

RICE ROOT DISTRIBUTION AND RICE-BASED CROPPING SYSTEMS FOR SUSTAINABLE SOIL–RHIZOSPHERE MANAGEMENT

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Abstract

*The root distribution and cropping system of rice (*Oryza sativa* L.) play a significant role in sustainable rhizosphere management. The distribution of roots is closely related to the physical properties of the soil and fertilization practices. The distribution of rice roots accords with the fertilization regime. Lowest bulk density was observed in a plot of NPK+compost at 0-5 cm. The cone penetration resistance of the compost plot had no difference from topsoil to subsoil up to 15 cm depth. The distribution of rice roots in the subsurface soil (below 20 cm depth) ranged from 5.8 to 12.6% in the tile-drained plots, while that in plots installed with no drainage ranged from 2.3 to 7.6%, which suggests that drainage systems cause deep root distribution. The cropping system is very important for environmental management of the rhizosphere. Rice cultivation after barley inhibited weed occurrence, especially *Echinochloa crus-galli*. The cultivation of Chinese milk vetch (*Astragalus sinicus* L.) improved soil fertility and soil physical properties under rice cropping. Also, soil desalting increased via rice cultivation under a vegetable–rice cropping system. Rice cultivation in greenhouse soil was a good method to manage a sustainable soil rhizosphere.*

Introduction

There are many factors in soil–rhizosphere management during rice (*Oryza sativa* L.) production. The root distribution and cropping system are important factors for sustainable soil–rhizosphere management. Rice root systems play an important role in uptake of water and nutrients from soil (Yang *et al.* 2004). Therefore, soil management is very important for root growth. It is well known that the root distribution of rice is related to nutrient absorption and soil–rhizosphere management. However, the findings on root distribution are limited due to the laborious nature of the work. Root distribution (as affected by fertilizer inputs, organic matter application and drainage condition) and related data are very important for sustainable soil–rhizosphere management. The effects of inorganic fertilizer and organic manure application on soil fertility and rice yield have been well studied. However, there has been very little research so far on the long-term effects of fertilization on rice root distribution. Drainage *vis-à-vis* fertilization is another issue for paddy soil management. Poor drainage and a high groundwater table are responsible for long-term flooded rice. In Korea, rice cultivation extended over 966,838 ha in 2005 (RDA 1992). It has been reported that Korean paddy needs to improve its associated drainage system by more than 65.6%. Continuously submerged conditions not only induce low water productivity but also have adverse effects on soil fertility and rice roots. Therefore, installation of a subsurface drainage system into paddy soil is commonplace for enhanced drainage and soil productivity. Rice root distribution is affected by soil physical properties like bulk density, drainage, porosity and soil compaction. Therefore, deep root systems are considered to reflect good soil health.

Key words: rice, roots, rhizosphere, fertilization, drainage, cropping system

Many kinds of cropping systems have been developed in Korea. The rice-based cropping systems have multiple benefits. Rice cultivation after barley cropping reduces weed occurrence. Rice–barley was a traditional cropping system in Korea. However it declined in many areas after the green revolution. But, as stated, it helps with the management of gramineae weeds which are the most difficult weeds to control during the rice cultivation season. The cultivation of leguminous green manure crops improves soil fertility and soil physical properties before rice harvesting (Mandal *et al.* 2003). Legume crops associated with rice cropping such as hairy-vetch and Chinese milk vetch have been cultivated as green manure crops. The cropping of vegetable crops has been popular in paddy since living standards started to improve in Korea. Vegetable cropping has been intensively practised under greenhouse soil. These crops are cultivated mainly during the winter in paddy soil. For rice cropping, fertilizer needs are reduced by the soil nutrient residues that remain after harvesting. Additionally, paddy has many general benefits such as desalting effects; alleviation of disease and pest incidence; and reducing damage generated by continuous cropping. Therefore there is a need to study environmentally friendly cropping systems for sustainable soil–rhizosphere management. This paper focuses on rice root distribution and rice-based cropping systems for sustainable soil–rhizosphere management.

Characteristics of root growth and soil under long-term fertilization

Field experiments were carried out at the National Yeongnam Agriculture Institute (Milyang), National Institute of Crop Science (NICS), Republic of Korea, to determine the characteristics of root growth of rice grown under different fertilizer applications and drainage systems in paddy conditions (Jeon *et al.* 2003). In order to investigate the characteristics of root distribution of rice (cv. Hwasambyeon), a long-term fertilized experimental plot was established in paddy soil belonging to a fine silty family of typical Halpaquepts. Fertilizer applications, comprising no fertilizer, compost, NPK and NPK+compost plot, have been consistently maintained for the past 36 years as well as an NPK+silicate plot for the last 22 years. In the NPK plot, 150 kg N (urea 46%), 100 kg P₂O₅ (fused phosphate 20%) and 100 kg K₂O (potassium chloride 60%) per hectare were applied. For the NPK+silicate plot, 500 kg SiO₂ (silicate 25%), and 10,000 kg rice straw compost per hectare were applied. This field had different soil chemical properties compared with general paddy in Korea because of long-term application of fertilizers and compost. The organic matter of compost and the NPK+compost plot were higher than farmers' fields; the pH in the NPK+silicate plot was increased dramatically by a build-up of calcium. These differences were higher in the topsoil than the subsoil (Table 1).

Table 1. Chemical properties of soil from a long-term fertilizer application experiment^{a)}

Soil layer	Treatment	pH (1:5)	OM (g kg ⁻¹)	Av. P ₂ O ₅ (mg kg ⁻¹)	Ex. cations (cmol ⁺ kg ⁻¹)		
					K	Ca	Mg
Surface	No fertilizer	5.7	27.9	27	0.07	3.3	0.72
	NPK	5.8	28.6	155	0.11	3.9	0.95
	NPK+silica	6.7	28.2	162	0.11	6.8	1.10
	NPK+compost	5.9	32.5	221	0.34	4.8	1.13
	Compost	5.7	32.3	71	0.32	3.8	0.80
Subsurface	No fertilizer	7.0	20.0	21	0.08	4.6	1.43
	NPK	7.5	18.3	39	0.08	5.4	1.73
	NPK+silica	8.2	18.7	32	0.08	7.7	1.62
	NPK+compost	7.5	21.3	70	0.28	5.7	1.83
	Compost	7.4	19.2	25	0.29	5.2	1.65

^{a)} The measurements were obtained after harvest.

