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Subsurface drainage effect on soil and rice crop

(Kesan sistem saliran di bawah permukaan tanah terhadap tanah sawah dan padi)

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Key words: subsurface drainage system, productive rice yield, soil bearing capacity, water table levels

Abstrak

Kesan sistem saliran di bawah permukaan tanah terhadap tanah liat lom berpasir di MARDI, Seberang Perai telah dikaji dari tahun 1995–2000. Paip saliran di bawah permukaan tanah dipasang pada kedalaman 45 cm dengan jarak 2, 4, 8, 16 dan 28 m masing-masing untuk menguji hubungan antara keupayaan galas tanah dengan kedalaman tanah untuk sistem saliran tersebut.

Kajian ini juga menilai keupayaan galas tanah dan kedalaman tanah yang berlainan terhadap jarak paip saliran. Aras air tanah yang berubah-ubah disebabkan oleh jarak paip saliran yang berlainan dan kaitannya dengan hujan juga dikaji. Keupayaan galas tanah meningkat dengan kedalaman tanah. Kedalaman 15 cm dan seterusnya mencukupi untuk menampung berat jentuai. Keupayaan galas tanah adalah lebih tinggi pada jarak paip saliran yang padat pada waktu hujan yang biasa, tetapi tidak begitu pada musim hujan atau kemarau. Hasil padi pada luar musim dan musim utama dari sistem saliran di bawah tanah telah dibandingkan dengan sistem yang sedia digunakan di stesen. Jurang hasil antara dua musim tidak nyata sekali dalam sistem saliran di bawah tanah dengan catatan purata hasil luar musim lebih tinggi sedikit daripada musim utama. Purata hasil pada kedua-dua musim dari sistem saliran di bawah tanah umumnya lebih tinggi apabila dibandingkan dengan petak yang tidak mempunyai kemudahan saliran tersebut pada sebarang musim.

Abstract

Studies on subsurface drainage were carried out on sandy clay loam soil in MARDI, Seberang Perai Research Station from 1995 to 2000. Subsurface drains installed at a constant depth of 45 cm and variably spaced at 2, 4, 8, 16, and 28 m were tested to establish a relationship between soil bearing capacity and soil depths in the installed subsurface drainage systems.

Additionally, soil bearing capacity at different soil depths in relation to the drain spacing were evaluated. Fluctuation of the water table levels due to the effect of subsurface drain spacing with reference to rainfall were also studied. Soil bearing capacity increases with soil depth which from 15 cm and beyond is strong enough to ably support the weight of a large combine harvester. Soil bearing capacity is higher at denser subsurface drainage intervals only when with normal rainfall, but not as indicative when at its extremes, being with too much or too little rain instantaneously. Rice yields from the off-season and main season between the subsurface systems were compared with conventional yields

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elsewhere in the station. It has been shown that in the subsurface drainage plots the yield gap between the two seasons was insignificant, but with the recorded off-season average yield being slightly higher than the main season. Average yields obtained under subsurface drainage systems were however noticeably higher when compared with harvest from fields without such a drainage facility irrespective of the season.

Introduction

Subsurface drainage has been widely used in developed countries for the last five decades, but it was only during mid-1980s that it began to be emphasized as a solution to waterlogging and soil salinity problems in irrigated areas of the developing world (Chieng and Visvanatha 1997).

In the late1980s, the Japanese government has encouraged the use of subsurface drainage for sustainable farming of paddy fields. Over half a million ha of paddy field have since been installed with various types of subsurface drain in the land consolidation projects (Ogino and Murashima 1992).

The main reasons for the installation of subsurface drainage in paddy field are to improve the soil and create more conducive working conditions for the use of farm machinery especially for large scale paddy plot farming as well as non-rice crop farming on paddy field (Ogino and Murashima 1993). The installed subsurface drainage system serves to hasten surface drainage of excess rainfall during crop establishment. This is to prevent total seedling submergence. Besides, it helps to remove excess topsoil water within the plough layer by subsurface drainage during crop harvest.

