Rice Culture in Asia

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Korean National Committee on Irrigation and Drainage
International Commission on Irrigation and Drainage

Rice Culture in Asia

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Preface

In front of you is the publication on "Rice Culture in Asia" as prepared by an editorial committee under the capable chairmanship of our Vice President Prof. Dr. Soon-Kuk Kwun, with contributions of many authors. The initiative for this publication was taken by the Asian Regional Working Group of the International Commission on Irrigation and Drainage (ICID) at its 6th meeting in 2000, Cape Town, South Africa. The initiative was adopted by the Korean National Committee (KCID).

On the Asian continent by far the majority of rice is produced and consumed. The experience and know how as available in this continent is the basis for the future of the production of this important staple crop and the role of irrigation and drainage with respect to this specific type of cultivation. That underlines the importance of this publication, which gives a clear and comprehensive overview by its historic setting, its integrated approach, its future outlook and its specific country reports.

ICID is a scientific and technical non-governmental international organisation. The objectives of the Commission are to stimulate and promote the development and application of irrigation, drainage, flood control, river training and environmental management in all their technical, economic, social and environmental aspects, as well as the needed research leading to the use of modern techniques. In his strategy theme presentation during the meeting in Oxford, Great Britain, 1997, Vice President Hon. Prof. Luis Pereira draw the attention for the fact that although irrigation for rice cultivation was by far the largest application of irrigation, ICID had paid so far relatively limited attention to this subject. With this publication an important step forward has been made.

I therefore like to congratulate wholeheartedly the Asian Regional Working Group and KCID with the result of their initiative and Prof. Soon-Kuk Kwun and his team with the result. I wish the readers that they may find in this publication the information that they can effectively apply in their own practice. All in all I sincerely hope that this publication will contribute to an improvement and extension of rice cultivation, especially in the Asian continent, where this will be very much needed in light of the increasing population and rapidly rising standard of living.

Bart Schultz

Prof. Dr. Bart Schultz
President
ICID

Preface

Rice is a staple food for Asian people, especially in East and Southeast Asia, and has a long history of cultivation for more than 10,000 years. Rice culture is the basis for Asian civilization, and much efforts have been made to achieve “green revolution” in many Asian countries during the past three decades. However, there have been few publications incorporating different experiences of various countries.

Korean National Committee on Irrigation and Drainage publishes this book for the commemoration of the 52nd International Executive Council Meeting and the 1st Asian Regional Conference of International Commission on Irrigation and Drainage (ICID) held in Seoul from 16th to 21st September 2001, following the recommendation of Asian Regional Working Group of ICID.

It is noticeable that rice-based Asian agriculture is celebrated with publishing of “Rice Culture in Asia” on the occasion of the 1st Asian Regional Conference after division from Afro-Asian Regional Conference because of their different cropping patterns between Asia and Africa.

Rice keeps human existence by the provision of foods, and paddy field has multifarious functions such as flood protection, prevention of soil erosion, groundwater recharge, and water purification etc. for better environment of globe.

Special rice culture in China, India, Nepal and Thailand are described, and Country Reports from China, India, Indonesia, Japan, Malaysia, Myanmar, the Philippines and Thailand are included in this book. Therefore, readers will enjoy different technologies and experiences on rice culture of Asia.

Finally, I deeply appreciate the authors and editors for their great contribution to this publication.

Huh, YooMan, Ph.D.
Chairman
KCID

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Soon-Kuk Kwun
Chairman of Editorial Committee
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1 Introduction

Mun-Hue Heu

Origin and diffusion of rice culture

Progenitor Rice belongs to the genus *Oryza*. Twenty-two species in the genus *Oryza* are described by Vaughan (Vaughan, D.A. 1994). Among these only *O. glaberrima* and *O. sativa* are cultivated; the rest are regarded as wild rice, some of which are utilized as human diet. *O. glaberrima* was derived from the wild-type *O. breviligulata* and *O. sativa* from *O. rufipogon. O. glaberrima* is cultivated only in areas along Niger river, and *O. breviligulata* is also confined to these areas. On the otherhand, *O. sativa* is widely spread between 53°N and 35°S latitude. Even though the two cultivated species show little morphological differences, their hybrids are highly sterile (Oka 1988).

The wild progenitor of *O. glaberrima* is *O. breviligulata* (or *O. barthii*). These species produce fertile hybrid population in the field. They have an annual growth habit and have similar botanical characteristics (Chang 1976).

O. rufipogon is distributed from Assam to China and Indonesia and varies between perennial and annual types, which differ markedly in life-history traits. Generally the perennial type have a higher out-crossing rate and lower seed production than the annual types. All IRRI' *O. rufipogon* collections are crossable with *O. sativa* and showed continuous variation from annual to perennial. Investigators suggest that several intermediate perennial-annual populations, which are regenerated by both ratoon and seeds, are most likely to be the immediate progenitors of cultivated rice because they have a high evolutionary potential (Oka 1988).

Domestication and diffusion of cultivation Domesticated plants differ from wild ones in life history traits as photo-sensitivity, seed spreading, and seed dormancy. Harvesting and seeding by man have caused selection for domesticated types. The genetic diversity of *O. sativa* cultivars is most prevalent in the area extending over Assam, Bangladesh, Burma, Thailand, Laos, and Ynnan China. Chang (1976) and Oka (1988) seems inclined to assume the rice domestication as the diffused process at the area in both space and time.

Where and when the common rice, *O. sativa,* was domesticated is yet unknown. De Candolle (1882) postulated that the first rice culture occurred in China, where the earliest historical records were discovered. Vavilov (1951) considered that the rice domestication occurred in India based on the rice genetic variations and the close interaction between wild and cultivar types (Oka 1988).

Recent archaeological excavations provide some clues to approach plausible assumptions. Rice remains, which were carbon-dated 6,570±210 B.C., were excavated at the neolithic culture sites at Mahagara, Uttar Pradesh India,. These findings indicate that rice was domesticated in northern India about 8,000 BP. In Thailand, the Sprit Cave and Non-Nok-Tah are also known as neolithic sites related to the rice remains of 8,000 BP. (Oka 1988). In China, several neolithic sites, where rice remains older than 10,000 aBP were excavated, have been reported in the northern Hunan province along Jiangjang River. Zhang states that, in China, the rice domestication started at the Nanring area at around 10,000~12,000 aBP and spread towards north and south evolving to the typical japonica and indica rice respectively (Zhang 2000). The archaeological findings show the rice culture spread over the Yangtze river basin in China by 5000 B.C., to the Han river estuary in Korea by 2000 B.C., and reached the north-western Japan by 300 B.C. (Im 2000). Diffusion of rice cultivation is estimated at approximately second millennium B.C. in Philippines and about 1500 B.C. in Indonesia. In Sri Lanka rice was the major crop as early as 1000 B.C. (Im 2000).