Root distribution was influenced by soil physical properties. Soil bulk densities at different depths under rice with different fertilizer application are shown in Figure 1. Bulk density was the lowest in the compost plot at 0-5 cm soil depth, but the highest bulk density was in the no fertilizer and NPK plots. The bulk density of the compost plot was significantly low at the 0-5 cm soil depth. Compost application could explain the high humus concentration in the soil. Soil porosity had the reverse trend compared with bulk density (data not shown).

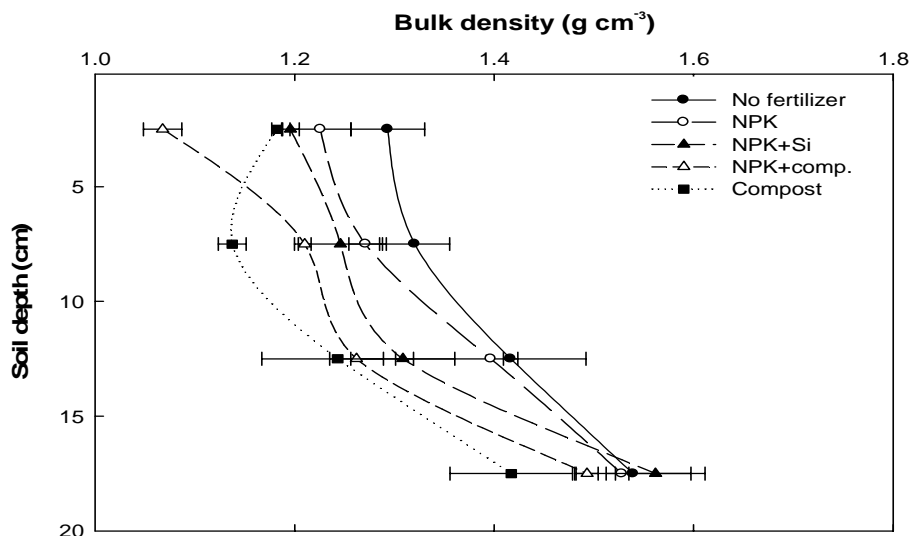


Figure 1. Soil bulk density at different soil depth under rice with different fertilizer applications. (The measurements were obtained after harvest.)

Cone penetration was measured for mechanical resistance of root growth and the working accessibility of agricultural machinery. Cone penetration resistances at different soil depths of paddy with different fertilizer application showed the same trends as bulk density (Figure 2). The cone penetration of the compost plot had no difference from topsoil to subsoil up to 15 cm.

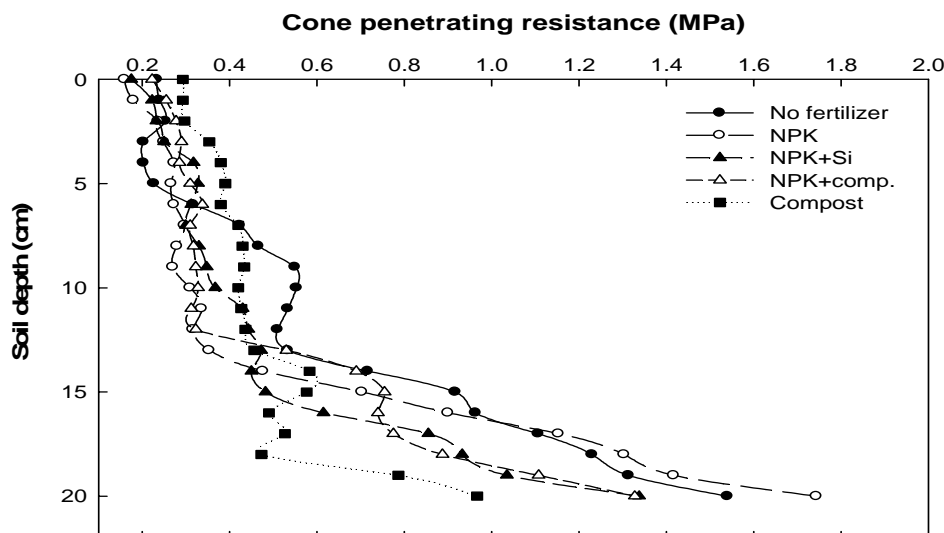


Figure 2. Cone penetration resistance at different soil depths under paddy with different fertilizer application. (The measurements were obtained after harvest.)

The subsurface root system is closely related to the aboveground shoot system. The dry weight of shoots increased as fertilizer amounts increased. But in the long-term plot, root weight followed the order NPK+Compost, compost and NPK+silicate in comparison with the NPK plot. The total root length

diminished in the following order: no fertilization, compost, NPK+compost (Table 2). The modified line intersection method was used for estimation of root length (Tennant 1975):

$$R = \pi AN / 2H$$

Where,

- R: root length (cm),
- A: area (cm²),
- N: no of intersects,
- H: total length of grid (cm)

The ranking of the Roots/Shoots (R/S) ratio followed the same trend as no fertilization, NPK+compost, compost and NPK+silicate. The R/S ratio ranged from 0.05 to 0.2 among cultivars. The R/S ratio increased with compost application. This led to shoot development as well as root growth.

Table 2. Growth characteristics of shoots and roots of rice grown under long-term fertilizer application^{a)}

Treatment	Shoots			Roots ^{b)} , 0-20 cm		R/S ^{c)}
	Plant height (cm)	Tillers (no. hill ⁻¹)	Dry weight (g hill ⁻¹)	Length (m hill ⁻¹)	Dry weight (g hill ⁻¹)	R/S ^{c)}
No fertilizer	76.2	8.5	20.3	156.6	2.511	0.124
NPK	89.9	11.5	29.4	119.6	2.524	0.086
NPK+silica	95.5	9.5	27.6	119.9	2.613	0.095
NPK+compost	96.7	12.5	30.1	152.6	3.165	0.105
Compost	87.3	11.0	28.6	153.9	2.727	0.095

^{a)} Root sampling was performed using the cylinder monolith method at the heading stage.

