Korean J. Crop Sci. 46(1): 6~11(2001)

Effect of Rice Cultural Practices on Water Percolation, Irrigation Requirement, and Nitrogen Leaching under Lysimeter Condition

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ABSTRACT : In this lysimeter experiment, temporal changes of water percolation rate, irrigation requirement and NO_3^--N leaching were investigated under different cultural practices that were no-till direct seeding on flooded paddy (NTDSF), till direct seeding on flooded paddy (TDSF), and transplanting. The highest water percolation rate of 3,001 l/m² was measured in NTDSF. Others were 2,551 l/m² and 2,210 l/m² in TDSF and transplanting. Water percolation rate in NTDSF and TDSF was increased by 36% and 15% compared to transplanting. Water percolation rates in all cultural practices were increased remarkably from the reproductive growth stage and relatively large amount of water loss through percolation was measured even after the reproductive growth stage. A total irrigation requirement was 3,469 l/m² in NTDSF and 2,898 l/m² in TDSF. That was equivalent to 45% and 21% of increase compared to 2,389 l/m² in transplanting. The largest NO_3^--N leaching through the entire rice growing period was 701 mg/m² in NTDSF and was followed by 494 mg/m² in TDSF and 465 mg/m² in transplanting. The ratios to the total amount of NO_3^--N leaching at the vegetative growth stage, reproductive growth stage and ripening stage were 31%, 41% and 28% in NTDSF; 21%, 48% and 31% in TDSF; and 18%, 48% and 35% in transplanting.

Key words : cultural practice, no-till direct seeding, till direct seeding, transplanting, water percolation rate, irrigation requirement, nitrate leaching

As a labor saving cultural system, the area of direct seeding rice cultivation has been increased since 1990 up to 70,700 ha in 1999 that is approximately 6.6% of the entire area of rice paddy field in Korea. No-till direct seeding on flooded paddy (NTDSF) reduces 5.1 hours of labor per 10a for land preparation (Park *et al.*, 1996). Since NTDSF does not disturb the physio-chemical property of soil, it can be considered as an available method for the sustainable rice cultivation. It should be emphasized, however, that a large amount of irrigation requirement is needed for direct seeding rice cultivation due to a longer growth duration in paddy field than transplanting (Lee, 1995). Moreover, irrigation requirement in NTDSF is remarkably increased by an accelerated water percolation (Chae, 1998).

According to Sanchez (1973a, b), water percolation is considerably larger in granulated soil than puddled soil and the amount of water retained by the soil is substantially increased by puddling. This is attributed to the physical changes of soil affected by puddling. When clay soil is plowed and harrowed, soil aggregates are broken down into a uniform mass (Koenigs, 1963). Subsequently, the macro- porosity of clay soils is decreased and their microporosity is increased by puddling, therefore, the water-holding capacity of the puddled soil is increased (Jamison, 1953). As a result, De Datta and Kerim (1974) reported that regardless of a plow pan which was formed by compaction during the puddling process, a puddled layer itself reduced the water loss through percolation in rice paddy, thereby, unpuddled soil received twice as much water (1,180 mm) as puddled soil (588 mm). However, studies on temporal changes of water percolation affected by cultural practices are hardly available.

It has been known that the total amount of water required for rice cultivation is on the average 1,240 mm in field operation (Yoshida, 1981). In an experiment, irrigation requirement by different cultural practices was 1,753 mm in NTDSF, 1,231 mm in TDSF and 975 mm in transplanting (Cho *et al.*, 1995). Besides, the irrigation requirement in NTDSF and TDSF was increased 37% and 59% more than transplanting, respectively (Chae, 1998). However, there is a lack of proper understanding on the temporal changes of irrigation requirement during the rice cultivation under various cultural practices. Considering the limited water capacity of rivers as a source of irrigation water and the unusual climatic changes of recent years, it is of importance to understand the effect of cultural practice on the irrigation requirement for the rice cultivation under water insufficiency.

