SHALLOW SUBSURFACE DRAINAGE FOR MANAGING SEASONAL FLOODING IN GANGES FLOODPLAIN, BANGLADESH†

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ABSTRACT

The impact of shallow subsurface drainage was investigated as a pilot study on a 0.13 ha plot of a farmer’s field located in Batiaghata, Khulna District, Bangladesh, in the floodplain of the Bay of Bengal. The drainage design differed from traditional subsurface tile drains in two respects: (i) the depth of drains was shallow (30 cm); and (ii) the design did not include a sump and accessories such as pumps (drainage outlets were tidal).

A monsoonal paddy rice crop followed by a winter sunflower crop was evaluated. The experimental treatment was a shallow subsurface drainage system with a drain depth of 0.3 m and drain spacing of 8 m. Measurements of surface flooding depth and groundwater table depth were made weekly and subsurface drainage discharge during managed drainage of the field was measured to determine system responsiveness. The managed subsurface drainage enabled the establishment of the winter sunflower crop 1.5 months earlier than the usual local practice, increased the yield and facilitated safe harvest, avoiding pre-monsoonal rainfall damage. Farmers expressed increased interest in managed subsurface drainage for its potential for early establishment of rabi crops and increased yields in the study area. This study outlines the potential benefits resulting from subsurface drainage in Khulna District. © 2016 The Authors. Irrigation and Drainage published by John Wiley & Sons Ltd.

KEY WORDS: subsurface drainage; groundwater table; field drains

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INTRODUCTION

Bangladesh constitutes part of the Ganges–Brahmaputra delta plain. Stretching from the Bay of Bengal northwards, the landscape is clearly defined by the three major rivers of the region, namely the Ganges, the Brahmaputra and the Meghna. These rivers define the physiography and agricultural development of the region. They carry huge amounts of water and sediment from a catchment stretching over 1.5 million km². The consequence is both a boon in the development of a fertile river floodplain in the delta and a bane from the resulting seasonal floods and drainage problems. Through flood control and drainage (FCD) systems the government of Bangladesh has striven to manage this natural phenomenon with mixed success and failure (Wester and Bron, 1998).

Bangladesh is characterized by a tropical and humid climate with four main seasons, namely, pre-monsoon (March–May), monsoon (June–September), post-monsoon (October–November) and the dry/winter season (December–February). With a climate greatly influenced by the Indian monsoon, Bangladesh receives an average rainfall of 2200–2500 mm yr⁻¹ with most of the rainfall (80%) occurring during the monsoonal season (Hussain, 2004). With such high-intensity rains, floods are a normal occurrence with occasional high-intensity flooding inundating as much as 70% of the country’s land mass. This is aggravated by the low and flat topography of the delta area.

The use of tidal rivers in the Bay of Bengal has been practised as a flood and drainage management system in the form of a cultural farming activity. The practice has been effective in managing the flooded and/or ponded surface water on agricultural fields but is not effective for managing the subsurface drainage (waterlogging) challenges that have bedevilled the farming environment of this area. The tidal canal system also poses a threat in being a pathway for salinization of these areas due to the entrance of saline seawater into the agricultural fields. Management of the tidal canal system has been efficient to minimize this impact but with changes in monsoonal flooding patterns (Hossain et al., 2012) (greater and more flooding events), compounded by a desperate need for farm-specific water provision, there are increasing management challenges to continued effectiveness in managing extended inundation and salinization by continued implementation of this method (Haque, 2006).

The economy of Bangladesh has its major strength in agriculture with a gross domestic product (GDP) contribution of 19.1% and as a source of employment to 50.3% of the nation’s labor force (Mohammad, 2010). Paddy rice cultivation in the floodplains of Bangladesh is a major activity supporting the majority of the rural population. Efforts to improve the productivity of the limited soil and water resources have seen a major push with land consolidation efforts and increased irrigation in the dry season (Hussain, 2004). However, these areas face the extremes of droughts and flooding due to changes in the monsoonal patterns. The flooding and waterlogging in the monsoonal season as a result of a high groundwater table, low permeability of topsoils and unsuitable drainage systems have hampered targeted efforts towards increased productivity (Bhuiyan and Undan, 1986). The removal of excess water has been shown to result in better aeration with corresponding microbial activity, improvements in soil porosity, tilth and better soil structure (Hill, 1976). For seasonally waterlogged soils, drainage enables faster warming up of the soils (Jin et al., 2008), thereby promoting warmer post-monsoonal soil temperatures that enable earlier winter sowing and germination. Soil drainage further improves the trafficability of agricultural fields (Goehring and Steenhuis, 1987; Madani and Brenton, 1995; Madramootoo et al., 1997) by up to 60 days in silty-clay loam areas. In Bangladesh, generally drainage is important for both lowering the groundwater table for optimal agricultural crop growth and to manage salinity (Hossain et al., 2012). Drainage has been shown to substantially increase crop yields through salinity management; for example, in Egypt yield increases of 14, 25–40 and 7–20% have been recorded for wheat, maize and rice, respectively (Ali et al., 2001).

