REPORT ON WORKSHOP ON THE SYSTEM OF RICE INTENSIFICATION, EXCHANGING EXPERIENCES IN CHINA, THE DEMOCRATIC PEOPLE'S REPUBLIC OF KOREA, AND INTERNATIONALLY

Hangzhou, China, February 28-March 2, 2010 – Norman Uphoff, CIIFAD (draft)

Given an indication of interest in considering whether the concepts and methods of the System of Rice Intensification (SRI), with appropriate modifications for climate, soil and other constraints, could contribute to improving rice productivity in the DPRK, a three-day international workshop was held in Hangzhou, February 28-March 2. This was organized and hosted by the **China National Rice Research Institute** (CNRRI), with support from **The Asia Foundation**. Impetus for this get-together came in part from some initial positive results that were seen from SRI evaluations done during the 2009 season.

This workshop happened to coincide with the **Lantern Festival**, which concludes the annual **Spring Festival** that is celebrated all across China and in other Asian countries. Hangzhou's Lantern Festival is said to be the most festive of all the celebrations in China, and the city-wide outburst of profuse, glorious and deafening fireworks the first evening added to the positive ambience for the proceedings. The workshop provided the DPRK delegation with a better idea of SRI experience in China, and thus this reporting on Chinese experience with SRI should be of interest to persons beyond the DPRK.

BACKGROUND: Interactions with the DPRK **Academy of Agricultural Sciences** (AAS) go back to March 1998, when two scientists from the Academy, one of them its vice president, visited Cornell University under the auspices of the **American Friends Service Committee** (AFSC), an NGO that engages in development and reconciliation efforts around the world on behalf of American Quakers and others. In December 2005, a larger AAS delegation visited Cornell under the auspices of The Asia Foundation and took an interest in SRI. Several NGOs that have people-to-people activities in DPRK including the AFSC, the **Mennonite Central Committee** (MCC), and the **New Zealand DPRK Society**, have shared information on SRI methods with agricultural cooperatives with which they are collaborating around Pyongyang, and several FAO staff members have taken an interest in supporting SRI evaluations and demonstrations.

When I contacted the DPRK Mission to the United Nations in New York City in November 2008 about possibly visiting DPRK to share what is known internationally about SRI, the Mission's First Secretary (who had read an article on SRI that appeared in the *New York Times in June*) responded positively and facilitated plans to get visas issued for myself and **Dr. Zhu Defeng**, senior CNRRI scientist who has functioned as SRI coordinator in China, to visit DPRK and meet with AAS and Ministry of Agriculture personnel. This was facilitated also by the FAO office in Pyongyang and The Asia Foundation, which offered travel support as part of its program to encourage scientific exchanges in which Cornell faculty had been involved. Unfortunately, a health problem that I encountered before the planned trip in March 2009, plus bad weather in the US that kept Jim Haldeman from Cornell from even reaching Beijing, led to cancellation of that trip. However, trials with SRI methods proceeded during the 2009 main season, so there was interest in knowing more about SRI and how it could be adapted to DPRK conditions.

Discussions with DPRK authorities through **Ed Reed** of the Asia Foundation and **John Odea** of the FAO office in Pyongyang led to agreement on holding an international workshop in China. This would involve Chinese rice scientists with experience in applying SRI methods, particularly in cold-climate conditions, and also myself, to give some international perspectives. CNRRI through its Director-General **Dr. Cheng Shihua**, agreed to host the workshop in Hangzhou, and Dr. Zhu and **Dr. Lin Xianqing**, who also has worked extensively with SRI in Zhejiang province, provided leadership for the arrangements. Chinese colleagues from Sichuan, Hunan and Heilongjiong provinces were also invited to share their experience, as were observers from NGOs working with cooperatives in DPRK on SRI methods and soil improvement.

PARTICIPATION: The DPRK delegation was headed by **Kim Jong Nam**, senior officer in the AAS' Department of Scientific Guidance. He was accompanied by **Ham Thae Son**, head of the Rice Cultivaiton Research Section in the Academy's Crop Cultivation Research Institute, and from the Academy's Rice Research Institute, **Choe Jin Myong**, head of the Rice Information Research Section, and **Jong Nam Ho**, researcher in the Heterosis Breeding Research Section.

From Sichuan province, **Prof. Zheng Jiaguo**, head of the Crop Cultivation Department in the Crop Research Institute of the **Sichuan Academy of Agricultural Sciences**, and **Prof. Ma Jun**, **Sichuan Agricultural University**, participated. Both Zheng and Ma have worked with SRI research and extension since 2001. From Hunan province, representing the **China National Hybrid Rice Research and Development Center** (CHNRRDC), was its Deputy Director, **Prof. Ma Guohui**. The Center through its Director, Prof. Yuan Long-ping, has been doing SRI evaluations since 2000-01.

From Heilongjiong province in the far north were **Prof. Jin Zhenxun**, **Northeast Agricultural University**, and **Huo Lijun**, senior agronomist in the **Heilongjiong Land Reclamation Bureau**. Representing Zhejiang province experience were Dr. Zhu and Dr. Lin. Also participating from CNNRI were **Zhang Yuping**, assistant professor; **Chen Huizhe**, associate professor; and **Pan Xiaofang**, program officer. The Chinese provinces represented were from the country's west, north, center and east.

Attending from the **Asia Foundation** were Ed Reed, Korea Representative, and **Chan Sang Moon**, Program Officer who has facilitated a number of exchanges with DPRK teams before. John Odea from the FAO Office in Pyongyang was unfortunately not able to participate as planned. Attending as observers were **Wu Na**, the AFSC's China and DPRK Country Representative, and her agricultural assistant **Zhang Yunyun**, and **James Frey**, MCC's Agricultural Project Officer for the DPRK, based respectively in Dalian and Beijing. The meeting was held in the Zhijiang Hotel in Hangzhou. Participants arrived on Saturday, February 27, and a cordial opening dinner was provided at the hotel that evening.

OPENING SESSION: The morning meeting on February 28 began with welcomes and brief remarks from **Dr. Zhu Defeng**, who served as the workshop's chair; **Ed Reed**, on behalf of the Asia Foundation; and myself representing the international SRI community that has developed over the last 10 years. China was the first country outside of Madagascar to validate SRI methods, so the start of this community can be dated from 1999 when researchers at **Nanjing Agricultural University** reported 9.2-10.5 t/ha yields with SRI methods. While such yields could be obtained with super-hybrid varieties and chemical inputs, the fact that they could not be obtained with a 50% reduction in water requirements made SRI interesting for Chinese conditions. Researchers at CNRRI, CNRRDC, SAAS and SAUm soon produced similar results, launching SRI in China.

SRI EXPERIENCE IN CHINA: After a tea break, **Dr. Zhu Defeng, CNRRI**, began with an overview of SRI in China. A few statistics made clear the importance of rice in China. This country produces 30% of the world's rice from less than 19% of the world's rice area. Zhu noted that yield growth in the rice sector has slowed since the mid-1990s, from almost 4% in the 1960s -- when spurred by the introduction of short-stature, high-yield varieties plus heavy use of N fertilizer -- to about 3% in the 70s and 80s when hybrid varieties were introduced, to 1% during the 1990s when yield growth decelerated, to then less than 0.5% in 2000-2005. Of particular significance is the low productivity of N fertilizer application in China (Table 1). While Chinese farmers apply 180 kg N per ha -- compared with 120 kg in Europe and 100 kg in the rest of the world -- they achieve only 35 kg of rice per kg of N fertilizer, the same as in the rest of the world, while European rice farmers are getting 2/3 more -- 58 kg rice per kg of N fertilizer.

Hybrid rice varieties in China are producing about 24% more per hectare than inbred varieties (6.57 vs. 5.31 t/ha average). But hybrids have not been improving much in yield or in spread in recent years. Zhu presented a graph showing rapid expansion of rice area under hybrids from 1975 to 1995, but the line for area under hybrids is almost flat since then. (Note: The PPT presentations referred to in this workshop report will be posted on the SRI website: http://ciifad.cornell.edu – so only some of the most salient or surprising tables and figures are included in an Annex to this report.)

Zhu noted that the elements of SRI methodology that have been most widely taken up in China are: sparser planting with younger seedlings, which saves labor and seed; reduced irrigation applications, which saves water; and higher ratio of organic-to-inorganic fertilizer, which contributed to more sustainable agriculture. These practices are more suitable to the new generations of improved varieties, give more efficiency in transplanting, water saving, higher yields, and greater profitability.

