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Percolation barriers increase and stabilize rainfed lowland rice yields on well drained soil

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ABSTARCT

Increasing rainwater utilization efficiency is a key factor in improving rice yields on well-drained soils. We evaluated the possibility of improving field rainwater storage through installation of subsurface percolation barriers. Polyethylene sheets were inserted at 25 cm and 40 cm depths in experiments at Ubon, northeast Thailand, and IRRI, Philippines, on soils ranging in texture from loamy sand to clay. The barriers maintained surface flooding throughout the growing season, whereas in non-barrier plots surface water accumulation was brief and severe drought stress was induced. Total dry matter yields in Ubon were increased from 1.6 t/ha to 6.2 t/ha with barrier installation. Grain yields ranged from 1.8 t/ha to 2.7 t/ha with barriers, but in both years were zero without. At IRRI yields ranged from 3.2-5.7 t/ha with barriers, and 1.5-3.3 t/ha without. The barriers also increased cropping intensity, allowing two rainfed rice crops per wet season in both sites. The positive results have stimulated subsequent work to develop barriers using more practical materials and insertion methods. If the technology can be made cost-effective, the concept of percolation barriers may be a significant technological advance in rainfed rice farming.

INTRODUCTION

In non-irrigated areas the opportunity to secure a successful rice crop is dependent upon unpredictable monsoon rains. Low soil moisture supply is generally the most serious factor limiting rice production, and rainless periods when the field drains are usually damaging to a rice crop (Moorman and Breeman, 1978). To reduce the risk of severe moisture stress due to drought, tropical rice farmers normally establish their crop during the mid-rainy season. Field bunding and levelling limits run-off and improves the capacity to store surface water. Despite these practices, rainfed lowland rice yields are erratic because of fluctuations in rainfall timing and intensity. The rapid soil drying after the rains cease also makes the production of post-rice crops risky.

Being a semi-aquatic species, rice tends to thrive best when water is continuously provided. In some soils, such as those with high organic matter content, some percolation (5 to 20 mm/day) may be essential to regulate soil temperature, leach phytotoxins from anaerobic decomposition, and enhance root activity (Lal, 1985). But in most tropical soils yield potential is maximized when the paddy field is kept saturated or submerged throughout crop growth (Isozuki, 1957; De Datta and Williams, 1968; Sahu and Raut, 1969). This aquatic miliew offers several advantages: Sufficient water supply, ease of land preparation, simplified weed control, more neutral soil pH, and greater availability of plant nutrients (Moorman and van Breeman, 1978).

Water loss due to percolation beyond the root zone is the dominant contributor to the high water requirement of rice, particularly in the light-textured soils with low water-holding capacity and deep groundwater table in paddy fields situated in the upper landscape. It is estimated that 50 to 80% of the total water applied to rice is lost through deep percolation (Ray and Pandey, 1969; Pande and Mitra, 1971; Yadav, 1972), with percolation rates ranging from about 1 mm/day in compact, fine-textured soils to several hundred mm/day in coarse-textured soils (Wann, 1978).

Shallow rainfed, drought-prone ricelands occupy over one-third of the Asian rainfed lowland rice area (Garrity et al., 1986). Two countries, India (7.3 m ha) and Thailand (3.2 m ha), account for 80 % of the drought-prone subecosystem in Asia. As much as one third of the paddy land in Northeast Thailand remains unplanted each year due to insufficient water for maintaining seedbeds and for transplanting (Craig and Baker, 1986). Up to 20 percent of the land that is transplanted fails because of periodic drought. The upper paddies although bunded, are planted last and may be successfully harvested in only three or four years out of ten (Craig and Pisone, 1985). The rainfed drought-prone ecosystem is important in most Southeast Asian countries, including Cambodia, Vietnam, Laos, and the Philippines. When combined with the drought- and submergence-prone subecosystem, more than one-half of the shallow rainfed area has serious problems of water stress (Garrity et al., 1986).