^{b)} Mean of root length and weight at below hill and mid-point of four hills.

^{c)} R/S dry weight.

There are some indicators to explain root growth. Root length and weight are related to soil volume and are referred to as root length density (RLD, cm_{root} cm⁻³_{soil}) or root weight density (RWD, g_{root} cm⁻³_{soil}). These are particularly useful for describing the spatial distribution of the root system. The specific root length (SRL, cm_{root} g⁻¹_{root dry weight}) is also used to give an indication of root thickness.

The mean root length and weight density of rice grown under different fertilizers and compost application are presented in Figure 3. The mean root length densities were high with no fertilizer, NPK+compost and compost in soil depth of 0-5 cm. As soil depth increased, the mean root length and weight density of rice were longer and deeper in the compost plot.

Compost application produced larger and more vigorous root systems. The improvement of soil physical characteristics (e.g. bulk density, soil hardness) from compost application would have accelerated root growth and may have provided a better rhizosphere environment for root growth. Optimum conditions for easy root growth are (1) no mechanical resistance and (2) sufficient nutrient supply. Thus most roots were distributed in the upper soil layer in the no fertilizer plot.

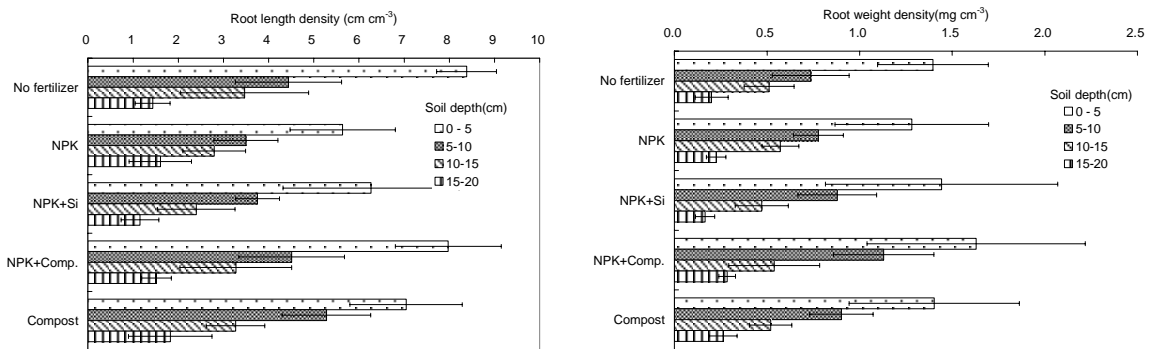


Figure 3. Mean root length and weight density of rice grown with different fertilizer applications. The cylinder monolith measurement method was used at the heading stage. The lines in the bars mean the standard errors of the above ones

Root thickness is changed by fertilization. The specific root lengths of rice influenced by long-term fertilization at the heading stage are given in Figure 4. The Specific Root Length (SRL) below the hill (BH) was lower than the midpoint of four hills (MH). As soil depth increased, the SRL was high and highest in the no fertilizer plot at the 0-15 cm soil depth. The SRL was lowest in the NPK+silicate plot at the 0-15 cm soil depth. Silicate application led to thick roots. The SRL was highest in the compost plot (BH) and NPK+compost (MH) at the 15-20 cm soil depth.

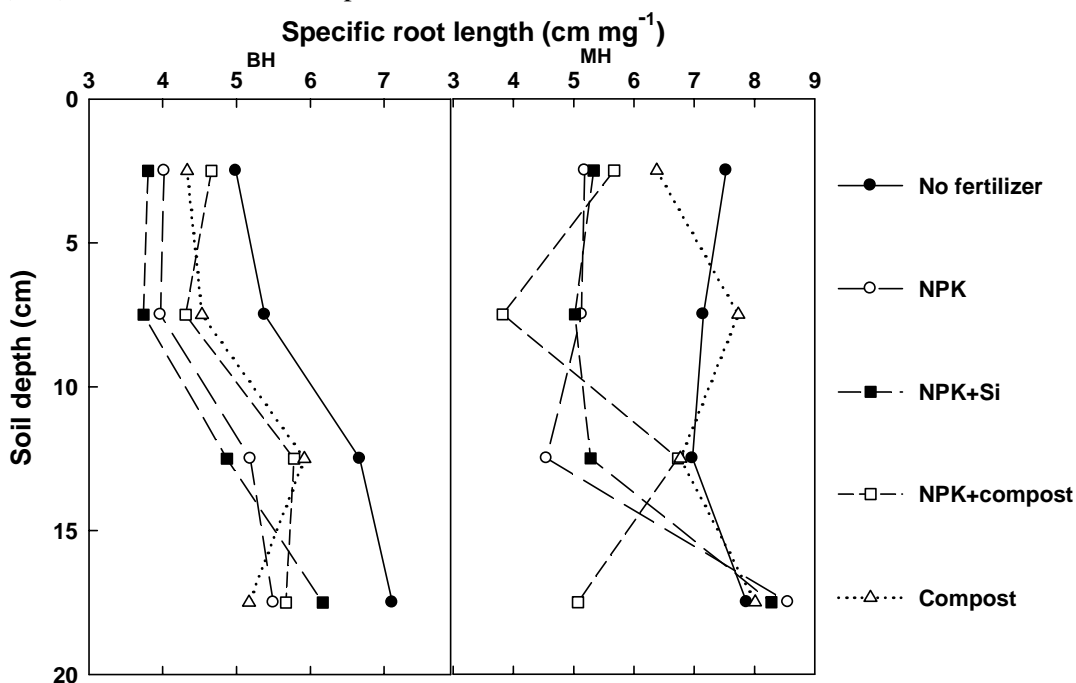


Figure 4. The SRL of rice influenced by fertilizer treatments. Root sampling was performed using the cylinder monolith method at the heading stage. BH and MH in the X axis indicate below hill and the mid-point of four hills

Root traits naturally affect yield and yield components. Correlation coefficients between root weight density at different soil depth, grain yield and yield components are shown in Table 3.

