induced by SRI practices and which offer rice plants protection against abiotic stresses. Evaluation by the International Water Management Institute (IWMI) (Namara, Weligamage and Barker, 2004) and the German

TABLE 1
Comparison of SRI and conventional methods of paddy cultivation

Parameters	SRI farmer I	SRI farmer II	Conventional practice
Total no. tillers	26	45	18
No. productive tillers	24	38	13
No. grains/plant	230	275	220
Yield (kg/ha)	7 500	9 750	4 056
Labour for planting		40	25
Labour for weeding		30	25
Labour for harvesting		20	20
Seed rate (kg/ha)	5	6	30

Source: MSSRF, 2004.

INTEGRATED SYSTEMS

SYSTÈMES INTÉGRÉS

SISTEMAS INTEGRADOS

TABLE 2
Root length density (cm/cm³) under SRI, SRA and farmer practices

Treatments	Soil layers (cm)					
	0-5	5-10	10-20	20-30	30-40	40-50
SRI with compost	3.65	0.75	0.61	0.33	0.30	0.23
SRI without compost	3.33	0.71	0.57	0.32	0.25	0.20
SRA with NPK and urea	3.73	0.99	0.65	0.34	0.18	0.09
SRA without fertilization	3.24	0.85	0.55	0.31	0.15	0.07
Farmer practice	4.11	1.28	1.19	0.36	0.13	0.06

Notes:

SRA = *Système de riziculture améliorée* (system of improved rice cultivation), which is the modern set of practices recommended by government researchers.

Measurements from replicated on-station trials, Beforona, Madagascar (Barison, 2002).

TABLE 3
Interaction of management practices, endophytic *Azospirillum* and yield in clay soil plots

Practice	Yield (tonnes/ha)	<i>Azospirillum</i> count in root tissue	Comments
Conventional methods, no nutrient amendments	1.8	65 × 10 ³	
SRI, no nutrient amendments	6.1	11 × 10 ⁵	
SRI, NPK fertilizer	9.0	45 × 10 ⁴	Yield increase of 50% with reduction of 60% in <i>Azospirillum</i> count indicates that plants are relying on inorganic N sources to achieve yield increase
SRI, compost	10.5	14 × 10 ⁵	Highest yield with an <i>Azospirillum</i> count 3 times more than with NPK

Agency for Technical Cooperation (GTZ) (Anthofer, 2004) show that SRI methods reduce farmers' risk of economic loss.

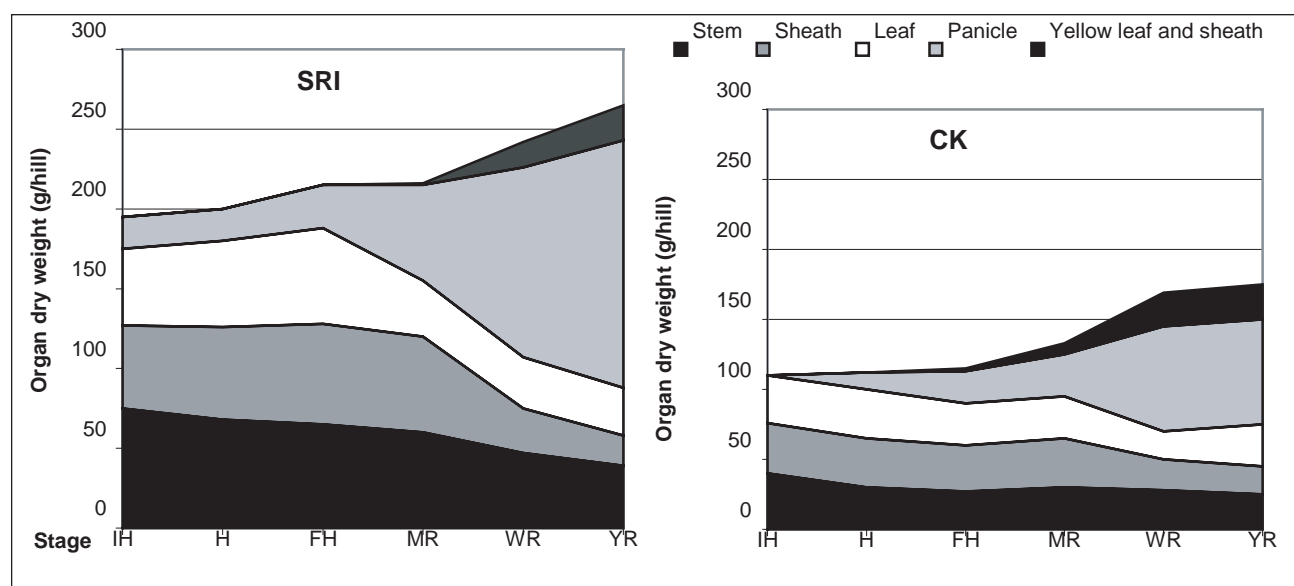
Further research is required to ascertain to what extent soil organisms contribute to improved rice plant performance when SRI is adopted. Nevertheless, changes in the *Azospirillum* populations living inside rice roots and associated with SRI practices were evaluated in replica trials (Andriankaja, 2001) and reported by Randriamiharisoa (2002). The changes in yield and microbial populations in response to different management practices are shown in Table 3.

