WATER MANAGEMENT AND SOIL FERTILITY FOR IMPROVED YIELDS

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Abstract

The 21st century is being called the "Century of Water". Soil fertility is governed by soil physical and chemical properties. Today many fertilizers are being applied in the field, and water is being contaminated; consequently there is a thrust towards the development of environmentally safe and sustainable agricultural practices that maintain soil and water health. In this context, industrial waste materials have to be well managed and mineral and organic fertilizers must be applied appropriately to each field plot after soil testing. In addition, to maintain water availability in adjacent surrounding areas, irrigation water should be managed efficiently.

Introduction

Soil fertility is greatly affected by the combined management of soil fertilizer and water. If this is done properly, soil fertility remains stable and fertile over the long term. Soil fertility is governed by soil chemical and physical properties. In general, chemical properties affect soil in the short term and physical properties (the basic structural framework) have a long-term influence. Soil physical properties are affected considerably by soil water availability.

Agricultural fields in Korea are productive and fertile, especially paddy fields. Soil fertility must be sustainable for enhanced food productivity and adaptable to environmental changes to maintain food quality and human and animal health. Although most Korean soils are fertile, in places intensive cropping and other subsidiary agricultural practices, such as orchards, demand heavy application of animal manure; this has resulted in accumulation of excess amounts of soil nutrients in the root zone, in particular NO_3^- and PO_4^{-3}. Soil conservation and watershed management for efficient water use are of critical importance to sustain farming activities and soil fertility. Generally, in summer there is enormous water inundation and flooding of farmland and watersheds. Korea frequently suffers from flood disasters in this season. Dams and canals as well as the embankments and bunds in the watershed area collapse and much good soil is lost. From the late 1960s to the early 1970s "The Improvement Works of Open Channels and Water Conduits" was conducted in line with "The Replotting and Consolidation of Farming Lands" and "The Drainage Improvement Works of Low Wet Land". During this time, many earth canals in watershed areas were cement-lined, and as a result water now flows without hindrance into fields and retains its velocity in channels, thus saving certain irrigation needs. Such a network of open channels facilitates farmers' field work and is important for maintaining paddy yields. As in other countries, crop yields in Korea are increasing. Also, combined water and fertilizer use has advanced, and water management technologies have stayed abreast with latter-day demands. However such techniques have not been disseminated to many farmers. In the near future, advanced irrigation technologies need to be more widely promoted among farmers.

Keywords: soil fertility, fertilizer, sustainable agricultural, industrial waste, organic fertilizer

Rainfall and water use in Korea

Annual rainfall in the Korean Peninsula averages from 1,300 to 1,400 mm. Seventy percent of this rainfall is usually concentrated from late June through early August.

Water use in Korea is not managed systematically. The Food and Agriculture Organization of the United Nations (FAO) classified Korea as a water-stressed country with per capita use of 1,500 m^3 *per annum*, although this varies annually and locally. Water use for agriculture is coupled with crop productivity and quality and surrounding environmental conditions. As shown in Figure 1, agricultural water use is diminishing. By 2011, agricultural water deficiency is likely in Korea (Table 1). Moreover drought recurs periodically at 10-year intervals. However 80% of the Korean paddy area is currently stable irrigation-wise as indicated in Table 2.