The mean of Root Weight Density (RWD) below hill between panicle numbers per plant revealed significantly positive correlation. Also the RWD mid-hill at the 15-20 cm soil depth between panicle numbers had significant positive correlation. It was reported that the Leaf Area Index (LAI), panicle number and root length had significant positive correlation among cultivars.

Table 3. Correlation coefficients between RWD at different soil depths, grain yield and yield components^{a)}

Sample location	Yield and yield components	Soil depth (cm)				
		0-5	5-10	10-15	15-20	Mean
BH ^{a)}	Panicle number per plant	0.581	0.497	0.016	-0.092	0.755*
	No. of spikelets per panicle	-0.030	-0.069	0.015	-0.254	-0.092
	Ripened grain(%)	0.154	-0.406	-0.683*	-0.452	-0.333
	1,000-grain weight	0.219	0.158	0.072	-0.309	0.252
	Yield	0.423	0.561	0.148	-0.169	0.673*
MH	Panicle number per plant	-0.112	0.404	0.070	0.662*	0.391
	No. of spikelets per panicle	-0.231	0.099	0.471	0.017	0.130
	Ripened Grain (%)	-0.345	-0.599	0.371	-0.430	-0.505
	1,000-grain weight	-0.293	0.207	0.051	-0.109	0.001
	Yield	-0.146	0.603	-0.057	0.510	0.425

^{a)} BH and MH indicate below hill and the mid-point of four hills.

* Significant at 0.05 probability.

Characteristics of soil and rice root distribution under subsurface systems

In general, installation of tiles into paddy soil has become common for improvement of drainage as well as soil productivity. The mechanism utilizes soil oxygen by roots and removes noxious agents deposited in the paddy soil.

The drainage system was established in paddy (Fine, mixed, mesic, family of Aquic Hapludalfs). The drainage spacing was 6 m apart at 0.8 m channel depth; channel width was 0.6 m with laydown of perforated PVC pipe (diameter 150 mm). The pipes were surrounded by crushed stone (0.3 deep) and a 0.1 m deep rice bran layer. Fertilizer applications were: conventional-fertilizer plot, controlled-release-fertilizer plot and no-fertilizer plot. In the conventional plot, 110 kg N (urea 46%), 45 kg P₂O₅ (fused phosphate 20%) and 57 kg K₂O (potassium chloride 60%) per hectare were applied. Controlled-release fertilizer was applied (70% N) compared to the conventional plot. Distribution of rice roots (cv. Hwabongbyeon) was investigated at horizontal distance of 0.15 x 0.05 m and vertical distance of 0.4 x 0.1 m.

This experiment was carried out to investigate the changes in soil physicochemical characteristics, rice root distribution and growth of rice grown under the tile drainage systems for three years at the National Yeongnam Agriculture Institute (Milyang), NICS.

Water depth decreased during rice growth but markedly increased in the subsurface drainage plot (Figure 5). The average water depth decrease was 7.90 mm day⁻¹ and 5.28 mm day⁻¹, in the subsurface and conventional plots, respectively, during the rice cultivation period. Water depth decrease for proper rice growth was reported as 10-20 mm day⁻¹ in Korea.

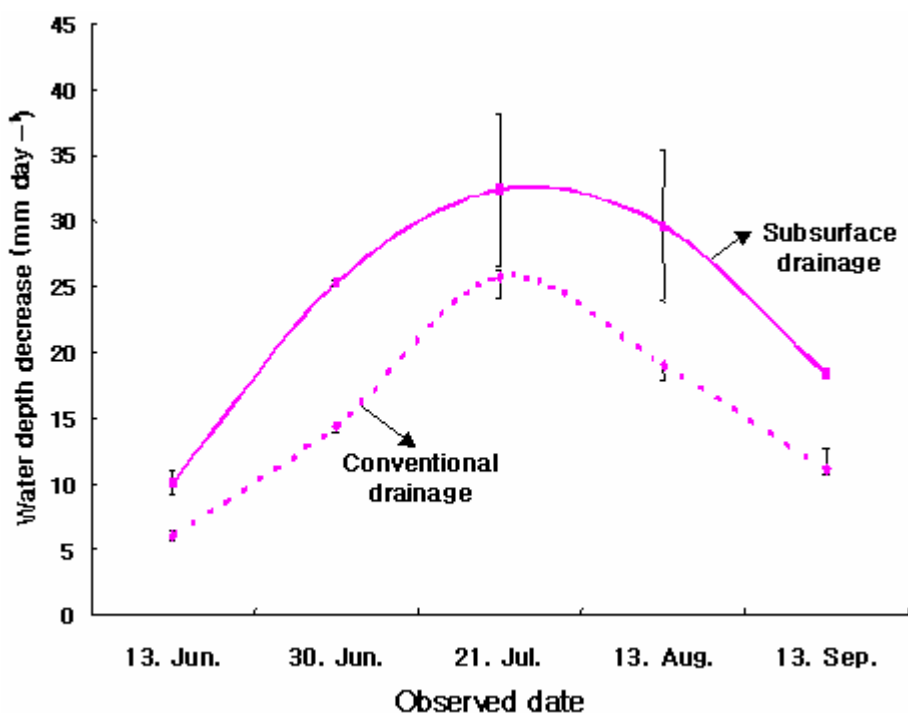


Figure 5. Changes in water depth decrease during rice growth

Changes of inorganic N ($\text{NH}_4\text{-N}$, $\text{NO}_3\text{-N}$) in water solution, measured at different rice growth stages are presented in Table 4. Leaching of nitrate was higher in the subsurface plot than in the conventional plot at the planting stage. The flows of N in the soil were divided into convection, diffusion and dispersion. But these flows were controlled by water pressure because of flooding in the paddy. Soils have no positive charges, so nitrate moves freely with water. Among fertilizers, $\text{NO}_3\text{-N}$ in effluent was lower in the controlled-release fertilizer plot compared to the conventional subsurface plot. The risk of nitrate contamination in groundwater can be reduced if controlled-release fertilizer in the subsurface drainage system is applied.