Differentiation between indica and japonica *Oryza sativa* has differentiated into two cultivar groups, indica and japonica, and show differences in many characters, but there are some overlapping variations between them. There is a common misbelief that indicas have long slender grains and japonicas short or round ones. Possibility of wrongly distinguishing the rice cultivars based on the ratio of length/width of grains is estimated at up to 39% (Oka 1988).

The dynamics of indica-japonica differentiation remain unknown. According to Oka the population of wild progenitors such as *O. rufipogon* are not differentiated into the indica and japonica types, but showed latent tendency to be differentiated, particularly in Chinese genotypes. In general, perennial type shows japonica genotype and annual related to indica genotype.

Glaszman (1987) examined 1688 native cultivars from different Asian countries for allelic frequencies at 15 isozyme loci and analyzed the data through a multivariate technique. The results showed that 95% of the cultivars were divided into six groups. When the six groups were compared with the varietal groups classified by morphological characteristics, group I corresponded to the indica and group VI to the japonica type.

Differentiation within indica and japonica groups Cultivars are developed into different ecotypes based on the environments where the rice is cultivated such as geographical localities, temperature of seasons, and cultural managements. For instance, in Bangladesh, seven indica ecotypes are classified as follows:

Boro Winter rice, transplanted, cold tolerant, and grown December to May.
Aus Summer rice, broadcast or transplanted, grown April to August.
Broadcast Aman Autumn rice, broadcasted, grown April to December.
Transplanted Aman Autumn rice, transplanted, photoperiod sensitive, grown July to December.
Rayada Deepwater rice, long duration, broadcast sown in mixture with Aus. grown March to December.
Ashina Deepwater Aus, broadcast, grown April to September
Hill rice Upland fields, usually sloping hillsides, direct seeded, grown June to September.

Japonica varieties are distributed over a wide range of latitudes and divided into temperate-japonica and tropical-japonica. The name javanica was used for the tropical-japonica in the past, but at present more people are inclined to use tropical-japonica due to its precise meaning.

Production and consumption of rice in Asia

Production World rice production ranged from 517.4 to 527.4 million tons during 1989-93. The major rice producing countries are China, India, Indonesia, Bangladesh, Thailand, Vietnam, Myanmar, and Japan. They produce over 10 million metric tons of rough rice, which accounts for nearly 84% of world rice production and 92% of Asian production. Asia as a whole contributes about 92% of the world's rice harvest (IRRI 1995, 1997).

The rice area harvested during the same period was about 148.4 million ha, 89% of them in Asia. The yield of rough rice varies drastically from country to country mainly due to the irrigation facilities. Improved irrigation is vital in increasing the yield. Most rice-cultivating area in Pakistan and Japan are irrigated. In Indonesia, the Republic Korea, the Philippines, and Vietnam, more than 50% of the rice cultivating area has irrigation facilities. In Myanmar, Thailand, and Bangladesh, less than 30% of total rice area is irrigated (IRRI 1995, 1997).

Rice ecosystem IRRI has shown the rice ecosystem distribution of rice growing countries. The rice ecosystem is classified mainly by the water regime of rice field. They are: 1) Irrigated rice, 2) Rain-fed lowland rice, 3) Flood prone rice and 4) Upland rice. IRRI survey shows that, 53% of total rice area worldwide is irrigated, 27% is rain-fed lowland, 8% flood prone, and 12% upland. Most irrigated rice areas are found in Asia (55%), while the least irrigated rice areas are in Africa (17%). Rain-fed lowland rice is highest in Asia (29 %) and lowest in Latin America. Most rice area in Latin America are upland (IRRI 1997) (Table 1.1).

Consumption

Most Asian countries rely almost entirely on domestic production to feed their populations. IRRI statistics show that there are wide variations in milled rice consumption in terms of kg/capita. The highest, Myanmar consumes 195 kg/capita/per year, followed by Bangladesh at 143 kg, Indonesia 136 kg, Thailand 130 kg, China 91 kg, Philippines 87 kg, India 70 kg, and Japan 60 kg. The ratio of calories provided by rice varies from 31% in India to 77% in Myanmar. As in China and India the largest rice production country is not necessarily the one with high dependency on rice for diet. Rice is the staple food for about 59% of the world population. Globally 23% of the total calories come from rice. Only 4~5% of global rice production was traded each year from 1980 to 1995 (IRRI 1995).

In Laos and northeast Thailand, glutinous rice is the staple food. In other cultures it is prepared in special forms of food for religious or ceremonial occasions. Alcoholic beverages made from rice can be found throughout the rice growing areas.

Table 1.1 Distribution of rice ecosystem

Country	Total rice area (1,000 ha)	Percentage			
		Irrigated	Rain-fed	Flood prone	Upland
Asia	132,240	55	29	8	8
Bangladesh	10,245	22	47	23	8
Cambodia	1,910	8	48	42	2
China	33,019	93	5	-	2
India	42,308	45	33	7	15
Indonesia	10,282	72	7	10	11
Japan	2,049	99	-	-	1
Korea (PDR)	1,200	67	20	-	13
Korea (REP)	1,208	91	8	-	1
Lao PFR	557	2	61	-	37
Malaysia	691	66	21	1	12
Myanmar	4,575	18	52	24	6
Nepal	1,412	23	66	8	3
Pakistan	2,097	100	-	-	-
Philippines	3,425	61	5	2	2
Sri Lanka	791	37	53	3	7
Thailand	9,271	7	86	7	1
Vietnam	6,303	53	28	11	8
Latin America	6,299	33	7	2	59
Africa	7,034	17	21	20	42
Australia	89	100	-	-	-
USA	1,123	100	-	-	-
Rest of World	1,031	88	-	-	12
World	147,816	53	27	8	12

Socio-economic importance

As a stable food According to the IRRI statistics, rice provides 23% of global human per capita energy and 16% of per capita proteins. The rice endosperm is highly digestive and nutritious though the protein content is relatively low. Rice also provides minerals, vitamins, and fiber. For the majority of Asians who eat rice, the grain accounts for a remarkably high proportion of total caloric intake. By 1992, caloric intake in Asia was 2,531 calories /person per day with 35% coming from rice based on a per capita consump - tion of 85 kg /yr (IRRI 1995).