Greater root growth with SRI methods may be stimulated and supported by the production of phytohormones by aerobic bacteria and fungi that live in the soil and on and inside the roots. These organisms are known to produce auxins, cytokinins and other plant growth-promoting compounds in the rhizosphere (Frankenberger and Arshad, 1995). Recent published research from China has shown that soil rhizobia which enter the rice plant through its roots – and then migrate to the stem and leaves – contribute to significant increases

in leaf chlorophyll, photosynthesis and crop yield (Feng *et al.*, 2005). Plant science thus needs to expand to include microbiology as an integral discipline, not an allied field of study.

USDA research has also shown how DNA expression in leaf cells – specifically genes that affect senescence and the production of chitins that confer certain disease resistance – are affected by changes in the way that plants are managed together with the soil, water and nutrients that they utilize (Kumar *et al.*, 2004; Mattoo and Abdul-Baki, 2006). The cytokinin, which is produced in the roots, affects canopy growth, while auxins synthesized in the canopy reciprocally affect root growth and performance (Oborny, 2004). Rates of leaf photosynthesis, for example, are affected by what is going on in the soil, and direct connections exist between root and soil conditions and genetic functioning in the leaves. Tao (2004) reported that SRI plants have better growth rates as indicated by the relative changes in dry weight of different rice plant organs (stem, sheath, leaf and panicle), as well as senescence in the leaf and sheath (in yellow), as rice plants move through their different stages of growth (Figure 2).

FIGURE 2
Relative and absolute comparisons of SRI and control (CK) plants of same variety



Source: Tao, 2004.

RESULTS OF SRI UTILIZATION AND POTENTIAL CONSTRAINTS

The simplest yardstick for measuring and comparing crop performance is yield, expressed in terms of output per unit of land, as this resource has often been the limiting factor of production. But yield by itself is not an adequate criterion of assessment, and it is not the most important to farmers. Total factor productivity is more meaningful; in addition to kg of rice produced per unit of land, it is also important to consider output per day or hour of labour, per cubic metre of water, and per unit of capital.

Table 4 summarizes the analysis of the results of 4 800 comparison trials in diverse locations in eight countries: Bangladesh, Cambodia, China, India, Indonesia, Nepal, Sri Lanka and Viet Nam (Uphoff, 2006).

Not all SRI practices were used (or used as recommended) in all evaluations; there is, therefore, potential for improvement if the methods are applied fully and correctly, as seen in factorial trials (Randriamiharisoa and Uphoff, 2002).

Labour requirements

The data from India (Table 1) show that labour requirements for the three main operations increased by 38 percent with SRI. However, the returns (measured in kg of rice per day) also increased greatly – by 73 percent.

The data are from the first season of SRI practice. SRI labour requirements typically diminish as farmers become familiar with the methods; eventually, SRI can require less labour per ha (Barrett *et al.*, 2004).