Table 4. Changes of inorganic N in water solution, measured at different rice growth stages

Drainage	Fertilizer treatment	Planting date		Tillering		Panicle initiation	
		$\text{NO}_3\text{-N}$	$\text{NH}_4\text{-N}$	$\text{NO}_3\text{-N}$	$\text{NH}_4\text{-N}$	$\text{NO}_3\text{-N}$	$\text{NH}_4\text{-N}$
----- mg l^{-1} -----							
Subsurface	CF ^a)	7.87	0.98	1.03	0.91	0.44	0.10
	CRF ^b)	6.31	0.47	0.94	0.86	0.36	0.07
	NF ^c)	4.04	0.42	0.71	0.61	0.48	0.07
Conventional	CF	2.98	4.64	0.79	0.60	0.57	0.41
	CRF	2.94	4.06	0.53	0.70	0.59	0.12
	NF	0.51	2.51	0.42	0.34	0.43	0.10

^a CF: Conventional fertilization, ^b CRF: Controlled-release fertilizer, ^c NF: No-fertilizer.

The chemical properties of experimental soil after harvest under different drainage systems are shown in Table 5. Organic matter, available phosphorus and cations were lower after the harvest than before the experiment in subsurface drainage. There were no differences in chemical properties between after harvest and before the experiment in conventional drainage.

Table 5. Chemical properties of experimental soil after harvest

Drainage	Soil layer	Fertilizer treatment	pH (1:5)	O.M (g kg ⁻¹)	Av. P ₂ O ₅ (mg kg ⁻¹)	Ex. cations (cmol ⁺ kg ⁻¹)		
						K	Ca	Mg
Subsurface	Top	CF ^{a)}	6.2	36.3	143	0.49	3.7	0.71
		CRF ^{b)}	6.1	36.7	156	0.54	4.2	0.97
		NF ^{c)}	6.1	36.0	134	0.39	5.0	0.89
	Sub	CF	7.3	35.5	131	0.64	6.7	1.67
		CRF	6.9	36.5	128	0.62	7.7	1.97
		NF	6.9	37.2	127	0.61	7.3	1.92
Conventional	Top	CF	5.8	37.5	131	0.53	4.7	0.86
		CRF	5.8	39.7	143	0.66	5.4	0.79
		NF	5.7	38.4	115	0.44	5.3	0.65
	Sub	CF	7.0	33.4	99	0.40	7.9	2.50
		CRF	7.2	35.0	104	0.42	7.1	2.00
		NF	6.9	32.8	118	0.39	6.9	1.82

^a CF: Conventional fertilization, ^b CRF: Controlled-release fertilizer, ^c NF: No-fertilizer.

A comparison of cone penetration resistance in different drainage systems is presented in Figure 6. The cone penetration resistance of conventional drainage dramatically increased in 12-18 cm soil depth. There was no major difference in cone penetration resistance *vis-à-vis* subsurface drainage in all of the soil depths.

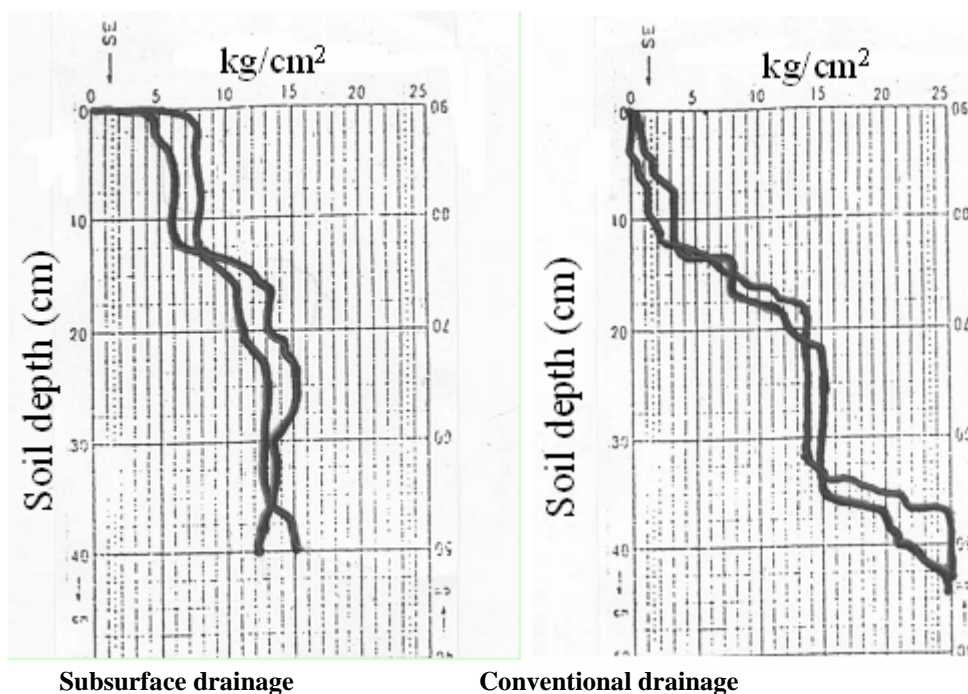


Figure 6. Comparison of cone penetration resistance in different drainage systems, measured after harvest

Root dry weights influenced by drainage and fertilizer are shown in Figure 7, measured at different vertical depth after harvest. In drained plots, the proportion of roots was estimated to be as much as 87.4 to 94.2%, distributed in the 0-0.2 m soil depth, while the estimate of root distribution in the soil surface of the plots without drainage installation was 92.4 to 97.6%. Distribution of rice roots in the subsurface soil (below 0.2 m depth) ranged from 5.8 to 12.6% in the tile-drained plots, while those in no drainage-installed plots ranged from 2.3 to 7.6%, which suggests that drainage systems caused deeper root distribution. Rice roots in the controlled-release fertilizer plot had better distribution in the subsoil than in the conventional fertilization plot. Rice roots in the no fertilizer plot were higher in conventional drainage compared to subsurface drainage at 0-0.1 m soil depth but were higher in subsurface drainage at 0.1-0.4 m soil depth.