Mid-season drainage generally improves rice plant growth and leading probably to crop yield increase subsequently (Matsushima 1970). The implementation of subsurface drainage system improves root zone soil layer conditions, particularly by keeping soil layer aerobic to activate functions of paddy roots which resulted in higher yields than before, when soil layer conditions were anaerobic (Okamoto 1997).

The trenching type of subsurface drainage system is most commonly used. It consists of drain pipes and envelope materials such as gravel and rice husks. Drain spacing varies from 7 m to 15 m, with 10 m being a popular distance. Trench depth is about 50 cm and the width ranges from 20 cm to 35 cm depending on the trencher used and diameter of the drain pipes (Murashima and Ogino 1994). Deterioration of drainage capacity has been observed after the completion of drainage pipe installation. Research focusing on this problem revealed the importance of the placement of envelope materials to sustain the drainage capacity. Vlotman et al. (1997) provided scientific criteria, from which guidelines are now available to determine the necessity for drain envelopes and the selection of envelope materials to protect subsurface drains installed in any soil type.

Stability of the soil can be evaluated for the approximation of opening sizes required to provide a safe and permanent drain envelope. Logically, experiences on drainage in the temperate zone cannot be of any direct or accurate reference to the needs in the humid tropics (Warin et al. 1997). Prolonged heavy rainfall affects not only the design drain flow rates but also soil transfer mechanisms. In particular, more surface run-off and interflow (lateral flow due to perched water table) are expected.

A mega subsurface drainage project, the Rajasthan Agricultural Drainage Research Project (RAJAD) was initiated in 1991 to conduct research and technology transfer in subsurface drainage to control salinity and waterlogging problem and to lower the water table for sustainable agricultural production (Rakesh and Mundra

1997). The RAJAD project scheduled to run from 1992 to 1999, covered an initial target area of 25 000 ha. The effect of subsurface drainage system on both water table depth and crop yield in Mit Kenana pilot area was evaluated during the period from 1992/3 to 1994/5 (Kenawey et al. 1997). Results showed some obvious increase in crop yields of rice, maize and wheat, having benefited from the implementation of the subsurface drainage system.

Economic analysis showed that the subsurface drainage system had helped in increasing crop yields as well as improving soil productivity and consequently the total economic value of such a production system.

From the economic point of view, material cost of denser spacing is more expensive than work cost for installation even at a deeper level. Selection of the maximum drain depth is influenced to a large extent by the in situ soil environment. Crop yield increase would be of primary impact despite extremely high initial cost of such a drainage system development, which eventually would be cost effective once land production is maximized (El-Hawary et al. 1997). A wise and careful selection of drainage system design is to be expected in ensuring the economic return be maximized even from an expensive capital outlay. Since the 1980s the assured and continual usage of fertilisers for both the seasons has been speculated to be more yield enhancing in the main season for it to have overtaken the normally higher yield in the off-season before that time. Generally lower yield in the present off-season has also been said to have resulted from inconsistent water, mostly being insufficient throughout the crops but at times with sudden excess requiring management attention immediately.

The purpose of this study is to record changes, on-farm water table levels fluctuation and crop performance from the effect of subsurface drainage at different field densities.

Materials and methods

Studies of the subsurface drainage project were conducted from 1997 to 2000 in MARDI Station, Seberang Perai where the soil texture of the research plot may be classified as sandy clay loam with proportions of sand, clay and silt at 55, 37 and 8% respectively. Over the duration of this study, the same research plot has been upgraded gradually and systematically as shown in the layout plan *(Figure 1).*

Perforated 3-inch high density polythene (HDPE) corrugated pipes wrapped with a polyweave net were placed in trenches measuring 30 cm wide and 60 cm deep. The pipes were then encased in a mixture of sand and gravel to a circumference thickness of 10–15 cm *(Figure 2).* Finally, the trenches were filled with dug earth to the original level. The installed pipes, at a constant depth of 45 cm, were variably spaced at 2, 4, 8, 16 and 28 m apart. These pipes eventually drain through the wall into the open perimeter ditch. The purpose of using polyweave and envelope was to prevent soil from entering into the pipe thereby averting sedimentation and blockage. A three-sided u-shaped concrete perimeter ditch with dimensions of one-meter width and depth was constructed for collecting drainage water from the subsurface drains.