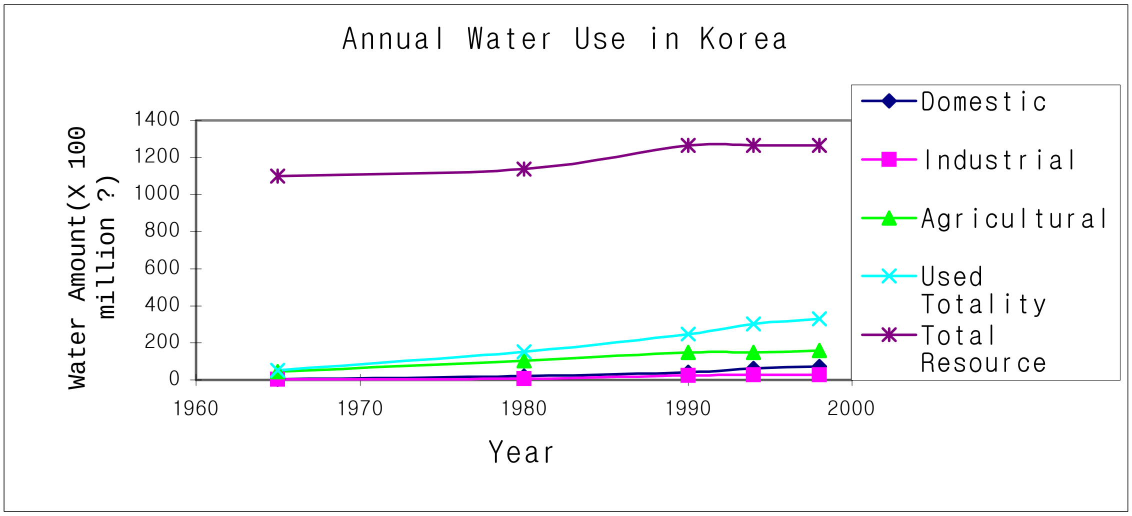

Figure 1. Sectoral usage of Korea's water resources

Table 1. Long-term perspectives for agricultural water use in Korea
(Unit: million m^3 *per annum*)

Demands	1997	2001	2006	2011
Total	15,809	15,875	15,986	16,193
▶ Paddy area	13,006	13,272	13,620	13,967
○ Stable irrigation area	10,553	11,584	12,491	13,053
○ Unstable irrigation area	2,453	1,688	1,129	914
▶ Upland area	2,572	2,669	2,790	2,930
○ Command irrigation area	94	251	447	644
○ Non-command irrigation area	2,478	2,418	2,343	2,286
▶ Livestock husbandry	231	241	259	274
○ Livestock breeding	200	209	226	240
○ Processed meat production	31	32	33	34
▶ Operational water saving	-	Δ 307	Δ 683	Δ 978
○ Canal/channel lining	-	Δ 300	Δ 600	Δ 800
○ Auto-irrigation system	-	Δ 7	Δ 83	Δ 178
1996 planned water supplies	-	15,027	15,226	15,150
Supply/demand balance	-	▼848	▼760	▼1,043

Source: Ministry of Construction and Transportation of Korea.

Table 2. Trends in the change of paddy and stable irrigated areas

(unit: × 1,000 ha)

Paddy area	**1985**	**1989**	**1993**	**1997**	**2000**
Total	1,237	1,257	1,136	1,052	1,072
Stable[*]	948 (76.6)[**]	985 (78.4)	956 (84.2)	882 (83.8)	880 (82.1)
Unstable	289	272	180	170	182

*Stable irrigated area on municipal or governmental basis. Irrigation is possible when drought occurs.

** Numbers in parentheses denote the percentage of corresponding area to total paddy area cultivated.

Waterlogging in paddy fields is important to maintain rice productivity and a healthy soil environment. Formerly in paddy agriculture, Korean agronomists attempted to apply direct seeding to field plots to save production costs, labour and water. But this method has many shortcomings such as insect/pest infestation, weed incidence, decreased yields and degraded soil fertility. Crop water consumption involves evapotranspiration (ET_o), maximum evapotranspiration (ET_m) and actual evapotranspiration (ET_a). To characterize local water requirements, ET_o was measured using a reference plant (Kentucky blue grass) using a lysimeter; the water table level was controlled at 50 cm below the soil surface as shown in Figure 2. Estimations can also be made via the Penman-Monteith model equation using weather factors. ET_m means the evapotranspirated maximum water amount in response to the local weather condition — each crop is measurable under this condition. ET_a is the actual consumed water amount of each crop in the existing soil water state of the root zone during growth, and is quite difficult to measure.