The agricultural sector of Bangladesh is dominated by paddy rice. The country has three main cropping seasons: kharif-I (pre-monsoon), kharif-II (monsoon) and rabi (winter/dry) with three rice varieties associated with each season, these being aus, aman and boro. During the wet season, local aman rice is extensively grown in coastal areas with yields of 2.5–3.0 t ha⁻¹. Traditionally, the transplanted aman rice–fallow has been the dominant cropping pattern, especially in the Khulna, Barisal and Patuakhali regions (Haque, 2006). Some challenges that have occasioned this are noted as rainfall variability, uncertain onset and recession dates of the seasonal floods, and risk of droughts that restrict the aus and aman rice crops. First, harvesting of the aus rice is hampered under the persistent waterlogged conditions, especially if harvesting is to be carried out mechanically. Muirhead et al. (1996) posited that mechanical cultivation in wet soils is a challenge for reasons beyond the constraints in the use of machinery, but also such operations result in compaction of the fields and destruction of soil macropores that further constrain the soil’s ability to conduct and drain excess water (Madani and Brenton, 1995). Then the farmers cannot cultivate rabi crops (non-rice) due to excess soil moisture for a longer period after the harvest of wet-season rice. When the soil is ready for plowing the optimum sowing period of rabi crops will already be over, so the farmers have to leave the land fallow as late establishment will not only reduce yield, but also increase the risk of crop failure by rainfall at the later growth stage of rabi crops.

A study to assess the effectiveness of shallow depth subsurface drainage systems for managing prolonged soil wetness after the monsoon in the heavy silty-clay loam soils...
of Khulna, Bangladesh, at the field level was thus implemented. The study evaluated the field-level impact of subsurface drainage located at shallow depths as can be implemented by individual farmers in view of challenges occasioned by communal management of the traditional tidal canals, and the prohibitive costs of deep subsurface drainage systems. The shallow subsurface drainage design differed distinctly from traditional subsurface tile drainage systems in that the depth of the drains was shallow (0.3 m) and the design did not include sumps and accessories such as pumps (drainage outlets were tidal drains extensively present in the study area).

In this paper, we present the results of the study to evaluate the use of a shallow subsurface drainage system to manage seasonal flooding, carried out in Khulna District in 2013. The study does not claim to document the cost–benefit assessment and/or comparative assessment in view of other drainage systems possible. Rather we present a basic case of feasibility of this technology as a basis for further consideration and evaluation.

STUDY SITE

The study site is located in Hetalbunia village, Upazila-Batiaghata, Khulna District, Bangladesh (22.735°N, 89.510°E) (Figure 1). The long-term annual average minimum and maximum temperatures are 12.5 and 35.5 °C, respectively, and a mean annual rainfall of 1710 mm. The soil texture of the field is silty-clay. The saturated hydraulic conductivity of the soil in the study site was estimated at 85 mm day\(^{-1}\) based on the dominant silty-clay soil type of the area (Clapp and Hornberger, 1978). The study field was bordered by drainage ditches, similar to tidal drains, on three sides and by an access road on the northern side (Figure 2). The drainage ditches have an access outlet to community tidal drainage canals, being connected with a sluice gate that drains off into the tidal river at a distance of 1.5 km from the field. The field is situated within the influence zone of two sluice gates, but due to poor management and maintenance of the main sluice-gate canal and heavy-textured saline soil, the drainage of the field is very poor.

This pilot study was conducted on a 0.13 ha plot for one growing season with paddy rice in the aman and sunflower in the rabi seasons. The field was divided into six field plots with a drainage line at the boundary of each plot. The plots were 8 m wide and the length ranged from 30 to 37 m. To compare the hydrological performance of the shallow subsurface drainage (SSSD) system a control site was selected at a research field of the International Rice Research Institute (IRRI) located in the same village on an undrained field, 2 km from the pilot study (Lat. 22.726°, Long. 89.519°) with similar characteristics. This site was used to countercheck
the hydrological status of the study plot, especially with respect to the groundwater level, to assess the performance of the shallow subsurface drains. No cropping comparisons were assessed from the control site as the crop variety planted was different.

