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UPLAND RICE FOR THE HIGHLANDS: NEW VARIETIES AND SUSTAINABLE CROPPING SYSTEMS TO FACE FOOD SECURITY. PROMISING PROSPECTS FOR THE GLOBAL CHALLENGES OF RICE PRODUCTION THE WORLD WILL FACE IN THE COMING YEARS?

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UPLAND RICE FOR THE HIGHLANDS: NEW VARIETIES AND SUSTAINABLE CROPPING SYSTEMS TO FACE FOOD SECURITY. PROMISING PROSPECTS FOR THE GLOBAL CHALLENGES OF RICE PRODUCTION THE WORLD WILL FACE IN THE COMING YEARS?

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SUMMARY: The highlands and high elevation areas of the inter-tropical regions of Asia, Africa and Latin America where rice is often the staple crop and food, are often characterised by a poor and fragile environment. Rapid demographic growth has broken the balance between the productivity of the traditional agricultural systems and the nutritional and cash-income needs of the population having to face food security.

The high plateaux of Madagascar are a typical example of this situation. Rice is the staple food in this densely populated area. Farmers traditionally grow irrigated or rainfed lowland rice wherever possible, with admirable developments in inland valleys and terraces on hillsides. But as early as the end of the 1970s, the population has had to face the challenges of a growing demand for rice, the stagnation of rice yields in irrigated lowlands, and the scarcity of new lowland areas which could be devoted to rice cultivation. In other respects, because of the lack of suitable varieties, they couldn't grow upland rice on their vast upland stretches. Indeed, upland rice growing was limited to altitudes lower than 1,200 m.

In the mid-1980s, CIRAD and FOFIFA launched a research program for the highlands with the aim of pushing forward the frontier of upland rice growing areas in high elevation areas of the tropics. This program was then consolidated with research on cropping practices that ensure the sustainability of upland rice based cropping systems.

The program started in the high plateaux of Madagascar, and soon became a cross-continent collaborative research project – Andean area of Colombia and high altitude area of tropical China. Its results have opened up new prospects for some of the poorest farmers of the inter-tropical areas. Thanks to the creation of a new generation of upland rice variety, cold tolerant, of a short duration and of adapted eating qualities, it is now possible to cultivate upland rice as high as 1,800m above sea level. Rice cropping systems based on direct seeding on permanent plant cover without soil tillage were tested. The results are promising. As the new varieties proposed match the farmers' real needs, adoption is spectacularly fast in Madagascar as well as in the Colombian Andean areas.

The global challenges of rice production the world shall face in the coming years are not very different from the ones already faced by the population of the high plateaux of Madagascar: a growing demand for rice while the dominant irrigated model of rice production is running out of steam. In this context, upland rice, thanks to quasi-unlimited cultivation areas and to the improved and sustainable cropping systems now available, offers promising prospects, complementary with the irrigated rice cropping system.

I. INTRODUCTION

In many inter-tropical regions of the world, highlands and high elevation areas, more than 750m above the sea level, are characterised by rugged terrain, poor access to markets, environmental degradation, and a high incidence of poverty. These areas are also often inhabited with ethnic minorities that are socially and politically disadvantaged. For these populations, food security remains a daily combat.

Upland rice is one of the main staple crop or staple food in inter-tropical highland areas. It is grown in rainfed, naturally well-drained soils without surface water accumulation, usually without phreatic water supply, and usually not bunded. Land slopes vary from 0 to more than 30%. The most common cropping system is shifting cultivation. Farmers plant a rice crop alone or in association with other crops such as maize, yam, beans, cassava, or banana. The same field is used for 1 to 3 years until soil fertility declines and weed and pest infestations increase. They then abandon the land and return to previously abandoned farmland or start cropping on other available virgin land. The rice varieties used are of the traditional tropical *japonica* type characterised by a vigorous and tall plant stature, very long panicle, low tillering ability and, often, a long growth duration. Grain yield varies from 1 to 3 t/ha depending on fallow duration and soil fertility. One variation of shifting upland rice cultivation is the pioneer cultivation where fallow is replaced by perennial vegetation. Rice is inter-cropped with young fruit and forest trees for 2-3 years (intercalary cultivation). As the trees grow, they shade a wider area and less rice is planted. In many Asian countries, (Indonesia, Vietnam, China,…) this practice is becoming popular under rubber trees.

