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IMPROVEMENT OF WEAK FOUNDATION OF PADDY FIELDS BY SUBSURFACE DRAINAGE SYSTEM

– FIELD STUDIES IN THE MUDA IRRIGATION PROJECT AREA –

TSUNEO YAMASHITA

TROPICAL AGRICULTURE RESEARCH CENTER

MINISTRY OF AGRICULTURE, FORESTRY AND FISHERIES, JAPAN

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Tropical Agriculture Research Center
Ministry of Agriculture, Forestry and Fisheries
Yatabe, Tsukuba, Ibaraki 305, Japan

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IMPROVEMENT OF WEAK FOUNDATION OF PADDY FIELDS BY SUBSURFACE DRAINAGE SYSTEM
— FIELD STUDIES IN THE MUDA IRRIGATION PROJECT AREA —

Tsuneo YAMASHITA*

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*Kyushu National Agricultural Experiment Station
Izumi, Chikugo, Fukuoka 833, Japan

Tropical Agriculture Research Center
Ministry of Agriculture, Forestry and Fisheries
Yatabe, Tsukuba, Ibaraki 305, Japan

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ABSTRACT

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Underground drainage in paddy fields may contribute to the consolidation of the soil bearing capacity of the fields at the time of harvest in order to facilitate farm operations.

The present field study was carried out in test plots located in the Muda Irrigation Project Area, Malaysia.

The soil conditions peculiar to the area are known to contribute to the formation of a weak foundation in the rainy season. When large machines operate during the off-season harvesting period, the weak soil conditions make farm operations difficult. Under such circumstances, it is necessary to increase the soil bearing capacity by improving the drainage. From the results obtained during the investigation, it was demonstrated that the soil bearing capacity increased year after year, especially in the plots with complete underground drainage. However, the soil bearing capacity increased only slightly during the interval between the onset of drainage and the harvesting period. Since the drainage of the surface water was difficult to perform during such a short period, the soil was insufficiently dried. Supplementary underground drainage is necessary to drain fast and uniformly the surface water of the fields and the excess water in the soil zone.

CONTENTS

I. Introduction

The study was carried out to increase the soil bearing capacity by soil drying through the establishment of an underground drainage system in heavy clay paddy fields. Underground drainage in paddy fields may contribute to the consolidation of the soil bearing capacity of the fields at the time of harvest in order to facilitate farm operations.

The present field study was carried out in test plots located in the Muda Irrigation Project Area, Malaysia. In the area, studies on "Farm mechanization on weak soil foundation in the Muda Irrigation Project Area" were carried out by Shigeo Yashima, Hisao Anyoji, the author and others from 1971 to 1980.

Yashima observed that the trafficability of agricultural machines had been decreasing year after year the introduction of double cropping in the area. This phenomenon was attributed to the fact that the drying period of the field surface was shortened from 6 or 7 months to 2 or 3 months due to double cropping of rice and that the hard layer located at a 10 to 20cm depth under the field surface was damaged by mechanized farm operations due to the large size of the machines[7]. The present irrigation and drainage infrastructure, which provides a canal density of 10 m/ha, is grossly inadequate to meet the demands of modern agriculture in the Project Area[4].

From the results of the study, emphasis is placed on the need to lower the ground water table rapidly to 30cm or less so as to promote successful mechanization for double cropping. In order to lower the ground water table, the author suggested that each canal at a depth of about 70cm should be set at a spacing of 100m to 300m. These canals can meet the dual purpose of irrigation and drainage, although separation of irrigation and drainage canals is preferable[7].

Anyoji studied the problems pertaining to the trafficability of machines for double cropping of paddy in the area. For a good trafficability, the average soil bearing capacity within a depth of 25cm should exceed 2.0 kgf/cm^2 for the experimental medium-sized combine harvester e.g. "KANAN", and 8.0 kgf/cm^2 for the large-sized combine harvester e.g. "CLAES". It is however possible to maintain the degree of soil hardness required for the operation of medium-sized combine harvesters under water by shallow ploughing, in using a machine with a low ground contact pressure to which a shallow ploughing tiller is attached. Even if this method were to be applied, it would appear that the conditions would still not be suitable for the operation of large-sized combine harvesters[1].

The Muda Irrigation Project Area which is located in the Northwestern part of Peninsular Malaysia, is a flat coastal alluvial plain straddling the states of Kedah and Perlis. The Muda Area covers a net area of 96,000ha (237,000 acres) of paddy land presently under the Muda Irrigation Scheme, with another 2,500ha (10,000 acres) on its fringes[4].

The major problems in the Area, which limit agriculture, are the unsatisfactory condition of irrigation and drainage as well as labour shortage especially during the trans planting and harvesting periods. In the Area, where the development of secondary facilities was completed in 1970, the development of tertiary facilities should be promoted to overcome the difficulties so as to suppy and drain water to and from each plot and to build farm roads in orders to utilize the machines. A program of mechanization, particularly during the period of peak labour demand is underway to enable farm activities to be performed according to proper planting schedules.

The weak soil foundation of fields resulting in poor trafficability during the off-season harvesting time and main-season puddling time has been recognized as a serious problem impeding the development of mechanization in this area. Therefore, it is important to improve the weak foundation of fields by drainage in order to carry out mechanization.

The harvesting period of the off-season crop corresponds to the wet season and paddy fields are inundated with water during this period. Soil hardness is low but almost constant when soil is under water[1].

Problem of drainage is due to the difficulty to drain the surface of the fields in the existing plots because of the uneveness of the surface level and the absence of any tertiary and on-farm drainage system. Thus drainage of water cannot be performed at all and excess water from rain runs from plot to plot via open cuts in the boundaries, and drainage water reaches the plots at a relatively low elevation, which are often located in the vicinity of the existing tributary drainage system[7].

It is difficult to desiccate the fields by evaporation alone within the limited number of days that are continuously dry during the wet season. However, it is possible to increase the soil hardness by providing underground drainage facilities in the fields and improving the drainage system outside the plots.

In the area, surface drainage which is only the first step towards desiccation is very difficult to achieve in the infield area of existing plots because of the unevenness of the surface, even if the drainage system outside the plots were to be improved. Furthermore, it is difficult to increase the soil hardness by evaporation alone since there are only a few dry days during the wet season. It therefore appears that in addition to evaporation subsurface drainage facilities should be introduced in the fields[1].

This was the conclusion from field studies carried out to improve the weak foundation by subsurface drainage in order to promote farm mechanization and achieve proper water management.

II. Paddy Field Drainage and Purpose of the Studies

1. Purpose and process of drainage in paddy fields

1) Purpose of drainage

The purpose of drainage of paddy fields is to improve the field conditions so as to increase the productivity of land and labor, and to imporve the yield and quality of rice.

Technically speaking,

(1) In the large-sized plots soil hardness should be adequate enough to enable farm mecahnization in order to increase the productivity. These fields must dry up fast and uniformly.

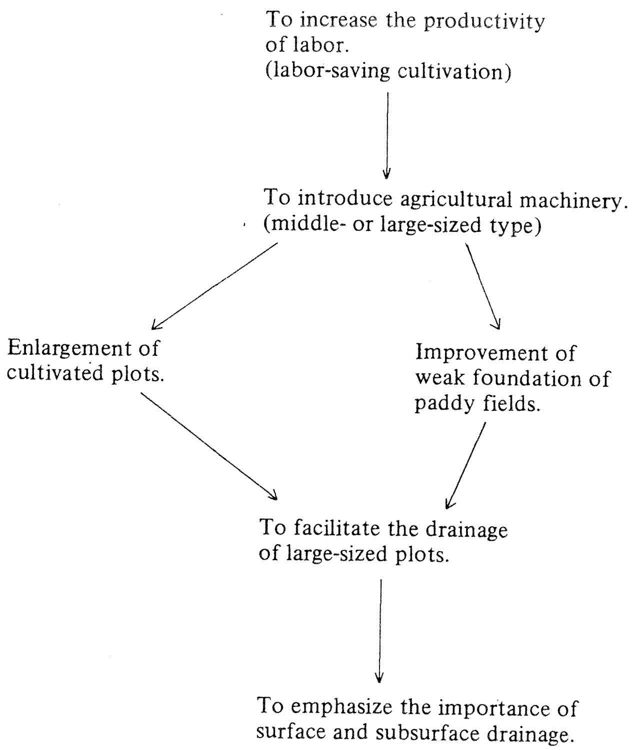
(2) Optimum water duty is required to remove toxic soil substances, to place the dissolved materials under flooding conditions, to supply dissolved oxygen, and to hasten heat transfer.

(3) Such measures should protect the paddy plants from flood damage caused by the surface water in the field. The surface water must be removed early. Sub-main and main drainage canals are necessary to keep the water level of the terminal drainage canals (the water level of the terminal canal is about one meter below the field surface) at a low level.

(4) To enable the soil of paddy fields to dry up, soil water should be controlled and the underground water table should be lowered.

Therefore, it is necessary to construct surface drain ditches as well as an under-drainage system in paddy fields.

Namely:



2) Process of drainage of fields

The process of drainage of paddy fields is described as follows[2]. Water inflow and outflow in paddy fields is illustrated in Figure 1-1.

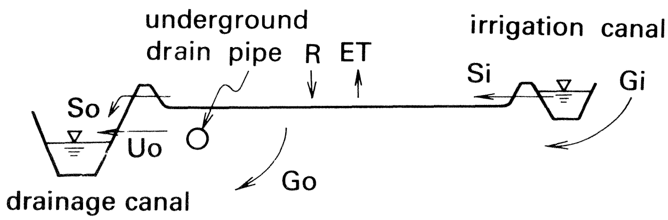


Fig 1–1. Inflow and outflow of water in paddy fields.

Inflow water (A) = Irrigation water (Si) + Rainfall (R) + Subsurface inflow from adjacent fields (Gi)

Outflow water (B) = Evapotranspiration (ET) + Surface drainage water (So) + Subsurface drainage water (Uo) + Percolation (Go)

The balance of soil moisture in fields is determined by (A–B), and the soil moisture can be reduced by the following procedures:

(1) Interception or prevention of "Gi"

(2) Promotion of "So"

(3) With respect to "Uo" and "Go": removal of residual water on field surface and lowering of soil moisture content by the construction of underdrains and lower drainage canals.

(4) Decrease of soil moisture by the acceleration of "ET".

Methods (2) and (3) are most important when drainage is needed for the cultivation of rice plants. Hence, the water level management of drainage canals is especially important for operations (2) and (3).

There are two aspects in the drainage of paddy fields, namely surface drainage and subsurface drainage. As for the discharge capacity of these two forms of drainage, the former is far superior to the latter. The excess water in the terminal paddy fields, therefore, should be removed by surface drainage at first and then by subsurface drainage (with underground drain, etc.) to remove residual water.

Underdrainage is required in paddy fields where the ground water table cannot be sufficiently lowered even by drainage canals and surface drainage. From the viewpoints of soil bearing capacity and growth of upland crops, the need for underdrainage depends on whether the ground water table can be lowered from 30 to 50cm below the field surface within two or three days after surface drainage[2].

Yashima and Ezaki demonstrated how to lower the ground water table rapidly to 30cm or less after rainfall by their studies in the area[7].

The recent concept in Japan on this subject has been described in the "Underdrainage Planning Standard in Japan" (1973, Sep.). This stated that "Underdrainage discharge should reach 20 to 50mm/day, depending on land levelling, field size and permeability of soil in a block (a border lot). There is no difference between paddy fields, and upland fields with regard to the discharge".

The two kinds of excess water to be removed by underdrainage consist of the residual surface water and the gravitational water in soil according to this guide. The principal role of underdrainage was formerly considered to be the removal of the latter, but recently, the role of underdrainage in the removal of residual surface water has also been regarded as important based on the results of several surveys and studies. Especially, in paddy fields, with clayey soils, it is considered, based on the pF-soil moisture curve, that the drainage discharge of soil water is not abundant and the majority of underdrainage discharge is derived from the residual surface water. The refilling zone of the underdrain and cracks in the top soil and subsoil are also considerably effective. These mechanisms are represented schematically in Figure-1-2. In Japan, the amount of residual surface water measured is about 20 to 60mm in general.

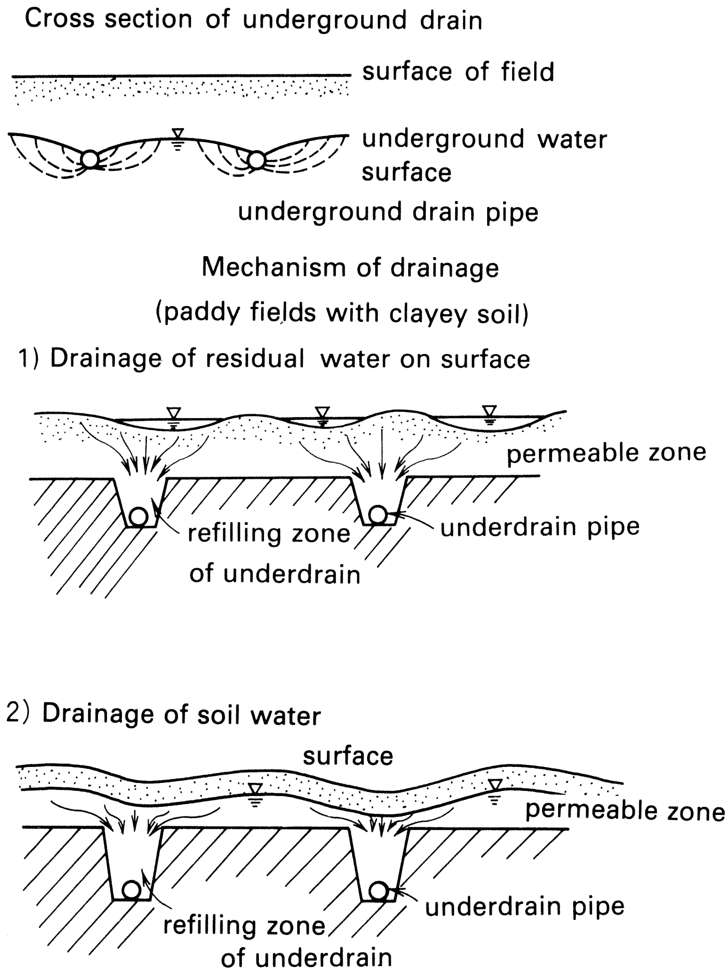


Fig 1–2. Mechanism of drainage by underdrain[2]

Poor drainage may be due to the following factors:

(1) Surface drainage is determined by the slope of the field surface, location of drainage canal and size of field.

(2) The effectiveness of subsurface drainage is associated with the coefficient of permeability of soil, paddy field conditions (water management and methods of cultivation, location of underground water level and drainage canal).