Most rice is consumed in polished form. Although significant amount of nutrient losses occur during polishing, brown rice cooking is nevertheless unpopular because of the inferior palatability and digestive disturbances. Parboiling rough rice before milling is practiced to minimize the nutritional losses due to milling and improve the palatability when cooked. In some areas of Thai and Laos, people prefer glutinous rice for daily consumption (Juliano 1985).

Sustaining environment Rice thrives under flood conditions. In monsoon areas rice cultures are most adaptive to control floods particularly in the hilly areas with stairy paddy fields, compared with other crops. In the hilly area bunded paddies function as small reservoirs, keeping rain water instead of washing away surface soils and run away small rainfall. The evapotranspiration at the rice field during dry season compromises the heating air.

Special use of rice Rice is being consumed in many specialty uses. Glutinous rice and scented rice are used for religious or ceremonial occasions in different cultures. The alcoholic or non-alcoholic fermentative beverages made of rice are found throughout the rice-producing areas (Juliano 1985). Preference for rice food products such as puffed rice, cakes, and snacks are increasing. Industrial processing of the rice hull, rice bran, rice germ, and rice flour is also growing.

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2 Rice Production and Consumption

Kwang Ho Kim

2.1 Trend in rice production

World rice harvest areas ranged from 152.0 to 157.2 million hectares during the 1998-2000 period, while it was 115.5 million hectares in 1961 (Table 2.1). Almost 90% of these areas are in Asia. India has the largest rice harvest area amounting to 44.6 million hectares during 1998-2000 (Table 2.2). China ranks second with 30.5 to 31.6 million hectares, followed by Indonesia, Bangladesh, and Thailand.

During the last four decades, rice harvest area has significantly increased in Africa and Oceania. Asia, the homeland and the largest rice grower, on the other hand, did not show the notable increasing trend of rice harvest area during the last two decades. Additional land that could be used for harvesting rice has become scarce, so most rice-producing countries have shifted from expanding crop areas to increasing yield as a way of maintaining growth in domestic rice production.

Table 2.1 World rice harvested area and production

Year	World	Asia	Africa	Europe*	N & C America	South America	Oceania
				Harvested area, 1,000 ha			
1961	115,501	106,958	2,913	448	1,238	3,911	34
1971	134,808	122,774	4,134	786	1,375	5,688	41
1981	145,796	129,844	5,057	981	2,298	7,498	118
1991	147,816	132,240	7,034	1,017	1,763	5,659	102
1999	157,176	140,555	7,872	594	2,060	5,964	130
2000	154,996	138,783	7,721	613	1,976	5,749	155
				Production, 1,000 tons			
1961	215,678	198,802	4,318	1,845	3,435	7,136	143
1971	317,877	292,286	7,414	3,138	5,344	9,371	324
1981	411,791	374,311	8,570	4,086	10,633	13,401	790
1991	517,410	474,130	13,721	4,291	9,153	15,344	770
1999	606,656	551,275	16,167	3,178	11,489	21,897	1,106
2000	597,155	597,155	17,711	3,077	11,055	20,435	1,422

(FAO STAT 2001)

* Including former USSR up to 1991

Table 2.2 Rice harvest area, production, and yield per hectare of major rice producing countries

Country	1998			1999			2000		
	Area 1,000 ha	Product 1,000 tons	Yield kg/ha	Area 1,000 ha	Product 1,000 tons	Yield kg/ha	Area 1,000 ha	Product 1,000 tons	Yield kg/ha
India	44,598	128,928	2,891	44,607	132,300	2,966	44,600	134,150	3,008
China	31,572	200,572	6,353	31,637	200,346	6,333	30,503	190,111	6,233
Indonesia	11,716	49,200	4,199	11,963	50,866	4,252	11,523	51,000	4,426
Bangladesh	10,113	29,708	2,938	11,700	34,000	2,906	12,000	34,925	2,910
Thailand	9,900	22,784	2,302	10,080	23,313	2,313	10,048	23,403	2,329
Vietnam	7,362	29,145	3,959	7,648	31,394	4,105	7,650	32,000	4,183
Myanmar	5,458	17,075	3,128	5,800	19,887	3,429	6,000	20,000	3,333
Korea, Rep	1,056	6,779	6,417	1,059	7,271	6,868	1,072	7,067	6,592
Others	14,829	47,076	-	16,061	51,898	-	15,387	51,081	-
Asia total	136,604	531,267	3,889	140,555	551,275	3,922	138,783	543,737	3,918
World	151,998	578,768	3,808	157,176	606,656	3,860	154,996	597,155	3,853

(FAO STAT 2001)

Global rice production was 215.7 million tons of rough rice in 1961 and has been increased up to 606.7million tons in 1999, almost tripling over the past 40 years. The annual production growth was about 3% during the last three decades throughout the world. Rice production has been remarkably increased by almost fourfold during the past four decades in Africa, and nearly 10 times in Oceania (Table 2.1).

Asia as a whole contributed about 91% of the world's rice harvest during 1998-2000. The major rice-producing countries are China, India, Indonesia, Bangladesh, Vietnam, Thailand, and Myanmar. These countries account for nearly 81% of world rice production (Table 2.2). In 2000, China contributed about 32% of the total world rice production, while India registered a 22.5% share.

During 1961 to 2000, the production of rough rice in Asia has increased from 198.8 to 597.2 million tons, almost tripling.

However, the recent trend in rice production indicates a rapid deceleration in growth. The annual growth of rice production in Asia was estimated as 3.2% during 1965-1975, 2.8% during 1975-1985, and 1.6% during 1985-1995. China and India, which contributed almost 55% of world rice, show lower growth production rates after mid 1980s, while Bangladesh, Myanmar, and Vietnam still show higher annual growths. Rice production has decreased after 1970 in Japan and after 1990 in Republic of Korea mainly due to the reduction of rice-planting area.

World and Asia average rice yields almost doubled from 1.87 and 1.86 tons per hectare in 1961 to 3.85 and 3.92 tons per hectare in 2000, respectively. China, Japan, and Republic of Korea produced more than 6 tons of rough rice per hectare between 1998 and 2000. Outside of Asia, USA, Australia, Egypt, Greece, and Spain are the rice-producing countries, which yielded higher than 6 tons per hectare. The world's highest yield of rough rice is recorded as 9.54 tons per hectare in Australia, and Republic of Korea is the top ranker of rice yield per hectare in Asia during 1998-2000.