On the other hand, it was assumed that the large amount of water percolation in NTDSF and TDSF may result in greater NO_3^--N leaching loss. In an experiment conducted under silty loam condition, NO_3^--N loss through leaching was 10.4 kg/ha (Han *et al.*, 1998) Moreover, N leaching losses caused

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by a high percolation rate decreased rice yields (De Datta and Kerim, 1974). However, temporal changes of NO_3^--N leaching losses during rice cultivation has been scarcely investigated because of the technical difficulties of measuring such losses in the field. As a result, the purpose of this lysimeter experiment was to investigate the temporal changes of water percolation rates, irrigation requirements and NO_3^--N leaching during rice growing period under NTDSF, TDSF and transplanting condition for the low-input sustainable agriculture.

MATERIALS AND METHODS

The lysimeter experiment was conducted at the research farm of Dankook university in 1999. The plastic lysimeter was 94 × 49 × 64 cm in size, 4,606 cm^2 of surface area and 0.32 m^3 in volume. To prevent an abnormal changes in the soil temperature of lysimeter, soil was piled up and styrofoam was placed beside the lysimeter (Fig. 1). The soil was sandy loam (clay 22.1%, silt 34.1% and sand 43.8%) with pH 5.3, organic matter 1.4%, and 106.3 ppm available P_2O_5 contents. Three different cultural practices which were no-till direct seeding on flooded paddy surface (NTDSF), till direct seeding on flooded paddy surface (TDSF) and transplanting were applied by a completely randomized design with four replications. Since rice was cultivated for two years in the lysimeter prior to this experiment, soil condition of the lysimeter was considered to be settled as field condition. Besides, the tillage of soil was accomplished by hand until a degree similar to field condition was attained.

Rice cultivar, Chucheong-byeo, was seeded on both direct seeding plots and seedling box for transplanting. Seventy-two pregerminated rice seeds were sown directly in direct seeding plots on 5 May, and thinned to 36 plants at 4th leaf stage. 26 days old seedlings were transplanted with spacing of 30 cm × 15 cm (3 seedlings per hill and 12 hills per lysimeter) on 1 June. Fertilizer application rates were N-P-K=18-12-14 kg/10a in direct seeding plots and N-P-K=15-10-12 kg/10a in transplanting plot. Split application of nitrogen was applied at the rate of 40% (basal) : 30% (4-leaf stage) : 20% (panicle initiation stage) : 10% (heading stage) in direct seeding plots, and 50% (basal) : 30% (tillering stage) : 20% (panicle initiation stage) in transplanting plot. Phosphorus was applied as a basal, and potassium was applied at the rate of 70% (basal) and 30% (panicle initiation stage). Flooding depth was maintained 1~5 cm throughout the rice growing period. Other cultivation managements were applied by standard methods.

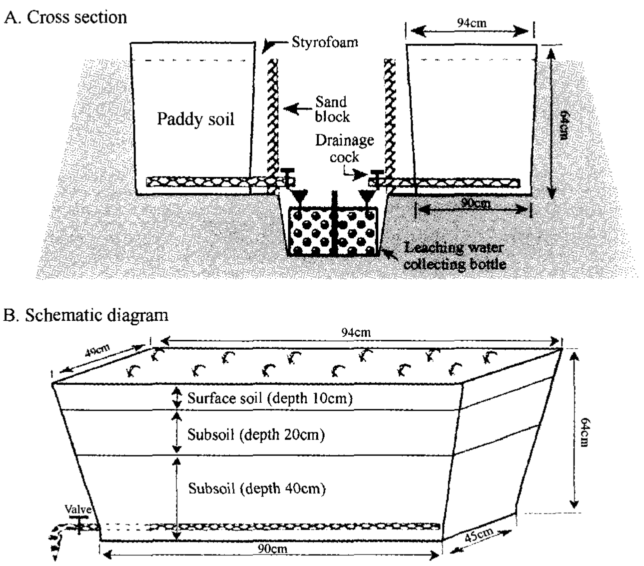

Fig. 1. The cross section and schematic diagram of lysimeter experiment.