If these conditions worsen, paddy fields become poorly drained. If the drainage facilities outside the field do not enable to drain the excess water in the area, the water level in the canal will rise, and it becomes difficult to use effectively the subsurface drainage system and to increase soil hardness in fields. In this case, it is necessary to rearrange the drainage facilities (example, construction of tidal gate, drainage pump, drainage canal, weir, etc.).

If the soil texture is characterized by heavy clay, where drainage is difficult, it is necessary to improve the soil zone.

3) Relationship between trafficability and soil hardness

It is well-known that the soil bearing capacity can be increased by drainage. Generally, it may be possible to increase the soil hardness of fields by draining the surface water and decreasing the amount of soil water. One of the methods enabling to improve soil hardness consists of rearranging the subsurface drainage system as commonly practiced in Japan.

Incidentally, the value of the soil bearing capacity is also an indicator of the relationship between the cone index and shear resistance. This relationship enable to calculate the trafficability index.

Anyoji and Thavaraji[1] demonstrated that to achieve a good trafficability the average soil bearing capacity within a depth of 25cm should exceed 2.0 kgf/cm^2 for experimental medium-sized combine harvesters, e.g. "KANAN", and 8.0 kgf/cm^2 for large-sized combine harvesters, e.g. "CLAES". They also showed that it is difficult to increase soil hardness by evaporation alone within the limited number of continuously dry days during the wet season. It, therefore, appears that in addition to evaporation, subsurface drainage facilities have to be introduced in the field.

Another report dealt with the relationship between the sinkage of the combine "KANAN" and the values of the cone index, as illustrated in Table-1. From the results obtained it appears that it is difficult to operate machines in paddy fields with a weak foundation (less than 2.0 kgf/cm^2) during the rainy season in this area. Therefore, it is necessary to improve the water management and methods of cultivation in paddy fields.

Table 1. Relationship between cone-index values and the trafficability of the combine "KANAN".

Cone-index (kgf/cm^2)	Conditions of trafficability
More than	
	Little sinkage
3.0	
	Sinkage was less than 15cm.
2.0	
	Sinkage was less than 20cm.
1.0	
	It was occasionally difficult to operate the machine due to the sinkage.
0.5	
	The machine came frequently to a stand still.
Less than	

Note: Cone-index is the average value of measurements performed each 5cm from 5 to 30cm depth.
Reference: Report on Meeting between MADA and TARC.

2. Outline of research

The research aimed at introducing new engineering technology, and at carrying out evaluation studies. The subsurface drainage system in paddy fields was established to improve the weak foundation, increase land and labor productivity by achieving good water management.

The main problems for the effective utilization of farm machinery are the transport of the machines to the fields and trafficability in the fields. These problems can be solved if the construction of farm roads which is included in the tertiary development scheme is promoted.

The author attempted to tackle the trafficability problem. In the Muda Irrigation Project Area the cropping schedule is outlined in Figure-2. It is important to improve the trafficability of farm machines during the off-season harvesting period and main-season puddling period. Since these periods coincide with the rainy season, it is difficult to increase the soil bearing capacity by drying up the fields and it is necessary to drain rapidly and uniformly the surface and subsurface water.

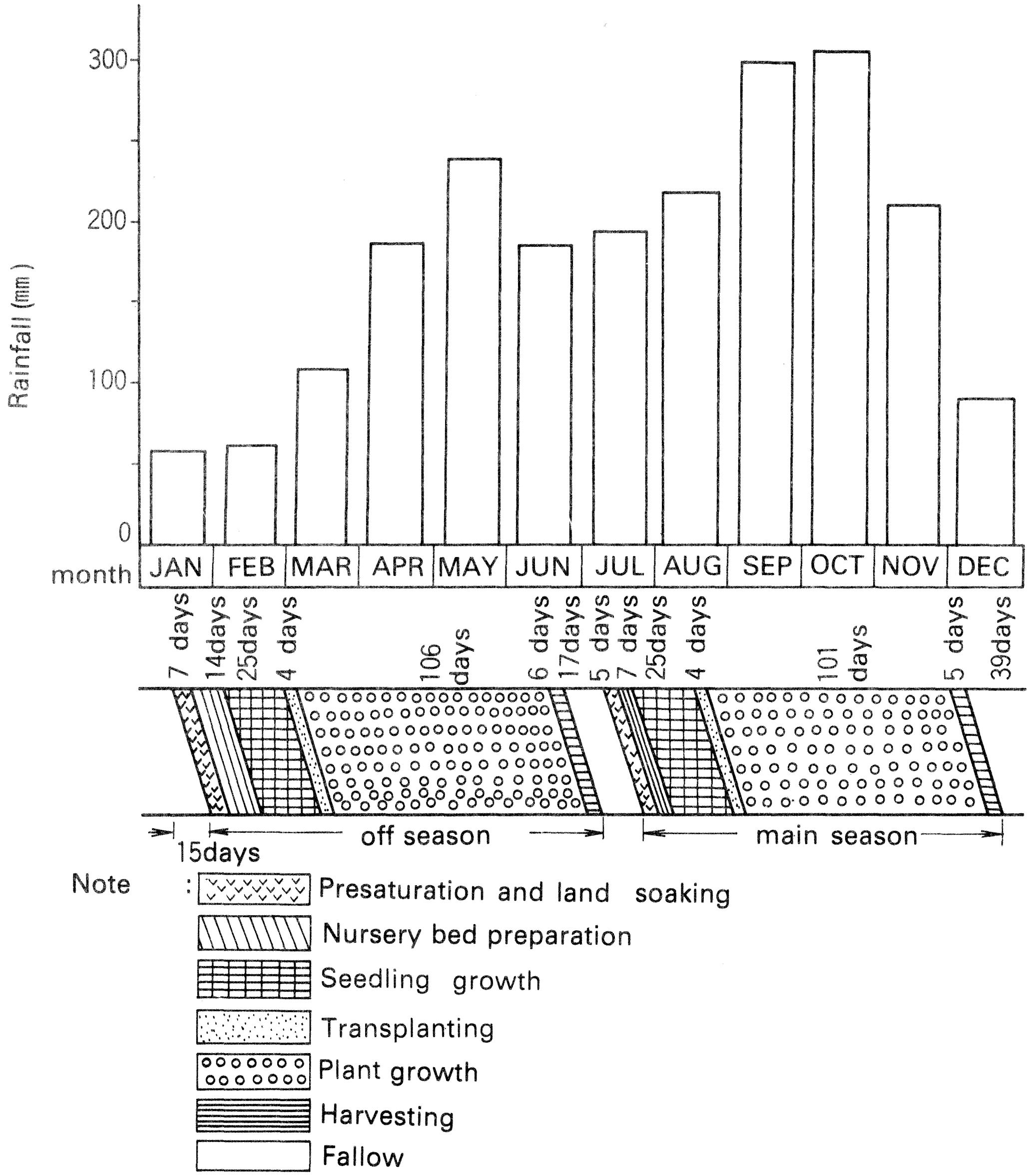


Fig 2. Calendar of cropping schedule in relation to rainfall [6)]

Technically speaking, to enable farm mechanization in such paddy fields, fields must dry up fast and uniformly. This can be achieved by controlling soil water and lowering the underground water table by combining surface and subsurface drainage.

Therefore, studies were carried out at test plots located at the Telok Chengai Experimental Station to evaluate the subsurface drainage system. The test plots were constructed and in Chapters V and VI evaluation studies are described.

The studies carried out by the author were as follows:

1) It is important to survey the soil hardness in the test plots in order to analyse the process of changes in soil hardness during the farm operations and to compare the effectiveness of soil drying by subsurface drainage. The soil hardness was surveyed for analysis of the annual changes for the purpose of comparing the effectiveness of the subsurface drainage system, and to determine the relationship between the drainage discharge, water level and soil bearing capacity in the test period.
2) The factors contributing to the rapid and uniform drainage of surface water which are related to the land levelling gradient in the field, ground water level, rearrangement of cracks, soil permeability, etc. were investigated in the test plots.
3) Soil physical properties

   Generally, after subsurface drainage is established in paddy fields, the soil structure changes slowly, and a hard layer develops while the water duty in depth increases due to the expansion of cracks and vapor phase in soil.

   Therefore, it is important to investigate the soil physical properties as follows:

   * Soil moisture content * Three phases of soil
   * Soil density * Mechanical analysis of soil
   * Permeability test * Test of slaking properties of soil
4) Basic studies to increase the soil bearing capacity

   (1) Changes in the soil bearing capacity due to evaporation.
   (2) Experiments to establish a method for increasing the soil bearing capacity.
   (3) Changes in the coefficient of permeability after soil puddling.
   (4) Test of slaking properties of surface soil and subsoil.

III. Construction of Subsurface Drainage System in the Test Plots

The research project consists of the evaluation of the drainage effectiveness after the construction of the test plots. The test plots were constructed at the Telok Chengai Experimental Station, namely No. 16, 17, 18 and 19 plots from March to July 1978. Before and after the construction of the test plots, the evaluation studies were conducted by the author.

1. Design of test plots

The author designed the layout of the subsurface drainage system in the test plots to conduct his studies, as illustrated in Figure-3-1. In the field, three drain types were built as follows (Figure-3-2).

(1) Complete underdrains

This is the standard underdrain system used in Japan. At that time, the ditches were dug using a backhoe, and P.V.C. pipes 4 inches in diameter incruding many slits (1/8 inches width and 8 inch length) which were provided in the surrounding area were laid in the ditch and covered with paddy husks as permeable materials. The gradient of pipes was 1/1200 with an average depth of 65cm. Paddy husks were used to expand the zone where drains can collect water, and also due to the fact that these materials are available locally.

(2) Blind underground drains

During the construction stage, the ditches were dug by using a rolling ditcher (digging depth was 45cm, without grade and pipe), filled with paddy husks (setting depth was 30cm) and backfilled with soil (backfilling at a depth of 15cm). The terminal part of these drains was connected to the P.V.C. pipes and rearranged (under the border of the side of the drainage canal).

This type of construction is more economical and rapid than type (1).

(3) Mole drain

This type is used for supplementary underdrainage. In the case of low permeability of soil, it is necessary to break up the soil mechanically to more than 40cm down in depth by using a mole drain to build the water paths. Mole drains were additionally made so as to have them run perpendicular to the complete underdrains.

The method aimed at digging a hole inside the soil with a mole drainer set behind a tractor, and to drain the excess water in the soil through the hole. Materials for drainage were not used with this method.

These types of drainage were designed as follows.

(i) Plot with combination of complete underdrain and mole drain .... Lot No. 16
(ii) Plot with complete underdrain .... Lot No. 17
(iii) Plot with blind drain .... Lot No. 18
(iv) No drainage system in the field .... Lot No. 19

The blind drain and complete underdrain were constructed at different intervals, namely 5m, 9m, 20m and 27m for the investigation.

An open canal for drainage was established along the shorter side of the test plots. Each plot provided direct access by means of an open drainage canal.

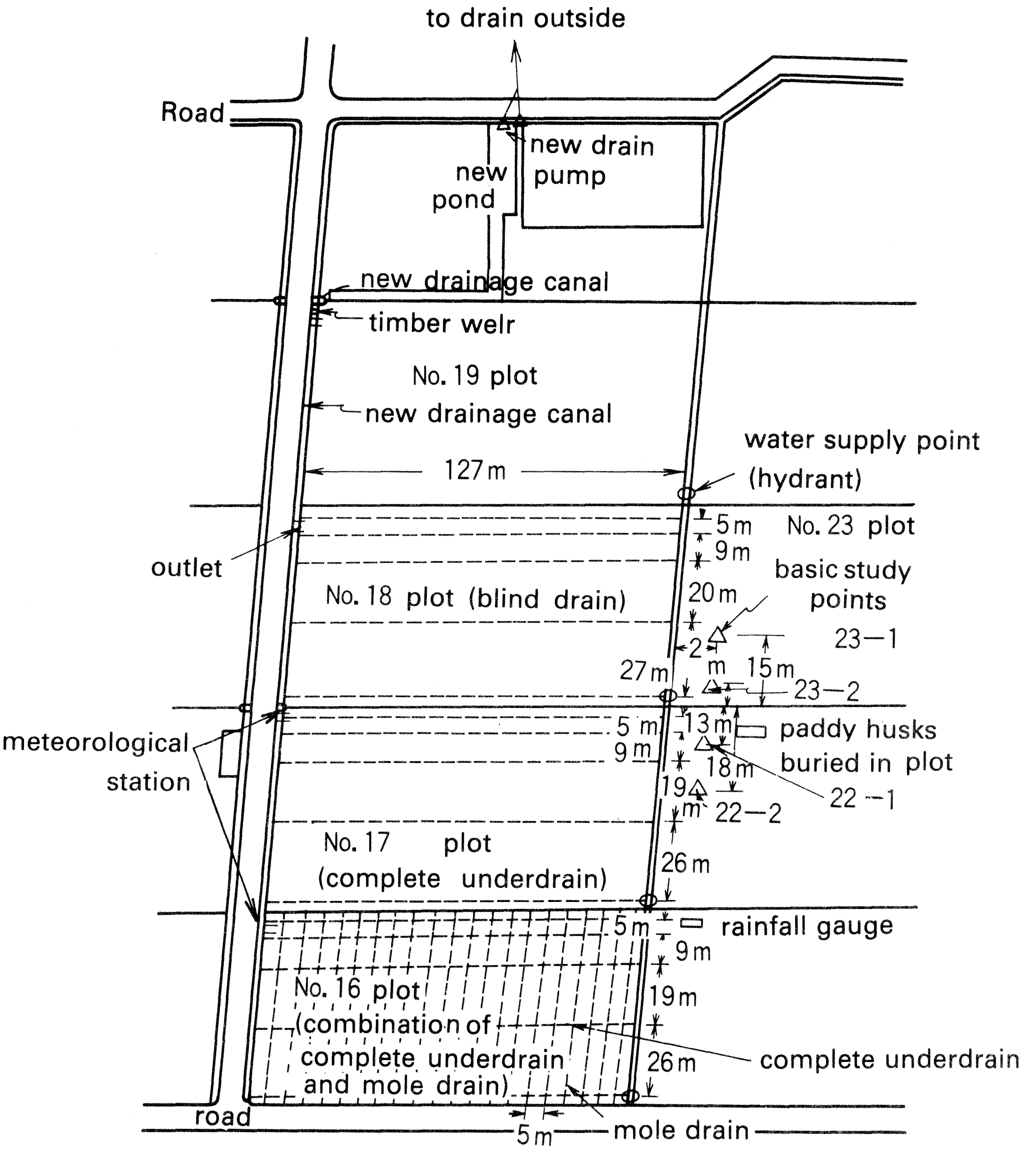


Fig 3–1. **Inflow and outflow of water in paddy fields.**

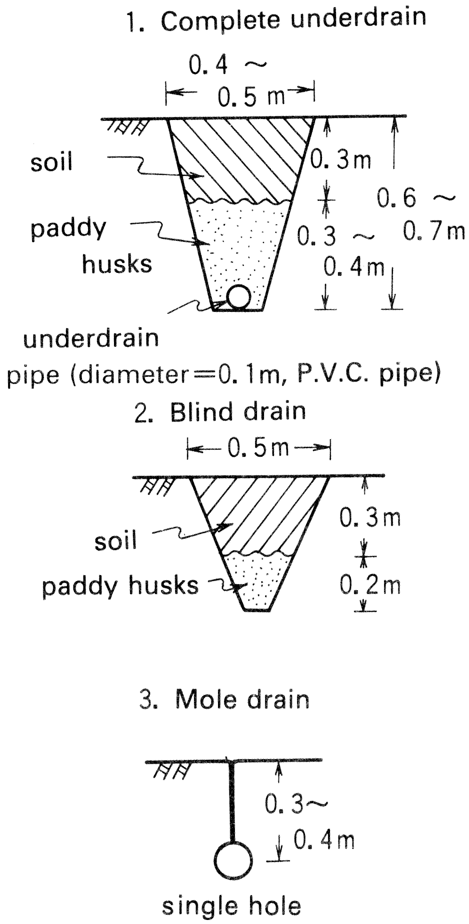


Fig 3–2. Type of subsurface drainage

2. Construction of test plots and analysis of performance

The construction of the test plots was completed by MADA. During this period, the data of the construction were collected by the author, namely time for construction, manpower, required machinery used, etc. The soil conditions and the soil bearing capacity of the test plots before the construction are shown in Tables-3, 4 and Figure-11.