Nowadays, the environmental awareness of governments leads many to encourage the permanent cultivation of upland rice in rotation with other crops. Farmers in the highlands are all the more willing to change their practices because of land shortage. But such willingness often has to face the lack of improved cropping practices ensuring the sustainability of permanent upland rice based cropping systems.

The biophysical constraints that limit upland rice yield in highlands are numerous. Among the biotic constraints, weeds are the number one, followed by blast disease. The incapability of small farmers to afford weed control is one of the main causes of the shifting cropping system. Among abiotic stresses, depleted soils in major elements, soil chemical disorders related to low pH (from 4 to 7), and drought caused by erratic rainfall constitute the major constraints. In high elevation areas, in North-east India, Thailand, Burma, Indonesia, Vietnam, China, Central and West Africa and Latin America, … upland rice also suffers from low temperatures. Damages are worse than in irrigated rice where the water layer acts as a thermal buffer. Therefore, although irrigated rice is cultivated at altitudes above 2,000 m, upland rice is mainly confined to altitudes under 1,500m.

During the green revolution period, research programmes for upland rice were first focused on favourable environment. Breeding for yield potential attributes (plant height, tillering ability, and growth duration) has led to a large number of improved varieties yielding more than 5 t/ha under favourable environments. Then efforts were oriented mainly on drought tolerance, blast resistance, and tolerance to low soil fertility. Very little has been done in breeding for cold tolerance in upland rice. In the same way little progress has been made in areas of sustainable upland rice based cropping systems.

In the mid-1980s, the Centre de Coopération Internationale en Recherche Agronomique pour le Développement (CIRAD, France) and the Centre National de Recherche Agronomique et de Développement Rural (FOFIFA, Madagascar), launched a research program for the highlands with the aim of pushing forward the frontier of upland rice growing areas in high elevation areas of humid tropics through improved cold tolerance. In the mid 90s this program was consolidated with research on cropping practices that ensure the sustainability of upland rice based cropping systems. The results of this research program have opened up new prospects for some of the poorest farmers of the humid inter-tropical areas.

This paper is a review of the results of this research program, which began in the high plateaux region of Madagascar, soon became a cross-continent collaborative research project and produced new varieties, new cropping systems, and research methodologies which perform well in low altitude areas too.

II. UPLAND RICE VARIETIES FOR HIGH ELEVATION AREAS

II.1 The high plateaux region of Madagascar, an appropriate research site

The high plateaux region of Madagascar bring together particularly favourable socio-economic and bio-physical conditions for the implementation of research on cropping systems for upland rice and breeding for cold tolerance.

A farmer's high demand for upland rice due to lowland shortage: Rice is the staple food in the densely populated high plateaux of Madagascar (more than 200 inhabitants / km^2 in some areas). Farmers traditionally grow irrigated rice or rainfed lowland rice wherever possible, with admirable developments in inland valleys and terraces on hillsides. Magnificent rice terraces can be seen as high as 1,900m. Until the mid-70s, farming systems were mainly based on lowland rice cultivation and rice was the quasi-unique and beloved food. Rice consumption per capita, more than 200 kg/year, was one of the highest in the world. From this time, facing the saturation of wetland areas, the farmers of the region have developed new farming systems based on dryland or upland crops. Attempts have been made by farmers to introduce upland rice varieties used in the traditional slash and burn rice cropping system "tavy rice" of the humid forest of the Eastern coastal area of the country. But these varieties, cultivated mainly at altitudes below 750 m, were of too long duration fir the highlands above 1,200 m. Finally, in the absence of suitable upland rice varieties, farmers have chosen other crops, mainly maize associated with bean. Some tuber and roots (cassava, sweet potato and taro) are also cultivated. But all these crops were only stopgaps and a strong demand arose for short duration cold tolerant upland rice varieties (Rakotoarisoa, 1996).