Many rainfed lowland rice-growing areas actually receive a total amount of rainfall adequate for rice cultivation, but distribution within the growing season is problematic. Water stress could be avoided if the rainwater were more efficiently retained in the root zone against percolation and seepage. Likewise, in irrigated areas the efficiency of water use could be increased, and the irrigable area expanded, if the water requirement per field were reduced through improved retention of surface water.

The efficient husbandry of natural rainwater in rice fields can be a worthy alternative to the development of irrigation systems that attempt to deliver additional water from elsewhere. Most rainfed areas are on landscapes that are difficult and expensive to irrigate. Yet virtually all are located in areas that receive rainfall during the rainy season adequate to maintain a rice crop without supplemental water, if the rain water were lost only to evapotranspiration rather than to seepage and percolation.

Percolation can be reduced by increasing the degree of subsurface compaction, resulting in a more effective hard pan (Patel and Singh, 1986). Puddling is an old practice to control percolation. It decreases soil permeability and increases water retention capacity (Adachi and Inoue, 1988). But it is laborious and often has little effect on the soil physical properties, or consequently on yield, in sandy soils. In the ricelands of Northeast Thailand, farmers plow their fields mainly to soften the soil for transplanting, which must be done immediately afterwards (Herrera et al., 1989).

In Japan, percolation reduction by bulldozer compaction is popular (Tabuchi, 1988). The field application of 400 to 600 m3/ha of impermeable soil is also used for percolation control. Vinyl sheets are used in the sand dune district.

Percolation control by the placement of subsurface barriers presents an alternative for improved rice production that has received little attention. Physical barriers installed in the subsoil may be composed of a petroleum-based substance, such as bitumen (Rao et al., 1972), polyethylene (Parashar, 1978), or other plastic materials. They are spread or sprayed upon the subsoil surface after exposure by deep tillage, or impregnated into the soil under pressure. Advances in the development of such materials, and the engineering to apply them economically, indicate that such technologies may be feasible in the future.

We initiated a program of on-station and on-farm research to evaluate the effects of percolation barriers on the surface hydrology of rainfed drought-prone rice lands, and on rice productivity and crop intensity. The work was part of a collaborative project between the Thai Department of Agriculture and IRRI (Herrera et al., 1987). Research was conducted at the Ubon Rice Research Center, Ubon Ratchathani Province, and on three farms in varying landscape positions with fine sandy soils typical of Northeast Thailand. Similar work was conducted at IRRI, Los Banos, Philippines, on a clay soil located on a high landscape position on a well drained slope. This paper highlights some of the key results of the research in both countries.

EXPERIMENTAL CONDITIONS

The soil at the Ubon Rice Research Center (URRC) was of the Ubon Series (Aeric Palequult), strongly acidic (pH 4.4), and sandy (78.8% sand, 16.4% silt and 4.8% clay). It had no hardpan layer in the upper 100 cm of the profile. The ground water table in the dry season was very deep (>4 meters). Bulk density in the upper 40 cm ranged from 1.57 to 1.67 g/cc, but the infiltration rate was high (66.2 cm/day). The soil was quite infertile: Organic carbon 0.38%, cation exchange capacity 1.46 me/100 g ads, total N 0.02%, available P of 1.0 ppm, and K of 0.02 ppm.

Eight treatments were evaluated in four replications, including two treatments where a polyethylene sheet was buried at either a 25 cm (T1) or 40 cm (T2) depth. In two treatments the soil was similarly removed to 25 cm (T3) or 40 cm (T4), then returned with no plastic sheet installed. One other treatment (T5) had a plastic sheet buried vertically around the perimeter of the plot to control seepage. Two treatments were conventional undisturbed control plots, without (T6) or with (T7) perimeter bunds to impound surface water. In the last treatment (T8) the soil was removed to a depth of 25 cm to test the ability of the depression to store water. All plots were bunded except T6. The plots were subdivided to compare two rice establishment methods, dibbling and transplanting.