A large-scale evaluation of SRI in Cambodia, based on 500 randomly selected farmers (Anthofer, 2004), found SRI to be labour-neutral overall, with new SRI farmers needing more labour and experienced ones less. Farmers interviewed for an evaluation in China, where SRI use in one village had risen from just 7 in 2003 to 398 in 2004, ranked labour-saving as SRI's most attractive feature – more important than increased yield, water-saving or profitability (Li, Xu and Li, 2005).

TABLE 4
Summarized results from 11 comparative evaluations of SRI in 8 countries

Effect of SRI	Impact (%)	Range (%)
Yield increase (<i>tonnes/ha</i>)	52	21-105
Reduction in water use	44	24-60
Reduction in production costs	25	2.2-56
Increase in net income (<i>per ha</i>)	128	59-412

Source: Uphoff, 2006.

Water management

The most objective and serious limitation encountered to date with SRI is water control. For best results, farmers need reliable control over water during crop establishment. However, this is not always possible in monsoon areas, where SRI may, as a consequence, be unsuitable or, if applied, yields will be lower than elsewhere. Water control can be achieved in many places through investment in physical infrastructure or through farmer organization and cooperation. A reduction of 25 to 50 percent in on-farm water use produces substantial benefits if aggregated, but SRI has not been adopted on a scale wide or complete enough to know how much net benefit is attainable from reduced irrigation off-takes. WWF-India (World Wide Fund for Nature – India) has begun supporting SRI adoption because of its implications for the rice sector's water requirements (Murthy and Punna Rao, 2006).

Crop protection

With the cultivation of larger plants and the production of more grain, the challenge of crop protection increases. SRI farmers tend not to report losses through pests and diseases – which may be accounted for by the theory of trophobiosis (Chabousson, 2004). In some locations, measures may be necessary against nematodes, golden snails or other pests, but the most common evaluation is that SRI methods reduce crop losses caused by pests and disease. There are numerous reports by farmers stating that SRI rice does not need chemical protection.

Grain quality

Another benefit of SRI is improved grain quality. This may be due to the plants' larger, deeper root systems capable of accessing a greater variety and increased volume of nutrients, particularly micronutrients. Conventional root systems remain shallow and die back under hypoxic soil conditions. The data in Table 5 indicate that chalkiness is significantly lower in SRI-grown rice, which could justify a higher price. Even more important, from

an economic point of view, is the higher out-turn of milled rice from SRI paddy (rough rice). SRI paddy usually has fewer unfilled grains, and thus less chaff; it tends to be more resistant to shattering, resulting in fewer broken grains. Reports by farmers and millers from India, Sri Lanka and Cuba and research carried out in China (Jun, 2004) show that the milling out-turn from SRI paddy is approximately 15 percent higher.

It appears that the reduction in the application of synthetic fertilizers and crop-protection chemicals results in enhanced soil and water quality and improved human health. Furthermore, the denser grains obtained with SRI due to the larger, better functioning root systems, are likely to have higher levels of micronutrients. Further research and evaluation is required in both these areas.

CONCLUSIONS

SRI is a methodology for human resource development, not a technology to be transferred (Laulanié, 2003). Farmers should be involved in experimentation with the new methods and practices adapted to suit local conditions; farmers' knowledge and confidence are thus built up through their experience of using SRI. Farmer education is a benefit, not just a cost. While SRI can be promoted in a top-down manner, dissemination in participatory ways is preferable so as to build up human capabilities for decision-making and management. SRI is simple to learn for anyone who already knows how to grow rice: farmer-to-farmer interaction is the most effective way to spread SRI. The farmer field school methodology promoted by FAO is particularly suitable for SRI diffusion (Kabir, 2006).

Rather than replace the Green Revolution, SRI offers rice farmers alternative methods for increasing production (Uphoff, 2003). SRI is particularly suited to farmers who:

- have difficulty affording the inputs required by Green Revolution technology;
- face water shortages; or
- want to avoid risks such as lodging, drought or cold damage, caused by adverse climates.