A very selective climate: The Vakinakaratra prefecture -19°30 to 20°15 South-hosting the research program is the highest part of the Madagascar high plateaux region. Its climate is characterised by a 6 month long rainy season from mid October to mid April. The most rainy months are December, January, February and March. Total rain varies from 1,300 to 2,000 mm according to years and altitude. Hailstorms are frequent at the end of the rainy season. Heavy nebulousness may reduce sunshine duration to half the duration of day length. Average hygrometry is high, around 80%. Mean temperatures at 1,500m altitude vary from 17°C in October, the rice sowing period, to 20°C during the reproductive stage. Minima temperatures can fall below 10°C during early vegetative stage and are below 14°C during reproductive stage and grain filling. The night / day thermal amplitude is high (10 to 12 degrees) during the whole rice growing season.

Compared to other rice growing highlands in the world, the high plateaux region of Madagascar seems particularly selective as regards temperatures. Low temperatures slow down rice growth at almost all stages: panicular initiation is delayed and the grain filling and maturation stages are lengthened. Damages are worst with low temperatures at the seedling or reproductive stages. Low temperatures also have a negative effect on soil fertility. With low soil biological activities, nitrogen and phosphorus release is inhibited (Chabanne & Razakaminaramanana, 1996a).

II.2 A breeding program valorising local genetic resources

A vast program for collecting local varieties and introduction from around the world: The breeding program started with a vast program of collecting local varieties of irrigated rice. Cold tolerant varieties from altitude rice growing areas like Nepal, China and Peru, or from cold temperate rice growing areas in Japan, Korea, Bulgaria as well as varieties screened for cold tolerance by IRRI (IRCTN collection), CIAT and CIRAD were also introduced.

More than 900 locally collected or introduced varieties were first evaluated at 1,500m altitude. Only 55 entries, mainly local lowland varieties, were selected. Among them, those belonging to the *Latsika* family had the best performances regarding sterility rate, grain yield and tolerance to sheet blight. The *Latsika* family belongs to the temperate *japonica* group. Varieties of this family are traditionally cultivated in lowland ecosystems with altitudes above 1,800m. In addition to these varieties, a small number of improved short duration upland varieties developed by CIRAD and FOFIFA for medium altitude areas (750 – 1,000m) were also selected. No other upland entries - local *Tavy* varieties or introduced varieties – were able to settle their growth cycle and produce grain.

Classical and innovative breeding schemas: More than 200 crosses have been performed using the *Latiska* family as the cold tolerance donor. Progenies of these crosses were selected with the pedigree method at 1,500m altitude. In addition, using a male sterility gene, a gene-pool with a very wide genetic base has also been created. It stems from the inter-mating of more than 50 varieties of different geographic origins. The gene-pool was then used for recurrent selection for yield under low temperatures in upland ecosystem (Dechanet & al. 1996)

Early multilocal evaluation through international collaboration: As soon as the F5 generation, segregating material was evaluated over a wide range of agro-ecological environments in Madagascar and outside the country in Asia and Central Africa. In Asia the segregating material was evaluated in Nepal (Kathmandu, 1,600m altitude and Jumla 2,600m) and in the Yunnan province of China, 21°N – 24°N, 800-1,600m above sea level. In Central Africa, the material was evaluated in the altitude swamp of Burundi. These evaluations led to the nomination of a first set of new upland varieties in 1991 (Tao Dayun & al., 1996).

Confirmation of cold tolerance through physiological assessments: One of the most important causes of physiological disorders under low temperature is the imbalance between carbon fixation and mineral nutrient uptake. Indeed, although leaves quickly warm up with sunshine and start carbon fixation through photosynthesis, low soil temperatures inhibit the rhizospherous activities.