A major constraint on the rice sector generally, and a factor that will encourage or impede SRI spread, is agricultural labor shifts. The share of labor force in agriculture has fallen from 80% in 1960 to half that, 40%, in 2008. This means that for SRI to be adopted it must be labor-saving, not labor-intensive. In Sichuan and Zhejiang provinces, most farmers consider SRI methods as adapted to local conditions to be *labor-saving*, but more effort needs to go into addressing this constraint.

Planting density (hills/m^2) has been falling in China for many years, from about 50 (averaged over three seasons) in the 1960s, to 32 in the 1980s, and 23 in the present. So SRI is consistent with a trend that has been gaining force as farmers find that they can get better crop performance with fewer plants per unit area. Table 2 shows results of trials done by CNRRI researchers, showing how fewer number of hills per m^2 gives higher yield, although all four spacings evaluated were actually within the SRI range. Table 3 shows results of trials comparing continuous flooding with intermittent irrigation for two varieties, confirming an advantage for the latter, even without using other SRI practices.

One of the most interesting graphs was a comparison of grain production and fertilizer consumption over time (Figure 1). While the latter seemed to be raising the former for several decades, since the latter 1990s, although fertilizer consumption has continued to rise, grain production has declined. This indicates a negative marginal productivity, quite possibly reflecting changes in paddy soils, chemically and physically but likely especially biologically.

Zhu discussed what CNRRI scientists are considering the best integrated rice management techniques. They suggest starting with an appropriate high-yielding variety and reducing water applications. Trials showing the advantage of young seedlings indicated 13 days as an optimum age (Table 4). He also showed results of trials with different applications of N fertilizer, indicating 150 kg N per hectare gave higher yields than 180, 210 and 240 kg N applications, and also than 120 kg N, although the latter was not a significant difference. He also showed results of a comparison of yields with Jiayou 99 hybrid variety, where SRI gave 11.1 t/ha vs. conventional management (9.3 t/ha), a 19% difference.

Of the 1.73 t/ha yield increase in this comparison, 80% was attributable to increase in number of grains/m^2, 16% to number of panicles/m^2, and 4% to increased grain weight. In should be noted that most comparison trials of SRI methods in China so far have not evaluated full organic fertilization and active soil aeration. These practices have been considered by scientists to be too labor-intensive to be accepted by farmers. So SRI comparisons have been focused on young seedlings, lower plant density, and reduced water applications, with some addition of organic matter, and the results do not reflect the full agronomic potential of SRI methods as evaluated elsewhere.

Zhu showed pictures comparing SRI practices with Indica hybrid varieties in southern China and with Japonica varieties in northeast China. A particular innovation being promoted is starting seedlings in plastic trays, rather than seedbeds, and also a newer pot-mat seedling raising technology, different from mat raising in that it makes separation of seedlings much easier, with less root trauma. Comparisons of yield from pot-mat seedlings in five provinces showed a 9.6% yield benefit from this new technology. The pictures gave some good visual images of both the methods and the resulting plants.

SRI and Hybrid Rice: Prof. Ma Guohui, Deputy Director-General, China Hybrid Rice Research and Development Center based in Changsha, followed with a powerpoint presentation on 'The Progress of SRI in Super Hybrid Rice.' He started by recounting the evaluations of SRI that his Center began already in 2000, and his Center's hosting of the first international conference on assessment of SRI, at its winter research center in April 2002.

Ma listed the key elements of SRI, most of which are part of the 'modified SRI' (M-SRI) that his Center is utilizing: single seedlings and wide spacing; raising young seedlings in a carefully managed nursery; less water for irrigation; manual weed control without herbicides (this is not much done with M-SRI); and mulch compost application (done to some extent, as much as possible). Particular elements that he listed for M-SRI were: adaptable high-yielding varieties; reasonable (optimal) spacing; plastic tray nursery instead flooded nursery; both organic and chemical fertilizer; weed control with chemicals and manual weeding; adaptable implements for field tillage; and technical standardization (processing).

The Center has evaluated many hybrid varieties with SRI methods that it considers most suitable for Chinese farmers' situations, stressing avoidance of increased labor requirement. One set of bar graphs showed yield comparisons for five varieties. All gave about 12 t/ha with standard management, and 12.2 to 12.75 t/ha with M-SRI management, an SRI yield advantage of 3.6 to 10.5%. Other comparisons made with 7 new hybrid varieties showed similar gains with SRI, but it was also shown that varieties have different degrees of response to SRI management.

Ma presented a number of tables of results, which are given in the powerpoint posted. One particularly interesting findings was the diminishing returns to N fertilizer, where highest yield was obtained with 180 kg N per ha; but a marginal analysis showed that yields with 225 kg N and 270 kg N were only 2.1-3.2% higher than at 135 kg N per ha. He also had a number of detailed tables that evaluated factors like nursery methods (upland tray nursery 11.12 t/ha; upland nursery 10.31 t/ha; wet tray nursery 9.86 t/ha; and wet nursery 9.74 t/ha); leaf age at transplanting; spacing; fertilizer applications; water management methods; tillering patterns; effective tillering rates; and root weights.

One table, for example, showed combined organic and chemical fertilization surpassing both organic and chemical inputs for the two varieties evaluated. In another table, for the same variety M-SRI yield surpassed the control yield by 6% with the same level of N fertilizer applied; but more interesting, M-SRI yield was also higher than the control yield with 10% less and even 20% less N applied. Further, under M-SRI management, the productivity of N was 25% higher with a 20% reduction in N than when the full application was made.

The presentation showed that the Hybrid Rice Center has done a great deal of evaluation of SRI methods since 2001, and a publication was shown titled 'Theory and Practice of Modified System of Rice

Intensification for Super Hybrid Rice,' edited by Prof. Yuan, Prof. Ma and others. A listing of many trial results with different hybrids was shown where yield was over 800 kg/mu (over 12 t/ha). Also results from hybrid trials with SRI methods in Guinea were shown, with the hybrid GY032 reaching 9.2 t/ha, in a country where average paddy yields are well below 2 t/ha.

The last section of the presentation was on 'Key Issues for SRI Improvement.' This made the point that everyone agreed on: that SRI should be diversified to meet the diversity of conditions under which rice is cultivated. Ma listed four different ways to establish a rice crop following SRI principles, suitably adapted: transplanting, direct seeding, seedling broadcasting, and no-tillage cultivation. He also showed a picture of a mechanical seeder, suggesting that mechanization of SRI principles should be worked on. This is a movement already underway in Pakistan, Costa Rica and other countries.

Five areas where Ma suggested further efforts should be made to improve SRI were to find better ways to (1) raise young seedlings, (2) transplant young seedlings, (3) increase effective tillering, (4) increase the utilization efficiency of nitrogen, and (5) increase water use efficiency. In closing, Ma noted that most of the practices recommended from original SRI experience have been validated by research at the Hybrid Rice Center, and with appropriate modifications, they have been incorporated into the Center's recommendations for the best use of the hybrid rice developed in China.

Sichuan Experience with SRI: This presentation was followed by one by **Dr. Zheng Jiaguo**, head of the Crop Cultivation Center in the Crop Research Institute of the **Sichuan Academy of Agricultural Sciences** (SAAS) in Chengdu. He talked about 'Modified SRI and super high yield of hybrid rice in Sichuan Basin,' with inputs from two SAAS colleagues. Zheng started by noting that by 2030, to meet higher demand for rice consumption in China, farmers will have to produce 50% more paddy than today, which will be difficult given constraints on land and water. This task is all the more difficult because yields are already at a fairly high level in China. Researchers in Sichuan have validated the merits of SRI methods developed in Madagascar, but they have found most merit in transplanting younger seedlings, preferably 8-15 days old; planting the seedlings singly, rather than in clumps of 3-6 plants and with wider spacing; and keeping paddy soils moist but not continuously saturated during plants' vegetative growth phase. He noted approvingly my frequent comment that: "SRI is ideas, not a technology."

Given growing conditions in Sichuan province, Zheng said that some modifications had been beneficially made in the spacing patterns for SRI transplanting. What is called **'the triangular method'** involves reducing the number of *hills* per m^2 by half, but then in each hill (40 x 35 cm, about 7 plants per m^2), *three seedlings* are put in a triangular pattern 7-10 cm apart (Figure 6). This has the effect of increasing plant population by 50% while still applying the principle of wider spacing and increased exposure to sun and air circulation.