TABLE 5

Measured differences in grain quality with SRI and conventional methods, June 2004

Characteristic	SRI (3 spacings)	Conventional (2 spacings)	Average difference
Chalky kernels (%)	23.62 - 32.47	39.89 - 41.07	- 30.7
General chalkiness (%)	1.02 - 4.04	6.74 - 7.17	- 65.7
Milled rice out-turn (%)	53.58 - 54.51	41.54 - 51.46	+ 16.1
Head milled rice (%)	41.81 - 50.84	38.87 - 39.99	+ 17.5

Water control is the most objective and serious limitation to SRI encountered to date. For best results, farmers should have reliable control over water during crop establishment. In monsoon areas, this may not be possible: SRI may not be suitable or, if applied, yields will be less than otherwise obtainable. Water control can be obtained in many places where it is absent through investment in physical infrastructure or through farmer organization and cooperation. SRI creates incentives for organization and can assure a good economic return from investment. However, in many cases, lack of water control is not necessarily a constraint to SRI adoption. Optimal conditions for SRI adoption include irrigation with groundwater, because farmers have control over their water supply and there are incentives for reducing water application.

At present, SRI raises more questions than it answers. This should be regarded as good news by researchers, as SRI creates a large and promising research agenda.

Since SRI methods have been derived inductively, from observation and by trial-and-error, SRI should be amenable to further refinement and development. Also, it is quite possible that SRI will encounter certain problems or limitations in the future, which researchers could identify and develop counter-measures for. The basic mechanisms involved in SRI – enhancement of root growth and soil biological communities – might help improve the performance of other crops if better understood. SRI is still at an early stage of both theory and practice.

REFERENCES

- Andriankaja, A.H.** 2001. *Mise en évidence des opportunités de développement de la riziculture par adoption du SRI, et évaluation de la fixation biologique du l'azote*. Madagascar, École Supérieure des Sciences Agronomiques, University of Antananarivo.
- ANGRAU.** 2006. *Report of a meeting on the System of Rice Intensification (SRI)*, Acharya N. G. Ranga Rau, 29 June 2006 (available at ciifad.cornell.edu/sri/countries/india/inapfingerman06.pdf).
- Anthofer, J.** 2004. *Evaluation of the System of Rice Intensification (SRI) in Cambodia*. Report prepared for GTZ, Phnom Penh (available at www.tropentag.de/2004/abstracts/full/399.pdf).
- Barison, J.** 2002. Nutrient-use efficiency and nutrient uptake in conventional and intensive (SRI) rice cultivation systems in Madagascar. Crop and Soil Science Dept., Cornell University, Ithaca, NY (available at ciifad.cornell.edu/sri/theses/madgjoelithesis.pdf). (Master thesis)
- Barker, R., Dawe, D., Tuong, T.P., Bhuiyan, S.I. & Guerra, L.C.** 1999. The outlook for water resources in the year 2020: Challenges for research on water management in rice production. In *Proc. 19th Session of International Rice Commission*, Cairo, Egypt, 7-9 September 1998, p. 96-109. FAO, Rome.
- Barrett, C.B., Moser, C.M., Barison, J. & McHugh, O.V.** 2004. Better technologies, better plots or better farmers? Identifying changes in productivity and risk among Malagasy rice farmers. *Amer. J. of Agric. Econ.*, 86: 869-888.
- Calpe, C.** 2006. Rice contribution to food outlook 2006. Paper presented at 21st Session of the International Rice Commission, Chiclayo, Peru, 3-5 May 2006.
- Cantrell, R.P. & Hettel, G.P.** 2004. New challenges and technological opportunities for rice-based production systems for food security and poverty alleviation in Asia and the Pacific. Paper for International Conference on Rice in Global Markets and Sustainable Production Systems, FAO, Rome, 12-13 Feb. 2004.
- Cassman, K.G., Peng, S., Olk, D.C., Ladha, J.K., Reichardt, W., Dobermann, A. & Singh, U.** 1998. Opportunities for increased nitrogen-use efficiency from improved resource management in irrigated rice systems. *Field Crops Res.*, 56: 7-39.
- Chabousson, F.** 2004. *Healthy crops: A new agricultural revolution*. Charnley, UK, Jon Anderson.
- Darwin, R., Tsigas, M., Lewandrowski, J. & Ranases, A.** 2005. *World agriculture and climate change: Economic adaptation*. USDA Agriculture Economic Report No. 703. Washington, US Department of Agriculture.
- Doebelaere, S., Vanderleyden, J. & Okon, Y.** 2003. Plant growth-promoting effects of diazotrophs in the rhizosphere. *Critical Reviews in Plant Sci.*, 22: 107-149.
- FAO.** 2003. *World agriculture: Towards 2015/2030 – An FAO Perspective*. Rome, FAO & London, EarthScan.
- Feng, C., Shen, S-H, Cheng, H-P, Jing, Y-X, Yanni, Y.G. & Dazzo, F.B.** 2005. Ascending migration of endophytic rhizobia, from roots to leaves, inside rice plants and assessment of benefits to rice growth physiology. *Appl. & Environ. Microbiol.*, 71: 7271-7278.
- Frankenberger, W.T. & Arshad, M.** 1995. *Phytohormones in soils: Microbial production and function*. New York, Marcel Dekker.