The rainfall records during the construction period are shown in Table-17.

1) Complete underdrain

The complete underdrains were constructed from 23th April to 20th May. Ten lines of complete underdrains were constructed in the No. 16 and 17 plots at intervals of 5, 9, 19 and 26m.

The ditches about 0.4m in width and 0.75m in depth were dug using a backhoe, as illustrated in Table-2-1 and P.V.C. pipes were laid in the ditches manually (1 man/120m/hour). Originally, the author planned to use clay pipes, but since porous clay pipes were not available in the area, P.V.C. pipes with 1/8 inch slits were used as an alternative.

These were filled with paddy husks at a depth ranging from 25cm to 75cm manually (1 man/60m/day), and were backfilled with soil up to a 25cm depth also manually (1 man/60m/day).

The conditions for the construction were not favorable because heavy rainfall occurred frequently during the period (Table-17-2) and the surface of the field was kneaded resulting in a decrease of the trafficability in the test plots (Table-2-4). Therefore, the construction using the back-hoe was not suitable.

In Japan, machines for the construction of complete underdrains are available, consisting of trench excavator, rolling drain pipe, etc. Operations ranging from digging of ditches to laying of pipes can be completed rapidly at a rate of about 800 to 1200m/day. But the pipes used are small plastic corrugated pipes (diameter 5 or 6cm, with thin slits).

2) Blind underdrain

Five lines of blind underdrains were constructed in No. 18 plot at various intervals of 5, 9, 20 and 27m from 13th April to 6th May. The ditches were dug using a rolling ditcher, as illustrated in Table-2-2.

These drains were then filled with paddy husks manually (1 man/80m/day, the depth of filling ranging from 25 to 65cm), and thereafter they were backfilled with soil manually (1 man/60m/day, the depth of backfilling being within a range of 25cm). The outlet of these drains was connected to the P.V.C. pipes (diameter 2 inches) also manually (1 man/2 points/day, including labor time for digging and backfilling of the bonder).

The conditions during the construction were good because the field surface was dry.

When Nagaishi carried out research on underground drainage in Japan, he measured the permeability coefficient of paddy husks and gravels, as illustrated in Table-2-3[5]. The author confirmed that paddy husks are permeable materials, but are likely to decompose more readily in Malaysia than in Japan due to the high temperature. Therefore, permeability tests of paddy husks were carried out over 2 or 3 years and the results are illustrated in Table-2-3.

3) Mole drain

The mole drains were constructed on 3rd June. This type of drain was constructed using a mole drainer in the No. 16 plot, as illustrated in Table-2-5. This construction was very easy because the mole drainer was fitted behind a tractor (FIAT.640, 64PH) and could easily penetrate into the field. In addition, it was found preferable to level the surface of the field in order to maintain constant the level of the mole drain hole.

Table 2-1. Performance of the back-hoe.

Ditch No.	Digging time (hour)	Digging amount per hour (m^3/hour)	Digging time per 10m length (min)
16-1	2.6	14.6	12.5
16-2	3.0	12.7	14.4
16-3	3.0	12.7	14.4
17-1	3.2	11.9	15.4
17-2	3.0	12.7	14.4
17-3	3.0	12.7	14.4
17-4	2.25	16.9	10.8
17-5	3.0	12.7	14.4
Average		13.4	13.8

Note: 1) Length of ditch constructed: 125m Cross-section: $0.304m^2$ (0.80 × (0.45 + 0.31)/2).
2) Back-hoe: wheel type.

Table 2-2. Performance of the rolling ditcher.

Ditch No.	Digging time (min and sec)	Digging (length)	Digging amount per hour (m^3/hour)	Digging time 10m length
18-1	14min 30sec	120m	70	1.2min
18-2	10min 20sec	113m	93	0.9min
18-3	10min 40sec	123m	96	0.9min
18-4	13min 40sec	123m	75	1.1min
18-5	11min 10sec	123m	91	0.9min
Average			85	1.0min

Note: 1) Digging time includes the time when the machine was turning. The machine went back and forth 3 times (18-1) and 2 times respectively (18-2, 3, 4, 5,).
2) Tractor: FIAT 640. Digging speed: 2500r.p.m. during period of operation.
3) Cross-section: $0.14m^2$ (0.34 × (0.6 + 0.25)/2).

Table 2-3. Coefficient of permeability of various materials.

(1) Small gravel (2.0–9.0mm diameter), K=0.2–0.5m/sec
(2) Paddy husks (Japanese)

	Pressure (kgf/cm^2)	0.5	1.0	1.5
K (cm/sec)	Soaking for more 10 days	0.54	0.23	0.11
	Laid in field for more than one year	0.52	0.16	0.06

(3) Paddy husks (Malaysian)

	Pressure (kgf/cm^2)	0.5	1.0
K (cm/sec)	New paddy husks	0.38	0.22
	Laid in field for more than 3 years	0.20	0.11
	Laid near the underground drain pipe for more than 2 years	0.15 0.04	0.09 0.02

Note: 1) Data of (2) see reference (5), page 178.
2) The test of (3) was performed by applying the method of constant head permeability test.

Table 2-4. Soil bearing capacity during the construction of the test plots (1978).

Plot No.		16	17	18	19
Test period (month/day)	Depth (cm)				
5/24	0–25	8.49	5.94	4.64	3.89
	0–70	8.33	7.40	6.18	7.31
6/19	0–25	5.92	4.23	3.91	3.03
	0–70	6.71	5.75	4.98	4.98
7/5	0–25	2.97	3.31	2.41	1.59
	0–27	4.76	5.11	4.49	4.25

The values are the average for each 5cm, Unit: kgf/cm^2.

Table 2-5. Performance of mole drainer.

Construction line No.	Construction time (min and sec)		Turning time (sec)
4	2min	25sec	30
5	2min	50sec	15
6 , 7	3min	35sec	20
8	1min	50sec	30
9	1min	35sec	35
10	2min	25sec	35
11	1min	45sec	20
12	1min	40sec	20
13	1min	50sec	20
14	1min	45sec	35
15	1min	50sec	25
Average	1min	57sec	26

Note: Length of ditch constructed: 65 meters.

4) Discussion

The following observations were made.

(1) The data were insufficient resulting in inadequate management with regard to the schedule during the period of construction. Moreover, construction machines could not operate freely in the field. It is thus preferable to construct the drainage system under favorable weather condition, for example during the dry season when the trafficability of the machines is better.

(2) Construction of blind drains and complete underdrains

(a) The digging volume per hour by the ditcher was about six times as large as that with a back-hoe. The digging speed per 10 meters using the ditcher was about 14 times that with a back-hoe. The difference was due to the presence of favorable field conditions when the ditcher was used, and also due to the low trafficability

and poor field conditions for the back-hoe owing to its heavy weight.
However, the ditcher can not be used for digging at a depth of less than 45cm due to the limit in its performance.

(b) The results on the filling of paddy husks and backfilling with soil were very similar as regards labor requirements (about 1 man/60m/day). If the construction were to be done in the dry season, the loaded lorries could run in the fields, and labor requirements for delivery could be reduced.

(c) When the ditches were flooded by rain or seepage water during the construction, the ditch walls collapsed easily. To overcome this shortcoming, it is prefeable to have the drain pipes laid first in the husks and backfilled with soil in order to maintain the required depth of the pipes. These procedures were carried out as soon as the ditches were dug. It is also desirable that the fields be properly drained and dried during the construction period.

(3) Construction of the mole drain

This was completed very fast (construction time = 3 minute/100m). Since the mole drain holes were easily crushed and choked up (Figure-3-3), it was preferable to construct them once every year in the dry season and fill the holes with paddy husks. The investigation enabled to demonstrate that the holes of the mole drain were completely filled with soil.

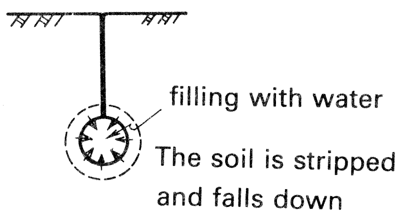


Fig 3–3. Slaking phenomenon of soil in the mole drain hole.

(4) There were considerable differences in the construction conditions of the three types of subsurface drainage. The construction of the complete underdrains was the most difficult to achieve because it required the use of large machines and complicated construction system. The construction of the blind drains was easy because a tractor could be used for the digging of the ditches and an underdrain with a small cross section was required as compared to the situation of the complete underdrains.

(5) Paddy husks are generally used as a permeable material for underground drainage systems in Japan. The paddy husks were also used as permeable materials in this study. There are no data on the decomposition of the paddy husks in Malaysia. Therefore, the author buried the paddy husks at No. 22 plot (Figure-3-1) in July 1977 in order to evaluate the suitability of paddy husks as a permeable material. When the burying of the paddy husks, the fields were slightly wet with rain before the presaturation

period and the underground water table reached a depth of 80cm.

After two years, permeability tests of the paddy husks, which were buried at No. 22 plot and were used as the material for underground drainage were conducted in August 1979. The planting schedule and the field conditions of No. 22 plot were similar to those of No. 16 ~ 19 plots.

From the results obtained, it was demonstrated that the color of the buried husks had changed little and that the coefficient of permeability had not appreciably decreased.

Moreover the paddy husks which were used as the material for underground drainage were slightly decomposed when mixed with soil and their coefficient of permeability decreased only little.

It is thus considered that paddy husks can be used as permeable materials based on the studies described above.

IV. Basic Studies on the Subsurface Drainage System

1. Changes in soil bearing capacity due to evaporation

The first study, which aimed at determining the relationship between the soil moisture content, the underground water level and the soil bearing capacity, was conducted when field water had evaporated in the dry season. These relationships were studied by measuring the water level in the auger hole, by soil sampling and by determining the soil bearing capacity using a cone penetrometer.

The determinations were carried out in the 22 and 23 plots (Figure-3-1) where the four auger holes were at first dug with a view to measuring the underground water level. Since field water was allowed to decrease by evaporation in the dry season, the soil bearing capacity was measured around the auger holes.

The experimental results are shown in Figure-4.

Conclusions are as follows:

(1) The soil bearing capacity (average value within a depth of 25cm) was inversely proportional to the soil moisture content (average value within a depth of 25cm). The period required for the soil bearing capacity to reach a value of 2.0 kgf/cm^2 and to increase it from 2.0 kgf/cm^2 to 8.0 kgf/cm^2 was identical.

(2) The soil bearing capacity was proportional to the square of the underground water level. When the underground water level reached 15cm the soil bearing capacity did not increase, but when this level was below 30cm, the capacity suddenly increased, suggesting that this level should be decreased by drainage in order to increase the soil bearing capacity.

(3) The underground water level was proportional to the square of the total evaporation quantity. Total evaporation amount ranging from 60mm to 90mm is required for obtaining an underground water level of 30cm. If the daily amount of evaporation is 5mm, 12 to 18 days will be required for evaporation. However, it is difficult to expect fine days continuously during the off-season harvesting period which coincides with the rainy season. Therefore to drain water within 2 or 3 days, evaporation should range from 10mm to 15mm and the drainage water discharge from 40 to 80mm.

After using the surface drain with the outlet, there was some residual water. Therefore, since drainage through evaporation only takes too much time, it is necessary to use the underground drainage system.

(4) The soil moisture contents decreased with evaporation (average about 3.5% moisture content for 10mm evaporation, based on Figure-4-5). This finding implies that it takes 17 days by application of the method of evaporation to reduce the soil moisture content from 90% (average moisture content before drainage of field soil) to 60% (beginning of increase of the soil bearing capacity).

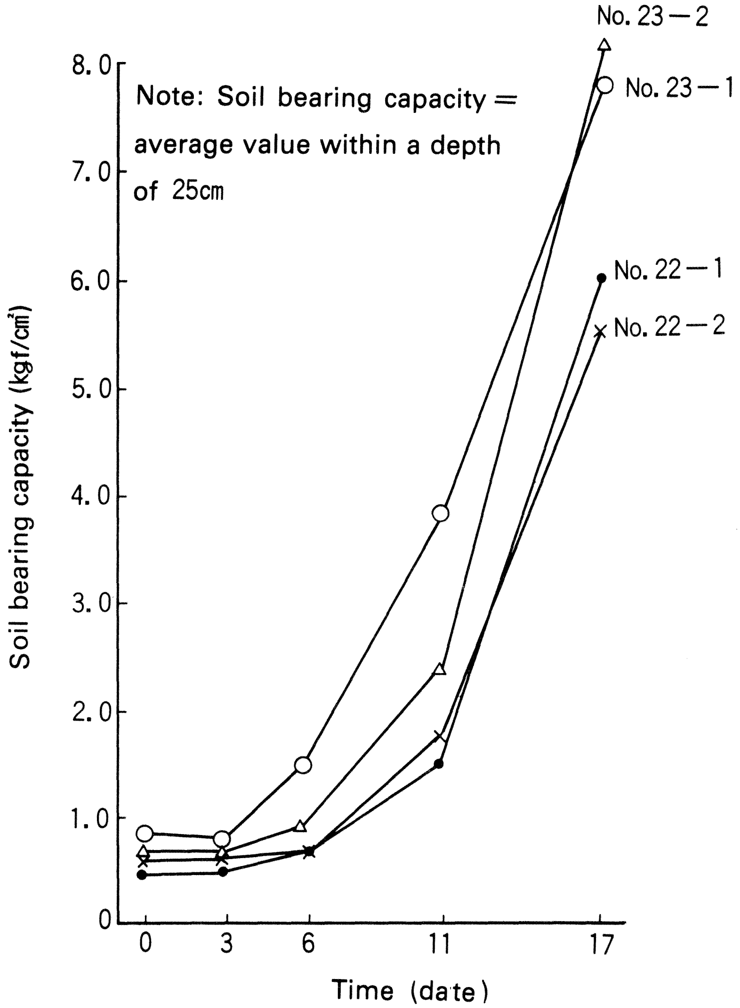


Fig 4—1. Changes in soil bearing capacity with time.