Average paddy yields are relatively high in Sichuan, about 8.5 t/ha. With SRI methods as introduced, yields could be enhanced by 20%; but by planting in a triangular way with oblong spacing, instead of a square with single plants spaced 25 to 30 cm apart, the yield could be raised by 55% (Table 5). Zheng reported on physiological evaluations he had done comparing SRI-grown rice plants with controls. The leaf blades were longer and larger; plant height and culm length were greater; the stem diameter of the fourth internode (from top) was 12% thicker than on control plants; leaf area index (LAI) was higher. Comparative measurements of leaf blade size, presented in Zheng's powerpoint are shown in Table 6. His comparison of LAI changes over time are seen in Figure 2.

Zheng said that Sichuan researchers early on identified a number of constraints for applying the original recommendations for SRI under their conditions. Single seedlings spaced in a square pattern did not maximize panicles per m^2, so the triangular method was developed. Farmers were used to transplanting large, 7-leaf seedlings, so some compromise was made on seedling age, although there was no disagreement agronomically that younger seedlings are better (Figure 3). Keeping the soil just moist, not flooded, required more labor for management, but pressures to reduce water requirements made this adjustment rational. Because there were not enough cattle being raised for an adequate manure supply, and farmers had no tradition of composting vegetative matter, farmers mostly have continued with chemical fertilizer, for convenience. However, it was realized that as much organic matter as possible should be applied to the soil. With such adjustments for original SRI ideas, the yield improvements noted above from modified SRI practices were achievable.

Modifications included raising seedlings in plastic trays, which permit farmers to get new seedlings from their nursery into the field quickly with no root disturbance, so there is little transplanting shock. With these practices, *wider* spacing is optimal than seen elsewhere, 40x45 or 45x50 cm. Labor scarcity has kept farmers from doing much mechanical hand weeding, which aerates the soil, so herbicides remain the most common means of weed control. Mid-season drainage is strongly recommended for control of tillers, to avoid plants putting out many unproductive tillers. And putting shallow furrows across fields permits better and more even water distribution and control in alternate wetting and drying (AWD).

It has been established that super hybrid varieties have higher yield potential than current inbred and local varieties, but with farmer practices, they do not always perform better. Numerous trial results cited by Zheng showed that SRI methods enable super hybrid rice (SHR) to express more of its potential. Evaluations of 11 SHR varieties found that four definitely performed better with SRI practices, but four yielded better with farmer practices than with SRI management; three did well, and similarly well, with both methods of cultivation.

On extension of SRI within Sichuan, the example of Guanhan City was given, where SRI was first used in 2003. It has now been used for six years, and the municipality average is 12.8 t/ha, a record for the Sichuan ecosystem. In 2005, SRI was designated by the provincial government as the preferred means for achieving high rice yields, and dissemination has progressed well since. Zheng presented data on the spread and results of SRI within the province as a whole, 2004-08 (Table 7). The area under SRI cultivation in 2009 was reported to be almost 251,000, with a total of 637,000 hectares of SRI over the 5-year period. Average SRI yield was 9.2 t/ha, 1.63 t/ha more than the average with current practices.

This increment produced an additional 1.04 million tons of paddy for Sichuan farmers, with lower cost and less water requirement. An economic analysis that Zheng reported showed the average yield with farmer practices to be 8.4 t/ha, while high-yield varieties (HYVs) with SRI averaged 9.75 t/ha, and super hybrid rice (SHR) with SRI produced 10.5 t/ha on average. Compared to average paddy income in the province, net economic income (RMB/mu) was 27% higher with HYV and SRI, and 40% higher with the combination of SHR and SRI. Zheng's conclusions from the Sichuan experience and Sichuan data were:

- A modified version of SRI suited to Sichuan agro-ecosystems can increase rice yield significantly in this province and maybe elsewhere. The modifications include: changes in transplanting density, leaf age, planting pattern, and field management.
- SRI is not a fixed technology but rather a set of ideas for creating a more beneficial growing environment for rice plants.
- As such, there should be continuing variations and evaluations by researchers and also by farmers to further modify and improve this system.

With this presentation, the workshop was adjourned for lunch, resuming in the afternoon with another report on Sichuan SRI experience from **Prof. Ma Jun, Sichuan Agricultural University**. This report will focus on points made by Jun that had not been made by Zheng before him. They agreed on what difficulties farmers faced for implementing SRI recommendations – handling young seedlings, getting enough organic matter, water management, and weeding -- but Jun added that transplanting young seedlings promotes earlier and faster tillering, and also raises the percentage of effective tillering, addressing a constraint that is common in Sichuan. Despite these challenges that farmers faced, the spread of SRI was very rapid in this province, as seen from Zheng's report.

Ma presented data from various trials, such looking at the interactive effect of seedling age and spacing on yield. One complicated table showed that spacing of 90,000 plants/ha at different ages, ranging from the very young 2-leaf stage to the 'middle-aged' stage of 5 leaves, gave higher yield than the very sparse planting of 45,000 plants or the moderate spacing of 135,000 plants. Usually in China, plant populations are over 200,000 plants/ha.

This is an effect separate from the young-seedling effect that Zheng reported on (Figure 3), though combining the two factors, young seedling and wider spacing, has benefits for tiller emergence and the growth of individual plants – except that 'too young' or 'too wide' will reduce yield. SRI involves finding optimum values for the different parameters, rather than applying a single 'best' value across the board.

Ma also presented data showing that optimum plant density depends on the level of soil fertility. It is counterintuitive but true that in better-quality soil, more sparse plant populations will perform better. When the soil is poorer quality, farmers are advised to plant more densely. His recommendation is that farmers plant 112,500-150,00 plants/ha in soil with low fertility, 112,500 plants/ha in medium-fertility soil, and 75,000-82,500 plants/ha in very fertile soil.

For planting pattern, Ma strongly endorsed the 'triangular' method that we had been told about (Figure 6). One table compared conventional cultivation (CK) with standard SRI methods and T-SRI (triangular SRI). The respective yields from replicated trials were 10.95, 12.95 and 15,075 t/ha, representing SRI increases of 18 and almost 38% from SRI methods over CK, starting from a very high yield level. He recommended 30-40 cm spacing between rows and between hills, and 10-12 cm spacing within hills between the three plants.

Ma discussed what he called "wet-dry-shallow-interval" water management for irrigation. This starts with transplanting young seedlings into well-leveled soil with no layer of standing water, and then maintaining shallow water to ensure that the seedling will turn green and survive. It can be difficult to have very precise leveling on large fields, so it may be advisable to make the field bunded in a set of smaller rice paddies, each of which is well-leveled and where water control is easier to maintain.

- At the early tillering stage, soil-aerating irrigation promotes tillering.
- At the late tillering stage, the paddy field is dried to further increase number of tillers (Ma said the objective was a total tiller number of 150-180x10^3/mu (22.5-27 million tillers/ha).
- At middle growth stage, from spike differentiation to heading, shallow irrigation of 2 cm or so promotes larger panicle formation.
- Then at late growth stage during grain-filling stage, alternately wetting and drying the paddy soil maintains root vigor, prevents leaves' senescence, and promotes grain filling.

Ma presented data from evaluations with three different varieties, showing that the highest yield and **water use efficiency** (WUE, kg rice/m^3 water) were achieved with 'wet-dry-shallow-interval' irrigation. But it was interesting to see that the results from what he called 'damp irrigation' (no water layer, and soil water potential (ψ_{soil}) of only -0.017±0.003 MPa) had almost identical WUE. 'Dry cultivation' with ψ_{soil} of -0.065±0.005 MPa) had definitely the lowest yields and WUE, as a result of too much water stress. Per plant yield with 'dry cultivation' was only about one-third of that from the more exacting water management of 'wet-dry-shallow-interval' irrigation.

The results of **fertilizer trials** with SRI methods were interesting. Compared to control (CK) yield of 5 t/ha, the four treatments of organic fertilization, chemical fertilization, 50% organic/50% chemical, and organic compound fertilizer all gave significantly higher yield (7.41-7.69 t/ha), 48-54% more than CK, but these yields were not significantly different from each other. However, a combination of organic + chemical + microbial activity fertilizer gave a yield of 8.81 t/ha, 76% more than CK and significantly higher (Table 8).

One consideration which Ma has researched is the impact of SRI practices on **grain quality**, having reported on this already in 2004 at a national rice conference in Haerbin. His analysis of grains of the same variety (Xieyou 527) found that the grains produced with SRI methods had only 28% chalky kernels compared with those grown conventionally, and 2.72% chalkiness compared to 6.95% in conventional grains. Also, milling outturn was higher: 73% milled rice from SRI paddy vs. 69%, and 55% head milled rice (whole grains) vs. 47%, indicating less breakage of the SRI grains during milling (Table 9). These differences will make more money for millers, or for farmers if they are paid the premium price for their higher-quality SRI paddy, which they deserve to receive.