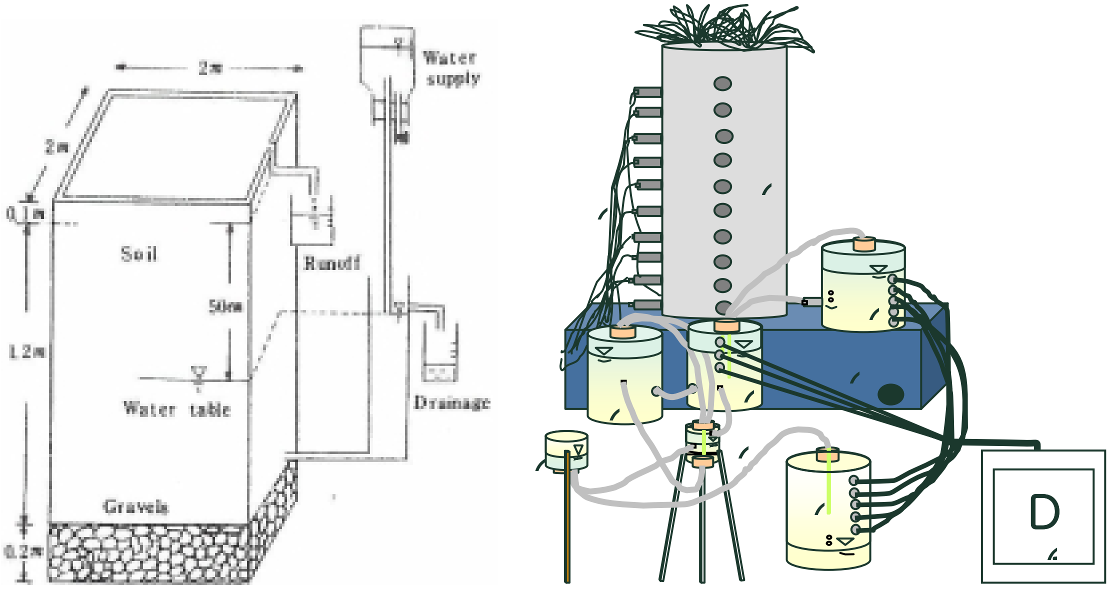

Figure 2. Lysimeter structures and controlling the water table depth

Table 3. Seasonal crop coefficients and crop water requirements measured by the water balance method in a monolithic lysimeter continuum

Crop	Tested years	Growth period	Seasonal crop coefficient Kc				Daily mean water consumption (mm)	Total water requirement (mm)
			Initial	Developed	Mid-	Late		
Soybean	8	May 20 - Oct.10	0.58	0.89	1.31	0.93	2.56	366
Maize	5	May 25 - Aug. 25	0.68	1.09	1.68	1.33	3.41	314
Sweet potato	5	June 1 - Oct. 10	0.67	1.08	1.32	0.99	2.79	383
Upland rice	7	May 10 - Oct. 10	0.68	1.01	1.31	1.08	2.68	410
Red peppers	9	May 15 -Oct. 15	0.53	0.96	1.06	0.82	2.27	347
Red beans	2	May 15 - Sep. 15	0.50	0.82	1.36	1.10	2.62	322
Groundnut	3	April 30 - Oct. 15	0.60	1.19	1.21	0.74	2.45	399
Perilla	2	May 15 - Sep. 30	0.73	1.10	1.37	0.84	2.85	393
Sesame	6	May 20 - Aug. 25	0.39	0.63	0.94	0.83	2.01	195
Barley	5	April 20 - June 10	-	1.31	1.69	1.17	3.92	317
Chinese cabbage	7	May 15 - June 10	0.68	0.93	1.32	1.13	3.14	144
	8	Sep. 10 - Nov. 10	0.62	0.94	1.25	1.16	1.92	117
Radishes	7	April 20 - June 30	0.58	0.95	1.20	1.11	2.63	187
	7	Aug. 25- Nov. 5	0.47	0.85	1.12	0.99	1.69	121