In-field improvement done to the plot were the installation of two water meters at the inlet, proper land levelling and the construction of two drain outlet structures that can control field as well as perimeter ditch's water levels at different heights.

For this study, transplanting machine was used to establish the crop in order to achieve crop uniformity. Three parameters, essentially to determine crop yield performance in general and detailed effect of subsurface drainage spacing on on-farm water levels and machine trafficability were recorded. The experiment was conducted as a randomised complete block design with three replicates.

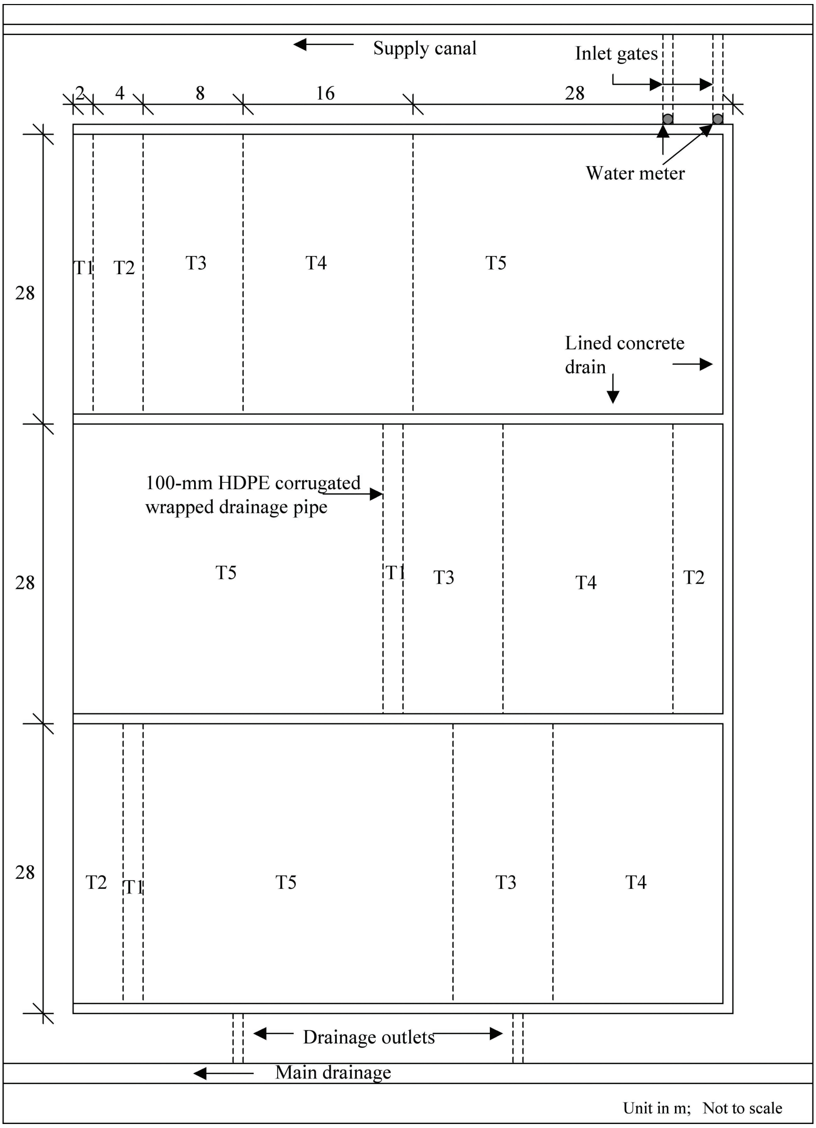

Figure 1. Layout of subsurface drainage project plot in MARDI, Seberang Perai

A hand held penetrometer was used to measure soil bearing capacity after drainage at 10, 15, 20 and 25 cm below ground surface. The measurement was first made when the field was completely drained (no standing water) at about 2 weeks before the paddy crop is due for harvesting.