2.2 Trend in rice consumption

Rice is the staple food for about 50% of the world's population. Globally, 23% of the total caloric supply comes from rice, and 57.8 kg of milled rice per capita was consumed in 1994-96 (Table 2.3). In Asian countries, rice supplies 35% of the total calorie intake, and 87.1 kg of milled rice per capita was utilized during 1994-96. Myanmar, Vietnam,

Table 2.3 Trends in milled rice utilization per capita in Asian countries *(unit:kg/yr)*

Country	1964-66	1969-71	1974-76	1979-81	1984-86	1989-91	1994-96
India	64.9	64.7	60.7	64.2	68.2	73.8	79.6
China	69.2	72.4	75.9	81.8	91.9	89.8	91.6
Indonesia	74.7	97.3	104.7	119.8	126.3	137.2	146.3
Bangladesh	154.3	149.3	132.2	132.4	132.1	139.4	151.4
Thailand	140.6	146.3	146.6	136.3	126.6	125.4	107.5
Vietnam	145.4	148.0	136.3	121.4	143.5	140.5	166.6
Myanmar	131.0	148.4	157.4	173.1	183.6	192.7	214.1
Korea, Rep	102.4	110.8	118.7	123.8	114.5	107.0	95.8
Asia	73.3	75.7	75.6	79.1	84.2	85.1	87.1
World	47.6	49.8	50.5	53.4	57.0	58.0	57.8

(FAO STAT 2001)

Cambodia and Bangladesh were the major rice consumers worldwide. During 1994-96, Myanmar people ranked the highest among the world rice consumers, consuming 214 kg of milled rice per capita per year. Vietnamese and Cambodians consumed 166.6 kg and 162.5 kg of milled rice per capita per year, respectively.

Table 2.4 Rice supply and demand during 1994-96

Region	Domestic supply			Domestic utilization			Calorie supply per day		
	Prod.	Import	Total	Food	Waste	Other	Total	Plant	Rice (%)
	—1,000 tons—						—cal—		
World	367,770	19,700	367,937	325,889	16,768	25,280	2,759	2,324	578 (21.0)
Asia	336,281	9,670	333,397	297,102	14,108	22,187	2,670	2,347	871 (32.6)
Africa	10,020		13,512	11,628	1,010	874	2,387	2,216	166 (7.0)
Europe	1,946		3,125	2,612			3,184	2,270	36 (1.1)
America									
N & S	6,809		5,926	4,628	559	739	3,307	2,504	104 (3.1)
South	12,029		11,569	9,528	1,115	926	2,765	2,205	301 (10.9)
Oceania	685		409	391			2,970	2,077	135 (4.5)

(FAO STAT 2001)

The two big rice producers in the world, China and India consumed near 80 to 90 kg of milled rice per capita per year. The amount of milled rice consumed per capita per year has been increasing during the past 30 years in most Asian countries, but decreasing trend was observed in Japan from late 1960s, in Republic of Korea and Thailand from mid 1980s.

In 1992, Cambodian people obtained 80% of food calorie from rice. More than 70% of food calorie was supplied from rice in Bangladesh, Myanmar and Vietnam, 67% in Lao PDR, 56% in Indonesia, and 31 to 40% in India, China, Republic of Korea, and the Philippines. This means that rice is the most important single calorie source in these countries.

2.3 Trend of international rice trades

Rice has a very thin trade market because only 4% of the rice produced every year is traded in the world market compared with 20% for wheat and 11% for coarse grains. Variable natural disasters such as droughts, floods, typhoon, diseases, insect pests, and high or low temperatures cause shortages and surpluses to occur from year to year, which make the world rice market highly volatile.

World milled rice imports or exports increased fourfold during the last 40 years, from 6.3~6.6 million tons in 1961 to 26.0 million tons in 1999 (Table 2.5). The quantity of rice traded in the world market doubled in 1999 compared with 1991 mainly due to the great increased import demand in Indonesia, Bangladesh, and Philippines, the three big rice importers in the world, whose rice import amounted to 7.8 million tons, 30% of the world's import trade in 1999. Other major rice importers are Iran, Iraq, Saudi Arabia, Malaysia, and Japan in Asia, Brazil in South America, Senegal and South Africa in Africa, and the former USSR.

Table 2.5 World rice imports and exports

Year	World	Asia	Africa	Europe	N & C America	South America	Oceania
			Imports, 1,000 tons				
1961	6,607(100)	4,825(73.0)	531(8.0)	775(11.7)	335(5.1)	74(1.1)	47(0.7)
1971	8,590(100)	5,572(64.9)	970(11.3)	1,007(11.7)	590(6.9)	26(0.3)	92(1.1)
1981	13,886(100)	6,921(49.8)	2,781(20.0)	1,805(13.0)	627(4.5)	321(2.3)	148(1.1)
1991	12,985(100)	4,057(31.2)	3,665(28.2)	2,092(16.1)	1,115(8.0)	1,340(10.3)	304(2.3)
1998	23,608(100)	11,990(50.8)	4,650(19.7)	2,608(11.0)	1,944(8.2)	2,040(8.6)	376(1.6)
1999	26,081(100)	14,483(55.5)	4,768(18.3)	3,090(11.8)	2,058(7.9)	1,312(5.0)	369(1.4)
			Exports, 1,000 tons				
1961	6,309(100)	4,379(69.4)	313(5.0)	397(6.3)	843(13.4)	314(5.0)	63(1.0)
1971	8,664(100)	5,504(63.5)	574(6.6)	559(6.5)	1,490(17.2)	419(4.8)	103(1.2)
1981	13,101(100)	7,929(60.5)	112(0.9)	1,003(7.7)	3,179(24.3)	578(4.4)	284(2.2)
1991	13,154(100)	8,465(64.4)	171(1.3)	1,266(9.6)	2,254(17.1)	552(4.2)	425(3.2)
1998	28,796(100)	21,517(74.7)	464(1.6)	1,413(4.9)	3,164(11.0)	1,688(5.9)	552(1.9)
1999	25,986(100)	19,008(73.1)	328(1.3)	1,494(5.7)	2,702(10.4)	1,785(6.9)	669(2.6)

*Values in parenthesis are yearly percentages to world imports or exports. (FAO STAT 2001)

Thailand, Vietnam, and India exported 13.6 million tons of rice which were more than 50% of the world’s rice export trade during 1997~1999. Thailand has remained the world’s largest rice exporter during the last four decades, and Vietnam has also started to be a major rice exporter from the late 1980’s. India, USA, China, and Pakistan were the major rice exporting countries in the world followed by Thailand and Vietnam during 1990’s.