The pilot subsurface system was installed during July 20–30, 2013. The SSSD system was installed at a drain depth of 0.3 m at the outlet end and drain spacing of 8 m, center to center. The drain depth and spacing were computed using Houghoudt’s equation for tile drain spacing. Polyvinyl chloride (PVC) pipes with an outer diameter of 100 mm with perforations made by burning holes through the pipes were used as drains. The drain lines were constructed with a minimum slope of 1%, east to west. Gravel and coconut coir were used as envelope materials around the pipe. The pipe ends were protected against entry by rodents and other animals by a fine wire mesh. The drains were designed to discharge into the open drainage ditch (tidal drain) at the western end of the field. The drainage ditch had a depth of 0.5 m, allowing for a hanging outlet for the shallow subsurface drains. The design depth for the SSSD system was chosen to take advantage of the existing tidal canal system, thereby eliminating the need for a drainage sump and an extensive pumping system. This is further projected to reduce the overall cost and operation and maintenance needs for the system.

For the most part of the aman growing season for the paddy rice, standard cultural and water management practices were followed. This involved continuous flooding. A midseason drainage of the surface ponding was implemented using the community-managed tidal canal to topdress N fertilizer on September 17, 2013. The SSSD system was used mainly for end-of-season water management to reduce the period of waterlogging normally experienced at the end of the aman paddy crop. The SSSD system was thus activated on November 11, 2013 and operated for up to 7 days depending on specific drains.

**MATERIALS AND METHODS**

Following the installation of the SSSD system the field plots were levelled and ponded according to the standard cultural practice by the local farming community. The study site was divided into field plots for replicability rather than for experimental differentiation. The field plots were instrumented with depth gages for monitoring the hydrologic performance across the season. Measurements of surface water ponding depth, groundwater level, soil moisture, rainfall and evapotranspiration were taken for the duration of the study. The crop growth parameters for the paddy rice and sunflower crops were also monitored, including yield performance. The monitored growth parameters for paddy rice included tillering, panicles, flowering, grain filling and physiological maturity.

Surface water ponding depth was monitored daily from the five plots by recording water levels on gauges installed within each plot. Groundwater levels were monitored weekly in the SSSD field and in the control field. Rainfall and evapotranspiration were monitored on a daily schedule using a standard rain gauge and a standard evaporation pan (Class A pan), respectively. The rainfall and evapotranspiration were monitored at the control field, managed by the Irrigated Rice Research Institute (IRRI), Bangladesh. Soil moisture was monitored from the five study plots with samples collected from three random locations from each plot, at three depths of 0–15, 15–30 and 30–45 cm. Soil moisture monitoring was initiated in early November, after SSSD was made functional and
continued weekly until the end, just before land preparation for the establishment of the sunflower crop on December 30, 2013. Soil moisture was determined by the gravimetric analysis method.

A crop of paddy rice (BRRI dhan54) was established by transplanting on August 20, 2013 (seed sown on seedbed on July 21, 2013 in a separate field). The seedlings were transplanted by dibbling at a spacing of 20×20 cm with 4–5 seedlings per hill. The paddy rice was managed following the local practice (applying Bangladesh Rice Research Institute (BRRI) recommendations) except for the subsurface drainage implemented in preparation for harvesting. The total fertilizer dose was 220–100–70–60–10 kg ha⁻¹ of the urea–TSP–MOP–gypsum–zinc combination. The plots were harvested on December 5, 2013. Sample areas of 5×2 m were harvested from each plot/block for yield assessments.

A following rabi crop of sunflower (High Sun-33) was thereafter planted on January 10, 2014 and harvested on April 25, 2014. The assessment of the sunflower crop followed a process similar to that of the paddy rice except that the crop was grown as a rain-fed crop utilizing residual soil moisture.

RESULTS AND DISCUSSIONS

Ponded surface water

The field was generally ponded for the duration of the paddy growth (Figure 3). The field was drained on August 31, September 17 and October 24 based on the community-managed surface drainage pattern to allow for field operations. The farmer further drained the study field 2 weeks before physiological maturity of the paddy by pumping water out of the field’s secondary tidal drainage canals, thereby activating the subsurface drainage system on November 9, 2013 to facilitate harvesting of his paddy (Figures 3 and 4). The system is thus shown to be able to support the existing tidal drain infrastructure, thereby lowering operational and management costs at the farm and village levels.