Agricultural water management technologies in Korea

Water management technologies have made remarkable strides in Korean agriculture. Soil water measuring techniques have advanced to the present auto-measured dielectric detection since the days of the oven-drying method. Irrigation techniques in the field have advanced to fustigation irrigation that controls water and nutrients simultaneously as opposed to the old furrow irrigation method. There are two irrigation categories: irrigation in the uplands and lowlands (paddy). Irrigation water is supplied from a source (e.g., well, river or reservoir) through canals or pipelines and diffused as uniformly as possible over the land. The detailed design of a scheme is usually carried out by an experienced engineer who works closely with agriculturalists and soil scientists. His job is to plan the layout of the irrigation system, select the right sizes for canals and pipes, select the structures for controlling water flow and select the method for irrigation. To operate an irrigation scheme it is not essential to understand the complexity of its design. However, a working knowledge of how water flows in canals and pipes and how it spreads across the land and infiltrates into the soil will help the irrigator or farmer to make full and proper use of his scheme. When this is understood, irrigation efficiency will be enhanced considerably.

Advances in upland irrigation technology

Irrigation technology in the uplands has made greater strides than its paddy counterpart. This is mainly attributable to advances in soil water measuring and controlling techniques for water flow in conduits. A good example is the wired (PSTN) or wireless network by dielectric constant measuring mentioned earlier (Figure 4). As irrigation technology advances considerable quantities of freshwater are saved.

Upland fields are mostly distributed on small-scale hillside areas. Upland irrigation technology is less advanced here.

Table 4. Progressive increase in irrigable upland hectareage throughout five main river basins in Korea

River basins	Upland acreage (A)	Irrigable hectareage				(B/A) ×100
		1986	1991	1996	2001(B)	
Hangang	199,785	5,994	9,989	15,982	19,978	10.0
Nakdonggang	212,970	3,450	4,689	-	14,406	6.8
Keumgang	96,255	5,060	6,890	13,480	21,400	22.2
Yungsangang	36,500	3,877	4,420	5,190	5,430	14.9
Seumjingang	25,916	1,083	1,805	1,805	1,805	7.0
Total	**571,426**	**19,464**	**27,793**	**-**	**63,019**	**8.6***

* The irrigable percentage based on total cultivated upland area nationwide in 2001 (as of 2001, 730,060 ha)

Recently upland fields are more heavily concentrated and have been converted from paddy areas. Upland irrigation is advancing progressively and employs various dynamic methods, in particular pressurized irrigation. Surface irrigation practices are declining and pressurized irrigation methods using sprinklers or drip emitters are mainly used. Irrigation efficacy or efficiency via these emitters needs to be tested periodically to save more water.