Changes in rice trade over the 1961-99 period for different regions of the world indicated that Asia’s share of global imports has fallen greatly from 73% in 1961 to 31% in 1991 and increased again to 55.5% in 1999 (Table 2.5). The decreasing trend of Asia’s share of rice imports in world market to 1991 was caused by the self-sufficiency in rice production as a result of green revolution in many Asian countries from 1970’s to 1980’s. But the significant demand increase in Indonesia, Philippines, and Bangladesh during 1990’s forced them to be the major rice importers and increased again Asia’s share of world rice imports after mid 1990’s.

2.4 Prospect of rice supply and demand in Asia

An IRRI’s economist predicted the following for rice supply and demand in Asia. With growing economic prosperity and urbanization, per capita rice consumption has started declining in the middle- and high-income Asian countries. But nearly a fourth of the Asians still have considerable unmet demand for rice. In addition, population is still growing at 1.5 to 2.8% per year in most Asian countries. Asia may not reach the phase of stationary population before the middle of the 21st century.

Rice production must increase by another 270 million tons over the next three decades in order to meet the growing demand. It is a daunting challenge to increase the rice supply of this magnitude, as land, labor, and water are becoming scarce with increasing competition from the fast growing non-farm sectors, and natural resources are already at a risk of degradation. If supply fails to keep pace with the growing demand, rice prices will increase, which, in turn, will have adverse impact on the alleviation of poverty in low-income countries.

Formulation of a strategy for mutual collaboration among Asian nations is needed to curb population growth, strengthen agricultural research, and develop irrigation and marketing infrastructures to reduce demand and exploit the untapped potential for increasing supply. International support is also needed to address the food insecurity problems in those parts of Asia still facing extensive poverty that poses threats to sustaining the natural resource base, and protecting the earth environment.

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3 Environmental Conditions for Rice Culture

Seong-Ho Yun

3.1 Climate and soil conditions during rice culture seasons and paddy fields in Asia

3.1.1 Climatic environment

The optimum climate condition for normal growth and development varies among rice ecotypes and with growth stages. Rice is grown in northeastern China at latitude 53° N, in central Sumatra on the equator, and in New South Wales, Australia, at 35° S. Rice is grown below sea level in Kerala, India, at or near sea level in most rice-growing areas, and at altitudes above 2,000 meters in Kashmir, India, and Nepal. It can be grown under upland and moderately flooded conditions, and in 1.5~5 meters water depth. However, most of the world's rice are grown in the tropics, and thus critical determining factor for growing rice appears to be temperature.

The tropical region comprises the area between the Tropic of Cancer (23° 27′ N) and the Tropic of Capricorn (23° 27′ S). Temperature remains high throughout the year in the tropics. However at high altitudes, even in tropics, the weather is cool. Köppen's definition uses the threshold monthly mean temperature for the coldest month of the year (Trewartha 1968). The monthly mean temperature of 18°C for the coldest month was used as a climatic boundary of the tropics.

The tropics include most rice-growing regions in South and Southeast Asian countries. Although rice is primarily a tropical and subtropical crop, the best harvests are obtained in temperate regions, such as Japan and Korea.

Temperature, solar radiation, and precipitation influence rice yield by directly affecting the physiological processes involved in grain production, and indirectly through diseases and pests. In the temperate regions, irrigated rice cultivation starts when spring temperatures are between 13 and 20°C; the crop is harvested before the temperature drops below 13°C in the autumn. In the tropics where temperature is favorable for rice growth throughout the year and irrigation is not available in most places, cultivation starts with the rainy season. The average dates of the onset and withdrawal of the monsoon are known for particular regions of South Asia. The starting time and duration of rain-fed rice cultivation are largely determined by duration of the monsoon.

In both tropics and temperate regions, the level of incident solar radiation primarily determines rice yield. The dry season crop usually produces higher yield than the wet season crop because it receives more solar energy in the tropics.

Low temperatures during rice crop season cause crop failure. In both 1980 and 1993, cool summer temperatures in Korea and Japan affected the crops. In addition, low solar radiation associated with excessive rainfall during ripening causes low yields. Shortage and termination of rainfall at any growth stage of rice plant can cause partial or total crop failure. In Thailand, more than 15% of the cultivated area totally failed because of either drought or flood for eight years during 1907 to 1965. In 24 of the 58 years, more than 10% of the cropped area was not harvested at all (Israngkura 1966). In both the tropics and temperate Asia, typhoons are also inevitable hazards.

3.1.2 Temperature

The monthly mean air temperatures vary with latitudes, as shown in Figure 3.1. The annual mean temperature decreases, and seasonal variation increases with increasing latitude. The remarkable characteristic of the tropical climate is seasonal uniformity in temperature. At Bangkok, Thailand, for example, monthly mean air temperatures range from 26.1°C in December to 30.5°C in April, a difference of 4.4°C. Important characteristics of temperate and tropical climates can be obtained by comparing seasonal variation and diurnal changes in air temperature. In the temperate region, the annual range exceeds the daily range; in the tropics, the daily range is greater than the annual range.

Extreme temperatures are destructive to plant growth and, hence, are used to define the environment under which the life cycle of the rice plant can be completed. The low and high critical temperatures, normally below 20°C and above 30°C, vary depending on growth stages. These critical temperatures differ according to variety, duration of critical temperature, diurnal changes, and physiological status of the plant.

3.1.3 Solar radiation

The average daily solar radiation available during the monsoon in the tropics is 1.5-fold lower than that in the temperate rice cultivation regions (de Wit 1958). However, rain-fed rice in the tropics must be grown when there is low solar energy due to the dependence of crops on precipitation. On the other hand, where irrigation water is available, rice can be grown during the dry season, the yield higher than that during the wet season due to the higher intensity of solar radiation.