It is noted that all the plot-monitoring points show similar responses of ponded water levels, except Plot 6. A discussion with the farmer informed us of an unstable soil surface and erosion deposits on this plot from runoff entering the field from the roadside, thereby modifying the parapet level set for surface ponding measurements.

At the initiation of the SSSD system the ponded water level was higher in the field with the subsurface drainage

Figure 3. Depth of ponded water within the field plots during the paddy growing season in 2013

Figure 4. Drainage for harvesting a field (a) before drainage and (b) after drainage

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system, than in the field without it. But once the subsurface drainage system was activated the drained field let out the surface-ponded water in 5 days compared to the undrained field, whose surface-ponded water took 17 days to drain off (Figure 5). This has the implication that the subsurface drainage system is effectively facilitating surface drainage benefits despite being fully submerged. This conforms with observations by Muirhead et al. (1996) that SSSD systems tended to show more rapid recession of the groundwater table than deeper drainage systems. This they attribute to the increased soil hydraulic conductivity of the soil closer to the drains as well as the surface-ponded water head above the field.

**Groundwater level**

The groundwater levels in the subsurface-drained and undrained fields show similar trends till November 6 when drainage through the subsurface drains was initiated. The rate of groundwater table reduction is thus noted to occur faster in the drained field than in the undrained field. Despite weekly recording of the groundwater level the readings show that the groundwater level is responsive to the drainage patterns occasioned by community canal openings and closures. The subsurface drained field shows a lower groundwater level throughout most of the paddy growing season, with greater sensitivity to rainfall inputs than the undrained field. It is notable that the groundwater table was not substantially lowered through the communal draining of the tidal canals. The surface-ponded water was drained completely but even in the subsurface drained field, the reduction of the piezometric level was only down to 20 cm below the soil surface over a period of 1 week. This supports recorded studies that subsurface drainage improves soil structure, enabling improved porosity and tilth (Hill, 1976). The groundwater level dropped to 40 cm below the ground surface in 7 days compared to 20 days in the undrained field, which is due to the greater capacity for groundwater removal through the subsurface drainage system. This is in agreement with observations by Muirhead et al. (1996) that also showed high flows and quicker drainage out of shallow drains whereas deep-set drains ran continuously for longer periods in their study. The system facilitated greater average field permeability by providing secondary drainage channels for excess groundwater percolation. This is greatly desirable for timely operations requiring access of traffic to the fields under time constraints, as is needed to implement targeted multiple cropping patterns. Though the drainage system was installed only at a depth of 0.3 m below the soil surface, water removal out of the field is noted to extend below the drain depth. This confirms the observations by other researchers (Fausey and Brehm, 1976; Astatkie et al., 2013) that SSSD removes as much water as deeper drains. It is also possible that the empty tidal drains facilitated deeper drainage after implementation of the SSSD system.

The simplicity of the shallow drainage system lies in its installation and hence operation. In this pilot study, at the end of the season, the farmer activated the subsurface drainage by pumping out of the boundary canals on November 9, 2013 using his regular dry-season irrigation pumping system. Consequently, the ponded water surface drained out approximately 11 days earlier than the undrained field (Figure 5), achieving a stable dry-season groundwater level of approximately 85 cm in 28 days in the subsurface drained field compared to 72 days in the undrained field. Similar observations were made by Lesaffre and Zimmer (1988) who noted sudden and brief high discharges followed by long-lasting tail recessions. Given the implemented early drainage of the fields before the rest of the area is drained

![Figure 5. Piezometric water level measured in the drained and undrained fields (2013–2014)](image-url)
naturally, the drained water can be stored in the tidal canals and/or ponds (limited water loss through seepage) and be reused for irrigation of the following crop, thereby offering extended assurance for establishment of the *rabi* crop.

**Monitoring subsurface drainage**

The discharge rates from each of the five drain pipes were monitored over the drainage period (November 11–17, 2013) by measuring the duration for collection of 20 l flow from the drain pipe outlet (Figure 6).