Ma commented on the importance of **seedling raising** as a factor affecting crop performance. It was interesting to see that despite his own evidence (see below) that transplanting younger seedlings is more productive, he suggested transplanting seedlings at the 5-7 leaf stage. He did recommend that seedlings be raised in upland (unflooded) nurseries, and he endorsed thin sowing in nurseries (10-20 grams/m^2). A graph that he presented (Figure 4) showed the effect of sowing density, ranging from 10 to 20 grams/m^2, interacting with transplanting age. However, all of the ages that were evaluated were considerably older than is recommended with SRI.

Another set of data that evaluated **seedling age** together with **spacing** arrangements did consider the effects of using really young seedlings (2-leaf) (Table 10). These trials used triangular method of transplanting and 40x40 cm spacing between hills was consistently superior for seedlings at the 2-, 5- or 8-leaf stage. However, it was also clear that 2-leaf seedlings outperformed 5-leaf and 8-leaf seedlings at all spacings, from 30 to 50 cm. If farmers knew how much yield they give up by continuing to plant older seedlings, they might develop the skills and techniques to capture this productivity for themselves, overcoming their reservations or apprehensions about using young seedlings. It was seen, not surprising, that 50x50 cm spacing did not produce enough tillers per m^2 to compensate for their higher tillering and grain filling per plant.

In conclusion, Ma said that even with the higher average yields in Sichuan province, SRI methods were generally increasing yield by 20%, and with adaptations the results could be even better. The highest yields with SRI methods are 650-853 kg/mu (10.75-12.8 t/ha), with farmers' net profit generally increased by ￥1,050-3,000/ha, about US$ 150-400). SRI practices have been setting new yield records, with most of the demonstration counties having yields >700 kg/mu (10.5 t/ha). He said that this has become a major technological innovation to increase rice yields in Sichuan province, and the government has designated it as a 'key technology' for rice production in the province in 2009 and 2010.

Heilongjiong Experience with SRI: It was helpful for the DPRK delegation that **Prof. Jin Zhenxun** from Northeast Agricultural University in Haerbin was able to make his presentation in Korean language, but other workshop participants had to rely entirely on his powerpoint presentation for information. The presentation by **Huo Lijun** from the Heilongjiong Land Reclamation Bureau was presented in Chinese language, but the powerpoint was also in Chinese, so not much can be reported in this English summary.

Neither of the presentations focused particularly on SRI, but rather on the rice sector in Heilongjiong, which was interesting to the DPRK scientists because of the climatic similarities with North Korea. In the 1990s, Prof. Jin Xueyong at Northeast Agricultural University developed a rice-management system which he called 3-S, which had many similarities with SRI: relatively younger seedlings (though in the cold climate of Heilongjiong this meant 45 days, not 15), wider spacing, lower plant populations, less water applications, and more organic matter. Unfortunately, this Prof. Jin passed away a few years ago, so he could not present his methodology. This Prof. Jin, a colleague at NEAU, knows about 3-S but emphasized a more standard system of production, concluding his powerpoint with a picture of an airplane spraying a very large rice field with insecticide. This may have impressed the DPRK participants but it represented a level of capital-intensity that was not very applicable for their circumstances.

Prof. Jin laid considerable emphasis upon starting with best high-yielding varieties, which can give yields of 10.6 to 11.8 t/ha according to data presented, impressive for this non-traditional rice-growing climate. While yield growth has been stagnant in China as a whole, there have been improvements over the past 10 years in Heilongjiong and expansion of rice-growing area. The management strategy is to get higher tillering in the seedbed, with a two-stage system of transplanting. Seedlings at the 2-2.5-leaf stage are transplanted at 30 days in soil blocks, spaced 2x2 cm, and they are after another month [?] transplanted 2-3 per hill at wide spacing. Data showed 40x16 cm spacing to give higher yields than 30x16 cm spacing, 0.5 t/ha more with low inputs and almost 1 t/ha more with high inputs.

There was also considerable emphasis on chemical fertilizer applications, recommending different schedules with less in the early growth stages and more in the latter. Irrigation was reduced, maintaining moisture at 30 days after heading. Finally, timely harvesting was emphasized, showing that the percent of milled rice declines beyond a certain maturation, as do taste-meter scores. The large fields shown in the pictures from Heilongjiong were said to resemble the large state-farm fields in DPRK, but the high degree of mechanization was not similar. Huo's presentation reinforced that of Prof. Jin in this and other respects. He referred to a 'three transformations' cultivation model which appeared to be an evolution of the earlier Prof. Jin's 3-S strategy.

Zhejiang Experience with SRI: The first day concluded with a presentation by **Dr. Lin Xianqing**, CNRRI, on evaluations of SRI methods in Zhejiang province. He started with data on **seedling age** which showed 13-day and 18-day seedlings superior in one site (Xiage) – 10 t/ha vs. 8.4 t/ha for 23-day seedlings, 8.2 t/ha for 8-day seedlings, 7.6 t/ha for direct seeding, and 7.1 t/ha for 28-day seedings; and 13-day seedlings best of all in another site (Baite) – 11.3 t/ha vs. 10.5 t/ha for 18-day seedlings, and the other ages less, down to 9 t/ha for direct seeding.

On **spacing**, trials at Xianju showed 9 hills/m^2 (33x33 cm) to give significantly better yield results than 12, 15 or 6 hills/m^2, which spacings were not significantly different from each other. In trials at CNRRI, 16 hills/m^2 (25x25 cm) gave significantly better results over two seasons. Regarding water management, other data showed shallow, wetting and drying (SWD) compared to traditional flooding, to reduce water consumption by 23% while raising overall water use efficiency by 23% and irrigation water efficiency by 60%. CNRRI researchers consider SWD the best alternative to conventional continuous flooding. It involves three shallow periods of irrigation (for transplanting, spraying insecticide and during flowering to booting stage), three wet periods (during tillering, panicle initiation, and during milky to mature grain stage), and one dry period (during late tillering stage for tiller control)

Lin reported some interesting data on the effects of alternative management practices on **soil biota**. Considering different combinations of water management and fertilizer applications, SWD combined with all-organic fertilization gave much higher populations of actinomycetes. These beneficial soil organisms were almost 5 times as numerous under SWD as with continuous flooding and use of chemical fertilizer (Table 11). Use of manure as fertilizer also had positive effects on net photosynthetic rate, stomatal conductance, leaf weight, and leaf area index (Table 12). These same trials found that spacing of 13.5 plants/m^2 gave higher values for all these parameters than either 7.5 or 19.5 plant/m^2.

Other data from trials with two varieties showed that SWD produced a higher **tillering rate** (more effective panicles) with SWD (64.1-69.7% compared to 51.3-53.6% for the flooded control plots). Flag leaf angle was much more favorable for **light interception**: 20.8^o with SWD compared to 88^o with flooding irrigation (Figure 5). SWD also showed benefits in terms of reduced incidence of disease. The index of **sheath blight** infection was only 14% as high in rice grown under SWD compared to neighboring control (CK) plots according to one data set (Table 13).

Lin reported also on the results of trials specifically evaluating physiological differences in rice plants grown with SRI practices compared with conventional practices on control plots, at flowering stage and 20 days after flowering. Net photosynthetic rate and stomatal conductance were significantly greater in SRI plants, as were the leaf weights measured (Table 14). SRI plants had higher LAI at flowering but the difference was not statistically significant, as it was 20 days later (3.29 for SRI vs. 2.09 for controls). An analysis of tillering, comparing SRI and control plants, found that the former had almost twice as many tillers, but also that they had 10% more primary tillers, 70% more secondary tillers, and 230% more tertiary tillers (Table 15). The much larger number of the latter was the result of avoiding transplant shock.

In conclusion, Lin showed pictures of the different operations and report on the cumulative effects of SRI introduction in Zhejiang province since 2005. In this five-year period, the provincial department of agriculture has calculated that SRI methods have been used on 688,000 hectares, with an average yield increase of 1.25 t/ha, amounting to an increase in paddy production of 862,000 tons, with a reduction in water and costs of production. The Governing of Zhejiang province is now personally taking an interest in SRI promotion, so CNRRI anticipates that the spread will be even more rapid in the future.

International Overview: The next morning, presentations started with my review of how SRI was developed in Madagascar and how it has spread around the world during the past ten years, starting with China, where scientists at Nanjing University, CNRRI, CNHRRDC and SAAS have given the lead in SRI validation and support of SRI extension. I showed pictures and results from many countries and discussed the basic principles underlying SRI. The presentation need not be reported here as it did not pertain directly to China or DPRK, and the powerpoint is available on the SRI website.