- Gani, A., Kadir, T.S., Jatiharti, A., Wardhana, I.P. & Lal, I.** 2002. The System of Rice Intensification in Indonesia. In N. Uphoff, E. Fernandes, L.P. Yuan, J.M. Peng, S. Rafaralahy & J. Rabenandrasana, eds. *Assessments of the System of Rice Intensification*, p. 58-63. CIIFAD, Ithaca, NY (also available at ciifad.cornell.edu/sri/procl/sri_14.pdf).
- Gasparillo, R., Naragdao, R., Judilla, E., Tana, J. & Magsalin, M.** 2003. *Growth and yield response of traditional upland rice on difference distance of planting using Azucaena variety*. Broader Initiatives for Negros Development, Bacalod City, Philippines (available at ciifad.cornell.edu/sri/countries/philippines/binuprst.pdf).
- Horie, T., Shiraiwa, T., Homma, K., Katsura, K., Maeda, S. & Yoshida, H.** 2005. Can yields of lowland rice resume the increases that they showed in the 1980s? *Plant Prod. Sci.*, 8: 257-272.
- Janssen, B.H., Guiking, F.C.T., van der Eijk, D., Smaling, E.M.A., Wolf, J. & van Reuler, H.** 1990. A system for quantitative evaluation of the fertility of tropical soils (QUEFTS). *Geoderma*, 46: 299-318.
- Jun, M.** 2004. Results of research on SRI at Sichuan Agricultural University. Paper presented at 10th National Conference on Theory and Practice for High-Quality, High-Yielding Rice in China, Haerbin, 26 Aug. 2004.
- Kabir, H.** 2006. The adaptation and adoption of the System of Rice Intensification (SRI) using the Farmer Field School (FFS) approach. University of Honolulu (available at ciifad.cornell.edu/sri/theses/kabirthesis.pdf). (PhD thesis)
- Kar, S., Varade, S.B., Subramanyam, T.K. & Ghildyal, B.P.** 1974. Nature and growth pattern of rice root system under submerged and unsaturated conditions. *Il Riso* (Rome), 23: 173-179.
- Kumar, V., Mills, D.J., Anderson, J.D. & Mattoo, A.K.** 2004. An alternative agricultural system is defined by a distinct expression profile of select gene transcripts and proteins. *Proc. Natl Acad. Sci.*, 10: 10535-10540.
- Laulanié, H.** 2003. *Le riz à Madagascar: Un développement en dialogue avec les paysans*. Paris, Editions Karthala.
- Laulanié, H.** 1993. Le système du riziculture intensive malgache. *Tropicultura* (Brussels), 11: 110-114.
- Li, X.-Y., Xu, X.-L. & Li, H.** 2005. *A socio-economic assessment of the System of Rice Intensification (SRI): A case study from Xinsheng Village, Jianyang County, Sichuan Province*. Beijing, Center for Integrated Agricultural Development, China Agricultural University (available at ciifad.cornell.edu/sri/countries/china/cnciadeng.pdf).
- Liesack, W., Schnell, S. & Revsbach, N.P.** 2000. Microbiology of flooded rice paddies. *FEMS Microbiol. Rev.*, 24: 625-645.
- MAFF (Ministry of Agriculture Fisheries and Forestry).** 2005. *Annual activities report of the System of Rice Intensification (SRI) Secretariat, Jan. - Dec., 2005*. Department of Agronomy and Agricultural Improvement, MAFF (available at ciifad.cornell.edu/sri/countries/cambodia/cambsecretariat05.pdf).
- Mattoo, A.K. & Abdul-Baki, A.** 2006. Crop genetic responses to management: Evidence of root-shoot communication. In N. Uphoff, A.S. Ball, E.C.M. Fernandes, H. Herren, O. Husson, M. Laing, C.A. Palm, J. Pretty, P.A. Sanchez, N. Sanginga & J. Thies, eds., *Biological approaches to sustainable soil systems*, p. 221-230. Boca Raton, FL, CRC Press.
- MSSRF (M.S. Swaminathan Research Foundation).** 2004. *2003-2004 Fourteenth annual report*. Centre for Research on Sustainable Agriculture and Rural Development, MSSRF, Chennai.
- Murthy, M.V.R. & Punna Rao, P.** 2006. New approach to irrigated rice cultivation. *Dialogue Bull.*, 19 (Jan.): 9-12 (also available at www.iwmi.cgiar.org/dialogue/godavari/files/Jan06-Bulletin-Final.pdf).
- Namara, R.E., Weligamage, P. & Barker, R.** 2004. *Prospects for adopting the System of Rice Intensification in Sri Lanka: A socioeconomic assessment*. Research Report No. 75. Colombo, International Water Management Institute.
- Ngimbu, H.** 2006. *Draft Report: Esek Farmers Cooperative Society – Results for the First SRI Harvest in Zambia, Southern Africa* (available at ciifad.cornell.edu/sri/extmats/zamesekpres.pdf).
- Nguyen, V.N. & Ferrero, A.** 2006. Meeting the challenges of global rice production. *Paddy Water Environ.*, 4: 1-9.
- Oborny, B.** 2004. External and internal control of plant development. *Complexity*, 9: 22-27.
- Peng, S., Buresh, R., Huang, J.-L., Yang, J.-C., Zhong, X.-H., Zou, Y.-B., Wang, G.-H., Hu, R. & Shen, J.-B.** 2004. Improving fertilizer-nitrogen use efficiency of irrigated rice: Progress of IRRI's RTOP Project in China. Paper presented at International Conference on Sustainable Rice Production, China National Rice Research Institute, Hangzhou, 15-17 Oct. 2004.
- Randriamiharisoa, R.** 2002. Research results on biological nitrogen fixation with the System of Rice Intensification.