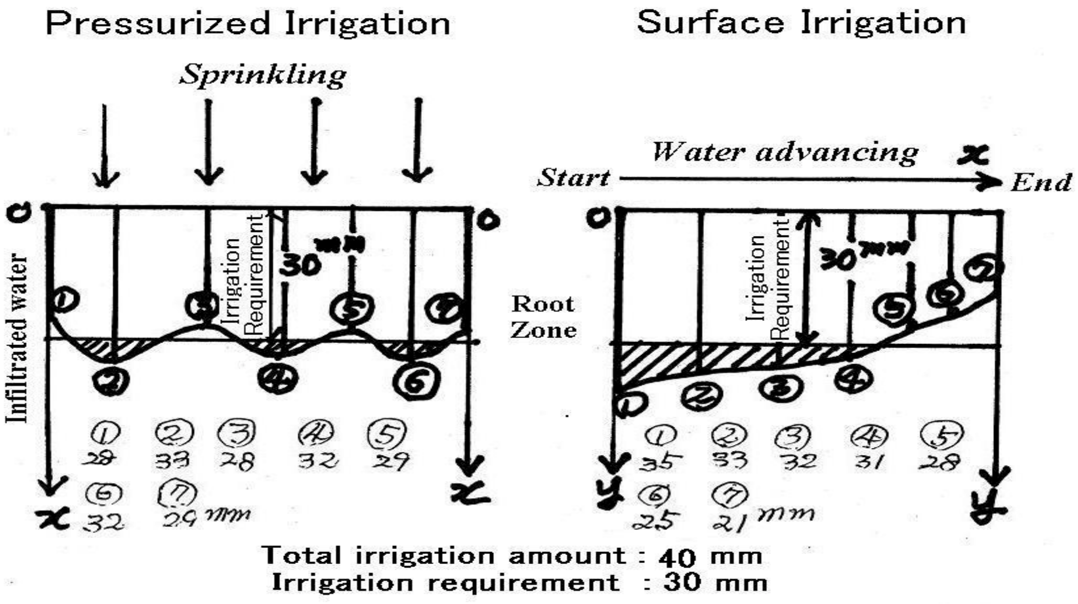

Figure 3 exemplifies simple testing of irrigation efficiency in an on-site field.

Figure 3. Irrigation efficiency calculated by measured soil water distribution in an in-situ upland field

1) Storage efficiency (E_s): 1) Storage efficiency (E_s):
Effective storage (mm): 204 Effective storage (mm): 194
=28+30+28+30+29+30+29 =30+30+30+30+28+25+21
average: 204/7=29.1 average: 194/7=27.7
$\therefore$ $E_s = 29.1/30 = 0.971$ $\therefore$ $E_s = 27.7/30 = 0.924$
2) Application efficiency (E_a): 2) Application efficiency (E_a):
Total received storage: 211 Total received storage: 205
=28+33+28+32+29+32+29 =35+33+32+31+28+25+21
average: 211/7=30.1 average: 205/7=29.3
$\therefore$ $E_a = 30.1/40 = 0.753$ $\therefore$ $E_a = 29.3/40 = 0.733$
3) Irrigation efficiency (E_f): 3) Irrigation efficiency (E_f):
$\therefore$ $E_f = E_s \times E_a$ $\therefore$ $E_f = E_s \times E_a$
= 0.971×0.753 = 0.924×0.733
= 0.731 (73.1%) = 0.677 (67.7%)