A plot of the drainage rates is presented in Figure 7. Drain pipe 2 failed to discharge any flows due to a blockage of the drain. Despite the similar drainage trends, the drain pipes (nos 1 and 5) showed reduced levels and shorter discharge durations. Field assessments suggest that drain pipe no. 1 was impacted by proximity to the boundary canal with possible side-drainage into the canal, rather than to the outlet. Drain pipe no. 5 was located next to a refilled field canal. This placed the pipe at a slightly higher elevation than the other drainage pipes. Unmonitored partial drainage thus occurred from the upper end of the drain pipe above the flooded field canal level, before the planned manual drainage was facilitated by pumping. A blockage in drain pipe no. 2 led to its failure to discharge and thus its data were not considered for this analysis. Considering the fact that D1 and D5 were influenced by field side-effects, and D2 was not functional, only D3 and D4 provided reliable and consistent data. Both curves show that the drainage volumes declined logarithmically with time, responding to changes in the saturated thickness above the level at which the drains were installed. The average discharge rates for drains D3 and D4 were thus used to compute an estimate of the effective hydraulic conductivity during the drainage period \( HC = 0.45 \ln(x) + 3.89 \). The effective hydraulic conductivity was thus estimated by extrapolating the drainage rate curve to start of drainage process \( (time = 0 \text{ min}) \), thus \( 3.89 \text{ min}^{-1} (20 \text{ mm day}^{-1}) \).

Based on these observations, we may postulate that the combined effect of change in hydraulic gradient and saturated thickness through which flow occurs within the soil on discharge rates is logarithmic.

**Precipitation and pan evaporation**

Data on precipitation and evaporation were collected at an off-site location (undrained field) that was located about 1 km from the test site. The data are thus considered representative of both locations. As expected, precipitation was realized within the monsoonal months with very little post-monsoonal precipitation (Figure 8; Appendix). Pan evaporation for the location, over the monitored duration, shows highest values in the period towards the end of the monsoon season, with reducing levels in the post-monsoon season.

![Figure 6. Timed bucket collection of drain flow to determine drainage subsurface drain rate](image)

![Figure 7. Drainage rate data plots for the effective subsurface drain pipes](image)
Soil moisture monitoring

In order to assess the impact of the SSSD system on the moisture status in the study plots, the weekly moisture status was determined. The moisture content within the top 15 cm was noted to be slightly elevated (Figure 9), a result attributed to the occurrence of a finer clay and silt layer due to puddling of the rice field. This resulted in a higher water-holding capacity and hence greater residual moisture content when compared to moisture contents of the deeper soil profiles. The soil moisture values further indicate stable moisture levels during the month preceding establishment of the sunflower crop (rabi crop) as well as across the field plots (Figure 10). It is postulated that since the two sites are in close proximity with similar cropping, evapotranspiration and rainfall, any variability in soil moisture content would be the result of either capillary rise or drainage/deep percolation processes. The similarity in field moisture contents thus suggests that the occurrence of these processes, if any, is similar. This indicates that SSSD does not over-drain the fields and risk establishment of the following crop. The general performance of the system can thus be assumed to be stable within the field plots over both time and space.

Paddy rice crop monitoring

To assess the agronomic status of the paddy, the crop was monitored at key cropping stages to evaluate the plant (tiller) population (Figure 11), plant heights (Figure 12) and yield components (Table ). The tiller numbers show minimal variability at different cropping stages and drainage plots except at the grain-filling stage. The plant heights, on the other hand, show expected biomass growth between tillering and panicle initiation and a slight increase in height with the development of the paddy heads.

The reduced number of plants (tillers) at the grain-filling stage was recorded following the impact of heavy rains and winds in the study site that led to damage of the crop as well as the death of some plants, as crop growth proceeded towards maturity. As a consequence the crop saw physical damage at flowering and grain filling.
The impact of the damaging winds and rains was experienced at the flowering stage of growth; hence no impact on the plant heights at the flowering and/or the grain-filling stages was observed (Figure 12).

The deleterious impact of the winds and heavy rains on the paddy rice is noted with the impact on yield components. Despite the high productive tillers (92%) the filled grain was only 46%, reflecting a yield loss of 54%. The average yield of 2.85
MT ha\(^{-1}\) was thus registered relative to a 5.5 MT ha\(^{-1}\) yield expected (considering 90% filled grains per panicle).

Winter sunflower crop monitoring

Following the earlier than usual harvesting of the paddy rice a winter crop of sunflower, High Sun-33, was sown on January 10, 2014. The crop was consequently harvested on April 25, 2014, which was more than 1 month earlier than farmer’s usual harvest. The standard cropping pattern without drainage in this study area has sunflower harvesting in the middle of May. This illustrates the flexibility in timing for this crop under a groundwater table management system (Table ).