The comparison of photosynthetic activity at different temperatures showed clear differences between the new upland rice varieties selected at 1,500m altitude and varieties coming from low altitude areas. For the first, photosynthetic activity has the highest efficiency at temperatures below 27°C, although for the second ones the optimal temperatures for photosynthesis activity range from 27 to 30°C. In the same way, roots' nitrate reductase activity is less sensitive to low temperature in varieties selected in high altitude than those coming from low altitude areas. (PUAR & al., 1996)

Yield stability analysis through multilocal and pluriannual trials: A network of multilocal trials was established in the high plateaux area of Madagascar in order to evaluate yield stability of the newly created varieties. Five sites were selected according to altitude, from 1,400 to 1,600m, and soil fertility, from rich volcanic soil to badly leached acidic and low cation exchange capacity soil.

Four years of multilocal trials led to the selection of a set of 5 varieties with large adaptability, yield potentials above 5 t/ha, growth duration varying from 145 to 166 days at 1,500m altitude, a large variability for plant height, as well as for panicle characteristics and grain shape (Chabanne & Razakaminaramanana, 1996b).

II.3 A strong commitment to support extension activities

Early partnership with extension services: Partnership with extension services was established as early as the first days of the research project. It concerned state-run extension services as well as para-statal services involved in rural development and NGOs involved in agriculture and assistance to farmers. This early partnership played an important role in the effectiveness of the release of the new varieties in the high plateaux region.

A vast network of on-farm trials and participatory evaluation: As soon as the nomination of the first set of upland cold tolerant varieties, a vast network of on-farm varietal trials was organised. Every year 100 to 200 on-farm trials were set up in partnership with extension services. Each trial included 2 to 5 varieties with different growth duration, plant architecture, and grain shape, in order to leave enough room for the farmers' personal choice.

Set up of a farmer's seed production system: It is well known that very often in the absence of an official seed production and distribution system, seed availability is an obstacle for the spread of new varieties. In order to avoid such a situation, the research team directly took charge of the production of basic seed for the new upland rice varieties and encouraged the production of commercial seed by extension services first, and by seed producer farms in a second step. The research team supervised the production of rice commercial seed by the extension services. They also organised training courses for the members of a farmer organisation for seed production and distribution.

II.4 Rapid development of upland rice in the highlands of Madagascar

Thanks to the research team commitment in support to extension activities, and thanks to the fact that cold tolerant upland rice varieties constituted an innovation which really answered the farmers' needs, the development of upland rice in the high plateaux area of Madagascar was spectacularly fast.

As early as 4 years after the nomination of the new varieties, a survey showed that more than 1,500 ha were already cultivated with upland rice at altitudes above 1,250m. The same survey indicated that more than 9,000 farmers (about 10% of the total of the target area) had adopted upland rice cultivation. The average upland rice surface for each farmer was about 1,500 m^2. Adoption was particularly high along roads and in villages that had hosted a varietal trial. Farmer to farmer spread of the new varieties was the most important factor in this rapid development. But the advertising and advising activities of the extension services also played an important role.

The farmers' motivation for the introduction of rice in their upland cropping systems was manifold. The 3 most frequent reasons given by farmers were: non-access to lowland rice growing areas, complementary production for subsistence and complementary production for sale. Thanks to the relatively short duration of the upland rice varieties, harvest is made one to two months earlier than lowland rice. This early harvest reduces the rice shortage period at the end of the rainy season and ensures high prices in the market. Surprisingly some farmers also declare adopting upland rice because of its improved eating qualities.

III. SOUTH - SOUTH PARTNERSHIP FOR SPREADING THE NEW TECHNOLOGY

As soon as the adoption of upland rice cultivation became a reality in the highlands of Madagascar, a new project was built with the aim of consolidating its development in Madagascar and promoting its adoption in other high elevation tropical areas. The first two areas chosen were the Andean area of Colombia and the high altitude area of tropical China. The choice of these areas was motivated by an already existing partnership and the fact that the populations in these areas face food security problems due to land saturation, environmental degradation, or access to cash income (Table 1).

In the Andean areas of Colombia there was no rice cultivation tradition but rice had a very important place in the rural population diet, with more than 150 kg per capita and per year. Rice purchase absorbs the major part of their cash income earned in coffee plantations. In China, upland rice is the principal subsistence crop for many ethnic minorities living in the mountainous area of the Yunnan province.