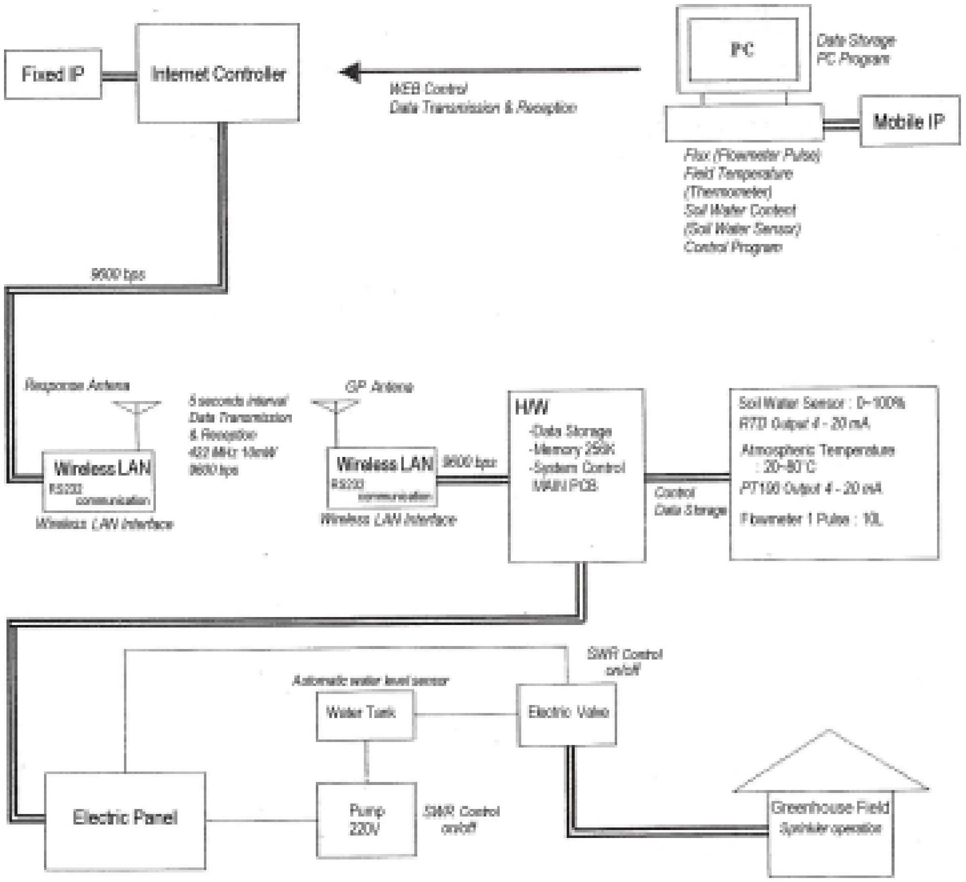

Figure 4. Wireless remote control irrigation system developed in 2001 (SWR = Soil Water Requirement)

Advances in paddy irrigation technology

Irrigation technology for paddy has advanced even more slowly than in the uplands. In paddy irrigation it is not easy to control water flow in wide conduits such as canals and open channels. Water control in paddy irrigation does not require expertise owing to the management of large volumes of water at the same time. In paddy cultivation much water is lost en route through open canals and channels. In order to control water flow speed in open channels properly, canals should be lined with cement and weirs, branched diversions, checks and falls need to be installed at appropriate locations. Irrigation efficiency in paddy areas is primarily dependent on the water flow rate in the canals delivering irrigation water. Of secondary importance is water consumption in the irrigation unit plot. Therefore, to promote irrigation efficiency in the paddy area, water loss must be stopped while delivering water through the canals before irrigation water enters the entrance gate of each unit plot. Flood irrigation submerges the plot with water up to a certain level. Irrigation efficiency depends on the submerged length and height of water in the unit plot. For this reason, irrigation efficiency in a rice field is equal to the ratio of water consumption of rice (ET_a) to the difference in the waterlogged level (DWL) above the soil surface during the rice-growing period. In the rice field, water consumption by the rice plant can be estimated theoretically by following the aerodynamic process in the micro-meteorological system enclosing the plant canopy. But in the aerodynamic estimation method it is difficult to calculate the rice crop's evapotranspiration values owing to many different parameters in the functional relation. Accordingly, an empirical equation can be used to infer evapotranspiration in rice plants:

$$ET_a = K_c \bullet ET_o \approx K_c \bullet E_o$$

Where, ET_a corresponds to the actual evapotranspiration rate (mm/day)
K_c corresponds to the rice crop coefficient (dimensionless)
ET_o corresponds to the reference evapotranspiration rate (mm/day)
E_o is equivalent to the evaporation rate from the free water surface (mm/day)

The K_c-value is measurable in the isolated lysimeter container (Figure 2) as one solid water-budget regime separated from the field soil.

Table 5. Changes in seasonal crop coefficient of rice by provincial area of Korea for the 1982 to 1988

Provincial area	**June**			**July**			**Aug.**			**Sept.**			**Mean**
	F*	M	L	F	M	L	F	M	L	F	M	L	
Northern	1.00	1.22	1.39	1.50	1.56	1.58	1.56	1.51	1.42	1.31	-	1.41	1.41
Central	1.07	1.24	1.39	1.50	1.59	1.65	1.68	1.68	1.66	1.50	-	1.51	1.51
Southern	1.10	1.27	1.41	1.52	1.60	1.66	1.68	1.68	1.65	1.60	1.55	1.52	1.52