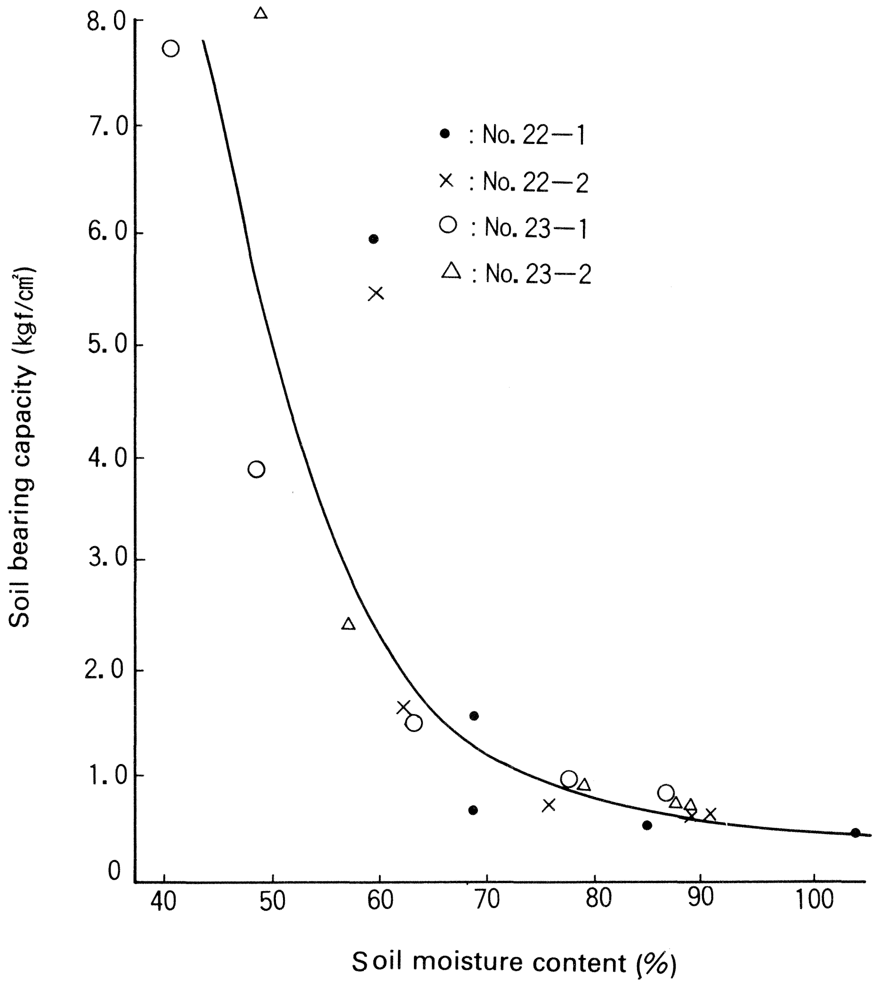


Fig 4–2. Relationship between soil bearing capacity and moisture content.

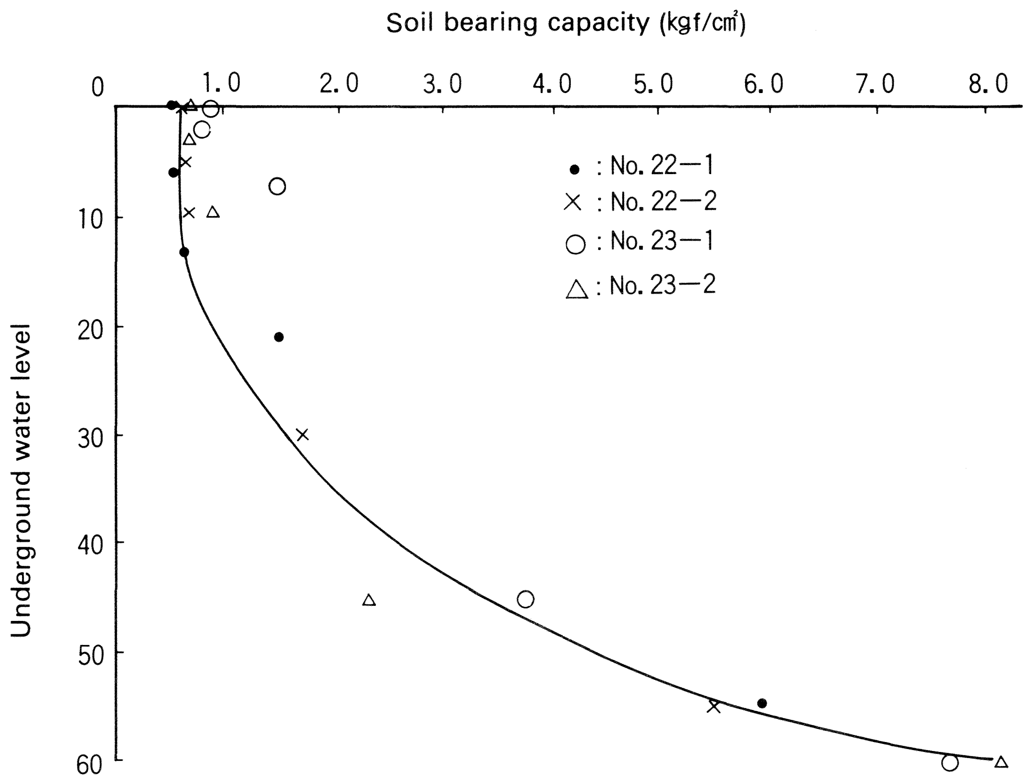


Fig 4–3. Relationship between underground water level and soil beariog capacity.

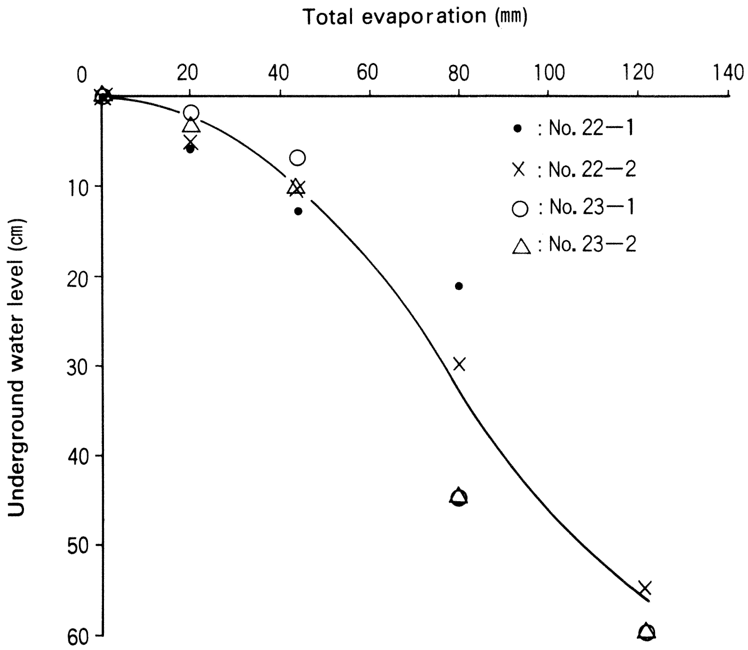


Fig 4–4. Relationship between underground water level and total evaporation.

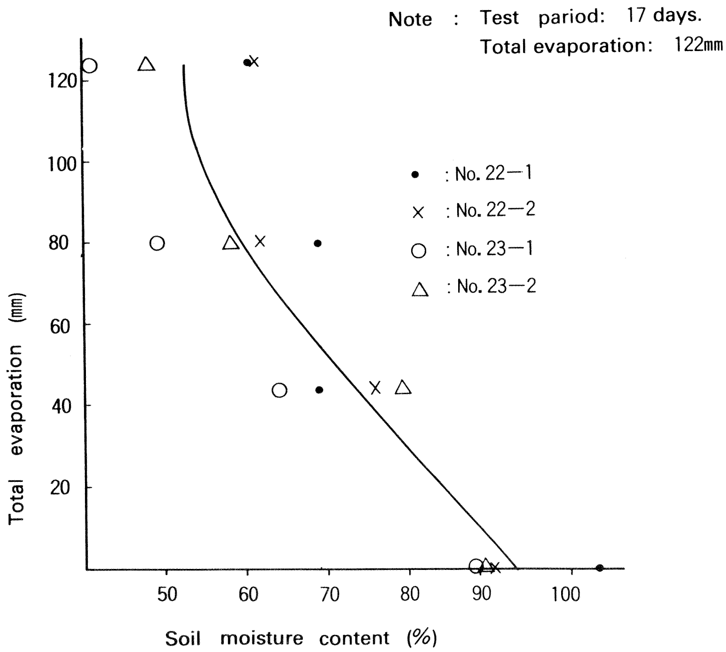


Fig 4–5. Relationship between total evaporation and soil moisture content.

2. Methods for increasing soil hardness in the laboratory

The second study was conducted using the same relationships as above by sampling the soils in plastic buckets from January to March 1978. The soil samples packed in the plastic buckets (volume 84 litre) were obtained from the Telok Chengai experimental plots. The use of plastic buckets enabled to control the underground water level. The soil bearing capacity, soil moisture contents and values of water level were determined to evaluate different drainage methods, namely drainage from bottom, underground level controlled approximately at 0, 10 and 30cm from the soil surface, and also evaporation alone from the soil surface.

The results are shown in Figure-5.

1) The soil bearing capacity (average value within a depth of 25cm) was inversely proportional to the soil moisture content (average value within a depth of 25cm). When the soil moisture content decreased from 100% to 60%, the soil bearing capacity increased to only 1.3 kgf/cm^2.

   However, when the moisture content decreased from 60% to 45%, the soil bearing capacity increased to 5 kgf/cm^2.

   This finding suggests that when the soil moisture content exceeds 90%, the amount of water is represented by excess water. This water should be drained rapidly. However less than 90% is drained by using a subsurface drainage system (Figure-5-3).

2) As a result, to obtain a soil bearing capacity of 2.0 kgf/cm^2 it takes 17 and 19.5 days by using bottom drainage, 24 days by evaporation only, 22, 24, 27 and 23 days by controlling the underground water level at 15, 30, 10cm and the same level of soil surface, respectively.

   These findings suggest that the soil bearing capacity was increased by bottom drainage. Since the soil samples were carefully puddled, the water within the soil moved with difficulty. Therefore, the drainage of the water was delayed and the increase in the values of the soil bearing capacity occurred later than in the field test.

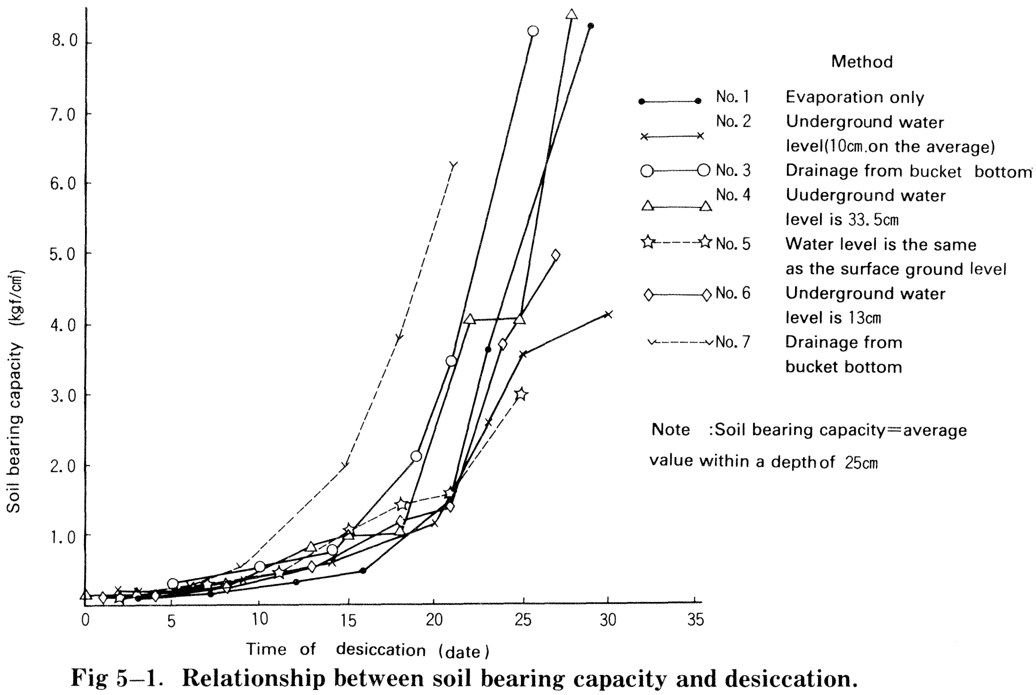


Fig 5–1. Relationship between soil bearing capacity and desiccation.