The amount of irrigation water, rainfall and water percolation rates were measured daily after direct seeding and transplanting. Irrigation requirement was the sum of the effective precipitation and daily measured irrigation rate. Evapotranspiration was calculated by subtracting the water percolation rate from irrigation requirement. Leaching water was sampled at one week interval and for five consecutive days after fertilizer application. The samples were filtered with Whatman (CF/G) filter paper and analyzed for NO_3^--N by Ultraviolet spectrophotometric method (APHA, 1995) : 50 ml of the filtrates was mixed with 1 ml of HCl (1*N*). NO_3^--N of the mixture was determined with UV-spectrophotometer (Varian Model : 1) at 220 nm wave length. NO_3^--N leaching loss was calculated by multiplying NO_3^--N concentration (ppm) in the leachate with the amount of water percolation (*l*).

RESULTS AND DISCUSSION

Changes in water percolation rate

Water percolation rates were high immediately after direct seeding and transplanting then decreased rapidly within a week. The rates were maintained at the level of 4.7~9.3 l/m^2/day in NTDSF, 2.3~7.2 l/m^2/day in TDSF and 3.0~6.3 l/m^2/day in transplanting until the end of vegetative growth stage (Fig. 2). However, the rates started to increase drastically after the middle of July, and then leached 39 l/m^2/day in NTDSF, 38.6 l/m^2/day in TDSF and 33 l/m^2/day in transplanting at the heading stage. Further increasing of water percolation was not observed after the heading stage. During the entire observation period, the maximum water percolation rate was measured at the late growing stage. The rate was the largest in NTDSF (39~43 l/m^2/day) followed by TDSF (36~39 l/m^2/day) and transplanting (31~37 l/m^2/day),

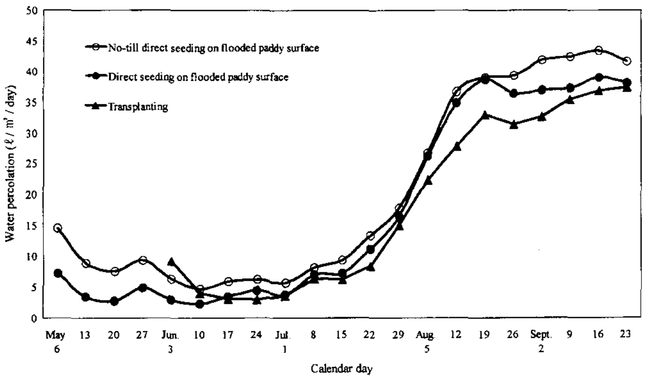

Fig. 2. Temporal changes in daily amount of water percolation as affected by different cultural practices under lysimeter condition of rice paddy soil.

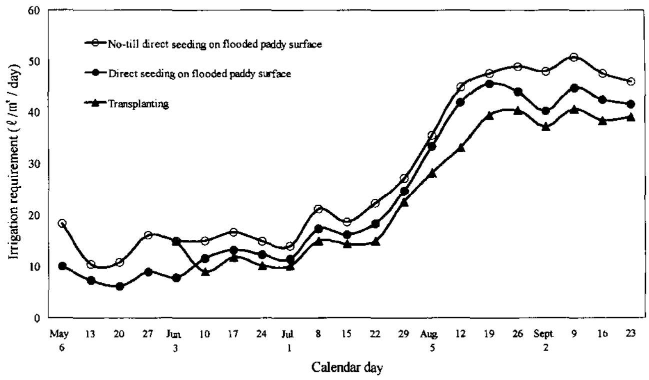

Fig. 3. Temporal changes in daily amount of irrigation requirement as affected by different cultural practices under lysimeter condition of rice paddy soil.

respectively. The total amount of water percolation during the rice growing period (Table 1) was the largest in NTDSF (3,001 l/m^2), and was followed by TDSF (2,551 l/m^2) and transplanting (2,210 l/m^2).

It has been known that the total number of roots reached their maxima at about 20 days before the heading stage (Hoshikawa, 1975). The number and weight of roots per stem were greater in direct seeding than transplanting (Hoshikawa, 1989). A compact rice root system composed of main axes was observed under much water percolation condition (FAPRC, 1993). From these results, it was interpreted that the increase of water percolation after the reproductive growth stage was attributed to soil pore spaces formed by the aging and partial rotting of roots, and this increase was greater in the direct seeding plots which had more number of roots. In the absence of the subsoil water table, the lysimeter soil condition may have exaggerated the results of this experiment. Nevertheless, it should be emphasized that the difference of water percolation rate was obviously affected by cultural practices.