* F = the first quarter of the month, M = the middle, L = the last

E_o-value is readily measured in a standard A-class pan. Required rice field water (DWL) in the plot is equal to the water shrinkage depth of the waterlogged level during the growth period. Consequently, if water balance factors are determined, actual irrigation efficiency (E_a, %) can be calculated as follows:

$$E_a\ (\%) = (ET_a/(DWL-R_e)) \ast 100$$

In the above equation, effective rainfall (R_e) is dependent on rainfall intensity and freeboard height according to the bund height in the field plot. Thanks to the development of hydraulic engineering technology, digitalized surface water level change is measurable in an in-situ field. Namely, the increment of rising water level is equal to the R_e-value when rainfall is diminishing.

Figure 5. Digitalized submerged water level depth measurement sensors

Fertilizer management and soil fertility in Korea

Soil fertility is vital to maintain crop yield and quality. The application of fertilizers enhances nourishment for the crop and promotes nutrient supply in the soil for good crop growth; it is indispensable for ensuring crop yield. Nitrogenous fertilizer is an artificial basic chemical fertilizer for enhancing crop productivity without which yields would diminish; thus manufactured chemical fertilizers have proved to be effective in the past. Nowadays there is a thrust towards enhancing quality in yields and ensuring environmentally friendly soil fertility. Due to the focus on increasing yields in the past, overfertilization has resulted in excess nutrients in the rhizosphere and soil fertility is unbalanced and in a poor condition. Optimum nutrition conditions are variable according to soil chemical and physical properties and weather conditions. Nowadays owing to new fertilization technology and erratic weather conditions agronomic management techniques need to be modified and adapted to particular environments. Rice, soybean and potato are staple foods in Korea. Varieties have been improved considerably as well as soil management techniques for good growth. Potato requires more fertilizer and generates more soil deterioration during cultivation. Soybean fixes nitrogen in the root rhizosphere, but potato does not and needs greater amounts of fertilizer and pesticide which result in soil nutrient loss.

Rice is a staple food crop for Korean people. Rice productivity per unit area has been increasing annually in Korea. However this has been juxtaposed by a concomitant rise in fertilizer use until recently. Rice yield increases have been attributed to use of chemical fertilizers and breeding of new productive rice varieties with high yields. But now, due to environmental concerns, consumers are opting for healthier and safer agricultural products of good quality. In turn, farmers favour high quality rice. In order to address this current trend, farmers are reluctant to grow the prolific rice varieties of lower grain quality of the past, such as Indica rice. In this context sustainable agriculture has to be encouraged. However, most farmers still apply many fertilizers assuming that they will obtain higher yields. Research indicates that there is a threshold beyond which fertilizer-N application cannot increase crop yield. Under these conditions there is the potential for contamination of ground and surface waters. There is also a perception that N fertilizers are inexpensive. This perception has some justification because investments in fertilizer N often provide large return in terms of increased yields. High returns on fertilizer investments are common when fertilizer-N alleviates N deficiencies in a crop. Because such high returns are possible, it often seems financially prudent for farmers to err on the side of using too much fertilizer rather than using too little fertilizer when they are uncertain about the amounts of N needed. Today, standard fertilizer application is shifting towards a tested optimum level for crops. Recently at the NIAST institute, a rationale for environmentally friendly fertilizer application was promoted for every crop via soil testing (Lee Chun-Soo *et al.* 2003). Organic compost application and amelioration of soil physical properties is of critical importance to acquire good quality crop products and a healthy soil environment. Compost residue and organic matter in the rhizosphere buffer soil chemical reaction and sustain crop yield. Also, humic acid is released from organic matter that chelates with other mineral solutes, and so forms chelates not only to retain plant nutrients in the soil but also to promote the mobility of fixed ions in soil media such as phosphorus and heavy metal ions. Besides, organic matter in the soil improves soil physical conditions by enhancing soil aggregates, soil aeration and water holding capacity.