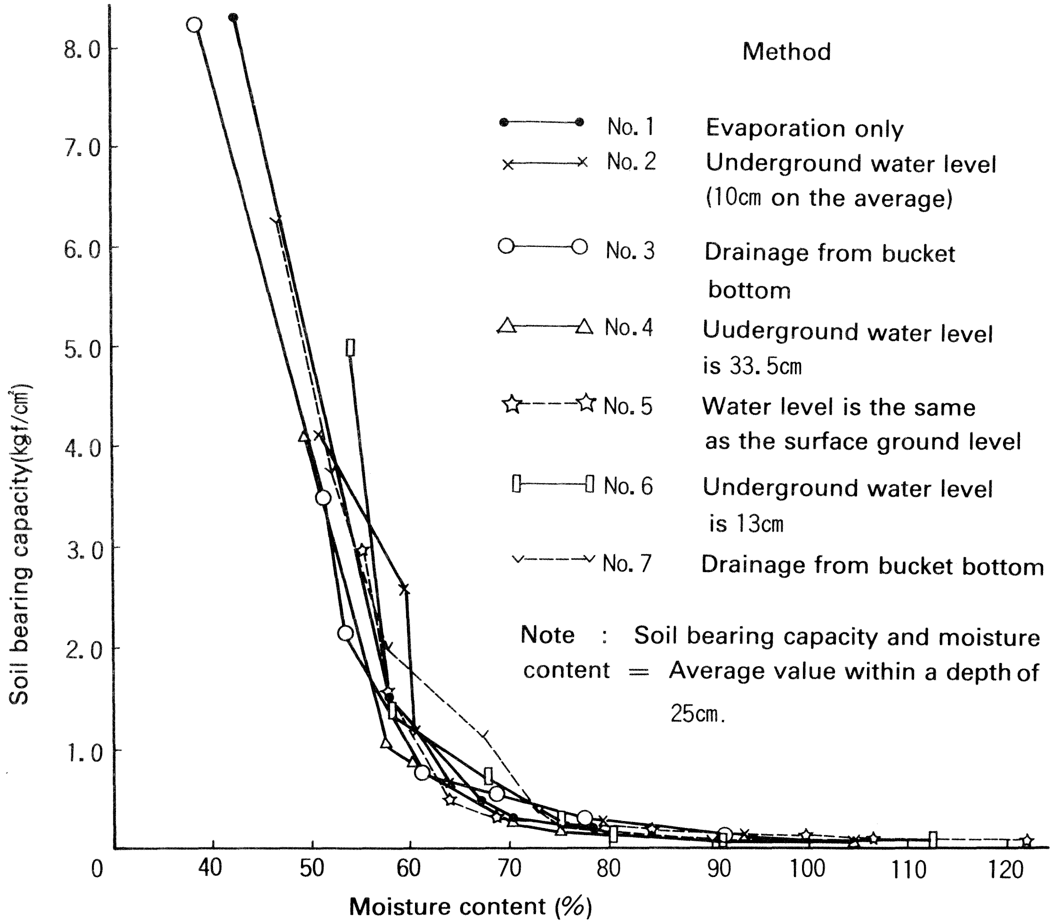


Fig 5–2. Relationship between soil bearing capacity and moisture content.

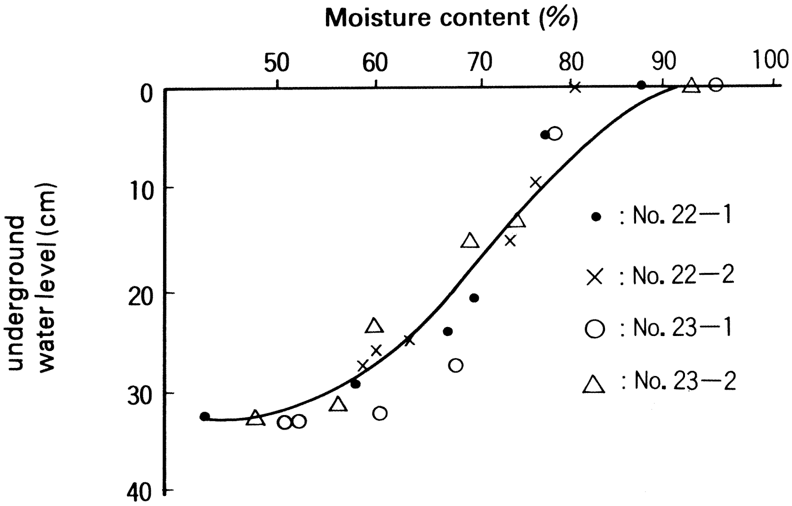


Fig 5–3. Relationship between the underground water level and moisture content.

3. Changes in the coefficient of permeability of the surface soil after puddling

Permeability tests were carried out to determine the coefficient of permeability of the soil on the surface of the field after puddling.

For the permeability tests, roughly crushed soil (coarse soil) and finely crushed soil (fine soil) were used. The cylinder was 10cm high and 10cm in diameter, and the weight of sampled soil was about 1,500g, as shown in Figure-6-1.

The soil samples were puddled strongly or weakly, after the soil was packed in the test cylinder. The cylinder bottoms were covered with a net. The tests were performed 1, 2, 3, 4, 6, 7, 11 and 15 days after mixing the soil. The equation used is as follows.

$$K_{15} = \frac{a \times L}{A} \times \frac{2.30}{t_2 - t_1} \times \log\frac{h_1}{h_2} \times \frac{\mu_t}{\mu_{15}}$$

Where:

K_{15} : Coefficient of permeability at 15°C (cm/sec)
a and A: Pipe and cylinder cross section area (cm^2)
h_1 and h_2 : Water level at the start and at the end of the test (cm)
t_1 and t_2 : Time when h_1 and h_2 were measured (sec)
L: Length of the cylinder (cm)
μ_t and μ_{15} : Coefficient of viscosty of water at the time of measurement and at 15°C

From the results of the tests illustrated in Figure-6-2, it could be demonstrated that the coefficient of permeability of fine soil after 11 days amounted to 1.0×10^{-5} cm/sec (no puddling), 1.0×10^{-6} cm/sec (moderate puddling) and 1.5×10^{-7} cm/sec (strong puddling). However, the coefficient of permeability of coarse soil was 3.0×10^{-2} cm/sec.

From the results, it appears that the coefficient of permeability did not decrease by minimum puddling, but that the permeability quickly decreased in fine soil and by strong puddling. Therefore, light puddling and dry cultivation are recommended.

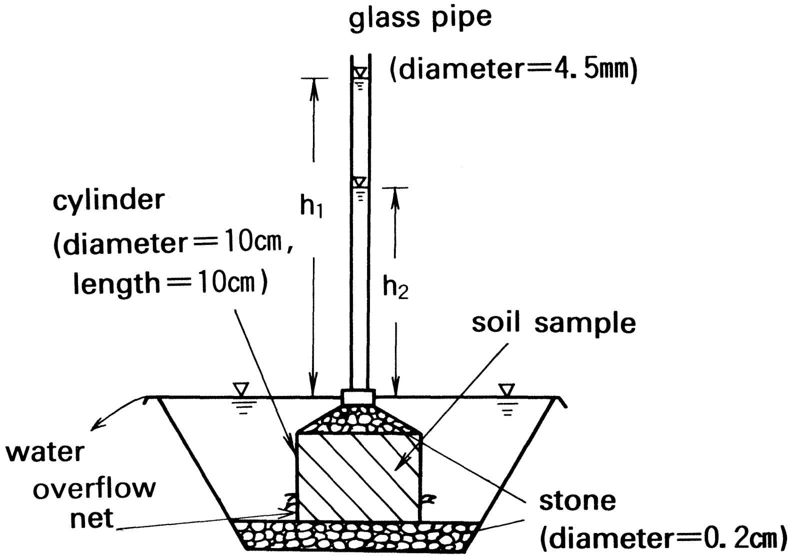


Fig 6–1. Permeability tester.

Percentage of soil blocks in sample

diameter of soil block (mm)	25.4	19.1	2.0	2.0 below	Soil moisture content (%)
coarse sample	1.7	37.4	42.9	18.0	6.75
fine sample	0	0.7	70.4	28.9	6.08

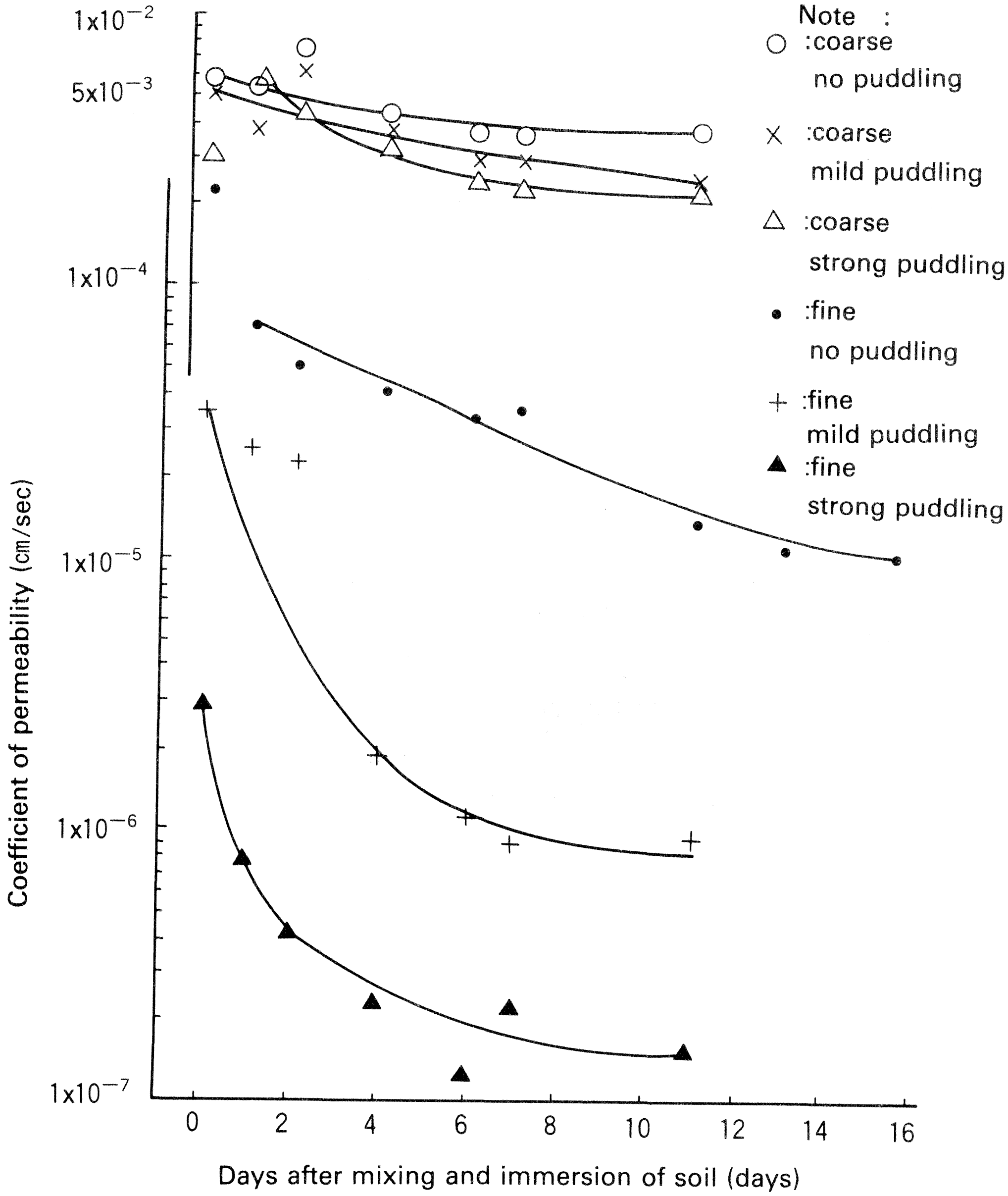


Fig 6–2. Coefficient of permeability of surface soil after puddling.

4. Test of slaking properties of surface soil and subsoil

When the mole drain was constructed in June 1978, the cross section of the hole (no material was used) compared with the mole diameter was about 80% (diameter about 8cm). After three weeks, the hole was blocked up to about 70% of the mole diameter with soil owing to inflow and slaking of soil. When the Japanese expert checked the mole drain hole after nine months, the hole was completely blocked with soil.

It was important to understand the reason why the water-paths (mainly cracks in heavy clayey soil) were blocked. There were two causes, of which the first was connected with slaking of soil after saturation, and the second was related to human works (for example, puddling with tractor). Therefore, the slaking characteristic of clayey soil, when soaked, is a very important physical property of soil which must be prevented for the improvement of clayey soil.

The test is not a standard method. The authors tested and modified Sato's method[6] as follows.

The samples collected at three different depths, namely 0–10cm, 30–40cm and 40–50cm from No. 16 plot in the test field were sifted (sieve diameter=2mm), and kneaded to reach a water moisture content similar to that of the liquid limit content. The thirty soil samples at each depth were moulded in a container, as shown in Figure-7-1.

The samples were dried naturally in the laboratory. After one day, the soil samples (three samples were used each time) were put on a net (diameter 3~4mm) in the cup and soaked with water, as shown in Figure-7-2.

After one day, the soil samples were removed and oven-dried, and measurements were carried out on soil from the top and bottom of the net. The slaking percentage after leaving the soil for 24 hours on the 3~4mm sieve in water were calculated according to the following formula.

$$\text{Slaking Percentage} = \frac{\text{Dry weight of soil slaking from net}}{\text{Dry weight of soil sample}} \times 100\ (\%)$$

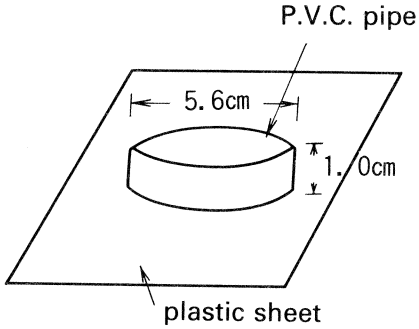


Fig 7–1. Container for slaking test.

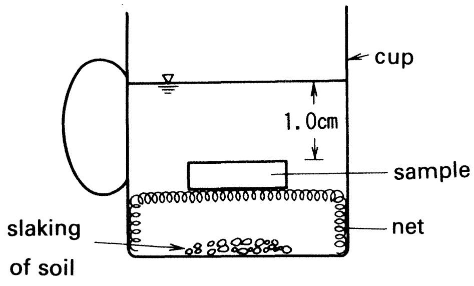


Fig 7–2. Slaking test.

The results of the test (Figure-8) showed that the maximum slaking percentage of the surface soil and of the subsoil at depths ranging from 30~40cm to 40~50cm amounted to 28%, 68% and 76% respectively. The maximum slaking value of the subsoil was observed when the soil moisture content was less than 20% whereas that of the surface soil was observed when the moisture content was 70%. The percentage of slaking of the surface soil was lower than that of the subsoil. Slaking of each type of soil was minimum when the moisture content ranged from 20% to 60%. Based on the results of the slaking test developed by Ezaki[3], slaking of the soil rapidly increased after 10 days of soaking in water. When the data of the soils in the Muda Area were compared with those of Sato[6], the former soils did not differ from the Japanese soils except for the low moisture content.

Since the soils in the Muda Area readily undergo slaking when the moisture content is less than 20%, the soil cracks tend to be blocked with soil following irrigation and puddling of the paddy fields.