During the same period, when water in the field has been completely drained out, small tube wells were installed to measure field water table levels. Each tube well was made from a 50-mm polyvinylchloride (PVC) pipe of 150 cm length. Holes were drilled around the pipe at regular intervals to about 50 cm from one end. These holes should enable water to flow in and out of the tube freely. The perforated end of the pipe was wrapped with plastic netting to prevent these holes from being blocked by loose soil and sedimentation. A hole with the same diameter size was dug to a depth of 120 cm in the middle of each treatment plot

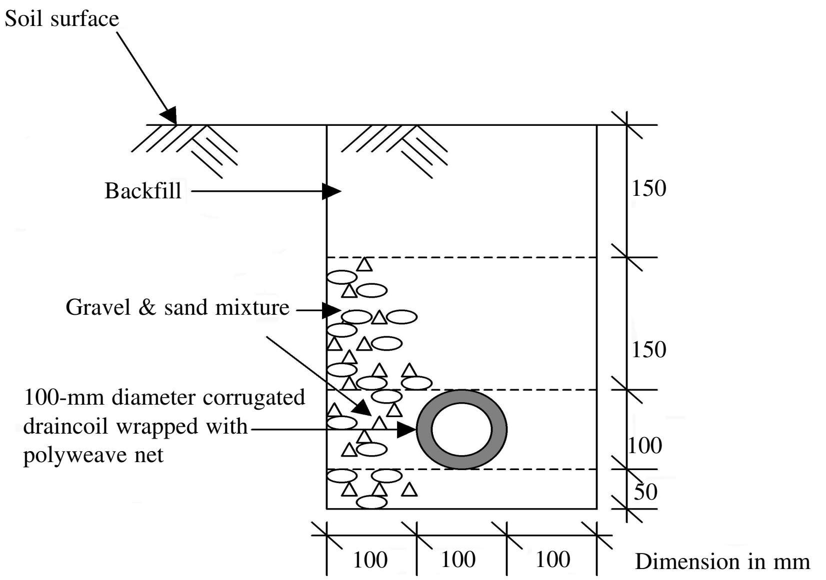

Figure 2. Detail cross section of subsurface corrugated draincoil installation in MARDI, Seberang Perai

for the wrapped tube well to be inserted into it. A water table indicator was used to measure the water levels which had earlier been allowed to stabilise.

Crop yield of each treatment was estimated using crop cutting test (CCT) method with three samples for each treatment. The CCT plot was 3 x 3 m^2 or its equivalent of 9 m^2. The harvested grains were dried, winnowed and weighed, then converted to per unit area crop yield.

Direct seeded yields from crops established differently outside the main experimental area of similar soil type but not subjected to subsurface drainage may not be analysed statistically together with yields resulting from subsurface drainage treatments proper.

This may at least be compared broadly based on collective information over a total of nine seasons' crops concurrently grown from within and outside the experimental area to highlight the probable effect of subsurface drainage.

Results and discussion

Effect of different subsurface drain spacing treatments on rice yield

The results of rice yields under subsurface drain spacing of 2, 4, 8, 16 and 28 m are shown in *Table 1.* Analysis of variance showed no significant difference at 5% level except for 97 off-season when comparing the crop cutting yields within each season. Two cropping seasons, 98 off-season and 98/99 main season, recorded much lower yields possibly due to the adverse effect of Al Nino and La Nina respectively.

When compared with the station average seasonal yield from main season 1995/96 to off-season 2000, yields from subsurface drainage plot were higher except in 98/99 main season. This could be due to the controlled flooding condition effect on the subsurface drainage plot against the ad hoc drainage as practised in the other fields within the station. Comparing the overall crop yield, the subsurface drainage mechanically transplanted trials yielded 4.57 t/ha while only 3.58 t/ha was harvested at the station direct-seeded row sown crop without any subsurface drainage.