- In N. Uphoff, E. Fernandes, L.P. Yuan, J.M. Peng, S. Rafaralahy & J. Rabenandrasana, eds. *Assessments of the System of Rice Intensification*, p. 148-157. Ithaca, NY, CIIFAD (also available at ciifad.cornell.edu/sri/proc1/sri_33.pdf).
- Randriamiharisoa, R. & Uphoff, N.** 2002. Factorial trials evaluating the separate and combined effects of SRI practices. In N. Uphoff, E. Fernandes, L.P. Yuan, J.M. Peng, S. Rafaralahy & J. Rabenandrasana, eds. *Assessments of the System of Rice Intensification*, p. 40-45. Ithaca, NY, CIIFAD (also available at ciifad.cornell.edu/sri/proc1/sri_10.pdf).
- Randriamiharisoa, R., Barison, J. & Uphoff, N.** 2006. Soil biological contributions to the System of Rice Production. In N. Uphoff, A.S. Ball, E.C.M. Fernandes, H. Herren, O. Husson, M. Laing, C.A. Palm, J. Pretty, P.A. Sanchez, N. Sanginga & J. Thies, eds., *Biological approaches to sustainable soil systems*, p. 409-424. Boca Raton, FL, CRC Press.
- Sato, S.** 2006. An evaluation of the System of Rice Intensification (SRI) in Eastern Indonesia for its potential to save water while increasing productivity and profitability. Paper for International Dialogue on Rice and Water, IRRI, Los Baños, 7-8 Mar. (available at ciifad.cornell.edu/sri/countries/indonesia/wwfindosato06.pdf).
- Satyanarayana, A., Thiyagarajan, T.M. & Uphoff, N.** 2006. Opportunities for water-saving with higher yield from the system of rice intensification. *Irrig. Sci.*, 1432-1319 on line (DOI: 10.1007/s00271-006-0040-1).
- Sinha, S.K. & Talati, J.** 2005. *Impact of the System of Rice Intensification (SRI) on rice yields: Results of a new sample study in Purulia District, India*. IWMI-Tata Water Policy Research Report 47. International Water Management Institute, India Program, Anand.
- Stoop, W., Uphoff, N. & Kassam, A.** 2002. A review of agricultural research issues raised by the System of Rice Intensification (SRI) from Madagascar: Opportunities for improving farming systems for resource-poor farmers. *Agric. Systems*, 71: 249-274.
- Subbiah, S.V., Kumar, K.M. & Bentur, J.S.** 2006. DRR's experience of SRI method of rice cultivation in India. Directorate of Rice Research, Hyderabad. Paper for International Dialogue on Rice and Water, IRRI, Los Baños, 7-8 Mar. 2006.
- Surridge, C.** 2004. Feast or famine? *Nature*, 428: 360-361.
- Tan, Z., Hurek, T. & Reinhold-Hurek, B.** 2002. Effect of N-fertilization, plant genotype and environmental conditions on *nifH* gene pools in roots of rice. *Environ. Microbiol.*, 5: 1009-1015.