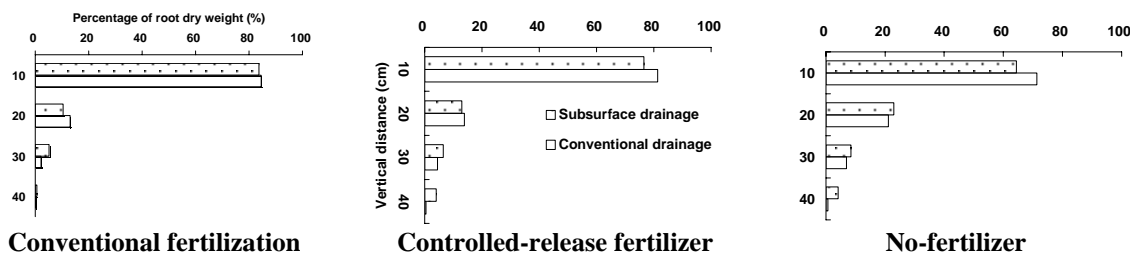


Figure 7. Root dry weight influenced by drainage and fertilizer, measured at different vertical depth after harvest

Root dry weights influenced by drainage and fertilizer are presented in Figure 8 and were measured at different horizontal distances after harvest. The horizontal distance of root distribution in the tiled plot was higher than that of the no-tiled plot at 0.05-0.1 m distance, but root distribution of the no-tiled plot was higher than that of the tiled plot at 0.1-0.15 m distance. This indicates that the horizontal distribution of roots in the no-tiled plot was wider than the tiled plot.

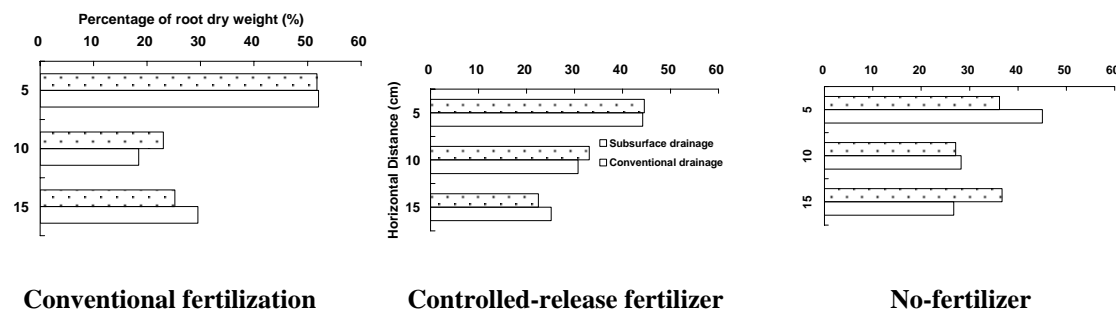


Figure 8. Root dry weight influenced by drainage and fertilizer, measured at different horizontal distance after harvest

The Rooting Depth Index (RDI) is presented in Figure 9; it was measured at harvest of rice grown under different drainage and fertilizer application systems. The RDI was higher in subsurface drainage than in conventional drainage. The highest RDI among treatments was found in the no fertilizer plot with subsurface drainage. Subsurface drainage caused a better physical and chemical environment in the soil, which led to deep rice rooting. Thus rice rooting in subsurface drainage exhibited higher RDI values than conventional drainage.

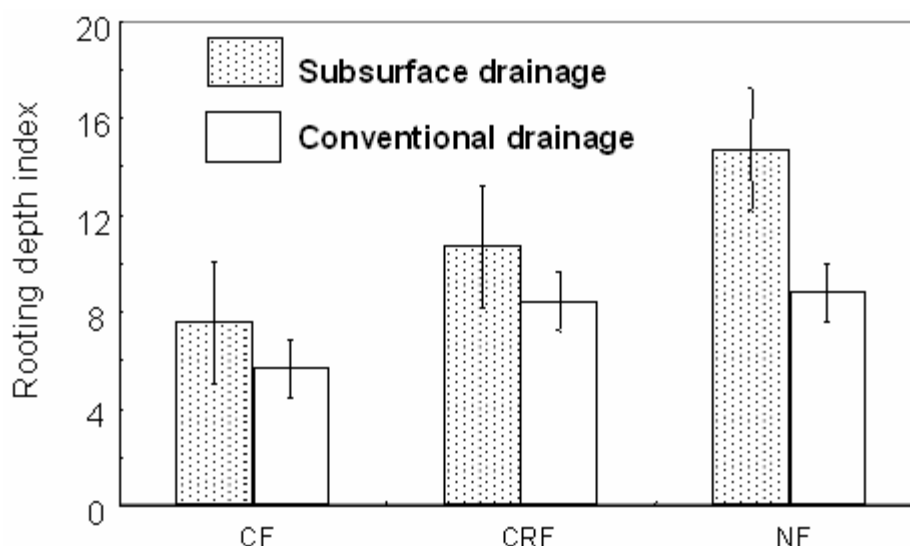


Figure 9. RDI measured at harvest of rice grown under different drainage and fertilizer application systems. RDI was calculated by the equation $\sum \text{mean of each soil depth} \times (\text{mean weight density} / 100)$. CF, CRF and NF indicate conventional fertilization, Controlled-release fertilizer and no fertilizer.

Grain yield and yield components as affected by drainage and fertilizer application systems are shown in Table 6. Field lodging of rice occurred due to typhoons in 1999 and 2000. Field lodging occurred slightly more in conventional drainage compared to subsurface drainage (data not shown). These findings generate the conclusion that rice yields can be increased in the tiled plots (improved ripened-grain ratio and 1,000-grain weight).