The soil at the IRRI research site in the Philippines was a clayey Typic Tropudalf of 44% clay, 40% silt and 17% sand. The site was well drained, being located on a high landscape position. Bulk density values at the onset of the trial ranged from 1.00 to 1.09 g/cc at the upper 40 cm depth. The soil was acidic (pH 5.4) and had a low N fertility level

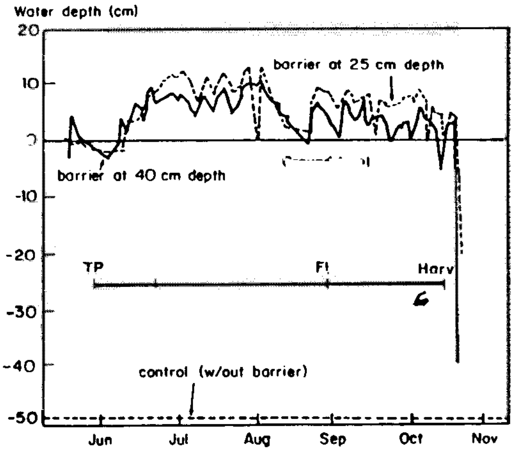

Fig. 1 Ground water levels in paddy plots with and without subsurface percolation barrier URRC, Thaialnd. 1989 wet season

(0.11%) and organic C (0.97%). The cation exchange capacity was 31.1 meq/100 gm soil and available P (Olsen) was 21.4 ppm. Five treatments were tested at IRRI: Percolation barriers at 25 cm (T1) and 40 cm (T2) depths; soil removed to 25 cm (T3) or 40 cm (T4) and replaced but without barrier installation; and a conventional undisturbed control (T5). Three transplanted rice crops were grown successively from 1989 to 1990.

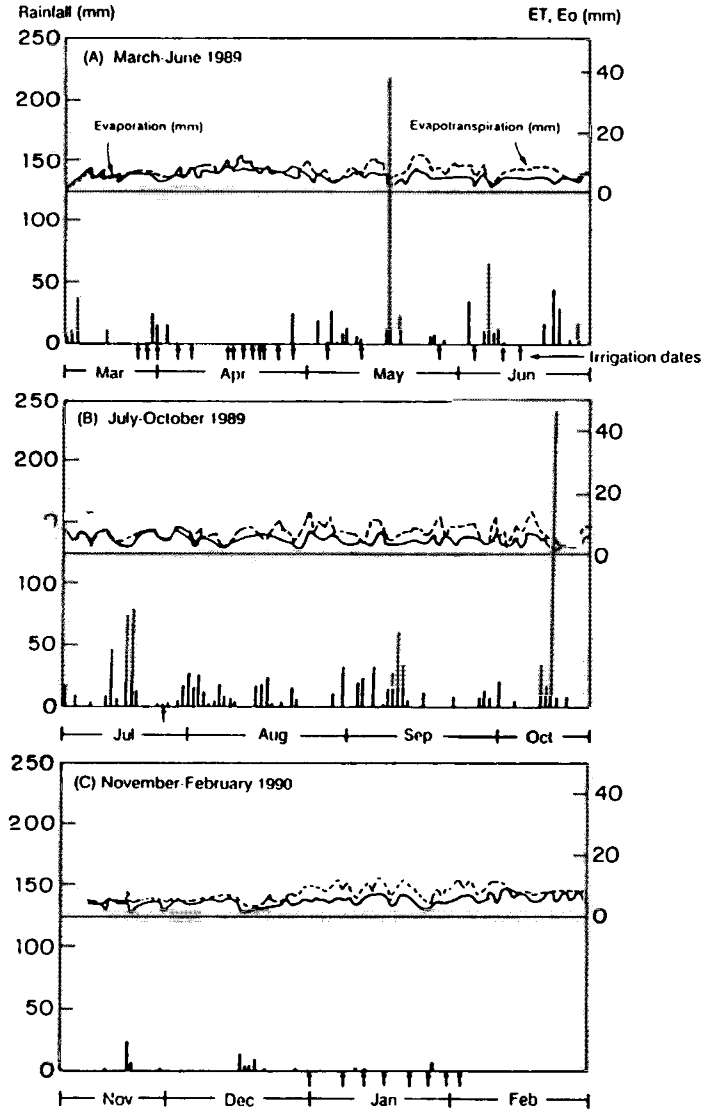

Fig. 2 Daily rainfall, pan evaporation and evapotranspiration values, and irrigation incidents. Percolation barrier trial. IRRI