- Tao, L-X.** 2004. Non-flooding rice farming technology in irrigated paddy field. Presentation at International Conference on Sustainable Rice Production, China National Rice Research Institute, Hangzhou, 15-17 Oct. 2004.
- Tao, L-X., Wang, X. & Min, S-K.** 2002. Physiological effects of SRI methods on the rice plant. In N. Uphoff, E. Fernandes, L.P. Yuan, J.M. Peng, S. Rafaralahy & J. Rabenandrasana, eds. *Assessments of the System of Rice Intensification*, p. 132-136. Ithaca, NY, CIIFAD (also available at ciifad.cornell.edu/sri/proc1/sri_29.pdf).
- Uphoff, N.** 2006. Increasing water savings while raising rice yields with the System of Rice Intensification (SRI). Paper for International Rice Congress, New Delhi, India, 9-13 Oct. 2006.
- Uphoff, N.** 2003. Higher yields with fewer external inputs? The System of Rice Intensification and potential contributions to agricultural sustainability. *Intl J. Agric. Sustainability*, 1: 38-50.
- Wang, S-H., Cao, W-X., Jiang, D., Dai, T-B. & Zhu, Y.** 2002. Physiological characteristics and high-yield techniques with SRI rice. In N. Uphoff, E.C.M. Fernandes, L.P. Yuan, J.M. Peng, S. Rafaralahy & J. Rabenandrasana, eds. *Assessments of the System of Rice Intensification*, p. 116-124. Ithaca, NY, CIIFAD (also available at ciifad.cornell.edu/sri/proc1/sri_27.pdf).
- Wardle, D.A.** 2002. *Communities and ecosystems: Linking the aboveground and belowground components*. Princeton, NJ, Princeton University Press.
- Yuan, L.P.** 2002. A scientist's perspective on experience with SRI in China for raising the yields of super hybrid rice. In N. Uphoff, E.C.M. Fernandes, L.P. Yuan, J.M. Peng, S. Rafaralahy & J. Rabenandrasana, eds. *Assessments of the System of Rice Intensification*, p. 23-25. Ithaca, NY, CIIFAD (also available at ciifad.cornell.edu/sri/proc1/sri_06.pdf).
- Zheng, J.G., Lu, X.J., Jiang, X.L. & Tang, Y.L.** 2004. The System of Rice Intensification for super-high yields of rice in Sichuan basin. In T. Fischer, N. Turner, J. Angus & L. McIntyre, eds. *New Directions for a Diverse Planet: Proc. Fourth International Crop Science Congress, Brisbane, Australia* (available at www.cropscience.org.au/icsc2004/poster/2/3/319_zhengjg.htm).
- Zhu, D.F. (ed.)** 2006. *The theory and practice of SRI*. Beijing, Chinese Press for Science and Technology in Agriculture. (In Chinese)