Table 1. Effect of different subsurface drain spacing treatments on rice yield

Treatment spacing (m)	Seasonal yield (t/ha)								
	95/96 (Main)	96 (Off)	96/97 (Main)	97* (Off)	97/98 (Main)	98 (Off)	98/99 (Main)	99 (Off)	99/00 (Main)
2	2.58	3.59	–	4.00a	6.70	4.38	3.07	5.91	4.81
4	3.50	3.62	–	4.67ab	6.21	3.72	3.26	5.17	4.61
8	3.91	4.11	–	4.76ab	6.60	4.10	3.06	5.59	4.71
16	4.17	4.17	–	5.54bc	6.35	4.01	2.97	5.77	4.85
28	3.82	4.00	–	5.80c	6.64	4.19	3.21	5.57	4.89
AVG	3.60	3.90	–	4.95	6.50	4.08	3.11	5.60	4.79
AVG St	3.63	2.79	5.22	1.93	3.2	3.39	4.66	3.94	3.50
Remark	Normal	Normal	Ins Inf	Normal	Normal	ElNino	LaNina	Normal	E. Sub

*Means followed by a common letter are not significantly different at the 5% level by DMRT
AVG = Average
AVG St = Station's average from direct seeded row sown crops without subsurface drainage treatments (not analysed statistically together with subsurface drainage treatments) for general comparison only
Ins Inf = Install infrastructure
E. Sub = Early submergence

Comparison of off-season and main season yields between subsurface drainage trials to average station yields

Seasonal average of mechanically transplanted crop yields from the subsurface drainage trials were 4.50 t/ha and 4.63 t/ha respectively for the main seasons and off-seasons extending from main season 1995/96 to off-season 2000. For the same period, the station's normally direct-seeded row sown average yields were 4.04 and 3.01 t/ha for the main and off-season crop respectively. Except for the main season 98/99, seasonal yields from the station were higher than yields from the subsurface treatments *(Table 1)*. Indirect though it may have been, such difference may largely be due to timely subsurface drainage particularly for the off-season crop, as yield potentials between mere transplanting and direct seeding seldom differ too extremely (Cheong 1995). Yield difference between the main and off-season were so much narrower from the subsurface drainage treatment as compared with the station's average where there has been a marked drop in yield for the off-seasons' *(Figure 3)*. Thus, the results have shown that subsurface drainage seemed to have benefited the off-season crops more than the main season crops in terms of yield, at least when sudden excess water may have been drained in time effectively through subsurface drainage.

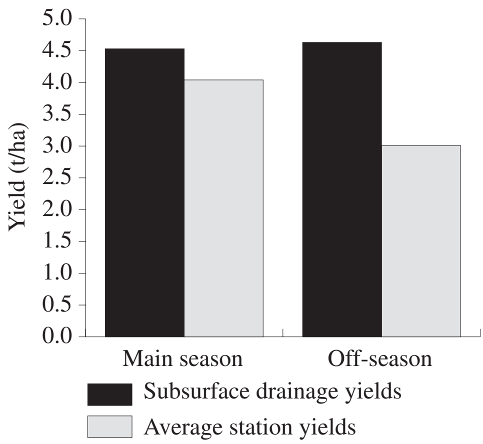

Figure 3. Comparison of main season and off-season average yield from surface drainage treatments against untreated composite yield elsewhere in the station

Relationship between soil bearing capacity and soil depths under subsurface drainage system

Results of soil bearing capacity for different soil depths at different subsurface drain

Table 2. Results of average soil bearing capacity (kPa) for different soil depths at different subsurface drainage spacings at 5 days after drainage (DAD) from 96 off-season to 99 main season at MARDI, Seberang Perai

	96 off-season	97 off-season	98 off-season	99 main season
DAD[1]	5	5	5	5
3rain[2]	55.1	0	16.6	16.3
Soil bearing capacity at 5 cm depth				
2 m	237	474	64	58
4 m	216	416	55	60
8 m	183	426	61	72
16 m	187	364	68	82
28 m	131	338	80	94
Soil bearing capacity at 10 cm depth				
2 m	419	760	486	152
4 m	363	703	315	107
8 m	314	801	445	154
16 m	310	699	392	185
28 m	262	616	424	166
Soil bearing capacity at 15 cm depth				
2 m	607	945	696	395
4 m	572	999	556	254
8 m	503	906	729	499
16 m	475	914	713	506
28 m	537	858	655	373
Soil bearing capacity at 20 cm depth				
2 m	835	873	850	659
4 m	770	892	825	644
8 m	827	958	849	782
16 m	788	957	860	788
28 m	802	908	827	713