BARRIER EFFECTS ON PADDY HYDROLOGY

The experiment at Ubon was strictly rainfed. Total rainfall during the growing season was 1429 mm in 1989, and 1606 mm in 1990. Water accumulated on the soil surface throughout the season in the plots with percolation barriers but was not retained for any length of time in plots without barriers (Figure 1). The surface soil condition permitted transplanting but the ground water level was below 50 cm throughout the season. Water accumulated more rapidly in the T1 (with the barrier at 25 cm depth) than in the T2 plots (with the barrier at 40 cm depth), but the plants in T1 also tended to dry faster during long breaks in the rains. Presumably this was because of a lesser volume of confined water in the soil profile and the more restricted root volume with the 25-cm barriers. The soil moisture content was lower in the shallow barrier treatment at the end of the 1989 growing season.

The trial at IRRI followed a partial irrigation protocol: During the first crop (1989 DS), irrigation water was applied frequently during lulls in the rains to meet an average daily evapotranspiration demand of 10 mm/day (Figure 2). During the 1989 wet season crop only one irrigation was applied since rainfall was fairly uniform. In the third crop, grown during the wet-dry transition period of 1989-90, irrigation was applied uniformly on a weekly basis in all treatments to meet the actual evapotranspiration demand of the crop. Due to the better retention of water, the total cumulative amount of irrigation water applied during the three crops in the barrier plots was only 46% of that applied in the plots without percolation barriers.

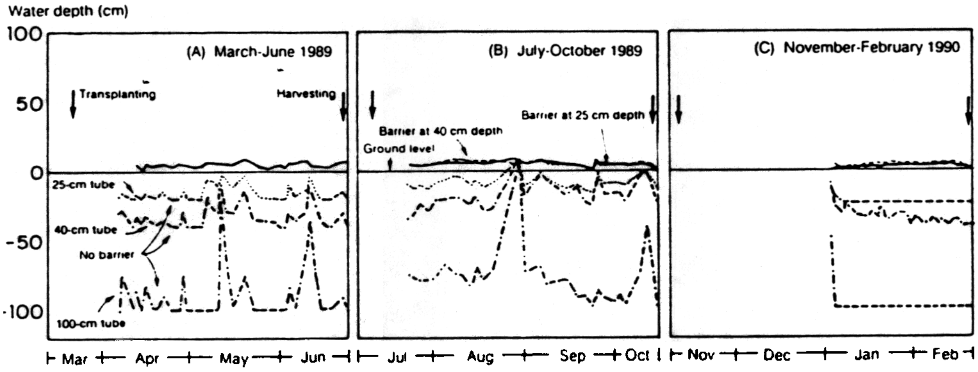

Fig. 3 Ground water levels in plots with and without subsurface percolation barrier. IRRI

During each of the growing seasons the barriers resulted in nearly constant surface flooding during most of the crop duration. varying in depth from 0.4 cm to 9.0 cm in the plots with percolation barriers (Figure 3). In contrast, the observation tubes were dry during most of the crop season in the plots with no barriers, indicating that deep percolation losses were occurring in these plots. It was only during heavy rains or irrigation events that the presence of a perched water table was briefly observed.