Changes in irrigation requirement

The effect of cultural practices on irrigation requirement is illustrated in Fig. 3. Until the early reproductive growth stage (Jul. 28), irrigation requirement was on the average 16.1 l/m^2/day in NTDSF, 11.6 l/m^2/day in TDSF and 12.5 l/m^2/day in transplanting. The irrigation requirement, regardless of cultural practices, was drastically increased after the panicle formation stage and its largest amount was observed at the heading stage that the highest was 49 l/m^2/day in NTDSF and it was followed by 44 l/m^2/day in TDSF and 40 l/m^2/day in transplanting.

It was known that the small water requirements of rice plant from the tillering stage through the heading stage caused by the continuing active dry matter production during this sink enlarging period (Matsubayashi *et al.*, 1955; FAPRC, 1995). In this pont of view, it is resonable to understand that the larger growth increments of shoot including the tiller numbers per m^2 in direct seeding plots resulted in the small amount of water requirement, but on the other hand, the higher amount of water percolation in the plots accelerated the increase of irrigation requirement after the reproductive growth stage. Therefore, the total irrigation require- ment during the rice cultivation period (Table 1) was the largest in NTDSF (3,469 l/m^2), and was followed by TDSF (2,898 l/m^2), and transplanting (2,389 l/m^2). In relation to this result, Chae (1998) previously reported

Table 1. The effect of cultural practices on the amount of water percolation, irrigation requirement and NO_3^--N losses under lysimeter condition of rice paddy soil during rice growing periods.

Treatments†	Irrigation periods (day)	Percolation amount (l/m^2)	Irrigation requirement (l/m^2)	NO_3^--N concentration (ppm)	NO_3^--N leaching (mg/m^2)
NTDSF	148	3,001a	3,469a	9.05	701.4
TDSF	148	2,551b	2,898b	7.37	493.6
Transplanting	121	2,210c	2,389c	6.28	465.1

†NTDSF : No-till direct seeding on flooded paddy
TDSF : Till direct seeding on flooded paddy
Means followed by different letters are different at p=0.05 by DMRT.

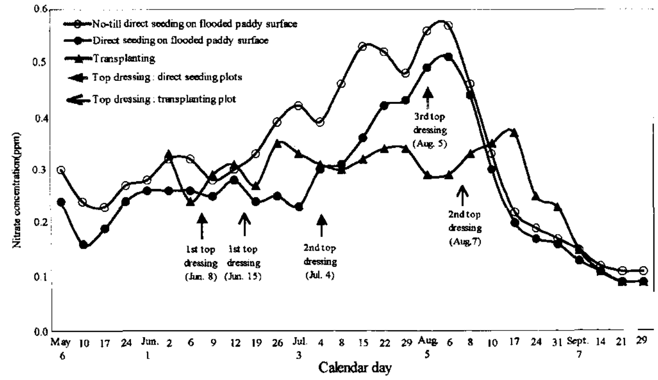

Fig. 4. Temporal changes in NO_3^--N concentration (ppm) of daily leachate as affected by different cultural practices under lysimeter condition of rice paddy soil.

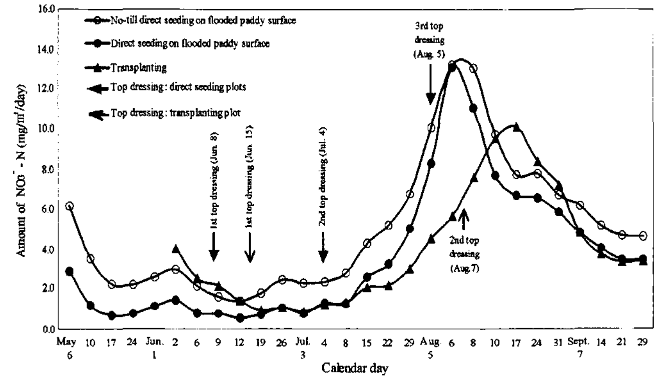

Fig. 5. Temporal changes in daily NO_3^--N loss (mg/m^2/day) through leaching as affected by different cultural practices under lysimeter condition of rice paddy soil.

that a total irrigation requirement was 3,770 l/m^2 in NTDSF, 3,249 l/m^2 in TDSF and 2,321 l/m^2 in transplanting, respectively.