[1]At least one recording before and several after, but not necessary at intervals with the same number of days were also made for each season
[2]Cumulative of three consecutive days' rainfall before soil bearing capacity recording

spacings are as shown in *Table 2.* Soil bearing capacity generally increases exponentially with increasing soil depth. To support combine harvesting without causing significant damage to the soil surface of paddy field, the required soil bearing capacity has to be 350 kPa. Recorded average values of soil bearing capacity were much higher than this required value when the soil depth is at 15 cm or more *(Figure 4).*

From the analysis of variance, the kPa results showed no significant difference at 5% level due to the drain spacing at each respective depths. However, the surface layer soil dries faster at shallower depths (5 cm and 10 cm) than the deeper layers (15 cm and 20 cm) especially during dry spell as depicted in *Figure 5.* The rate of soil bearing capacity increased at 18 and 14 kPa/day for the first five days after drainage for 5 cm and 10 cm depths respectively whereas 15 cm and 20 cm depths remain nearly constant during the same period. These phenomena happened similarly to all respective spacing treatments. The relatively consistent soil bearing capacity values at the depth around 15–20 cm below ground level suggest that

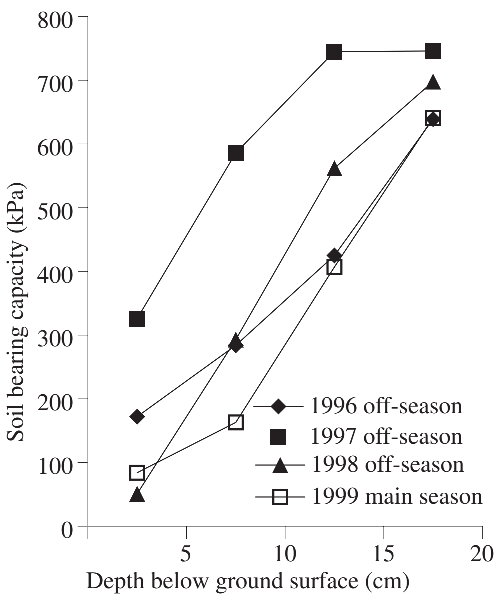

Figure 4. Relationship of average soil bearing capacity at different soil depths from different cropping seasons at MARDI, Seberang Perai

the plough pan most probably exists at this level.

Soil bearing capacity at different soil depths in relation to subsurface drainage spacing

Analysis of variance showed no significant difference at 5% level when comparing the soil bearing capacity at different depths to the respective drain spacing treatments. Soil bearing capacity was normally higher on the average at narrower drain spacing when the rainfall was moderate regardless of the soil depths (*Figure 6*). On the contrary, prolong and heavy rainfalls would always cause the readings of soil bearing capacity not different within the treatments. Soil bearing capacity at topsoil layers, 0–10 cm below ground surface, appeared to be quite dependent on the duration and intensity of rainfall while the lower layer at 10–20 cm, was more sensitive to waterlogged conditions generally.