In the tropics, the correlation between solar radiations for 45-day period before harvest from panicle initiation to crop maturity and grain yield was highly significant (De Datta and Zarate 1970). This result indicates that the amount of solar radiation received from as early as panicle initiation

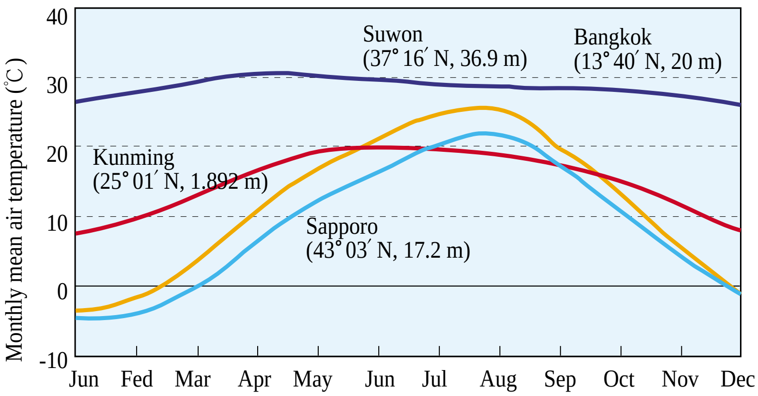

Figure 3.1 Monthly mean air temperatures (1961-90) at four rice cultivation sites of different latitudes and altitudes in Asia

until crop maturationis important for the accumulation of dry matter during this period. Starch accumulates markedly in the grain during the 30-day period following heading (Yoshida and Ahn 1968), and the total period of 40 days before maturity can be considered as the period of grain production.

3.1.4 Precipitation

Most rice cultivation regions in Asia are affected by the monsoon climate. In regions where temperatures are within the critical low and high ranges, precipitation is the most limiting factor in rice cultivation, particularly in rain-fed rice cultures. On the other hand, when irrigation is possible, growth and yield of rice are largely affected by temperature and solar radiation. It is extremely difficult to find a simple relationship between annual precipitation and grain yield, because of the unpredictable variation in frequency and amount of precipitation for a given place over time.

The amount and pattern of precipitation vary widely from one place to another, and from year to year. The precipitation patterns of four Asian rice-growing regions describe the basic distribution patterns (Figure 3.2).

Bangkok, Thailand, has a typical dry and wet monsoon climate. Only one monsoon brings most of the precipitation, and wet season is distinct from the dry. Rain-fed rice cultivation starts in May or June and the crop is harvested in November or December. Most rice-growing region in South and Southeast Asia show this type of climate. However, the duration of the rainy season and amount of precipitation vary with location.

Suwon, Korea also shows the typical East Asian temperate monsoon climate. About 60% of precipitation occurs during the Changma (monsoon), from late June to late July with 1,307 mm of annual precipitation. The transplanting rice cultivation has a crop season from May to October.

Kunming, Southern part of China, is located at a high altitude of 1,892 meters and subtropical latitude of 25° 01′ N. It shows a typical East Asian monsoon climate, with an annual precipitation of 1,002 mm. The rice cultivation season is relatively long due to cool summer, showing a monthly mean air temper ature of below 20°C even in the hottest month, July. The duration of rice cultivation is from March to November.

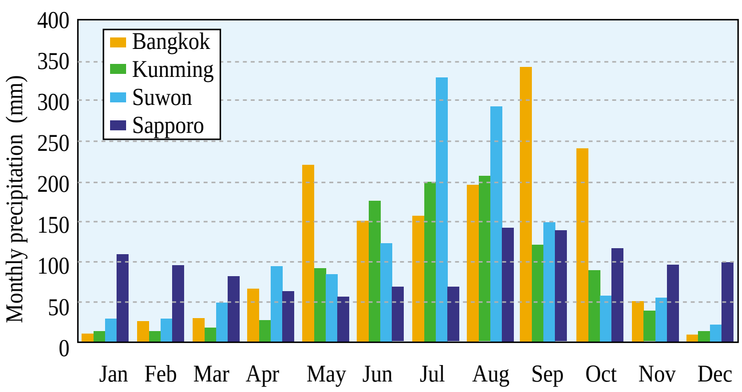

Figure 3.2 Monthly precipitation at four rice-growing places in Asia

Sapporo in Japan represents the northern limit of rice cultivation area in terms of the temperature. There is about 1,130 mm of annual precipitation, which distributed re-latively lower in April, May, June, and July than other months. However, it is enough for earlymaturing rice cultivation.

3.1.5 Topography and soil

Rice can be grown, under appropriate temperature regimes, wherever there is enough water to grow a crop. These not only include low-lying areas in floodplains, coastal plains, and valleys, where often more than enough water is available for maintaining lowland rice and water control must be practiced, but also include the paddy fields on steep and mountainous areas and vast upland areas. Lowland rice fields are formed into paddies that hold water during the land preparation and rice-growing periods. There are a number of rice culture systems, where water regime is variable. Rice is primarily a lowland crop, and its semi-aquatic characteristics is the key to the development of wet lowlands in Asia.

Rice is grown on a variety of soils ranging from waterlogged, poorly drained to well-drained. The terms, rice soil or paddy soil are not precise enough to be used to indicate the types of soil groups. The specific morphology and classification of paddy soils are unique. Most types of soils can be used to grow rice if water conditions are favorable.

Various systems for classifying paddy soils, specific for conditions where rice is grown under temporary surface soil saturation, have been devised. Each rice-growing country has in fact classified its rice soils using either a national or international system. A modern system of soil classification has evolved over the years by the USDA (USDA 1975), and their key profile characteristics are summarized in Table 3.1.

For rice cultivation, soils of fine to medium texture are most commonly used. A study (Kawakuchi & Kyuma 1974) with 410 surface soil samples collected from nine tropical Asian countries suggested that the clayey texture of rice soils results either from the sedimentation process in wide floodplains and deltas or from the basic nature of parent materials in the mountainous regions. Sandy texture is a result of either severe weathering of the materials of acidic rock origin or of direct inheritance from sandy sedimentary mate-

Table 3.1 Soil orders: Comprehensive Classification System (USDA 1975)

Order	Key profile characteristics
Entisols	Recent soils; little or no change from parent material
Inceptisols	Light colored subsoils; weak soil development
Mollisols	Soft, deep, dark soils; high base status of surface horizon
Alfisols	Subsoil horizon of accumulated clay; high base saturation; few or no weatherable minerals
Ultisols	Subsoil horizon of accumulated clay; low base saturation; few or no weatherable minerals
Oxisols	Uniform textured; friable profile high in oxides of iron and aluminum with kaolin clay
Vertisols	Dark soils; high in montmorillonitic clay, prone to shrink and swell; high cation exchange capacity
Aridisols	Mineral soils of dry regions with either calcium carbonate or salt accumulation
Spodosols	Strong brown subsoil underlying a gray to brown surface horizon; strongly acid
Histsols	Soils with more than 30% organic matter to a depth of 40cm

rials. Soil from Sri Lanka is predominantly sandy and contains little silt, whereas surface soil of Bangladesh is generally silty. The sandy nature and low silt content of soil in Sri Lankan are due to the development of residual or local alluvial materials, mostly poorly sorted materials derived from weathered gneissic rocks. The sedimentation process of the Ganges-Brahmapatura Rivers explains the silty nature of Bangladesh soil. Soil samples from Myanmar, Cambodia, India, Indonesia, Malaysia, the Philippines, and Thailand show similar textural Patterns (Kyuma 1978).