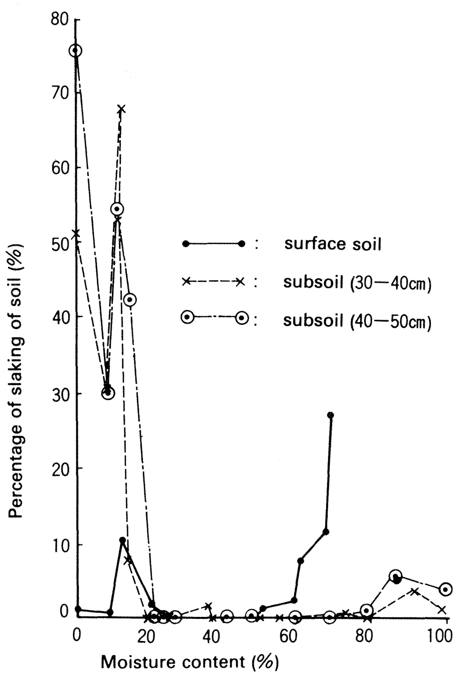


Fig 8–1. Slaking test.

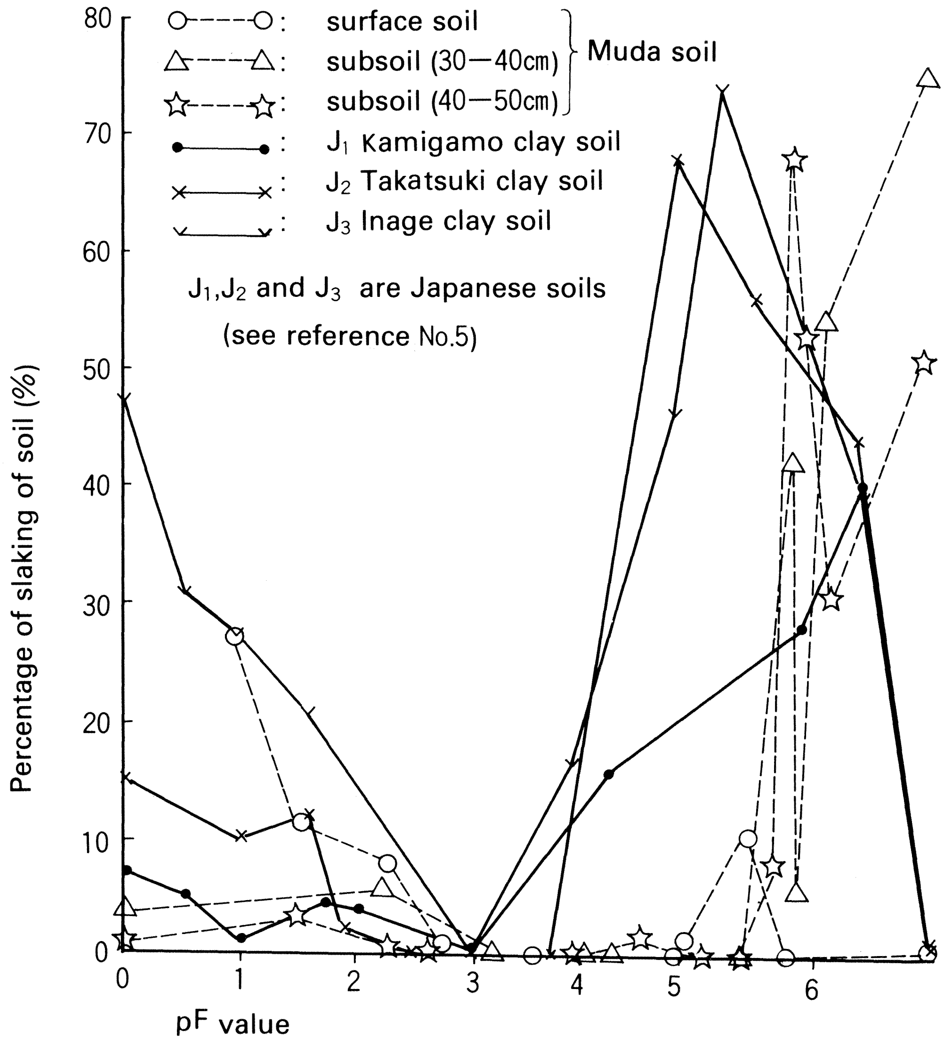


Fig 8–2. Comparison of slaking test between Muda soil and Japanese soil.

5. Measurement of soil moisture suction

The determination of the pF-soil moisture curve was performed in using the soil column method, the suction plate method, on air-dried and oven-dried soil. The soil samples which were of two types, undisturbed and disturbed soils were collected from the test field The samples of undisturbed soils were collected with a sample (100cc volume cylinder). The samples of disturbed soils were collected with an auger and packed in the cylinder after mixing the soil.

The results of the tests are shown in Figure-9. The changes of the soil moisture content from pF.0 to pF.2.8 in the undisturbed soil were very small, suggesting that it would be difficult to improve the drainage of this field.

However, since the soil moisture content in the dry season is less than 40% (Table-4-2, moisture ratio) it is necessary to drain the fields during the dry season so as to enable the formation of numerous deep cracks.

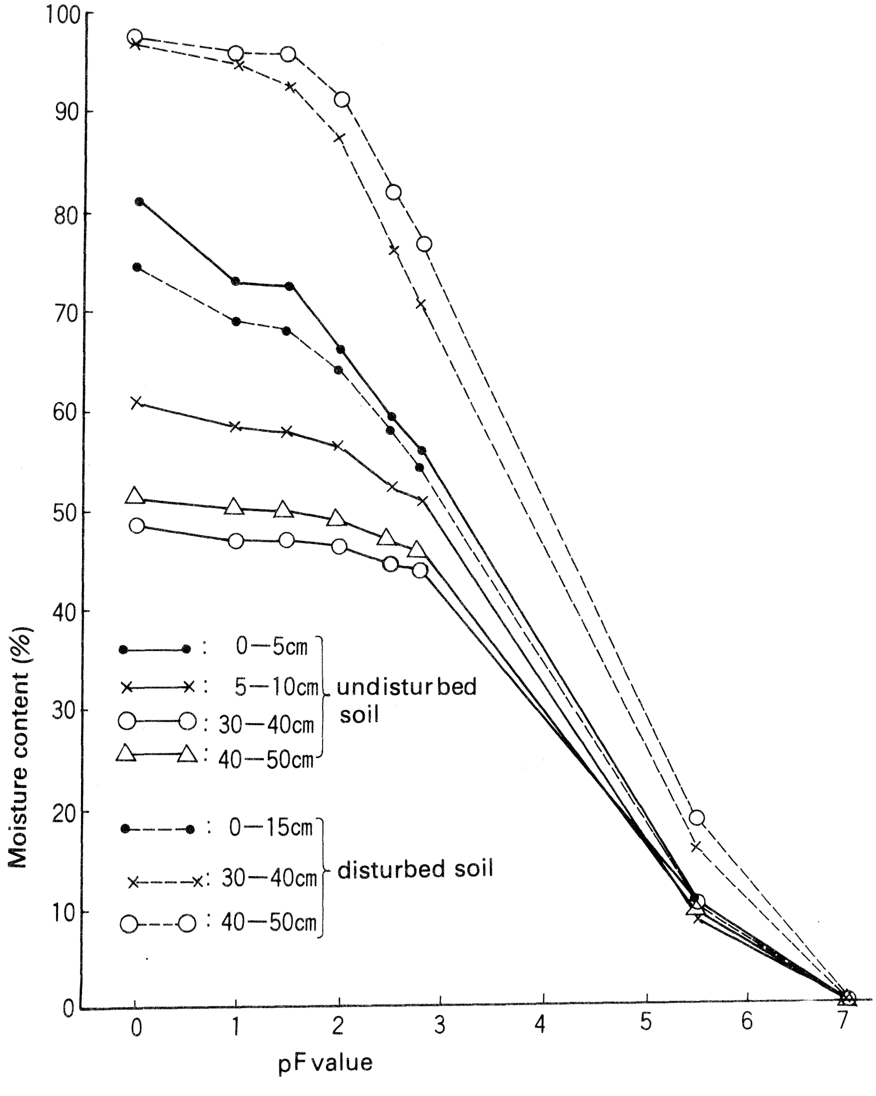


Fig 9. Soil moisture suction curve.

V. Evaluation Studies Prior to the Construction of the Test Plots

Evaluation studies before the construction of the test fields were as follows.

1) Investigations of soil hardness
2) Survey of soil profile
3) Analysis of the factors controlling
   * Land levelling * Coefficient of permeability

The location of the investigation points in the test plots is shown in Figure-10.

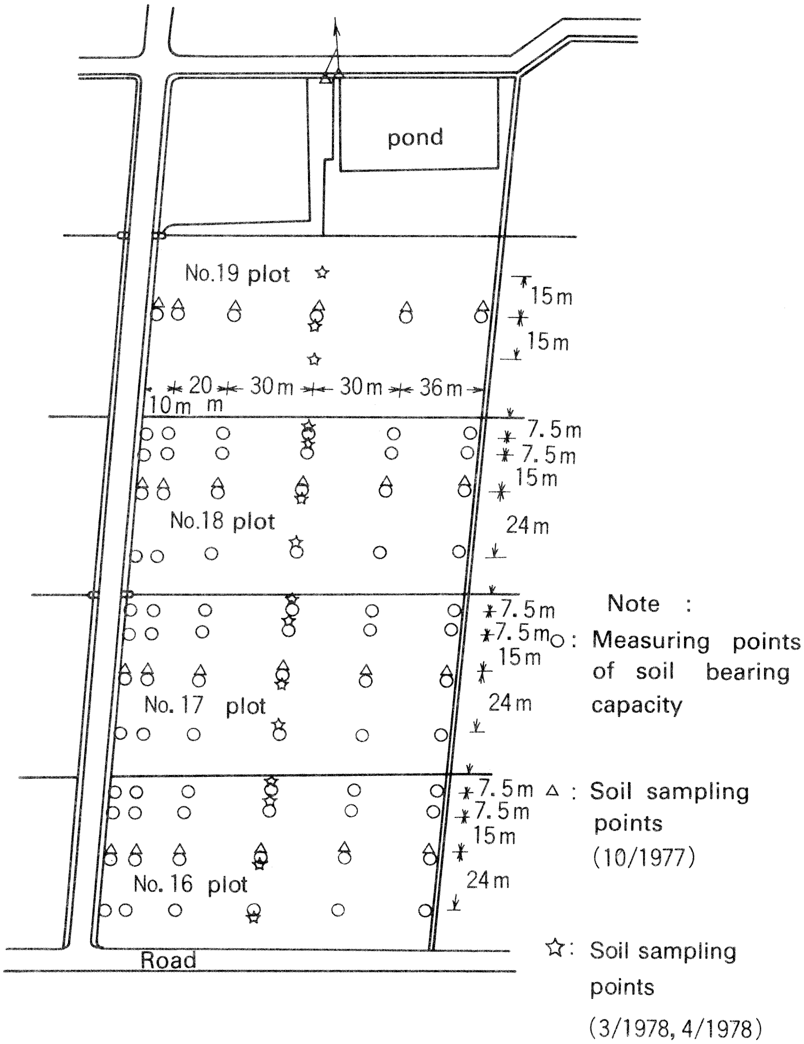


Fig 10. Location of measuring points before the construction of test plots.

1. Soil hardness

It is important to measure the soil hardness in the test plots in order to analyse the relationship between the trafficability of agricultural machines and the effectiveness of the subsurface drainage.

As the soil hardness varied with the field conditions, it was measured once every month with a cone penetrometer at the location shown in Figure-10.

Cone penetration index (qc value) indicates soil hardness and soil resistance in kgf/cm^2. The instrument used to measure the soil bearing capacity was the automatic cone penetrometer with a base projected area of $3.14cm^2$ and a cone angle of 30°. The results of the survey conducted from July 1977 to July 1978 are shown in Figure-11 and Table-3.

Changes in the soil bearing capacity from July to December 1977 were minimal since the fields were flooded. However the soil bearing capacity increased considerably from January to April 1978 since the fields became desiccated during the dry season. The rainfall data are shown in Table-17.

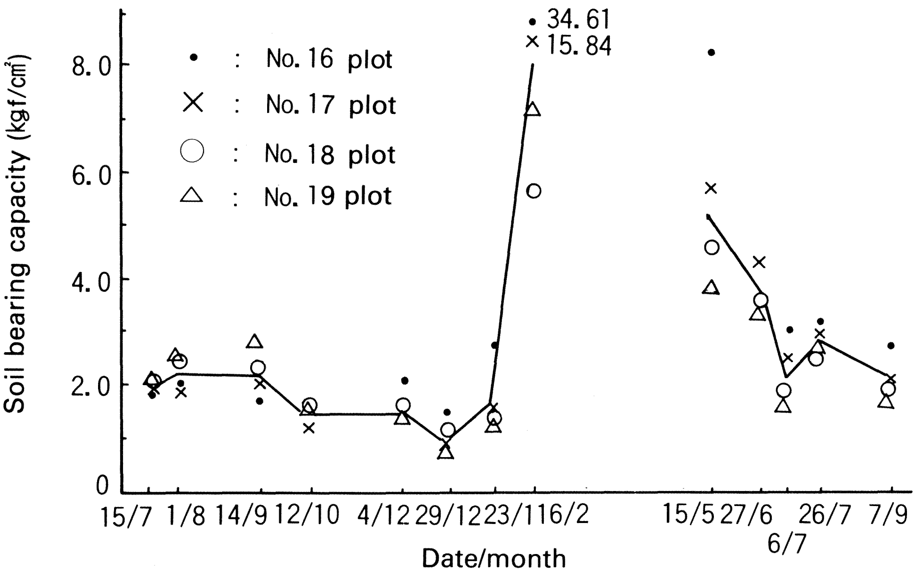


Fig 11. Annual variation of soil bearing capacity.

Table 3. Average soil bearing capacity in test plots.

Plot No.	16		17		18		19		
depth (cm) / date	0~25	0~70	0~25	0~70	0~25	0~70	0~25	0~70	Field conditions
14~16/7/1977	1.84	3.91	1.90	3.56	1.99	3.68	2.04	3.74	About 55 days after transplanting. Flooding.
30/7~1/8/1977	2.01	3.93	1.84	4.11	2.52	4.43	2.57	4.98	About 70 days after transplanting. Flooding.
13~14/9/1977	1.68	4.26	2.04	4.89	2.34	4.93	2.73	5.38	5 days after harvesting.
11~13/10/1977	1.39	4.59	1.21	4.33	1.59	4.40	1.46	4.56	Transplanting period. Flooding.
3~5/12/1977	2.09	4.94	1.43	4.85	1.49	4.83	1.33	4.37	About 50 days after transplanting. Flooding.
22~24/1/1978	2.73	5.00	1.57	4.37	1.37	4.13	1.23	4.29	About 95 days after transplanting. Flooding.
*14~19/2/1978	34.61	18.75	15.84	12.04	5.69	6.86	7.15	8.34	Harvesting period.
24~25/5/1978	8.52	8.26	5.68	6.72	4.53	5.96	3.70	5.44	Flooding condition.
19~20/6/1978	4.34	6.03	4.32	5.69	3.57	4.80	3.23	4.89	Flooding condition.
5~6/7/1978	3.02	4.90	2.75	4.76	1.86	4.01	1.51	4.15	First puddling.