BARRIER EFFECTS ON RICE PRODUCTIVITY

The crop-saving advantage of percolation barriers was striking in the fine, sandy soil at Ubon. Rice total dry matter for the treatments with percolation barriers in 1989 (Table 1) was nearly four times higher than that from the other treatments (6.16 t/ha for T1 and T2 vs 1.60 t/ha for the remaining treatments). Both the dibbled and transplanted rice crops gave superior total dry matter (TDM) and grain yields in the presence of the percolation

Table 1 Grain and total dry matter yields of dry seeded (DSR) and transplanted (TPR) rice as affected by soil manipulation to control percolation and seepage URRC, Thailand. 1989 and 1990 wet season

Treat ment no.	Soil treatment	1989 Total dry matter (t/ha)			Grain Yield (t/ha)					
		DSR	TPR	Average	1989			1990*		
					DSR	TPR	Average	TPR1	TPR2	Total
T1	With plastic barrier at 25 cm depth	6.88	5.15	6.02	1.77	1.79	1.78	1.52	1.45	2.97
T2	With plastic barrier at 40 cm depth	7.72	4.86	6.29	1.93	1.61	1.77	0.82	1.55	2.37
T3	No barrier, soil mixed up to 25 cm depth	2.66	1.86	2.26	0	0	0	0.02	0	0.02
T4	No barrier, soil mixed up to 40 cm depth	2.39	1.70	2.04	0	0	0	0.08	0	0.08
T5	With plastic barrier on sides, 40 cm depth	1.61	1.46	1.54	0	0	0	0.02	0	0.02
T6	Undisturbed control, withought bund	1.00	1.41	1.20	0	0	0	0.06	0	0.06
T7	undistrubed control with bund	1.43	1.07	1.25	0	0	0	0	0	0.00
T8	soil dug out to 25 cm depth	1.09	1.47	1.28	0	0	0	0	0.02	0.02

barrier (Table 1). There was little difference in yields due to planting method, although the dibbled total dry matter yields were higher than transplanted yields. About 1.8 t/ha of grains from a single rainfed crop in 1989 and a total of 2.7 t/ha from two crops in 1990 were harvested from the plots with the percolation barriers. Virtually no grain was harvested in those treatments without the barriers (Table 1).

Although total rainfall during the two growing seasons was adequate, the distribution was irregular and the rain water was quickly lost through deep percolation in the absence of the barriers (Figure 1), resulting in zero yield due to severe drought stress. None of the other soil manipulation treatments were effective in reducing the drought effect. This situation is typical of the hazard faced by rice farmers in Northeast Thailand, and other

Table 2 Rice grain and total dry matter yields at maturity as affected by the presence or absence of subsurface barrier to control percolation. IRRI, March 1989-February 1990

Treatment Number	Percolation barrier	Depth of barrier	Total dry matter (t/ha)*			Grain yield (t/ha)			
			Crop			Crop			
			Second	Third	Total	First	Second***	Third	Total
T1	With	25	9.38b	6.42b	15.80	4.42a	5.67a	3.18a	13.27
T2	With	40	12.06a	8.00a	20.06	**	5.25a	3.42a	13.00
T3	Withought	25	5.40c	3.45c	8.85	1.94b	3.10b	1.70b	6.74
T4	Without	40	5.05c	3.02c	8.07	1.82b	1.84c	1.54b	5.20
T5	Undisturbed control	-	5.74c	3.83c	9.57	2.21b	3.26b	1.86b	7.33
CV(%)			17	12		16	23.9	15	

Average of four replications. In a column, means with a common letter are not significantly different by DMRT at 5% level.

* No data for the first crop.

** Treatment discontinued due to a leak on the barrier.

*** Adjustment in yield was made for grain loss due to typhoon damage at ripening stage.

areas with similarly droughty sandy soils.

At IRRI the total dry matter and grain yields in all plantings were significantly higher in treatments with percolation barriers (Table 2). Rice total dry matter averaged across two crops for the barrier treatments (T1 and T2) was 17.9 t/ha, in contrast to 8.33 t/ha for those treatments without barriers (T3-T5). The total dry matter from the 40-cm barrier was significantly higher than that from the 25-cm barrier, but this was not reflected in terms of grain yield. Grain yields ranged from 3.18 to 5.67 t/ha in the presence of the barriers, and 1.54 to 3.26 t/ha without barriers. The total grain yield of the three successive crops, averaged across T1 and T2, was 13.14 t/ha, double that of the non-barrier (T3-T5) treatment average (6.42 t/ha), clearly demonstrating the effectivity of percolation barriers as a factor in increasing and stabilizing rainfed rice yields, even in a clayey but well-drained soil. Significant increases in rice yield due to the presence of percolation barriers have also been reported by Erickson et al (1968), Rao et al. (1972), and Patel and Singh (1986).