Table 1. Comparison of the characteristics and constraints of the three areas.

	Madagascar	**Colombia**	**China**
Target zone	High plateaux of Vakinankaratra > 1,250m	Andean area of Cauca prefecture > 1,700m	Mountainous area of Yunnan province > 1,500m
Population	Betsilo with high mastery in rice cultivation on terraces	Poor half-cast and Indian farmers	Ethnic minorities
Eating habit	Rice 3 times a day if possible	Rice & bean	Rice
Rice cropping system	Irrigated rice	None	Upland rice slash and burn
Major constraint	Saturation of inland valleys	Cash income for rice purchase	Shortening of the fallow period

III.1 Introduction of upland rice in the Andean areas of Colombia

A multi-partner approach: The partnership system built for the development of upland rice in the Andean area of Colombia included not only research institutions (CIRAD and CIAT) but also extension services, and farmers' organisations with their "Local agricultural research committees" (CIAL). This partnership system ensured taking into consideration the farmers' point of view as early as the beginning of the project.

Participatory varietal selection: A large number of lines created in Madagascar were introduced in Colombia and were directly evaluated in on-farm trial implemented by CIALs. Thanks to the completion of a large number of these participatory varietal selections, two lines were selected and have been nominated: Cirad 446 and Cirad 447. They are particularly drought tolerant and resistant to rice blast. The average yield obtained in on-farm trials was 3 t/ha at 1,800m.

Taking into account post-harvest problems: The participatory evaluation took into account not only the yield but also the farmers' preferences for grain quality and post-harvest problems, especially the de-hulling question. A manual de-huller was designed and samples were produced in partnership with a local manufacturer. The initial prototype has been improved through participatory evaluation. The final version enjoys a certain commercial success with 26 units sold over a few months.

A fast track seed production and distribution system: As soon as the two new varieties were nominated, seed production was undertaken by a specialised private operator. At the same time steps were taken to obtain the privileged Colombian statute of "improved varieties for small-scale production agriculture". This statute allows a fast track legal seed production and distribution.

When new technology meets real demand adoption is fast: Within 5 years more than 50 underprivileged Andean communities (which represent 3,000 families representing 17,000 persons) had already adopted upland rice cultivation. This rapid and massive adoption demonstrates the feasibility of developing rice cultivation in areas were farmers have no rice growing traditions. Convinced of the interest of developing upland rice in the Andean area of the country, the Colombia Institute for the Development of Science and Technology has decided to ensure the continuation of the project.

The results obtained in Colombia have been successfully transferred to Central America. The variety Cirad 447 has been adopted and is in the course of multiplication in Equator, Costa Rica and Honduras. The manual de-huller has been introduced in Equator for evaluation and distribution by and to local users. These achievements and their spreading have demonstrated to Colombian and Central American decision-makers the interest of rainfed upland rice for the poor communities. The development of upland rice cultivation is now in the local NGOs' hands. Their first technical reports are encouraging (Vales & al., 2003)

III.2 Innovative breeding approach for the Chinese highlands

In China, partnership was concentrated on plant material and scientific exchanges with the Yunnan Academy of Agricultural Science (YAAS) in charge of animating a network of departmental research centres.

A long term genetic improvement approach: In addition to the new varieties created in Madagascar, gene-pools of large genetic basis worked-out in Madagascar for cold tolerance and in Colombia for blast resistance were transferred to YAAS. YAAS uses this material in its breeding program. As an exchange, varieties of Chinese high altitude irrigated rice and low altitude rainfed upland rice have been introduced in Colombia and used as a source of cold tolerance.

Hybrid upland rice: Based on the Cirad expertise for upland rice F1 hybrid varieties established in Brazil and the YAAS expertise for hybrid seed production, an ambitious program has been designed to create and distribute F1 hybrid upland rice varieties in China. The program targets not only high altitude areas but also low altitude areas confronted with water scarcity due to increasing competition between the agricultural, urban and industrial uses of water resources.