DPRK Rice Sector and Its Improvement: Jong Nam Ho began the DPRK presentation with a focus on plant breeding, followed by **Ham Thae Son**, who addressed crop cultivation issues in the rice sector. The main season in DPRK for rice-growing is May-September, and mostly rice is monocropped, although there are also rotations with wheat, barley or potato in some areas. Rice is the country's main staple food. Unfortunately, the country has experienced some decline in rice yield largely due to unavailability of high-yielding and disease- and pest-resistant rice varieties, according to Jong. Also farmers have low inputs such as fertilizers and chemicals and frequent natural calamities, including severe high and low temperatures, and flooding and drought. (A review of FAO statistics shows considerable variation in average paddy yield. Average yield in DPRK during the 1990s was above the world average, 4.77 t/ha; however, the range was 2.5 to 7.6 t/ha. For the years 2001-2006, average paddy yield was 3.96 t/ha, whereas in 2007, the yield was 3.77 t/ha.)

Options suggested for increasing rice production included: integrated crop management (which could include SRI), higher inputs, better post-harvest technology, and sustainable farming methods, which would improve soil fertility. But the most urgent need stated in the report was availability of high-yielding rice varieties having resistance/tolerance to biotic and abiotic stresses that would be able to increase rice yield per unit area. Jong reviewed a number of plant breeding initiatives underway or planned in this regard. Work on hybrid rice development has been going on for a few years, including development of three-line varieties.

Ham's presentation on management improvements listed the following constraints that DPRK agronomists must deal with: short growing season for rice cultivation; cold temperatures in spring, and high temperatures and humidity in summer; disease, insect and weed problems; poor soil fertility; and shortage of implements, etc. for rice cultivation. Options suggested to deal with these problems were: variety selection; improvement of seedling raising; reasonable (optimal) planting density and pattern; and proper fertilizer application and water management. (All of these could be compatible with SRI use.)

Preferred varietal characteristics were listed as: over 10 panicles/hill, and more than 150 grains/panicle; grain weight of 30-34 grams/1,000 grains; height of 90-100cm; and erect upper leaves. Most farmers currently transplant at the 6-leaf stage and wash seedling roots before transplanting, which can cause considerable root loss. The modified methods of seedling raising now being promoted by AAS reduce seedling age to the 4-5 leaf stage, and seedlings are raised and planted in soil blocks, which reduces trauma to their roots. In this modified system, the dry weight of seedlings when they are transplanted is reduced from 80-100 grams to 30-60 grams, which is a positive move from an SRI perspective.

AAS researchers have concluded that *earlier transplanting* increases the number of tillers, panicles, and grains per panicle, improves solar radiation for the rice population, and prevents disease. A series of tables on the effects of *inter-row spacing* showed that 25 cm was better than 20 cm or 30 cm in terms of dry weight of plants (g/m^2), the growth rate of plants (g/m^2/day), and number of ripened grains per panicle and per m^2. So their research has confirmed the value of several SRI components already. Research efforts regarding *fertilization* still focus mostly on chemical fertilizater, but the effects of more refined timing of application are being studied. AAS recommendations for *water management* are reducing the total amount applied, with shallow water during the tillering stage, then a dry period at the non-productive tillering stage, and shallow water again after that.

During recent years, rice production has declined because of number of production constraints. These include: limited arable land; changeable and adverse natural climate conditions (critical high and low temperatures, drought and floods, etc.); soils with low fertility; lack of production inputs; weeds, insects, and diseases, especially bacterial blight and blast; lack of rice germplasm to develop better new rice varieties' and insufficient instruments for monitoring and research (need experimental equipment and facilities, etc.).

To address these constraints, it was suggested that limited arable land can be compensated for by increasing yield per unit area or by multiple-cropping. Fertility of soils can be enhanced by putting more organic materials (barnyard manure or compost, crop residues, and green manure) into the soil. Increasing inputs to agriculture (including fertilizer, herbicides, insecticides, fuel and farm machines, etc.) are recommended, as is development new rice varieties with higher yield potential and resistance or tolerance to stresses by combining conventional breeding with advanced techniques, especially biotechnology. There is a desire for collection and application of new rice germplasm through exchange, and for acquisition of more knowledge and experience on rice breeding and cultivation through frequent international workshops, seminars, and training courses, and so on. The improvement of rice cultivation techniques is expected to help DPRK producers to achieve maximum yield.

Some NGOs, including the American Friends Service Committee, have worked with AAS, the Ministry of Agriculture and other DPRK partners to test selected farm-level innovations that can help address some these constraints. In cooperation with KCSWP (Korea Committee with World People), AFSC has worked with the Soil Science Institute of AAS and four cooperative farms to experiment with seedling preparation in plastic trays (widely used in China). Positive results have encouraged the farms to increase rapidly the area using these innovations. However, further adaptation of SRI methods such as transplanting spacing and water management, local scientific experiment need to be established before it can be adopted widely. AFSC is also organizing study trips to China for AAS staff as well as farm

This presentation on the rice sector in DPRK was followed by a report by **Wu Na**, representative for the **American Friends Service Committee** (AFSC) working with China and DPRK. From 1990 to 2000, AFSC involvement with DPRK was mostly in humanitarian assistance, working in cooperation with the Korean Committee for Solidarity with World Peoples (KCSWP). In 2000, recognizing needs and opportunities to support more long-term improvement, the ASFC program shifted to agricultural development, focusing on improving soil fertility and assisting assessments of winter cover crops and forage. Since 2007, there has been direct involvement in improving on-farm production methods, working through KCWSP and with the Ministry of Agriculture and Soil Science Institute of AAS to assist several agricultural cooperatives in the Pyongyang area. This activity has included some trials with SRI, while also supporting institutional development at local and national levels to make longer-term advances in seed breeding and soil fertility.

The approach taken to SRI introduction has been a gradual one, proceeding in several experimental stages, starting with seedling development, then transplanting methods, and then dealing with water management. The process has acquired its own momentum in that once farmers started working with young seedlings, they also reduced their flooding of rice paddies to accommodate the small plants. The guiding concern has been to adapt to each farm's climatic and farming-system conditions. One popular innovation was to introduce plastic trays for raising rice seedlings. This saves both labor and water. After initial trials in 2008, which satisfied farmers that there could be some merit in the proposed changes in practice, in 2009 there were 250 hectares of SRI practice on four cooperative farms.

This past year, farmers were particularly interested in evaluating for themselves the effects of different spacings and conducted various trials. They are now satisfied that wider spacing is indeed beneficial.

Seedling age for SRI in DPRK needs to be adjusted because of the colder climate, although so far, farmers have not been willing to go in for really young seedlings. Even so, comparing two varieties, they found that just reducing the age at transplanting from 45 days to 36 days, with Pyong Do 11 variety, farmers could see the number of tillers/m^2 reach 640 vs. 440 with older seedlings; with Pyong Do 15, the comparison was 560 vs. 520. Most important, farmers reported that they could see that (modified) SRI plants were stronger, greener, and less susceptible to pests and diseases.

Wu Na reported that there was considerable excitement among farmers in 2009, contrasting with the skepticism of 2008. For the present year, there is recognition that more scientific experimental design is needed for their on-farm trials, to find the best combination of methods in each location. Wu No invited AAS scientists to work with the cooperative farms to ensure that correct conclusions could be drawn from the trials. More experiments on different transplanting densities need to be done, and farmers are looking into water-saving irrigation alternatives and ways of weed control. They are also exploring ways to increase the biomass that can be provided to the soil to raise its productivity.

That farmers on these cooperatives have demonstrated, at least under their agroecological conditions, that SRI methods can produce better phenotypes with reduced inputs gives impetus to further trials and demonstrations in the DPRK. There is need to determine systematically what *adaptations* should be made in the original SRI methodology, and what if any *limits* there are on the application of SRI ideas and techniques in this country. AFSC has already planned a team visit from DPRK to China and Vietnam later in March, for farmer managers, officials and farmers to see SRI and other innovations for themselves.

Jim Frey, an Agricultural Project Officer for the **Mennonite Central Committee**, reported on the MCC's work with similar cooperatives in DPRK. It also started with humanitarian assistance in the 1990s, but its program has shifted increasingly to conservation agriculture. A memorandum of understanding (MOU) was signed in April 2009 with the Ministry of Agriculture, after a year of discussion, to work with the Ministry and three cooperatives on sustainable agriculture innovations. The three cooperatives operate almost 3,000 ha, and all grow rice (one has 80% of its arable area in rice production).