IMPLICATIONS

These studies conducted on a sandy soil in Northeast Thailand and on a well-drained clay at IRRI indicated that percolation barriers enabled continuous surface flooding of rice fields from rainwater alone, throughout the crop cycle, even on excessively drained soils. Plots with no barriers had only brief flooding after heavy rains at IRRI, and none at all at Ubon. The latter situation induced severe drought stress on the treatments with no percolation barriers, resulting in virtually zero grain yields during the two years of the study. When polyethylene sheets were buried at depths of either 25cm or 40cm, rice total dry matter and grain yields at IRRI were dramatically increased. It is also apparent from the Ubon results (Table 1) that in addition to improved yields due to a more optimal water regime, the prolonged retention of paddy water due with percolation barriers may enable greater crop intensification. It was possible to grow two successive rice crops as opposed to one risk-prone crop. Greater surface flooding dependability also opens up greater potential for the incorporation of paddy field fish culture in the rice system.

The relative advantages of subsurface percolation barriers will depend upon the soil texture, nature of the hardpan, landscape position, and hydrological characteristics of the field. In situations in which seepage and/or percolation rates are high, such as in the sandy soils of Northeast Thailand, percolation barriers would be expected to have greatest advantage. In relatively favorable rainfed sites, where prolonged natural shallow flooding is more common, percolation barriers may not offer an advantage as great as that shown in these trials. It would thus be prudent to determine the geographic extent of drought-prone rice-growing areas that would be target environments for application of the technology.

Two critical tasks appear imperative: Barrier technology innovation, and detailed economic analysis. First, the results of these studies indicate that if subsurface barriers were inexpensive to install and maintain, their productive value in rainfed rice production would be substantial. The type of percolation barrier used in these studies is impracticable on a production scale: Plastic sheeting is expensive, its installation is laborious, and its effective lifespan is untested. Plastic sheeting was used only to explore the percolation barrier concept, awaiting the development of appropriate, less expensive materials, and simpler installation techniques.

Petroleum-based substances that are potential subsurface barrier materials are available, including asphalt and various plastics, but further research is needed to fully explore their potential and to develop ways to apply them. One concept is to use a tillage implement that can lift the subsoil a few centimeters, enabling the barrier material to be sprayed. An alternative concept is to inject the material at high pressure through the soil pores at the desired depth. Straightforward soil compaction is also an option to reduce percolation rates on sandy soils (Bhadoria, 1986).

Second, a thorough economic analysis is needed to establish the maximum level of investment costs in percolation barriers that would be economically viable. Development and maintenance costs of irrigation systems often range up to several thousand US dollars per hectare. These costs need to be compared with the prospective costs for percolation barrier installation. Barrier technology may become economically comparable or superior to irrigation development in some areas, when suitable barrier installation technology is available. The economic returns to barrier technology will also depend upon the duration that the barriers will remain effective against leakage and decomposition after installation. Barrier longevity will be influenced by the particular barrier material, the competence employed in its installation, and various field environmental factors. Longer term studies will be necessary to estimate these effects.

Increasing the productivity of drought-prone rainfed riceland by infrastructural investments to control percolation and seepage is a compelling notion. This concept has received little attention. The technology will require public support for implementation, but this is also true of irrigation and many other large-scale types of investment that have substantial installation costs but large social returns. The key will be whether the technology can be made sufficiently cost-effective to reap substantial returns on investment, public and private. If so, we may yet see the concept of percolation barriers implemented as a major technological advance for rainfed rice farming.

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