Zhu, D.F., Cheng, S.H., Zhang, L.P. & Lin, X.Q. 2002. Tillering patterns and the contribution of tillers to grain yield with hybrid rice and wide spacing. *In* N. Uphoff, EC.M. Fernandes, L.P. Yuan, J.M. Peng, S. Rafaralahy

& J. Rabenandrasana, eds. *Assessments of the System of Rice Intensification*, p. 125-131. Ithaca, NY, CIIFAD (also available at ciifad.cornell.edu/sri/proc1/sri_28.pdf).

Le système d'intensification du riz: utilisation de pratiques de culture différentes pour accroître la production de riz et les profits à partir du potentiel de rendement existant

Le système d'intensification du riz est une méthode qui permet d'obtenir davantage de phénotypes productifs à partir des génotypes du riz existants. Il modifie la gestion des plantes, du sol, de l'eau et des fertilisants sur le terrain avec des effets positifs sur les biotes du sol.

En transplantant les jeunes plants un à un, plus rapidement, avec plus de soin, en laissant davantage d'espace et en assurant des applications intermittentes d'eau pour maintenir l'essentiel les conditions aérobiques du sol, on obtient de meilleurs rendements tout

en diminuant les quantités de semences et d'eau utilisées. Les revenus nets des agriculteurs augmentent donc du fait des rendements accrus et de la baisse des coûts de production. Accueillis au départ avec une certaine réticence, les avantages du système d'intensification du riz sont maintenant reconnus dans vingt-quatre pays. Il convient en outre de noter que des besoins accrus en main-d'œuvre ont été nécessaires au départ mais qu'il est maintenant possible de réaliser des économies dans ce secteur.

Le système d'intensification du riz représente une mutation profonde, l'attention étant axée sur le développement d'un système racinaire important et vigoureux ainsi que sur l'abondance, la diversité et l'activité des organismes contenus dans le sol.

L'article fait état des résultats empiriques obtenus dans un certain nombre de pays permettant de mieux comprendre comment accroître la productivité du riz en respectant l'environnement et en obtenant des résultats positifs du point de vue socio-économique.

El sistema de intensificación del arroz: utilizar prácticas de cultivo alternativas para aumentar la producción y rentabilidad del arroz a partir de los potenciales de rendimiento existentes

El sistema de intensificación del arroz (SRI) es una metodología encaminada a producir fenotipos más productivos a partir de genotipos de arroz existentes. Cambia la forma en que las plantas, el suelo, el agua y los nutrientes se gestionan en el campo, con efectos positivos sobre la biota del suelo.

Al trasplantar plantones más jóvenes, individualmente, con mayor rapidez y cuidado, con un espaciado más amplio y con aplicaciones intermitentes de agua para mantener unas condiciones del suelo principalmente aeróbicas,

aumentan los rendimientos y se reduce la necesidad de insumos de agua y semillas. Los ingresos netos de los agricultores se incrementan debido no sólo a la obtención de rendimientos más elevados, sino también a la reducción de los costos de producción. Aunque inicialmente su aceptación resultó lenta, las ventajas de este sistema se han demostrado ya en 24 países. Además, tras una acentuación inicial de la intensidad del trabajo, se está consiguiendo ahora el ahorro de mano de obra.

El SRI representa un cambio de paradigma que atiende al desarrollo de sistemas radiculares amplios y firmes, así como a la abundancia, diversidad y actividad de los organismos del suelo.

En este artículo se facilitan datos sobre los resultados empíricos de una serie de países que ayudan a entender mejor la manera de aumentar la productividad de los factores en la producción del arroz de una forma inocua para el medio ambiente y beneficiosa desde el punto de vista socioeconómico.