One of the specificity in this program will be the use of gene-pools and recurrent selection to obtain male lines. Meanwhile 200 to 300 male lines are produced every year. Combined with about ten A lines, the system allows to test more than 2,000 new hybrids combinations every year.

IV CONSOLIDATION OF UPLAND RICE DEVELOPMENT IN THE HIGHLANDS OF MADAGASCAR

Since 2000, the cultivation of upland rice is spreading spontaneously and quickly in the highlands of Madagascar. It is no longer really necessary to promote the appropriate varieties. Faced to this craze of the highlands' farmers for upland rice, the research team makes its responsibility to consolidate the situation through:

- Selection of a new generation of varieties that, besides cold tolerance, integrate other agro-ecological constraints of the region, and support to local initiatives for the spread of new upland rice varieties.
- Focus research and development activities on the design and the spread of sustainable cropping practices based on the concept of "conservation agriculture".

IV.1 New varieties and support to local initiative

A new generation of varieties: Thanks to the completion of a large number of participatory varietal trials that took into account the preferences of farmers and consumers, three new varieties have been nominated and officially proposed for release: Fofifa 157, Fofifa 158 and Fofifa 159. The average yields obtained in on-farm trials at altitude varying from 1,400m to 1,750m are 2,2 t/ha, 2,5 t/ha and 2,8 t/ha respectively with a maximum of 5,8 t/ha, 7,1 t/ha, and 6,3 t/ha.

Seed production: Seed production for the Cirad-Fofifa varieties by the para-public extension service Fifamanor and by the Federation of seed producing farmers of Vakinankaratra (VMMV) has been organised and has begun. It includes five varieties currently proposed for release: Fofifa 133, 154, 157, 158 and 159.

Information and training: A specification and recommendation sheet for the cultivation of rainfed upland rice has been distributed in the Antsirabe region to different agricultural extension organisations. Currently, the research team, in partnership with the VMMV, Fifamanor, the government extension service and the NGOs TAFA and FIFATA, is working out the terms of reference for a complete technical support guide for upland rice based cropping systems. This project has now been integrated into the body of a multi-partner information system on upland rice cropping systems and conservation agriculture in Madagascar. In addition to a yearly actualised paper version, this guide will be available for consultation on the web.

IV.2 Sustainable cropping practices based on the concept of "conservation agriculture"

It is well known that the Madagascar highlands are a poor and very fragile ecosystem. Apart from some volcanic areas, soils are depleted in major elements, the cation exchange capacity is low, and the pH is highly acidic. Steep sloping lands with high runoff and lateral water movements are particularly prone to erosion. Cropping systems are based on manual or animal drawn tillage. Major upland crops are maize, bean, soya, and cassava during the rainy season, wheat, oat, potato, and vegetables in the dry season. Milk production is growing but it faces a dramatic shortage of forage. Manure is the only available source of fertiliser. Yields are very low and very sensitive to rainfall. The region is not food self-sufficient.

In order to help this traditional agriculture facing the challenges of food security, soil conservation and environmental protection, new cropping systems based on direct seeding on permanent plant cover without soil tillage developed in Brazil have been introduced and tested. In these systems, the soil is never tilled but permanently kept covered by dead or living mulch, which comes from plants in inter-cropping or relay-cropping systems. These plants have strong and deep root systems and can recycle nutrients from deep horizons for subsequent use by the main crops. They also have a high and fast biomass production and are able to grow in adverse conditions such as the dry season, on compacted soil or under high weed pressure. These cropping systems, are not only attractive economically, but they also propose solutions for soil preservation, and also for recovering soil fertility (*http://agroecologie.cirad.fr*).

Their transfer and adaptation to the high plateaux of Madagascar started in the early 90s, when upland rice was still absent from the area because of the lack of adapted varieties. Direct sowing experiments included the major crops of the area. These experiments were of course perennial as soil characteristics are improved gradually over 2 to 5 years. Direct sowing cropping systems - associating maize with a leguminous plant of the Arachi, Desmodium or Trifolium genus as live plant cover, or associating soya with a perennial graminacea of the Pennisetum genus, or a continuous intra-annual succession of bean and oat - increased yield two to three times over 5 years. When compared to traditional tillage based cropping systems, the new systems also appeared less susceptible to rainfall variability.