NO_3^--N leaching

The concentration of NO_3^--N in leachate was increased with N fertilizer application (Fig. 4). NO_3^--N concentration reached 0.57 ppm in NTDSF and 0.51 ppm in TDSF immediately after the third top dressing (Aug. 6) and decreased rapidly. Besides, the concentration in transplanting was the highest (0.37 ppm) 10 days after the third top dressing (Aug. 17). The rates of NO_3^--N leaching (Fig. 5) were increased shortly after direct seeding and transplanting, and then showed 1.4~3.0 mg/m^2/day in NTDSF, 0.7~1.5 mg/m^2/day in TDSF and 0.9~2.1 mg/m^2/day in transplanting until the end of vegetative growth stage (Jul. 8). However, NO_3^--N leaching was increased rapidly with the increase of water percolation rate in the end of vegetative growth stage. Consequently, the NO_3^--N leaching reached on the average 13.2 mg/m^2/day in NTDSF and 12.1 mg/m^2/day in TDSF during Aug. 6~8. On the other hand, NO_3^--N leaching measured in transplanting during Aug. 11~31 was 7.2~10.1 mg/m^2/day which was higher than direct seeding plots during the same period of time.

The third nitrogen top dressing in transplanting plot was applied 2 days later than direct seeding plots and its amount (3 kg/10a) was higher than direct seeding plots (1.8 kg/10a). Therefore, the difference of NO_3^--N leaching between direct seeding plots and transplanting plot in the late rice growing stage was attributed to the higher NO_3^--N concentration in transplanting plot (0.23~0.37 ppm) compared to direct seeding plots (0.16~0.22 ppm).

The total amount of NO_3^--N leaching (Table 1) was 701 mg/m^2 in NTDSF, 494 mg/m^2 in TDSF, and 465 mg/m^2 in transplanting, respectively. This is equivalent to the increase of 51% in NTDSF and 6% in TDSF compared to transplanting. In addition, NO_3^--N leaching during the vegetative growth stage, the panicle formation stage to the heading stage, and the ripening stage (Table 2) were 219, 286 and 197 mg/m^2 in NTDSF; 101, 237 and 155 mg/m^2 in TDSF; and 81, 223 and 161 mg/m^2 in transplanting. In other words, the ratios to the total amount of NO_3^--N leaching in NTDSF, TDSF and transplanting at each growth stage of rice were 31.3%, 20.5% and 17.5% in the vegetative growth stage, 40.7%, 48.0% and 47.9% in the panicle formation stage to the heading stage, and 28%, 31.4% and 34.6% in the ripen-

Table 2. NO_3^--N loss (mg/m^2) through leaching at the growth stage of rice as affected by different cultural practices under lysimeter condition of paddy soil.

Treatments†	Vegetative growth stage (May 5~Jul.22)	Panicle formation~ Heading stage (Jul. 23~Aug. 24)	Ripening stage (Aug. 25~Sept. 29)	Total
NTDSF	219.3 (31.3)	285.6 (40.7)	196.5 (28.0)	701.4 (100)
TDSF	101.4 (20.6)	237.1 (48.0)	155.1 (31.4)	493.6 (100)
Transplanting	81.4 (17.5)	222.7 (47.9)	161.0 (34.6)	465.1 (100)

†NTDSF : No-till direct seeding on flooded paddy
TDSF : Till direct seeding on flooded paddy
( ) : Percentage to total NO_3^--N loss in each cultural practice.

ing stage. These results indicated that in transplanting, NO_3^--N leaching was occurred mainly during the reproductive growth stage. In NTDSF, however, considerably large amount of NO_3^--N leaching was observed during the vegetative growth stage.