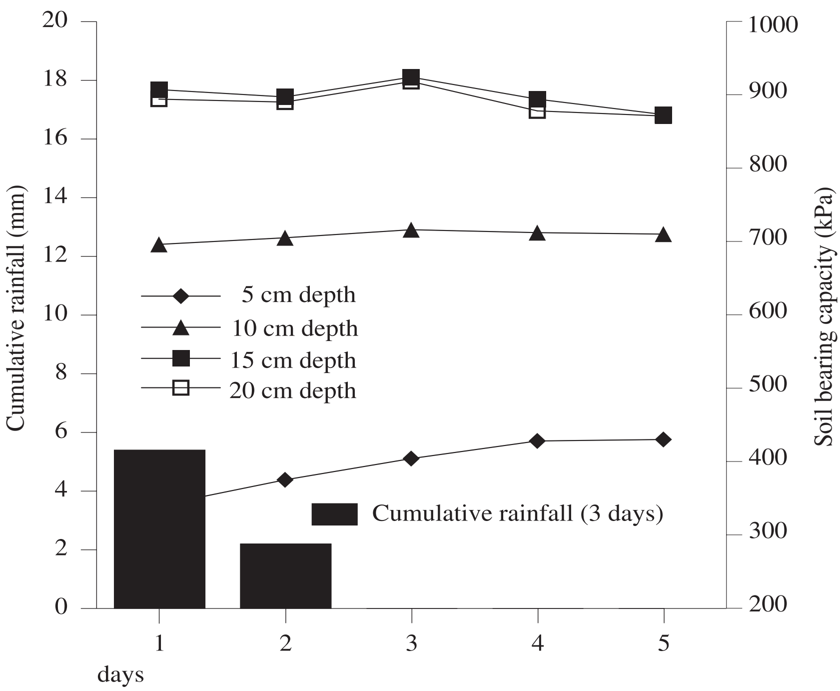

Figure 5. Soil bearing capacity in relation to different soil depths with influence of rainfall under subsurface drainage system

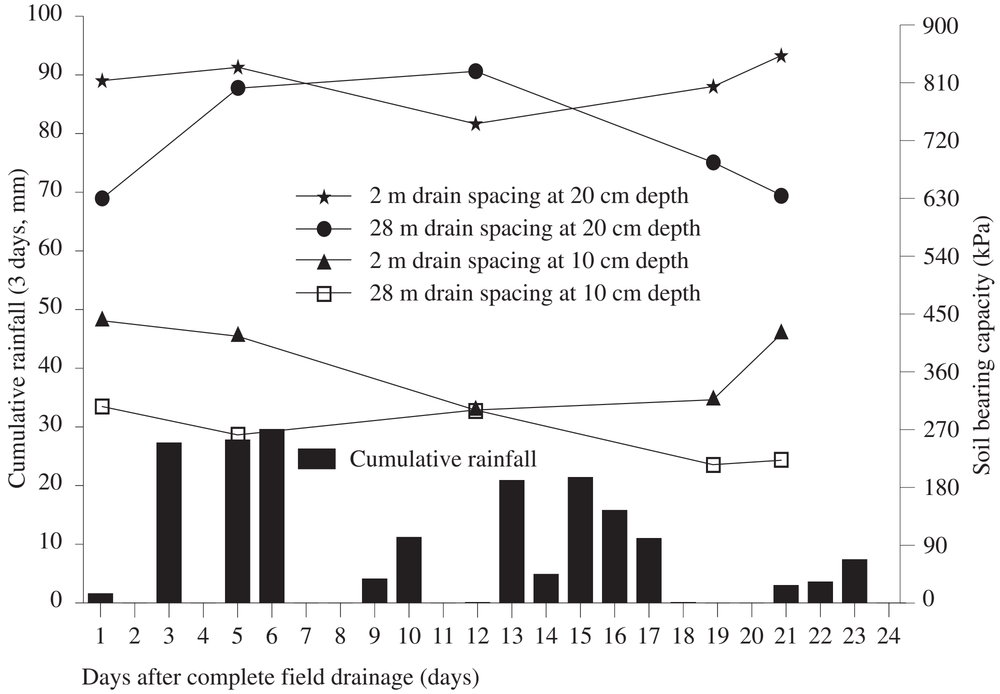

Figure 6. Soil bearing capacity at different soil depths in relation to subsurface drainage spacing

Effect of subsurface drain spacing on water table levels

As illustrated in *Figure 7,* during the wet season, the water table levels of the 2 m drain spacing were always lower when compared to 28 m drain spacing treatment. As the weather got drier, water table levels for both treatments dropped concurrently until at about 25 cm depth, about the position of installed drain when water table depths of the wider spacing treatment began dropping lower than the 2 m drain spacing. This phenomenon may possibly be due to controlled drainage practised in the system, where water levels in the drains were kept at controlled depths not less than 30 cm from the ground surface except during fallow period. Usually, when controlled drainage was practised, the closer spacing treatment attained the highest soil moisture content during the dry period and the lowest during the wet period.