Soil pH, before and after flooding paddy fields, is an important determinant in evaluating fertility and management of rice soils. The pH values of lowland rice soils vary greatly from country to country. Examples of the range of pH values of paddy soils in some South and Southeast Asian countries are given in Table 3.2.

Table 3.2 pH of plow layer soils of the paddy fields in selected countries (Kawakuchi 1973)

Country	Mean pH	Standard deviation	Number of samples
Thailand	5.2	0.56	95
Malaysia (West)	4.7	0.57	41
Sri Lanka	5.9	0.84	33
Bangladesh	6.1	0.95	53
India	7.0	1.12	73
Cambodia	5.2	0.76	16
Philippines	6.4	0.87	54
Indonesia (Java)	6.6	0.87	46
Korea	5.4	-	1,038
Japan	5.5	-	1,700

With regard to mineral composition, several types of Indonesian soils contain low silica and high iron, aluminum, and manganese. Soils from Thailand and Cambodia have extremely low phosphorous content, whereas Sri Lankan soil is highly siliceous and low in iron oxide, reflecting its sandy texture. Soil samples from India, Bangladesh, and Myanmar have intermediate levels of minerals (Kyuma 1978).

3.2 Trend of change in climatic conditions and disasters during recent years

3.2.1 Climatic change and rice culture

Climate changes strongly affect agriculture. However, scientists still do not know exactly how. Most agricultural impact studies are based on the results of IPCC SRES scenarios. The global-average surface temperature has been increasing since 1861. Over the 20th century the increase has been 0.6°±0.2°C. These results indicate that the global average surface temperature is projected to increase by 1.4 to 5.8°C over the period 1990 to 2100, raise sea levels, amplify extreme weather events such as typhoon and hot spells, shift climate zones poleward, and reduce irrigation water. These results are based on a number of climate models (IPCC 2001).

Increased concentration of CO_2 may boost crop productivity. In principle, higher levels of CO_2 should stimulate photosynthesis in certain crops including rice. Increased carbon dioxide tends to suppress photorespiration in these crops, making them more water-efficient. C3 plants include such major mid-latitude food staples as rice, wheat, barley, and soybean.

Climate and agricultural zones would tend to shift poleward. In the mid latitude regions, the shift is expected to be about 200~300 km for every °C of warming. Crops in which temperature is the limiting factor may experience longer growing season. For example, in Korea the crop period could be lengthened by 10~29 days for 2°C increase in annual mean temperature (Yun 1998).

Mid latitude yield may be reduce by 10~30% due to increased summer dryness. Climate models suggest that present leading grain-producing areas may experience more frequent drought and heat waves by 2030. Extended periods of extreme weather conditions would destroy certain crops, negating completely the potential for greater productivity through “CO_2 fertilization”. The poleward edges of the mid-latitude agricultural zones such as northern China, Japan, and Korea may benefit from combined effects of higher temperature and CO_2 fertilization. However, the temperature during ripening period of rice crop was much higher than the optimum temperature, and decreased with long anomalies of sunshine hour during the warm years of 1998~99 in Korea (Yun and Lee 2000).

3.2.2 Current climate variability

The climate variability ranges over several time and space scales, from small-scale phenomena such as wind gusts, and localized thunderstorms, to larger-scale features such as fronts and storms, to even more prolonged features such as droughts and floods, and to fluctuations occurring on multi-seasonal, multi-year time scales. In general, longer time-scale phenomena are often associated with changes in the atmospheric circulation that encompasses areas far larger than a particular affected region. At times, these persistent circulation features occur simultaneously over vast, and seemingly unrelated, parts of the hemisphere, or even the globe, and result in abnormal weather, temperature, and precipitation patterns throughout the world. During the past several decades, scientists have discovered that important aspects of this inter-annual variability in global weather patterns are linked to a global-scale, naturally occurring phenomenon known as the El Niño/ Southern Oscillation (ENSO) cycle. The terms El Niño and La Niña represent opposite extremes of the ENSO cycle.

During warm episodes (ENSO) the normal patterns of tropical precipitation and atmospheric circulation become disrupted. Abnormally warm water in the equatorial central and eastern Pacific give rise to enhanced cloudiness and precipitation in these regions. At the same time, precipitation is reduced over Indonesia, Malaysia, and northern Australia. Increased heating of the tropical atmosphere over the central and eastern Pacific during warm episodes affects atmospheric circulation features, such as the jet streams in the subtropics and in the temperate latitudes of the winter hemisphere. Jet streams over the eastern Pacific Ocean are stronger than normal during warm episodes. Furthermore, during warm episodes extratropical storms and frontal systems follow paths that are significantly different from normal, resulting in persistent temperature and precipitation anomalies in many regions.

During 1997/98 significant abnormal warming of sea-surface temperatures in the Pacific Ocean, off the coast of South America, has been observed and recognized as an El Niño warm event. The last two El Niño occurred during 1982/83, which caused severe flooding and extensive weather-related damages in Latin America and drought in parts of Asia, and 1991/92, which resulted in severe drought in South Africa.

On the other hand, during cold (La Niña) episodes, normal patterns of tropical precipitation and atmospheric circulation become disrupted, while, at the same time, precipitation is enhanced over Indonesia, Malaysia, and northern Australia. Therefore, the Asian rice ecosystem may be disturbed by these climate variability.

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4 Environmentally Beneficial Function of Rice Culture and Paddy Soil

Ki-Cheol Eom

Clear distinction between winter and summer monsoon and low temperature from autumn till the following spring are the climatic characteristics of Korea, which restricts rice cultivation to only once a year. Intensive rainfall during summer floods the lowland areas, because two thirds of Korean peninsula is topographically mountains and deep slopes. About 60% (600~800 mm) of annual precipitations is concentrated during summer (June-August), which is too much even for rice cultivation and other staple food crops. Therefore, rice cultivation in paddy fields has been a cropping system naturally adapted to supply staple food in Korea.