The evaluation of upland rice within the direct sowing experimental site of the high plateaux started in the late 90s when cold-tolerant and short duration upland rice varieties became available. The experiment included the upland rice – soya rotation and upland rice – oat + bean rotation. For a given crop rotation and a given fertiliser level, direct sowing upland rice yields are two to three times better than under the traditional cropping system based on manual or animal-drawn tillage (Michellon & al., 2001).

V. CONCLUSIONS AND PROSPECTS

V.1 Ensuring the sustainability of upland rice based cropping system

The objective of pushing forward the frontier of upland rice growing areas in high elevation regions of humid tropics was achieved through the creation of a new generation of upland rice variety, showing cold tolerance, short duration and adapted eating qualities. The adoption rate of upland rice cultivation by farmers in the highlands is high and gaining momentum. In the Andean area of Latin America the new varieties have even be given a nickname: RHICO for "Rice for Hillsides with Cold tolerance". In these underprivileged areas, the spread of the new upland rice varieties will undoubtedly help farmers, especially the poorest, to face food security.

But new varieties, even with very high performances, can not ensure the sustainability of the cropping systems in the fragile and often unfertile environment of the highlands. Cropping systems, based on direct seeding on permanent plant cover without soil tillage, seems to be a promising technical answer to the challenges of soil and water conservation and environmental protection that traditional agriculture is facing in these areas. Some farmers have already adopted these new cropping systems in the high plateaux of Madagascar as well as in the low elevation areas of Madagascar and in some other developing countries in Asia, Africa and Latin America. Efforts should be maintained for this development.

In Madagascar, a new Research Unit focussing on "Sustainable cropping systems and rice cropping" was created in 2001. Some 20 scientists from FOFIFA, CIRAD and the University of Antananarivo are working together for the improvement of the upland rice based cropping systems through a better understanding of the biological bases of conservation agriculture following an integrated pest and crop management approach. The Unit has also a capacity building objective and hosts some six PhD thesis research activities.

In Asia, the initiative of the Consortium for Unfavourable Rice Environment (CURE) to draw strategies for sustainable development of agricultural production systems in the mountainous regions of the Greater Mekong Subregion (GMS) countries, constitutes the best international framework for research and development efforts.

V.2 Upland rice, a new prospect for the global challenges of rice production the world will face in coming years?

As early as the mid 80s, the population of the high plateaux of Madagascar has been facing the challenges of a growing demand for rice, the stagnation of rice yields in irrigated lowlands, and the scarcity of new lowland areas which could be devoted to rice cultivation. The introduction of upland rice and sustainable upland rice based cropping systems has opened up new prospects for this population and were, therefore, adopted rapidly.

The global challenges of rice production the world shall face in the coming years are not very different from the ones already faced by the population of the high plateaux of Madagascar: a growing demand for rice while the dominant irrigated model of rice production is running out of steam. In order to meet demand, production should increase by about 20% in the 20 coming years. But yields of irrigated rice are not increasing any more or very slowly, irrigated areas are not extensible, competition with the non-agricultural uses of water and land is becoming sharper and sharper, and there are conflicts with environmental concerns.

In this context, the upland rice production model, often disparaged for negative environmental effects and low-unpredictable productivity, offers very promising prospects. Indeed, on the one hand, possibilities for the extension of upland rice cultivation areas are almost unlimited: tens of millions of hectares of land favourable to upland rice still remain uncultivated in the inter-tropical areas of Latin America and Africa. On the other hand, during the last 30 years, research programs have consistently improved the prospect of sustainable upland rice based cropping systems. For instance, in the Brazilian Cerados, yields of more than 5 t/ha are regularly obtained through cropping systems based on direct sowing of upland rice on permanent plant cover.

Likewise, upland rice seems to be a promising rice production system complementary with the irrigated cropping system.

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