Conclusion

Every season's rice yields were not significantly different between subsurface drain spacings of 2, 4, 8, 16 and 28 m except for 1997 off-season. The subsurface drainage trials yielded an overall 4.57 t/ha while the station's average yield without such treatment was only 3.58 t/ha over the same time frame. As compared to the non-treated plots, yield difference between the main season and off-season were so much narrower from the subsurface drainage systems in general. Apparently, with surface drainage, crop yield in the off-season may be comparable with the main season's but less so when without.

Soil bearing capacity increases exponentially with increasing soil depth. Soil bearing capacity records also indicated that soil strength at more than 15-cm depth can generally support a combine harvester (350 kPa) after complete field drainage. Values of soil bearing capacity at the depth around 15–20 cm were consistently high

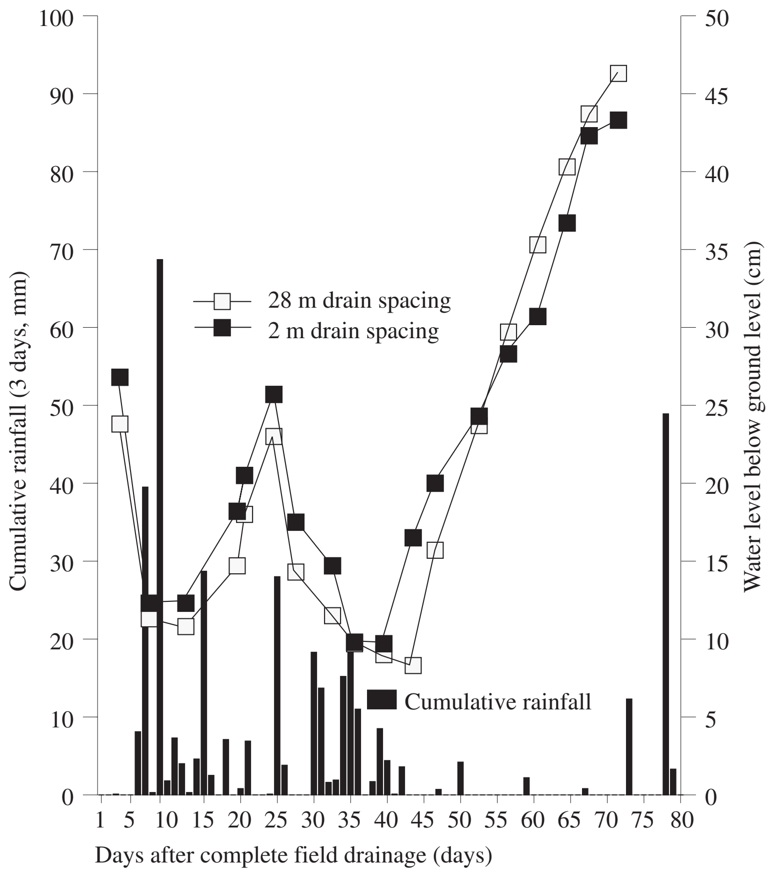

Figure 7. Effects of subsurface drainage spacings on water table levels after complete field drainage during 96 main season at MARDI, Seberang Perai

indicating perhaps that the plough pan probably exists at this layer. The average soil bearing capacity was normally higher at the closer drain spacings when the rainfall was moderate but extreme rainfalls often nullify this treatment effect. Water table level fluctuated accordingly with changes in weather conditions. During the wet season, water levels of the closer drainage spacing were usually lower compared to the wider spacing treatments. As the weather became drier, water levels of all treatments drop simultaneously but with wider spacings being faster and finally to a level lower than those at closer spacings.

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