Table 6. Grain yield and yield components as affected by drainage and fertilizer application systems in paddy

Treatment	No. of spikelets panicle ⁻¹			Ripened grain (%)			1,000-grain wt. (g)			Milled rice (kg ha ⁻¹)		
	'99	'00	'01	'99	'00	'01	'99	'00	'01	'99	'00	'01
Subsurface												
CF ^{a)}	74.3	85.4	95.5	72.8	80.8	84.8	25.2	26.5	21.9	4,400	5,280	5,820
CRF ^{b)}	71.5	88.9	95.6	74.8	81.4	88.2	24.9	26.4	22.8	4,360	5,470	5,710
NF ^{c)}	65.4	80.5	86.2	90.6	86.7	88.7	26.1	26.5	21.9	5,040	4,710	4,970
Non-drained												
CF	71.1	84.7	96.9	84.7	76.0	84.5	25.9	26.0	21.8	5,320	4,960	5,700
CRF	74.0	78.1	91.0	90.6	79.8	88.8	25.9	25.7	22.8	5,180	4,980	5,270
NF	65.8	76.4	79.0	93.8	90.6	90.3	26.2	26.3	25.6	4,020	4,290	4,360

^a CF: Conventional fertilization, ^b CRF: Controlled-release fertilizer, ^c NF: No-fertilizer

Rice-based cropping system

Rice–barley is the oldest cropping system in Korea. However this cropping system diminished in many areas of Korea where it had been practised for a long time after the green revolution.

But this traditional cropping system helps with weed management. The occurrence (No. m⁻²) and dry weight (g m⁻²) of weeds in different cropping systems are presented in Table 7. Common weeds are, *inter alia*, *Echinochloa crus-galli*, *Persicaria hydropiper*, *Monochoria vaginalis*, *Scirpus juncooides* and *Eleocharis kuroguwai*. The occurrence of *Echinochloa crus-galli* decreased dramatically after barley cropping.

Table 7. The occurrence (No. m⁻²) and dry weight (g m⁻²) of weeds in different cropping systems in paddy (21 July)

Treatment		<i>Echinochloa crus-galli</i>	<i>Persicaria hydropiper</i>	<i>Monochoria vaginalis</i>	<i>Scirpus juncooides</i>	<i>Aneilema keisak</i>	<i>Eleocharis kuroguwai</i>	Total
B ¹⁾	Weeds No.	3.7	11.1	33.3	51.9	3.7	11.1	114.8
	Dry wt.	0.5	6.6	4.9	8.2	1.2	1.7	23.1
B+H ²⁾	Weeds No.	22.2	0	63.0	44.4	3.7	7.4	140.7
	Dry wt	4.2	0	13.0	4.7	0.7	2.1	24.7
H ³⁾	Weeds No.	11.1	18.5	44.4	44.4	3.7	14.8	140.7
	Dry wt	2.7	10.7	7.3	4.1	0.4	9.7	35.0

1) Barley, 2) Barley + hairy vetch, 3) Hairy vetch; Source: Seong *et al.* 2004.

Barley, hairy vetch, and barley+hairy vetch plots after winter crops showed weed control of 93, 93, and 90%, respectively (Table 8). Rice cultivation after barley also controlled weeds. Rice yield after barley cropping was the highest among treatments due to high weed control (Table 9).

Table 8. Rice growth and weed control in different cropping systems with paddy

Treatment	20 Aug.		Weed control (% , 21 July)
	Plant height (cm)	Tiller no. hill ⁻¹	Transplanting (25 May)
Barley	95	12.1	93
Barley + hairy vetch	94	13.1	93
Hairy vetch	93	12.6	90
Control(weed dry weight)	-	-	349.0 g m ⁻²

Table 9. Rice yield and yield components by different cropping systems in paddy

Treatment	Heading date	Culm length (cm)	Panicle No. hill ⁻¹	No. spikelets panicle ⁻¹	Ripened grain (%)	1,000-grain wt. (g)	Milled rice (kg ha ⁻¹)
B ¹⁾	21 Aug.	72.9	13.0	90.5	77.0	23.5	4,250
B+H ²⁾	21 Aug.	73.6	14.1	89.5	70.8	24.3	4,070
H ³⁾	21 Aug..	69.9	11.3	80.7	87.5	23.3	3,380

1) Barley, 2) Barley + hairy vetch, 3) Hairy vetch; Source: Seong *et al.* 2004.

The importance of leguminous green manure crops in rice-based cropping systems as well as all other cropping system cannot be overexaggerated. The importance of leguminous green manure crops for improving soil fertility and soil physical properties has received increasing attention in recent years.

The chemical properties of Chinese milk vetch cultivated soil before rice seeding are shown in Table 10. Soil pH was influenced by Chinese milk vetch cultivation. Also soil organic matter contents increased apparently through incorporation of Chinese milk vetch. NH₄-N, available phosphorus and exchangeable cations in soil had the same trend as organic matter.

Table 10. Chemical properties of soil cultivated with Chinese milk vetch before rice seeding

Treatment	pH (1:5)	O.M (g kg ⁻¹)	NH ₄ -N (mg kg ⁻¹)	Av. P ₂ O ₅ (mg kg ⁻¹)	Ex. cations (cmol ⁺ kg ⁻¹)		
					K	Ca	Mg
Bare soil	5.6	19	1.5	106	0.4	6.3	2.0
CMV ¹⁾ soil	6.1	25	6.2	161	0.5	8.1	2.8

CMV: Chinese milk vetch; Source: Jung *et al.* 2001.

The improvement in soil physical conditions as a result of build-up of organic matter by incorporation of Chinese milk vetch was associated with a decrease in bulk density and increases in porosity and soil aggregates (Table 11).

Table 11. Physical properties of soil cultivated with Chinese milk vetch before rice seeding

Treatment	Hardness(mm)		Bulk density (g cm ⁻³)	Porosity (%)	Aggregation (%)
	Top	Sub			
Bare soil	17.9	24.0	1.24	53.4	68
CMV ¹⁾ soil	14.9	18.2	1.18	55.6	80

CMV: Chinese milk vetch; Source: Jung *et al.* 2001.

Yield and growth of rice after Chinese milk vetch using different seeding methods are presented in Table 12. Compared with conventional direct seeding, rice yield was the highest in the soybean seeded plot because of sufficient panicle numbers. The yields of other treatments were 3,350 to 3,720 kg ha⁻¹.

Table 12. Yield and growth of rice after Chinese milk vetch using different seeding methods

Treatment		Culm length (cm)	Lodging degree (0-9)	No. of panicles m ⁻²	Ripened grain (%)	Milled rice (kg ha ⁻¹)
Conventional	-	76.2	5	386	85.3	4,890
CMV ¹⁾ soil	Soybean seeded	78.4	0	321	90.0	4,530
	Drill seeded	72.0	0	234	90.0	3,350
	Broadcasting	73.9	0	268	90.7	3,720

CMV: Chinese milk vetch; Source: Jung *et al.* 2001.