Note: Soil bearing capacity was measured by Yamanaka's tester up to a depth of 20cm and by cone-penetrometer at a depth ranging from 20 to 70cm.

Unit: kgf/cm^2

Changes in the soil bearing capacity which depends on the distance from the drainage canals were minimal (Figure-12). Soil hardness varied with the test plots but No. 16 plot was the hardest among the plots and No. 19 plot was the weakest due to differences in the level of the field surface in each plot. The level of the field surface of No. 17, 18 and 19 plots was 3.6, 16.3 and 24.3cm lower than that of No. 16 plot.

The soil bearing capacity on 24th March and 19th June 1978 was high since there was a short period after the dry season. After irrigation water was supplied and puddling was carried out on the field surface, the soil bearing capacity decreased.

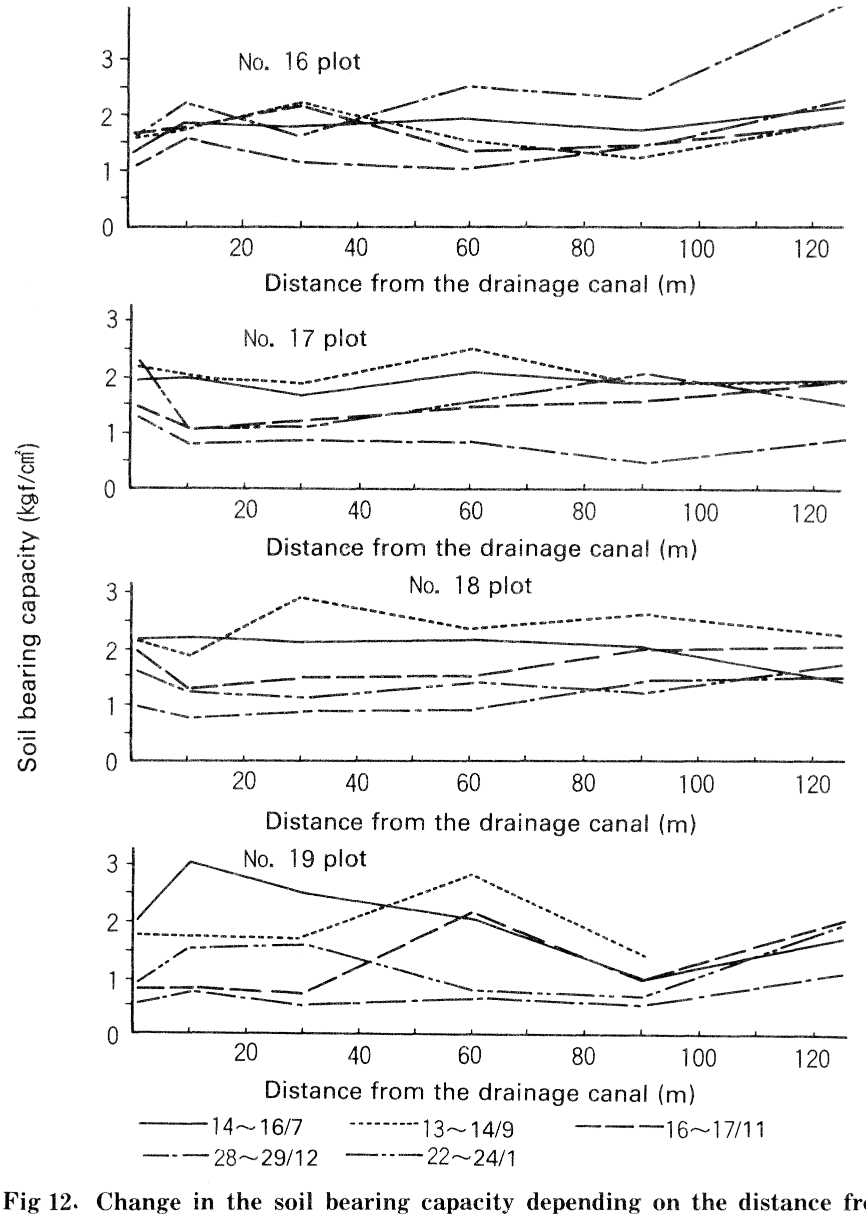


Fig 12. Change in the soil bearing capacity depending on the distance from the drainage canal (1977～1978)

2. Survey of soil profile

In order to analyse the soil physical conditions during the dry and wet season, soil profiles were observed and soil samples were taken from the test plots (No. 16, 17, 18 and 19 plots) in early October 1977 (wet conditions), mid-March and mid-April 1978(dry conditions) .

Thereafter, the physical characteristics of soil were analysed at the MADA-Engineering Division Laboratory.

1) Sampling method and sampling points

Undisturbed soil samples were mainly collected in a metal cylinder (diameter 5cm, height 5.1cm, volume 100cc) and disturbed soil samples were collected in plastic bags by scooping each field as illustrated in Figure-10.

2) Determination of soil physical properties

Parameters examined were as follows.

(1) Soil moisture content after sampling
(2) Three phases of soil (solid, liquid and gaseous phase)
(3) Specific gravity
(4) Soil density (wet and dry)
(5) Atterberg limits (liquid limit, (L.L), plasticity limt (P.L) and plasticity index (P.I)
(6) Mechanical analysis of soil

These analyses were conducted in the laboratory according to the procedure recommended by the Japan Industrial Standard (JIS).

3) Results

From the results illustrated in Table-4 the following conclusions were drawn.

(1) The soils at all the surveying points were heavy clay soils (clay percentage about 70%).
(2) Clay percentage, liquid limit value, solid phase and specific gravity increased in proportion to the depth.
(3) Dry soil density in the samples collected in September 1977 increased with depth, but in the samples collected in March and April 1978 the values of density showed a peak of depths ranging from 10 to 30cm.
(4) Solid phase of soil at depths ranging from 20 to 60cm gave higher values than Japanese marine clay soil, suggesting that this layer was compressed. For references, clay minerals of Telok Chengai soil are shown in Table-5. It is generally assumed that the Muda area soil consists of marine clay soil.
(5) Soil hardness measurements using Yamanaka's soil hardness tester indicated a decrease in proportion to the depth.
(6) In March 1978 the samples were collected by using a 100cc cylinder and by digging the field with cubes (50 x 50 x 10cm or 30 x 30 x 10cm).

The values of soil density and three phases varied with the type of collection because the cube samples included cracks. The crack volume was responsible for the difference between the vapor phase of the cylinder and cube samples since it was larger in the cube samples than in the cylinder samples (Table-4-2 and 8-2). Based on the results obtained, it appears that the use of the digging cube is superior to that of the cylinder during the dry season.

(7) From the results of plasticity chart illustrated in Figure-13, Muda-clay soil could be considered as a high-plastic inorganic soil.

Table 4-1. Soil physical characteristics

Sampling date 26/9~5/10/1977

Plot No.	Depth (cm)	Moisture ratio (%)	Specific gravity	Soil density (g/cm^3)		Three phases of soil (%)			Atterberg limits (%)			Mechanical analysis (%)		
				wet	dry	solid	liquid	gaseous	L.L	P.L	P.I	clay	silt	sand
16	0–10	68.8	2.58	1.556	0.925	35.9	63.1	1.4	76.8	32.9	42.3	69.2	29.9	0.9
	10–20	55.6	2.60	1.648	1.063	41.0	58.7	1.1	79.0	35.3	43.7	68.5	29.6	2.0
	20–30	48.9	2.60	1.689	1.138	43.8	55.1	2.1	81.2	34.3	46.9	71.3	28.1	0.7
	30–40	45.1	2.62	1.695	1.171	44.7	52.5	2.8	90.6	33.5	57.1	72.8	25.6	0.7
	40–45	44.9	2.66	1.713	1.180	44.6	52.8	1.3	95.3	32.4	62.9	75.3	24.0	0.7
17	0–10	76.2	2.60	1.494	0.855	32.9	63.9	4.3	86.0	36.2	49.8	74.1	24.9	1.0
	10–20	62.5	2.59	1.612	0.998	38.6	61.4	0.9	83.6	35.4	48.2	72.7	26.4	0.9
	20–30	51.9	2.61	1.693	1.120	42.9	57.3	0.6	85.1	34.0	51.1	74.3	24.2	1.0
	30–40	44.5	2.66	1.736	1.203	45.2	53.4	1.6	93.7	31.4	62.3	76.7	22.2	1.1
	40–45	44.8	2.71	1.733	1.147	44.2	53.6	2.2	101.1	31.3	69.8	78.6	19.5	2.0
18	0–10	70.0	2.59	1.566	0.925	35.7	64.2	0.8	80.5	34.3	46.3	70.9	27.5	1.6
	10–20	55.5	2.60	1.684	1.088	42.2	59.6	0.1	81.3	34.4	46.9	69.2	28.6	2.2
	20–30	48.1	2.62	1.730	1.170	45.1	56.1	0.5	86.0	31.3	54.7	71.2	26.2	2.6
	30–40	43.6	2.66	1.743	1.214	45.7	52.9	1.4	88.2	31.4	56.8	73.2	25.3	1.5
	40–45	43.4	2.70	1.752	1.223	44.9	53.0	1.8	97.8	29.9	67.9	74.3	24.0	1.7
19	0–10	69.0	2.57	1.555	0.924	36.0	63.2	1.5	79.3	35.3	43.9	68.7	30.0	1.3
	10–20	54.2	2.59	1.635	1.075	41.6	57.8	1.4	80.3	33.2	47.1	68.4	30.4	1.2
	20–30	45.1	2.60	1.754	1.210	46.0	54.5	0.1	80.3	31.5	48.9	69.3	29.0	1.7
	30–40	40.4	2.64	1.763	1.254	47.6	50.7	1.7	86.9	30.3	56.6	70.0	28.5	1.5
	40–45	41.5	2.69	1.755	1.241	46.2	51.4	2.4	96.8	29.8	67.1	73.6	26.3	1.7

Table 4-2. Soil physical characteristics.

Sampling date 10 ~ 26/3/1978

Plot No.	Depth (cm)	Moisture ratio (%)	Specific gravity	Soil density (g/cm^3)		Three phases of soil (%)			Mechanical analysis (%)			Soil hardness
				wet	dry	solid	liquid	gaseous	clay	silt	sand	
	0–10	23.4	2.61	1.724	1.397	53.6	32.8	13.9	77.3	22.2	0.5	28.3
	10–20	24.1	2.62	1.816	1.464	55.5	35.3	8.9	75.8	23.8	0.5	29.1
	20–25	16.5	2.64	1.863	1.489	56.4	36.8	6.9	76.8	22.6	0.8	27.7
16	30–35	28.0	2.70	1.761	1.396	52.8	39.6	7.6	70.3	29.0	0.7	22.8
	40–45	39.0	2.69	1.767	1.272	47.3	49.6	3.2	67.4	31.5	1.1	17.7
	50–55	41.4	2.70	1.743	1.233	45.7	51.5	3.3	75.4	24.0	0.6	14.6
	60–65	44.2	2.69	1.732	1.202	44.7	53.1	2.3	71.0	25.2	3.8	–
	0–10	20.7	2.55	1.464	1.213	47.5	25.3	27.2	76.3	23.3	0.5	28.0
	10–20	27.5	2.59	1.751	1.375	53.3	37.6	9.3	74.0	25.3	0.7	28.2
	20–25	28.9	2.62	1.856	1.439	55.0	41.6	3.4	73.5	25.6	0.9	26.5
17	30–35	35.6	2.62	1.766	1.306	49.7	46.5	3.8	78.0	21.0	1.0	22.3
	40–45	40.4	2.72	1.804	1.281	47.1	51.9	1.1	73.5	24.6	1.9	16.5
	50–55	43.1	2.70	1.766	1.235	45.7	53.2	1.1	68.0	31.5	0.5	15.6
	60–65	41.5	2.71	1.765	1.247	46.0	51.7	2.3	63.5	32.0	4.5	–
	0–10	28.5	2.58	1.672	1.035	50.6	37.0	12.5	70.3	29.0	0.8	27.2
	10–20	31.7	2.60	1.756	1.333	51.3	42.4	6.5	73.5	25.6	1.6	25.4
	20–25	34.1	2.65	1.796	1.340	50.5	45.7	3.9	74.8	24.2	1.6	22.1
18	30–35	40.0	2.67	1.752	1.253	46.9	50.1	3.2	79.0	19.6	1.4	16.3
	40–45	42.5	2.72	1.725	1.270	44.2	51.5	4.1	76.0	22.7	1.3	13.0
	50–55	42.1	2.73	1.720	1.210	44.3	51.0	4.7	80.0	18.2	1.8	–
	60–65	44.3	2.74	1.711	1.156	43.3	52.5	4.2	74.0	23.4	2.2	–
	0–10	27.3	2.57	1.551	1.219	47.4	33.3	19.4	65.3	33.8	0.7	26.5
	10–20	32.9	2.59	1.794	1.350	52.1	44.4	3.6	66.2	33.0	0.9	24.1
19	20–25	35.5	2.60	1.760	1.299	49.9	46.1	4.0	68.5	30.2	1.3	18.7
	30–35	27.2	2.64	1.794	1.317	49.9	47.1	2.4	71.5	27.1	1.3	14.7
	40–45	41.9	2.62	1.735	1.223	46.7	51.2	2.1	71.5	27.2	1.3	14.0
	50–55	43.2	2.68	1.705	1.191	44.4	51.4	4.2	–	–	–	12.5

Table 4-3. Soil physical characteristics.