These farms share with most others the problem of low soil fertility. Soils in area are generally eroded, highly acidic, and low in organic matter (soil carbon). Some of the causes for this are excessive tillage, excessive fertilizer applications, and continual removal of plant matter from the fields without return. With soil building as a goal, the collaborative project seeks to:

- Reduce tillage -- through conservation agriculture: stopping or reducing ploughing, maintaining soil cover, and introduction of no-till seeders that minimize soil disturbance and ease labor constraints
- Improve soil fertility -- by using green manures (a mixture of hairy vetch and rye seed is being evaluated) plus timely (slow) release of nutrients in the soil, and
- Increase plant residues left on field -- for better retention of moisture and nutrients and to improve soil ecology.

All of these practices are basically compatible with SRI and MCC sees some opportunities to utilize these methods for the benefit of the cooperatives it is working with. First, rice is an important crop on project farms, and using fewer plants/m^2 means using less seed. SRI is in line with overall project goals of managing and improving soil fertility. The big concern is whether or not the methods will be judged too labor-demanding. It was noted that in China, SRI is commonly views as labor-saving, but there will be more labor required per hectare while the methods are being learned. If the results are very attractive, or if SRI can be quickly made labor-saving, this hurdle should be manageable. Capacity building through training and other sharing of knowledge and skills is a major part of the project. MCC also engages in relationship building, people to people, and the farmer-to-farmer approach widely used for SRI is quite congenial.

FOLLOW-UP: This presentation by Jim Frey concluded the morning's session, and after lunch, there was a whole-group discussion of possible next steps. All specifics will need to be further discussed and negotiated among the respective organizations and with relevant authorities, so this report will not try to summarize the discussion in any detail. It can be reported that there was interest expressed in further joint work on SRI and related approaches that can more beneficially utilize available land, water, labor and capital resources.

The DPRK team considered that perhaps the best next step would be for a delegation of DPRK scientists, officials, farm managers and farmers to visit China and/or other countries like Vietnam during a growing season (not much rice was being grown in China in early March). The visits to China and Vietnam that have already been planned by the AFSC for later March could help to get this process started. MCC will also be assisting its collaborative partners in DPRK to do SRI evaluations in the coming season, having already laid the groundwork for trials and demonstrations.

The Asia Foundation has some limitations on what it can finance, not being a donor agency but rather a facilitator of scientific and cultural exchange as well as leadership and institutional development. But Ed Reed said that the Foundation would want to be supportive of further learning and application on SRI. That evening, the Director-General of CNRRI, Dr. Cheng Shihua, hosted a workshop closing dinner and reiterated the statements of Dr. Zhu that CNRRI will be glad to continue cooperation with counterparts in DPRK on rice development, and specifically on SRI, for which the Institute has given leadership in China. CIIFAD's Sustainable Rice Systems program, which I represented, will continue to support SRI interests and initiatives in DPRK with information as it has been doing with other countries around the world and can facilitate visits and exchanges.

All participants expressed satisfaction with the foundation of information and mutual good will that was strengthened during the two days of workshop session. On Tuesday, March 2, workshop participants visited the CNRRI center an hour's drive from Hangzhou, to meet with some of the staff and to see the facilities. CNRRI hosted workshop participants at a splendid lunch in a restaurant near to CNRRI, and in the afternoon, there was sightseeing, particularly around the justifiably renowned West Lake, giving participants an opportunity to see something of Hangzhou beyond the hotel and for informal interactions. There was a less formal but no less fine 'final dinner' that evening at the hotel, and participants returned to their respective homes the next day.

ANNEX

Table 1: Nitrogen application and productivity in various regions internationally

Region	China	Europe	World
Nitrogen application (kg N/ha)	180	120	100
Yield (kg rice/ha)	6.4	7.0	3.5
Productivity of N fertilizer (kg rice/kg N)	35	58	35

Table 2: Effects of plant density on yield and its components for hybrid rice (Yueyou 938), Xianju

Plant density (hill/m^2)	Panicles (no./m^2)	Ratio of panicle (%)	Grain number/ Panicle	Fertility (%)	1000 grain weight (g)	Yield (t/ha)
15	208.4	51.5	173.1	93.9	26.6	8.95b
12	232.4	60.8	161.5	92.8	26.7	9.06b
9	248.9	69.2	157.5	90.9	25.7	9.79a
6	202.4	59.2	173.0	91.6	25.9	8.86b

Table 3: Comparison of yield and its components in different water management regimes

Variety	Irrigation method	Panicles (no/m^2)	Grain number/ panicle	1000-grain weight (g)	Yield (t/ha)
V1	Flooding	222	154.9	26.6	9.15
	Intermittent	216	163.6	26.3	10.09
V2	Flooding	234	141.5	25.5	8.40
	Intermittent	223.5	166.6	24.6	8.69

Table 4: Relationship between seedling age and yield and its components of hybrid rice (Yueyou938) after green manure applications in Xianju, Zhejiang

Seedling age (days)	Grain yield (t/ha)	Grains (1000/m^2)	%	1000 grain weight (g)	%
0	8.78	35.6	100	25.4	100
8	8.53	36.1	101	26.2	103
13	9.47	44.0	124	25.6	101
18	9.09	43.8	123	25.4	100
23	8.71	37.5	105	25.8	102
28	8.34	36.5	103	26.3	104

Table 5: Yield response to different planting patterns in rice in Sichuan province

Transplanting pattern	Yield (t/ha)	Compared to CK	
		Increase in t/ha	Increase in %
CK	8.65	--	--
Original SRI	10.42	1.77	20.4
Oblong and triangle SRI	13.39	4.74	54.8

Table 6: Leaf blade size (cm) in response to SRI

Planting pattern	3rd leaf		2nd leaf		Flag leaf		Average	
	Length	Width	Length	Width	Length	Width	Length	Width
SRI	64.25	1.57	71.32	1.87	57.67	2.17	64.41	1.87
CK	56.07	1.43	62.03	1.57	48.67	2.01	55.56	1.67

Table 7: SRI extension and results in Sichuan Province, 2004-08

Year	2004	2005	2006	2007	2008	2009
SRI area (ha)	1,120	7,290	57,500	116,667	204,000	251,333
SRI yield (t/ha)	9.10	9.44	8.82*	8.99	9.41	9.11
Conv. yield (t/ha)	NA	NA	NA	7.5	7.71	7.62
SRI increment (t/ha)	NA	NA	NA	1,489	1,698	1,492
SRI increase in yield (%)				19.8	22.0	19.5
SRI added net income/ha (RMB)				1,574	1,956	NA

* Drought year
Source: Provincial Department of Agriculture; combining tables from Dr. Zheng and Dr. Ma

Table 8: Comparison of yield and its components under different kinds of fertilizer

Treatments	No. of effective panicles $\times 10^4$/ha	Spikelets /panicle	No. of filled grains/ panicle	Seed setting rate %	1000-grain weight (g)	Grain yield t/ha	Yield increase± %
Blank (CK)	117.82	228.23	178.27	78.12	22.44	5.00c	-
Organic fertilizer	171.44	212.19	161.20	76.00	23.08	7.41b	+48.2
Chemical fertilizer	170.34	242.80	192.70	79.37	22.72	7.66b	+53.2
1/2 organic +1/2 chemical fertilizer	168.41	246.31	196.12	79.62	22.81	7.59b	+51.8
Organic compound fertilizer	166.21	249.85	195.10	78.09	23.30	7.69b	+53.8
Organic + chemical + microbial activity fertilizer	182.46	260.99	199.00	76.25	22.39	8.81a	+76.2

Variety：2480/881

Table 9: Effect of SRI practices on rice quality

Treatments	Length/width	Percentage of chalky kernel (%)	Chalkiness (%)	Brown rice (%)	Milled rice (%)	Head milled rice (%)
A	2.89a	32.47c	4.04c	83.70a	73.22b	50.17c
B	2.81a	30.05d	3.17d	83.71a	74.00a	53.26b
C	2.79a	23.62e	1.02e	84.48a	72.87b	61.2a
D	2.77a	41.07a	7.17a	82.32b	68.38d	47.99d
E	2.77a	39.89b	6.74b	83.66a	69.98c	46.65e

Variety : Xieyou 527

A , B, C = SRI with ***planting densities*** of 45,000/ha, 90,000/ha and 135,000/ha, respectively

D, E = Conventional cultivation with ***planting densities*** of 90,000/ha and 180,000/ha respectively

Table 10: Grain yield and its components under different seedling ages and spacing