Rice yield after Chinese milk vetch using different cultivation methods is shown in Table 13. The effect of Chinese milk vetch was higher at transplanting than at direct seeding. But rice direct seeding has many merits under the Chinese milk vetch and rice cropping system, such as labour saving.

Table 13. Rice yield after Chinese milk vetch using different cultivation methods

Cultivation method	Treatment	Application amount	Milled yield (kg ha ⁻¹)
Transplanting	Conventional	110 kg ha ⁻¹	5,163
	Chinese milk vetch	35.4 M/T ha ⁻¹	5,072
Direct seeding	Conventional	150 kg ha ⁻¹	5,551
	Chinese milk vetch	35.4 M/T ha ⁻¹	4,832

Source: National Institute of Crop Science, RDA, 2002.

On-farm research was carried out to investigate the effect on rice growth after vegetable cultivation. Three factors were considered: cropping year, soil depth and texture. Salt content was calculated by EC before/after rice cropping. The salt content percentage ranged from 75.9 to 82.4% after the first rice cropping, but dropped to 3.6 to 7.5% after the second cropping (Table 14). After the second rice cropping, salt content dramatically decreased in paddy succeeding hot pepper. According to soil depth in paddy succeeding melon, salt content ranged from 88 to 90% in the surface soil and 33.8 to 48.9% in the subsoil.

Table 14. Salt content¹⁾ after rice cultivation in a hot pepper and rice cropping system and soil depth in a melon and rice cropping system

Treatment	Hot pepper-rice		Melon-rice	
	Hot pepper-rice	H-R-F-R ²⁾	Surface	Sub-surface
CF ³⁾	75.9	7.5	88.0	35.3
NBF ⁴⁾	81.8	3.6	89.5	48.9
NTD ⁵⁾	78.2	5.3	89.4	33.8
NF ⁶⁾	82.4	3.8	90.0	48.4

1) Salt content (%) = (EC before experiment - EC after experiment)/EC before experiment X 100.

2) H-R-F-R: Hot pepper-rice-fallow-rice.

3) CF: conventional fertilization, 4) NBF: no basal fertilization.

5) NTD: no top dressing, 6) NF: no fertilizer.

Salt content was higher in coarse loamy soil than in fine loamy soil. Among treatments, salt content was highest in the no fertilizer plot (Figure 10).

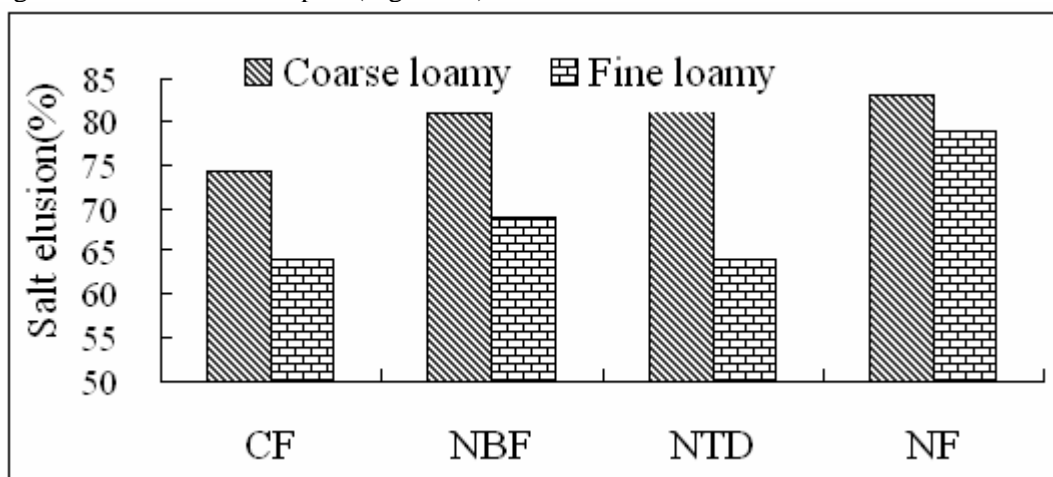


Figure 10. Percentage of salt content under rice cultivation in different soil textures with or without fertilizer application. For CF, NBF, NTD and NF, see Table 14.

Rice yields of the no fertilizer plot in greenhouse soil by different years, cropping systems, soil texture and cultivars are presented in Table 15. Rice yield after vegetable cropping depended mainly on cultivation years and soil texture due to the exploitation of built-up nutrients.

Table 15. Rice yield of the no fertilizer plot with greenhouse soil by different years, cropping systems, soil texture and cultivars

Year	Cropping system	Soil texture	Cultivar	Milled rice (kg ha ⁻¹)
1998	Pepper-rice	Fine loamy	Geumobyeo 2	4,500
1999	Pepper-rice-fallow-rice	Fine loamy	Geumobyeo 2	3,900
1999	Melon-rice	Fine loamy	Geumobyeo 2	4,210
2001	Pumpkin-watermelon-watermelon-rice	Fine loamy	Hwayoungbyeo	4,200
2001	Watermelon-rice	Coarse loamy	Hwayoungbyeo	3,710

Our results showed that desalting of soil increased after only one rice cultivation in vegetable–rice cropping systems, regardless of preceding crops, soil depth and texture.

Conclusion

Application of organic sources into paddy soil can improve the root distribution in the subsoil layer and magnify the soil rhizosphere. Compost application also resulted in improved organic matter status, which led to better soil physical condition, reduced bulk density and cone penetration resistance which ultimately increased root distribution widely and deeply. The conventionally drained system decreased the improvement of rice roots. The subsurface drainage system showed deep root systems due to continuous water percolation. Based on rice growth and nutrient leaching, therefore, the benefits of subsurface drainage could be synergistic when combined with controlled-release fertilizer. The water recycle system should also be considered. Relative to cropping systems, barley cultivation and green manuring in the context of rice-based cropping will result in better soil properties and an improved rhizosphere environment. Rice cultivation in greenhouse soil was a good method to manage a sustainable soil rhizosphere.

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