COMMUNITY PERSPECTIVE ON IMPACT OF SUBSURFACE DRAINAGE STUDY

To assess the perceived impact of the subsurface drainage study a survey was carried out among five farmers, with both fields within the tidal canal reach area (about 1.5 km from the tidal canal) as well as fields outside the reach of the tidal canal. Four farmers with knowledge of the drainage project were interviewed regarding their perspectives on the study. All agreed to the observed ability for timed and early harvesting enabled by the drainage system and especially the yield quality control obtained under the drainage system, as harvesting could be done under more controlled conditions than with the traditional system. The farmers further expressed a willingness to pay for similar practices with more information in management. It was realized that there are production and time allocation gains that arise from a subsurface drainage system. Despite these gains there is also concern about the high costs of installing and effectively operating such a system. This study did not quantitatively assess the benefit–cost value of the system, but a semi-structured survey of the study farmer and other local farmers indicated keen interest in adopting the technology at the rate of costs incurred in this system.

The farmers expressed concern about the possible impacts of subsurface drainage with regard to access to irrigation water for the rabi crop and subsistence fishery offered by the presence of the canals under no pumping in the traditional system. It is proposed that further economic and social studies be carried out to provide a comprehensive evaluation of the potential for upscaling this technology. Also further technical assessments on the most effective design are necessary to ensure a more cost-effective system. The farmers’ lack of experience with SSSD technology also calls for modalities for capacity building and greater information dissemination on the technology.

CONCLUSIONS

The study results clearly demonstrate the potential impact in managing field operations by implementing SSSD in the study area. By combining the existing surface drainage systems and the subsurface drainage, a uniform and timely ripening of grains was achieved. The drainage also facilitated harvesting by enabling even drying of grains and managed access to fields for the harvesting operation.

With no loss in the cultivable field area by implementing this technology, the benefits are only limited by the cost of installation. This cost is weighed against the gains in timely operations, improvement in yields and achievable better yield quality. It has a significant chance of adoption and ease of implementation with currently available resources such as the irrigation pumps and tidal drain discharge of drainage water.

It is notable that after the harvest of the paddy rice field tillage was immediately possible as the soil moisture in the field was well managed, thereby facilitating faster establishment of the following sunflower crop. This can guarantee farmers in this region a second crop without delaying the regular cultivation cycle, thereby enhancing the earnings of the farmer and increasing productivity of fields. Further, a major concern for farmers in this area is the potential loss of the late-planted rabi crop especially when the onset of the monsoon is early. This risk is significantly avoided by using the drainage system, as the early establishment ensures early harvest before the rainy season starts, hence addressing one of the main concerns of the farming community. The use of field ditches/canals for subsistence fishery is a limitation to this technology that needs further assessment, but a temporary solution suggested by the study site farmers to allow water back into the ditches immediately after harvest offers a plausible
solution. This can be effective if a limited number of farmers are implementing the technology in any specific area and/or a temporary storage pond is available to hold the drained water. These options offer possible mitigation alternatives that still need verifiable testing for effectiveness.

Another major constraint for resource-poor farmers in the adoption of such technologies is the high cost of installation and the technical challenges of management. These concerns are greatly alleviated by adopting the shallow drainage system rather than the deeper drain systems that need collection sumps and bigger pumping systems for drainage discharge to outlets. By having shallow drainage the cost of installation is reduced while the need for pumping is minimized, as the drainage pipes can drain almost freely into the existing drainage canals. This technology therefore offers great promise as a drainage technique for areas with a high density of small-scale, resource-poor farmers. The technology is also highly adaptable to this environment where no deep penetrating equipment is to be used (Fausey and Brehm, 1976).

RECOMMENDATIONS

Further assessment of detailed cost–benefit analyses of the changed production with the installation of an improved drainage system should be considered to evaluate the affordability of the technology from an economic point of view. The realization that technology does not solve all development problems underlies the concern about adoption of subsurface drainage by resource-poor farmers in the target area. The expression of interest among farmers needs to be cultivated through governmental and private-sector linkages to offer target farmers higher-value cropping systems and training to make the investment in the technology achievable. The adoption of SSSD will thus depend on the long-term cost–benefit considerations realized from the farmers’ perspective. A need for further assessment on optimal system design, economic evaluation and sustainable management practices for this technology are thus suggested in this area. As for addressing the adaptive capacity of farmers and to enhance dissemination of the technology, it is proposed that further joint experimentation between farmers and researchers be implemented. This will assist in adapting scientific approaches to local practices for increased adaptability of the technology.

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APPENDIX.

Ponded Surface Water Levels

Precipitation, mm

Daily Pan Evaporation

Rainfall & Pan Evaporation

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