Treatments		Effective panicles ($\times 10^4$/ha)	Spikelets Per panicle	1000-grain weight (g)	Seed setting (%)	Yield (kg/ha)
A1	B1	207Aa	175Bc	28.2ABCbc	77.8Bd	10,168Bb
	B2	**177Cc**	**212ABa**	**30.4ABab**	**85.0ABabc**	**11,889Aa**
	B3	155Dd	220ABa	29.9Aa	85.6Aab	9,606BCb
A2	B1	197Bb	182ABbc	28.5BCc	80.5ABbcd	9,920BCb
	B2	**156Dd**	**205ABabc**	**29.4ABCabc**	**86.8ABabc**	**9,935BCb**
	B3	133Ee	216Aa	28.5ABCabc	88.6Aab	8,464Dd
A3	B1	176Cc	181Bc	27.4Cc	82.4ABcd	9,151Dd
	B2	**133Ee**	**214ABab**	**28.4ABCbc**	**88.0ABabc**	**9,448CDc**
	B3	113Ff	206ABab	29.1ABCbc	86.6Aa	6,927Ee
CK		159Dd	156Dd	26.5CDc	66.5Ce	7,347Ef

A1, A2, A3= transplanting seedlings with 2, 5, 8 leaves, respectively.
B1, B2, B3= triangular SRI with spacing of 30×30 cm, 40×40 cm, 50×50 cm, respectively.
CK = Conventional cultivation , transplant seedlings with 8 leaves, spacing16.7×33.3 cm

Table 11: Number of actinomycetes under different fertilizer and water management regimes

Treatment	Number (10^6)	Treatment	Number (10^6)
I1-F1	66.3 c	I2-F1	52.3 b
I1-F2	119.7 b	I2-F2	84.4 a
I1-F3	259.6 a	I2-F3	93.3 a

I1 = SWD   I2 = CK
F1 = Chemical fertilizer
F2 = 50% organic, 50% chemical fertilizer
F3 = All organic fertilizer

Table 12: Physiological characteristics of rice leaves at flowering stage as influenced by manure and density

	Net photo-synthetic rate (µmol CO_2 m^{-2} s^{-1})	Stomatal conductance (mol H_2O m^{-2} s^{-1})	Specific leaf weight (g m^{-2})	Leaf area index (LAI)	Leaf dry weight (DW) (g $plant^{-1}$)
Manure					
No manure	22.19±1.54	1.37±0.11	40.97±4.75	6.34±0.78	1.01±0.11
15 t ha^{-1} manure	25.67±1.35	1.47±0.25	46.49±3.79	7.01±0.76	1.13±0.06
Density					
7.5 hills/m^2	23.29±2.28	1.45±0.21	42.26±4.77	5.73±0.49	1.04±0.10
13.5 hills/m^2	25.46±2.08	1.46±0.19	45.90±5.06	6.99±0.32	1.12±0.11
19.5 hills/m^2	23.04±2.21	1.35±0.20	43.02±5.80	7.30±0.48	1.06±0.11

Table 13: Effect of SWD on the incidence of sheath blight

Irrigation method	Incidence in hills (%)	Incidence in tillers (%)	Index of sheath blight (%)
SWD	60	9.6	2.1
CK	100	50.7	14.9

Table 14: Physiological characteristics of rice leaves as influenced by SRI

Physiological characteristics	Flowering stage		20 days after flowering	
	SRI	CK	SRI	CK
Net photosynthetic rate ($\mu mol\ CO_2\ m^{-2}\ s^{-1}$)	25.46a	22.18b	15.53a	11.66b
Stomatal conductance ($mol\ H_2O\ m^{-2}\ s^{-1}$)	1.46a	1.29b	0.58	0.52
Specific leaf weight ($g\ m^{-2}$)	45.90a	39.22b	59.44a	53.15b
Leaf Area Index	6.99	6.83	3.29a	2.09b
Leaf dry weight ($g\ plant^{-1}$)	1.12a	0.96b	1.27a	1.11b

Means followed by different letters are significantly different at the P = 0.05 level of confidence according to Duncan's Multiple Range Test.

Table 15: Number and distribution of tillers in SRI and control rice plants

Tiller emergence	SRI		CK	
	Tiller number per plant	Percent of total	Tiller number per plant	Percent of total
1st branch (primary)	7.8	19	7.1	31
2nd branch (secondary)	20.4	50	12.3	53
3rd branch (tertiary)	12.6	31	3.8	16
Total	40.8	100	23.1	100

Figure 1: Grain production and fertilizer consumption in China

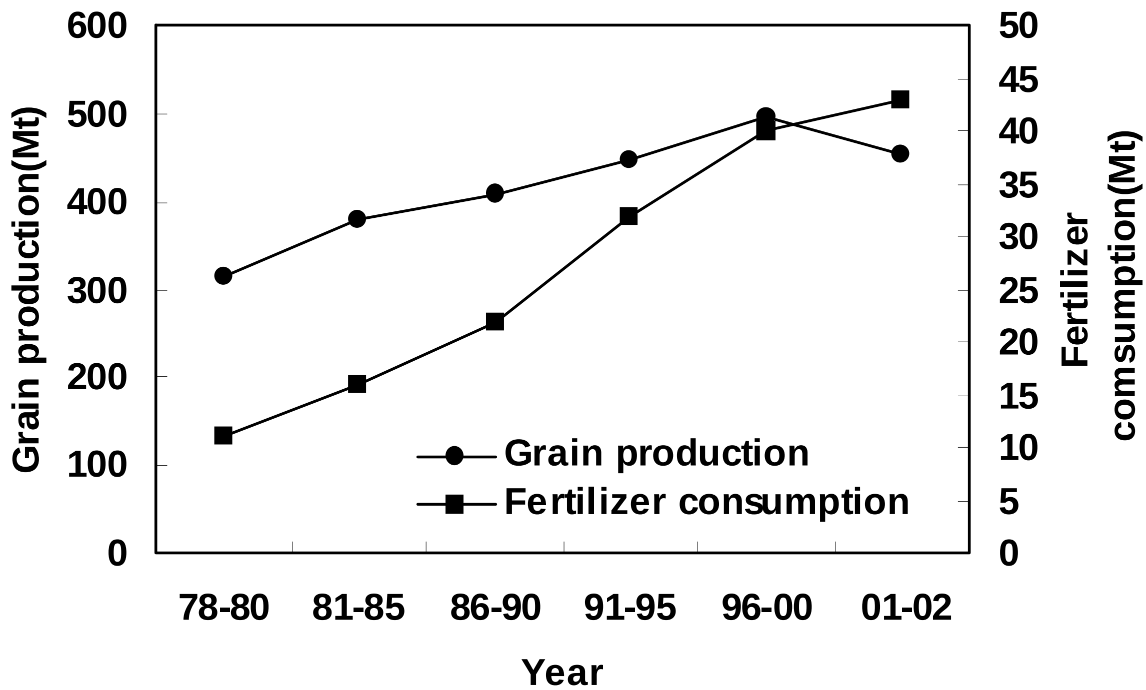


Figure 2: Dynamic change of leaf area index (LAI) in response to management practices