Table 6. Soil chemical properties of agricultural land in Korea

Land use	Year	pH(1:5)	OM ($g\ kg^{-1}$)	Avail. P_2O_5 ($mg\ kg^{-1}$)	Exch. K ($coml_c\ kg^{-1}$)	Avail. SiO_2 ($mg\ kg^{-1}$)
Paddy	1980	5.7	23	107	0.27	88
	1990	5.6	25	128	0.32	72
	2000	5.7	22	136	0.32	86
Upland	1980	5.8	19	231	0.59	-
	1990	5.5	24	538	0.64	-
	2000	5.9	20	572	0.79	-
Greenhouse	1980	5.8	26	945	1.01	-
	1990	6.0	35	1,092	1.27	-
	2000	6.3	34	975	1.67	-

Table 7. Distribution of soil drainage classes of agricultural land in Korea (as of 1992)

Drainage class	Paddy (ha)	Ratio (%)	Upland (ha)	Ratio (%)
Excessive	4,912	0.4	71,112	8.1
Well	14,861	1.2	733,118	83.5
Moderately well	461,976	35.9	73,029	8.3
Imperfectly	625,931	48.6	1,179	0.1
Poorly	180,566	14	46	0.005
Others	0	0	17	0.002
Total	1,288,249	100	878,501	100

Water and fertilizer management for securing crop yield and quality

Optimum water and fertilizer management in the field is a short cut to generating healthy crop yield and quality. Therefore soil properties and functions must be addressed suitably.

Even if the need for fertilizer management is critical, water management must come first because water is the basic channel for supplying all inorganic and organic materials in the soil. Therefore, farmers must achieve optimum soil water conditions to secure high crop yields and they should manage the irrigation water and facilities to save expenditure. In order to recognize water conditions in the field, farmers need to measure the soil water content in the rhizosphere. A few decades ago, it was difficult for farmers to measure soil water content with the rudimentary measurement tools available. But recent dielectric probes enable this to be done digitally and farmers can now assess water conditions more easily (Table 8).

Table 8. Dielectric probes for measuring soil moisture

Propagation mode	**Commodity brand**	***Manufacturer***
FDR	WT-1000 FloriCom θ-Probe $ECH_2O^{®}$-10	Mirae Electronics Co. (Korea) Netafim Irr. Engineering Co. (Israel) Delta Devices Co. (G. Britain) Decagon Devices Inc. (USA)
TDR	Trime Trase	Imko GmB&H (Germany) Soil Moisture Co. (USA)

Thanks to these advanced measuring techniques, automatically controlled water management facilities are being installed in many farm communities. There is a wide diversity of automatic water management technologies for greenhouse and hydroponics culture. Such advanced technologies could address water management in farmers' fields, especially as paddy fields use a vast volume of agricultural water. In the 21st century, "The Century of Water", it is expected that water will become a tradeable commodity between countries that are either rich or deficient in water supply. Therefore, in the agricultural sector, which consumes a large volume of water, the saving of water is essential. In the Asian monsoon climatic zone, paddy culture consumes too much water. Efficient water use in paddy fields is critical for saving agricultural water, especially as freshwater is not easily conserved and regenerated. Even if rainfall is abundant, freshwater becomes unusable if it is not well managed. In the context of water saving, farmers too need to recognize water amounts entering their own paddy plots and canal losses en route from the reservoir source.

Concluding remarks

The 21st century is being called the "Century of Water". Soil fertility is governed by soil physical and chemical properties. Today many fertilizers are being applied in the field, and water is being contaminated; consequently there is a thrust towards the development of environmentally safe and sustainable agricultural practices that maintain soil and water health. In this context, industrial waste materials have to be well managed and mineral and organic fertilizers must be applied appropriately to each field plot after soil testing. In addition, to maintain water availability in adjacent surrounding area, irrigation water should be managed efficiently.