It has been known that N loss through leaching during the rice cultivation is site- and season-specific, but the estimated leaching loss of fertilizer N was known to be 5~25 kg N/ha (Craswell *et al.*, 1979). Although the soil of this experiment was sandy loam and its OM content was relatively low (1.4%), a certain amount of NO_3^--N leaching which could cause the water pollution was not observed. Therefore, it was concluded that NO_3^--N leaching may not be a critical issue of environment under rice cultivation condition in Korea unless it is sandy soil or an excessive N application. In general, it was assumed that NO_3^--N leaching in rice paddy occurred mainly either in the beginning of transplanting or after supplementary fertilizer application. However, in this experiment, the considerable amount of NO_3^--N leaching was observed in the panicle formation stage as well as in the ripening stage. Therefore, it was thought that nitrogen application should be managed carefully until the harvesting season.

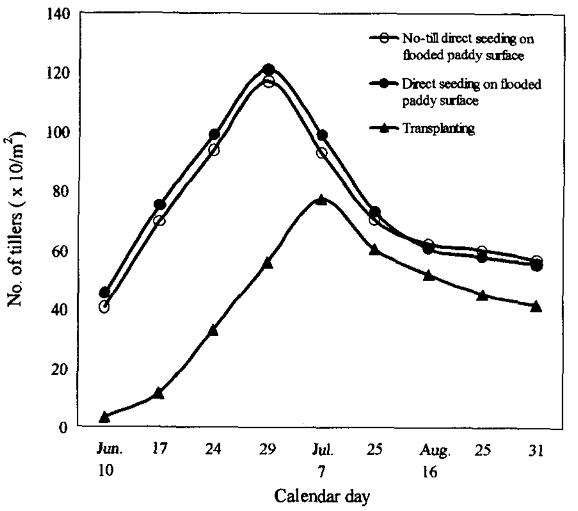

Fig. 6. Changes in tiller number of rice as affected by different cultural practices under lysimeter condition of paddy soil.

Growth and yield of rice

Tiller number at the maximum tillering stage was 1,206/m^2 in TDSF and 1,168/m^2 in NTDSF and 758/m^2 in transplanting (Fig. 6). It was thought that higher tiller number in direct seeding plots compared to transplanting plot was because the emergence of tillers was initiated without transplanting injury, and tillering node was lower due to shallow seeding on the flooded paddy. Besides, the maximum tillering stage was 8 days earlier in direct-seeding plots (Jun. 29) than transplanting plot (Jul. 7).

Rough rice yield was higher in TDSF than NTDSF (Table 3). This was attributed to the difference of water percolation rate between TDSF and NTDSF. According to Sharma *et al.* (1989), water percolation aggravated nutrient losses at OM content less than 51 g/kg. Therefore, it was interpreted that the larger water percolation rate in NTDSF caused greater N loss and less N uptake, thereby, rice yield was significantly lower in NTDSF.

It has been known that the yield of directly seeded rice in general is lower than transplanting due to unstable seedling stand, weed emergence and lodging (Park and Lee, 1992). However, in this experiment which was conducted to investigate the patterns of water percolation rate, irrigation requirement and NO_3^--N leaching loss, the negative factors in the direct seeding rice cultivation were prevented. Besides, the different amount of fertilizer was applied to direct seeding plots and transplanting plot for the proper management of cultivation. Therefore, it was interpreted that the larger amount of fertilizer application and more panicle numbers per m^2 in direct seeding plots resulted in the higher yields in the plots compared to transplanting plot.

Table 3. Yield and yield components as affected by different cultural practices under lysimeter condition of paddy soil.

Treatment†	Heading date	No. of panicles per m^2	No. of spikelets per panicle	1000 grain wt. (g)	Grain filling ratio (%)	Rough rice yield (kg/10a)
NTDSF	Aug. 24	491	68	24.2	83.6	668
TDSF	Aug. 24	525	65	24.1	86.1	705
Transp.	Aug. 26	419	70	24.7	88.4	648
F-value	-	61.33**	21.63**	NS	5.31*	49.53**
LSD.05	-	6.98	0.56	-	1.05	4.15

†NTDSF : No-till direct seeding on flooded paddy
TDSF : Till direct seeding on flooded paddy
Transp. : Transplanting
*,** : Significant at 5% and 1% level, respectively.

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