OECD has made a movement to restrict rice cultivation globally. They regard the emission of methane gas from the rice fields as an artificial factor that increases the earth temperature via greenhouse effect. However, several countries including Korea, Japan, China, and southeast and south Asian countries in the monsoon area could not follow the advice of OECD, because rice cultivation has been a climatically, topographically, and historically well-adapted cropping system in these areas. Some developed countries also asserted that subsidies for agriculture increased contamination of natural environment with chemicals and fertilizers, thus support to agriculture should be stopped. However, the Asian countries also could not follow this contention, since agriculture has a major responsibility to supply food to the starving people and use of chemicals and fertilizers is indispensable to obtain maximum yield and quality. In addition there exist much greater beneficial effects of agricultural production activity on the natural environment, even though use of chemicals and fertilizers exerted some adverse impacts on the environment. Therefore, we must consider the integrated impacts of agricultural production activity on natural environment.

4.1 Quantification of the beneficial impact of rice cultivation on natural environment

4.1.1 Flood control capacity

The most common natural disaster in Korea is flooding during summer due to the topographic and meteorological characteristics. Fortunately, rice plants actively grow during this time under paddy field condition, harboring vast amount of water similar to a large Dam. The levee of the rice field functions like the dike of Dam. Water reservoir capacity of the rice field during the rainy season in Korea could be calculated using the following formula.

Water reservoir capacity of the rice field (mm) = (levee height - water depth) + (coefficient of permeability × duration of the flood each time) (1)

Average height of levee is 26 cm, water depth for growing rice is 4.5 cm, coefficient of water permeability of the rice field is 7.6 mm/day, and duration of the flood at each time is average three days in Korea. Thus the amount of water reservoir capacity calculated is 237.8 mm, or 2,378 cubic meters per hectare. Total amount of water reservoir capacity of rice field during the flood season in Korea can be determined by multiplying the amount of water reservoir capacity by total rice field area of 1.163 million hectares which is about 2.77 billion cubic meters.

4.1.2 Ground water recharge

Importance of water in human life is beyond discussion. The most important source of water used daily by man is the ground water. Since the rice field is usually filled with water, water percolated through soil moves into the ground. About 55% of the percolated water flows into river via drainage and underflow, which is used for living and industrial water. The remaining 45% is reserved as underground water.

Percolation rate of water into the ground in Korea is almost equivalent to the hydraulic conductivity in saturated soil. In this case, the water percolation rate is 7.6 mm per day. Duration of water percolation, which can be calculated by the weighted mean from the cultivation area and duration of rice growth, is 137 days. Amount of water percolated into underground through rice field, which would have flowed directly into river and sea if there were no rice fields, was 468 mm and 4,685 cubic meters per hectare as determined using formula 2.

Underground water reservoir capacity = percolation rate × duration of submergence × (1 - rate of water flow directly into river) (2)

Total amount of the recharging capacity of the rice field in Korea for underground water is about 5.45 billion cubic meters. This amount is equivalent to 2.9 times the available storage capacity (1.9 billion cubic meters) of Soyang Dam, the largest dam in Korea. As the consumption of water is expected to continuously increase, dependence on the underground water would also increase. Therefore, we must consider the importance of the recharging capacity of rice field for underground water.

A shortage of underground water due to excessive use will cause the ground to shrink, which would result in the collapse of the ground. For example, the ground was sunken 30 cm in Paju-gun county, Gyeonggi province by excessive pumping out of the ground water. This aroused the importance of recharging the ground water through the rice fields, the economical value of which is too great to be calculated.

4.1.3 Air- cooling effect during hot summer

When water evaporates from the surfaces of rice fields and plants into the atmosphere, it takes up heat from the air, lowering the atmospheric temperature. The amount of water evaporated from the rice field during hot summer in Korea could be calculated using formula 3.

Amount of evaporation for cooling effect = amount of daily mean evaporation during hot season × number of days of hot season (3)

Evaporation from the rice field is 3.35 mm per day on the average, amounting to a total of 450 mm during the hot summer. Amount of water evaporated from one hectare of rice field is 4,500 tons and 5.23 billion tons for the whole rice fields in Korea. If we were to calculate the value of the water evaporated from the rice fields to reduce the atmospheric temperature, it would amount to US$ 1,154 million.

4.1.4 Protection of soil erosion

Soil has various important functions such as ion exchange, disintegration, and filtering as well as retaining water and nutrients. Soil erosion, therefore, worsens the natural environment and the fertility of soil for various forms life including crops. There are several factors affecting soil erosion (Table 4.1). Using formula 4, Universal Soil Loss Equation (USLE), the amount of soil loss calculated from one hectare of upland field is 22.4 tons amounting to a total of 17,050,000 tons for the whole upland area (761,000 hectares) in Korea.

Table 4.1 Factors and their components affecting soil erosion

Factor	Component
Topography	Slope level, slope length, slope direction
Rain	Rainfall strength, rainfall period, amount of rainfall
Soil characteristics	Soil texture, organic content, water moving rate
Soil management	Plowing method, soil covering
Kind of crops	Paddy field or upland, growth stage, degree of soil covering

Amount of soil loss (ton/ha/yr) = (Raining factor × soil factor × slope factor × crop factor × soil management factor (4)

Rice field is flat with no slope and is bound with levee, therefore, should suffer no soil loss, but instead retain soil eroded from the upland. This suggests that the rice field has a capacity to protect against soil erosion by at least the amount of soil loss from the upland. Direct flow of the eroded soil from the slope into a river elevates the bottom of the river and pollutes water. Total expense to return the soil eroded via soil dressing will amounts to US$ 99.6 million at minimum (US$ 5.88 /ton).

When the soil erodes, nutrients in the soil particles are released. This pollutes the streams and rivers as well as decreases the soil fertility. The amount of nitrogen, which is the most important nutrient for crops and an adverse water pollutant, lost every year through soil erosion in Korea is as much as 18,800 tons.

4.1.5 Atmosphere refreshing effect

Photosynthesis of plant ($6CO_2+6H_2O \rightarrow C_6H_{12}O_6+6O_2$) has dual functions to clean the atmosphere via CO_2 uptake and O_2 generation. The amount of CO_2 consumption and O_2 generation could be determined using formula 5, which varies depending on the yield and carbon content of the product. Rice is the highest in total yield per unit area and carbohyd rate contents of rice is 78.1%, which is higher than other crops.