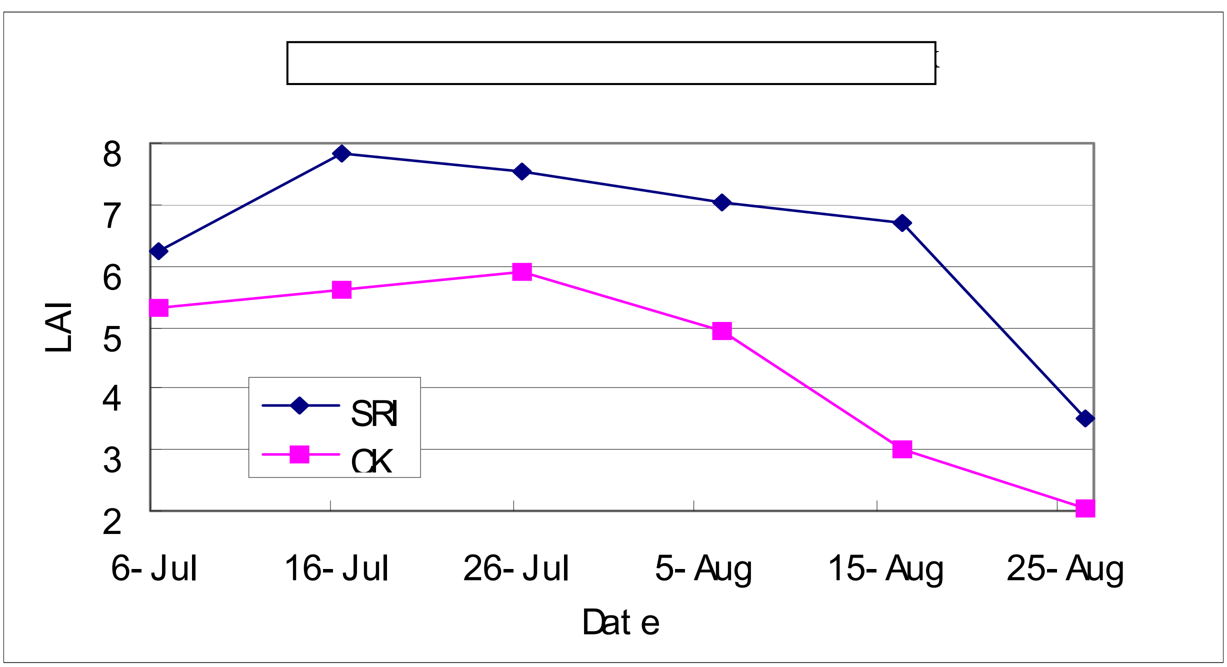


Figure 3: Yield (kg/mu) from seedlings at different stages of growth, from 3 to 7 leaf stage

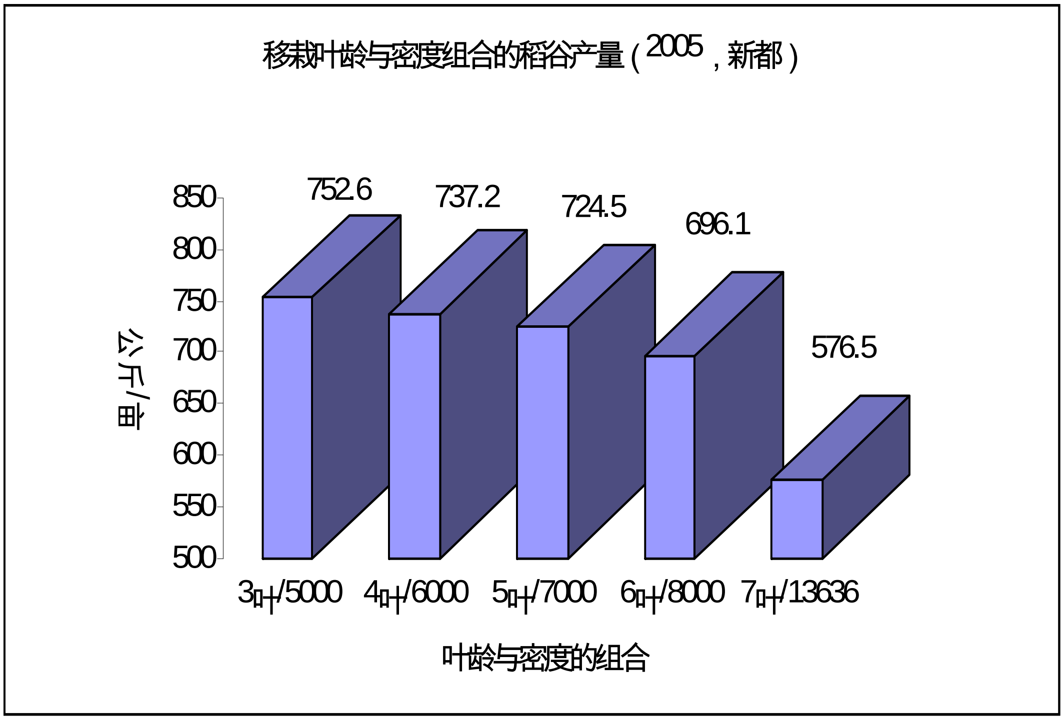
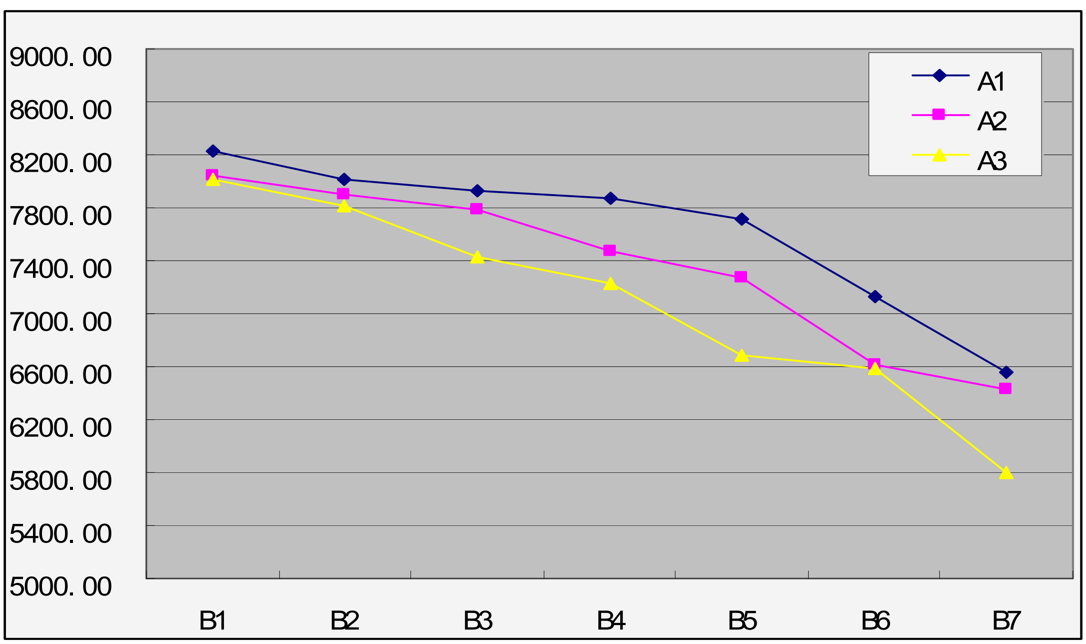


Figure 4: Effects on yield of different sowing densities and seedling age at transplanting



A_1, A_2, A_3: **sowing densities** of seed sown on nursery bed at 10, 15, 20 grams/m^2, respectively
B1 to B7: **seedling age at transplanting** of 40, 46, 52, 58, 64, 70, 76 days, respectively
Y axis on left shows **Yield in t/ha**

Figure 5: Effect of SWD irrigation management on canopy light transmittance rate for two varieties at different plant heights (A = SWD; T = CK)

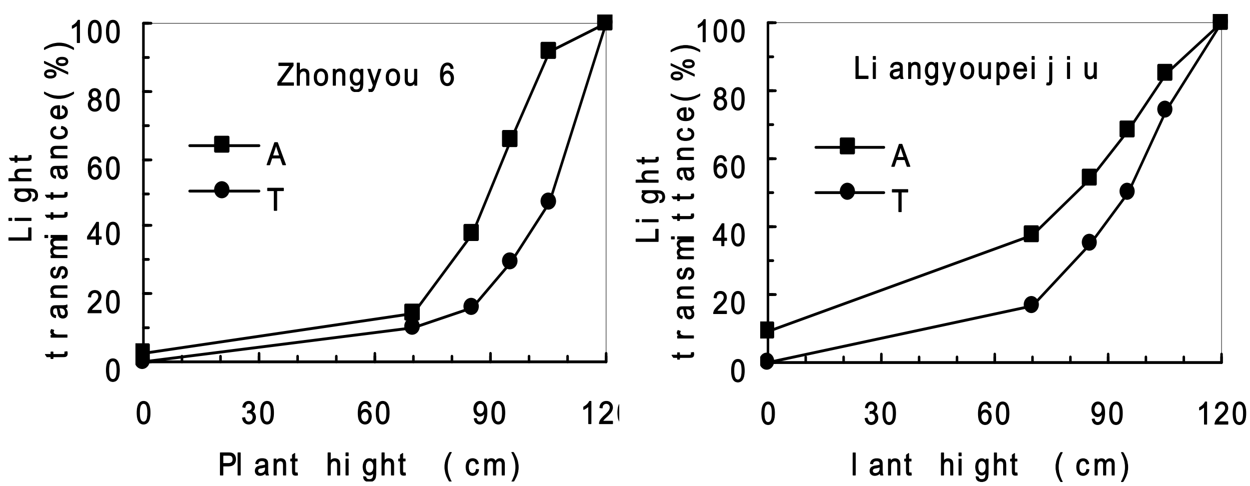


Figure 6: Diagram of 'Triangular' planting method with SRI