Sampling date 11 ~ 12/4/1978

Plot No.	Depth (cm)	Moisture ratio (%)	Specific gravity	Soil density (g/cm³)		Three phases of soil (%)			Atterberg limit (%)		
				wet	dry	solid	liquid	gaseous	L.L.	P.L.	P.I.
	0–10	35.4	2.61	1.693	1.249	47.9	44.1	8.1	74.4	33.1	41.3
	10–20	38.3	2.62	1.733	1.254	48.0	48.5	4.1	75.6	33.4	42.3
16	20–30	25.7	2.64	1.821	1.343	50.7	47.9	1.3	91.1	32.9	58.3
	30–35	37.0	2.70	1.812	1.325	50.3	48.8	2.3	104.0	27.4	76.6
	40–45	42.9	2.71	1.757	1.231	45.7	52.6	2.0	101.5	29.9	71.6
	0–10	35.5	2.55	1.556	1.150	45.0	40.8	14.3	73.4	34.3	39.1
	10–20	39.8	2.59	1.668	1.200	46.5	47.6	6.0	76.8	33.1	43.7
17	20–30	37.5	2.62	1.773	1.291	47.6	48.2	2.5	81.8	33.9	47.9
	30–35	41.6	2.63	1.755	1.240	46.8	51.5	1.4	92.5	30.2	62.3
	40–45	44.2	2.72	1.751	1.215	45.0	53.7	1.8	102.5	29.6	72.9
	0–10	38.8	2.58	1.608	1.161	44.9	44.7	10.4	75.1	33.9	41.2
	10–20	40.9	2.60	1.715	1.217	46.8	49.8	3.5	76.3	32.7	43.6
18	20–30	38.8	2.66	1.811	1.305	49.0	50.6	0.6	85.9	31.0	54.9
	30–35	41.1	2.69	1.781	1.262	47.0	51.9	1.1	98.0	32.5	65.5
	40–45	44.8	2.74	1.780	1.230	45.0	55.0	0.1	98.5	31.4	67.1
	5–10	42.5	2.57	1.558	1.093	42.5	46.5	11.0	71.5	35.2	36.3
	10–15	47.9	2.61	1.631	1.103	42.3	52.8	5.0	74.5	33.7	40.8
9	20–25	39.2	2.60	1.806	1.298	49.9	50.9	0	76.5	31.6	44.9
	30–35	38.0	2.60	1.848	1.339	51.5	50.8	0	83.0	31.6	51.4
	40–45	40.6	2.62	1.801	1.281	48.9	52.0	0	90.5	30.7	59.8

Table 5. Clay mineralogy of Telok Chengai soil[7]. (by Kyuma, Kawaguchi)

Soil No. (Soil Series Name)	M-8 (West, Marine) (Telok Chengai)		
Horizon	I	IV	VI
Depth (cm)	0 ~ 10	40 ~ 55	80 ~
Clay mineral composition			
Kaolin	30	35	35
Illite	5	10	10
Others	65	55	55
Mont.	+++	++	++
Verm.	+	++	++
Mixed	+	++	+
Al-inter.	–	–	–
Gibbsite	–	–	–
Quartz	+	+	+

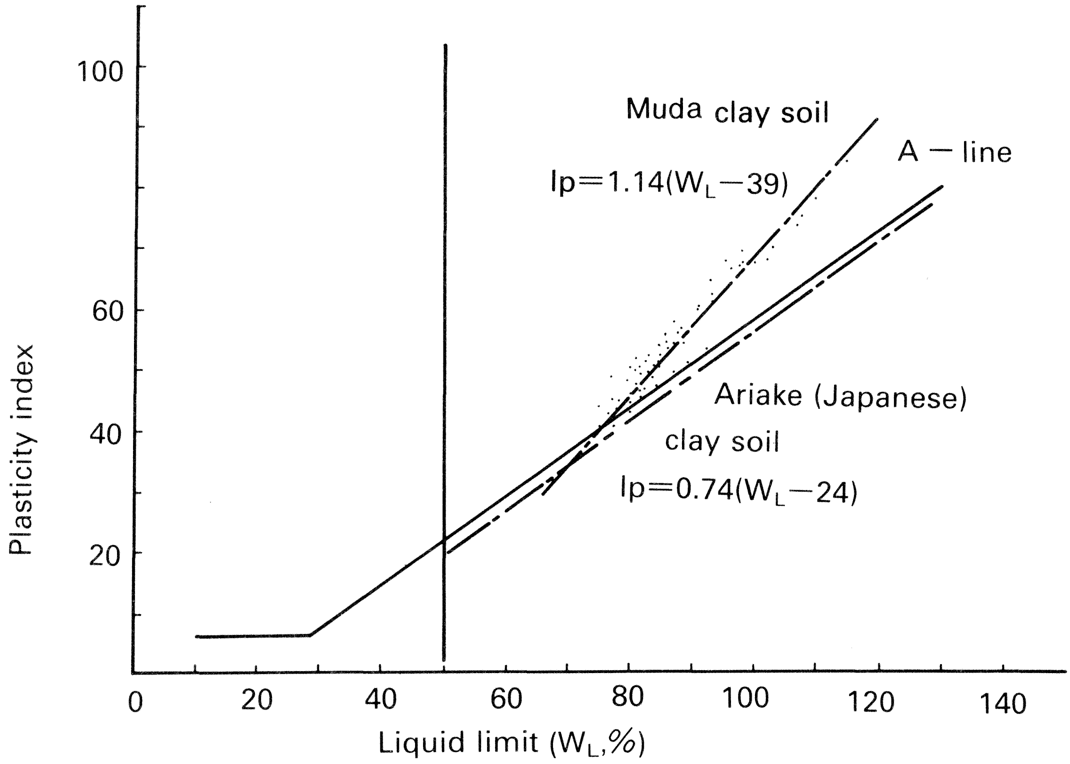


Fig 13. Plasticity chart (Japan Unified Soil Classification).

3. Surface drainage

It is necessary to analyse the factors which affect water drainage, namely the field conditions including land levelling, slope of field, arrangement of cracks, coefficient of permeability, etc.

1) Land levelling

Land levelling should be performed to minimize the amount of residual water for drainage. According to the Japanese basic design for planning "The degree of land levelling should be within the range of ±5cm of the average elevation of land, and slope of the land must be zero or slightly inclined towards the drainage canal".

Land levelling of the test plots was studied by using a leveller at intervals of 5m. The results of the survey are illustrated in Table-6.

There were differences in the land surface in the range of ±5cm (No. 16 plot), ±4cm (No. 17, 18 and 19 Plots) which accounted for 80% of the surveying points in the test plots. Since the land surface did not always show a declivity towards the outlet of the drain, standing water readily appeared in the field.

Table 6. Percentages of class frequency distribution of land level height.

Date of survey: 11/3/1978

class (cm) \ Plot No.	16	17	18	19
± 0	8.7	9.0	8.0	11.6
± 1	22.2	29.8	23.2	27.7
± 2	15.1	21.8	19.3	23.5
± 3	15.4	14.7	19.6	13.5
± 4	9.3	11.2	10.9	10.6
± 5	10.3	5.1	7.4	5.5
± 6	7.4	5.8	4.5	4.8
± 7	8.0	1.3	4.8	1.6
± 8	2.6	1.0	1.6	1.0
± 9	0.6	0	0.6	0
±10	0	0	0	0.3
±11	0	0.3	0	0
±12	0	0	0	0
±13	0	0	0	0
±14	0.3	0	0	0
80% of class (cm)	± 5	± 4	± 4	± 4

2) Coefficient of permeability of soils

Since most of the soils in the Muda Area consist of marine heavy clay, the coefficient of permeability was low. Determinations were performed four times (December 1977, March, May and June 1978), as illustrated in Table-7, and the measuring points were the same as the sampling points illustrated in Figure-10. The methods for the determination of the permeability test were the auger-hole method (December 1977 and March 1978) and tube method (May and June 1978). These methods are as follows:

(1) Auger-hole method (illustrated in Figure-14)

This method which is simple is used in dry fields. At first a hole (about 10cm in diameter) is dug with an auger, and water is supplied to the hole; the water level and time are measured by using a scale and clock.

Formula;

* For $3h < Tu$

$$K_{20} = \frac{Q}{2\pi h^2} \times \left[\log_e \left\{ \left(\frac{h}{r}\right) + 1 + \left(\frac{h}{r}\right)^2 \right\} - 1 \right] \frac{\mu_t}{\mu_{20}}$$

* For $h \leqq Tu \leqq 3h$

$$K_{20} = \frac{3.Q \cdot \log (h/r)}{\pi h \cdot (h + 2Tu)} \times \frac{\mu_t}{\mu_{20}}$$

where;

K_{20}: Coefficient of permeability at 20°C (cm/sec)

Q: Permeability volume (water supply volume) per unit second (cm^3/sec) $Q = \pi r^2 (h_1 - h_2)$

h_1, h and h_2: Water level from hole bottom at the start, during and at the end of the measurements (cm)

r: Radius of auger hole (cm)

Tu: Water level from underground water level (cm)

μ_{20} and μ_t: Coefficient of water viscosity at 20°C and t°C

(2) Tube method (illustrated in Figure-14)

This method is used in flooded fields. At first, the cylinder (diameter 10cm) is pressed into the soil and the measuring pipe connected to the cylinder is stood erect Pipe water level and time are measured.

$$K_{20} = \frac{a \cdot L}{A} \times \frac{2.30}{t_1 - t_2} \cdot \log \frac{h_1}{h_2} \times \frac{\mu_t}{\mu_{20}}$$

where;

K_{20}: Coefficient of permeability at 20°C (cm/sec)

a and A: Cross section area of pipe and cylinder (cm^2)

L: Distance of cylinder penetration to soil (cm)

h_1 and h_2: Water level in the pipe at the starting and end of the measurements (cm)

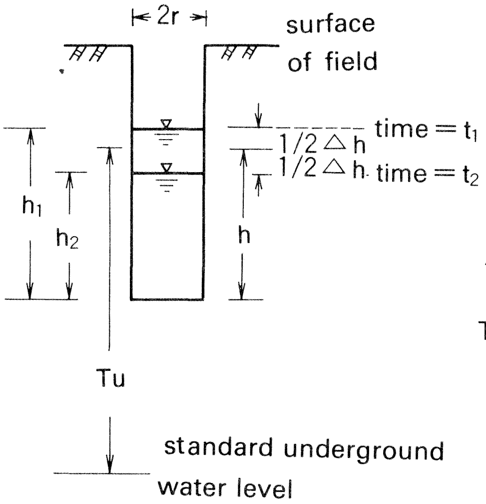
t_1 and t_2: Time when h_1 and h_2 are measured (sec)

μ_{20} and μ_t: Coefficient of water viscosity at 20°C and t°C

In the calculations it was assumed that the underground zone was saturated with water and that was no soil outside the cylinder.

As a result, the coefficient of permeability within a 20cm depth in the dry season (March 1978) was larger (10^{-3} cm/sec and over) than that in the presaturation period or after harvest (from 10^{-3} to 10^{-5} cm/sec). Flooding and puddling were responsible for the decrease of the permeability coefficient. The coefficient of permeability at a depth ranging from 20cm to 60cm in the dry season was almost the same as that in the wet season.

1) Auger hole method



Note :

h_1 and h_2 : Water level in the auger hole at the starting and end of measure-ments.

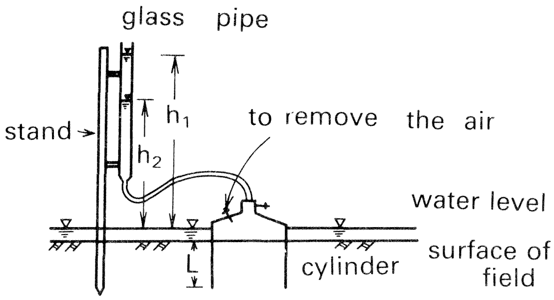
t_1 and t_2 : Measuring times for h_1 and h_2.

$$\triangle h = h_1 - h_2 \ , \quad h = h_2 + \frac{1}{2} \triangle h$$

Tu : Distance from central part of water level h to the standard underground water level (cm).

r : Radius of auger hole (cm).

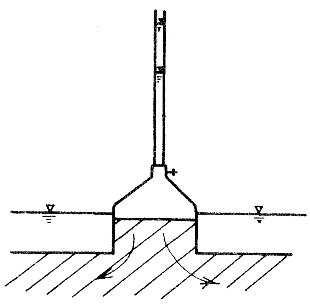
2) Tube method.



Note :

L : Distance of penetration of cylinder into soil (cm).

h_2 and h_2 : Water level in the glass pipe at the start and end of measure-ments (cm).



In this calculation. it is assumed that the underground level was saturated with water and that there was no soil outside the cylinder.

Fig 14. Methods applied for performing the permeability test.

Table 7. Coefficient of permeability

Plot No.	16		17		18		19		Method
	Depth (cm)	C.P.	Depth (cm)	C.P.	Depth (cm)	C.P.	Depth (cm)	C.P.	
After harvest (12/1977)	0–10	1.50×10^{-3}	0–10	2.02×10^{-3}	0–10	2.44×10^{-4}	0–10	8.97×10^{-4}	auger hole method
	10–20	1.26×10^{-5}	10–20	2.70×10^{-5}	10–20	6.74×10^{-6}	10–20	1.44×10^{-5}	
	20–30	3.39×10^{-7}	20–30	8.04×10^{-6}	20–30	2.22×10^{-6}	20–30	6.42×10^{-7}	
			30–40	4.64×10^{-7}	30–35	7.84×10^{-7}	30–37	8.30×10^{-7}	
End of dry season (3/1978)	0–25	3.90×10^{-2}	0–15	1.33×10^{-2}	0– 9	8.44×10^{-3}	0–10	1.02×10^{-2}	auger hole method
	25–40	2.70×10^{-3}	15–22	2.65×10^{-5}	9–15	1.15×10^{-5}	10–20	2.18×10^{-5}	
	40–50	2.86×10^{-4}	22–44	2.52×10^{-6}	15–20	1.98×10^{-6}	20–35	6.42×10^{-7}	
	50–60	1.14×10^{-5}			20–50	1.56×10^{-6}			
Presaturation period (5/1978)	0– 8	1.86×10^{-3}	0– 8	4.56×10^{-3}	0– 8	2.18×10^{-3}	0– 8	3.62×10^{-3}	tube method
	8–16	1.14×10^{-3}	13–21	1.18×10^{-5}	10–20	2.69×10^{-5}	10–18	5.38×10^{-5}	
	17–24	2.75×10^{-5}	28–34	5.75×10^{-6}	23–28	5.44×10^{-6}	22–28	9.67×10^{-5}	
	24–30	4.61×10^{-7}	37–41	3.73×10^{-7}	30–40	3.68×10^{-7}	39–43	4.65×10^{-5}	
Flooding period (9/1978)	14–22	3.40×10^{-7}	17–24	4.19×10^{-7}	9–25	8.90×10^{-7}	9–17	9.65×10^{-7}	tube method

Note: Unit of coefficient of permeability: cm/sec.

3) Investigations on cracks in the field

Since excess water is mainly drained through the cracks to the underground drain pipe, cracks represent water paths. It is necessary to investigate the volume and depth of the cracks. At the sampling points, the cracks of the surface field were carefully observed and their topography drawn on the P.V.C. sheet. After observation, holes were dug in order to observe and measure the crack volume and depth in March 1978.

The results obtained are shown in Table-8-1. The average volume of the cracks in the surface of No. 16, 17, 18 and 19 plots was 24%, the average volume of the cracks at a 20cm depth in plots 16 and 17 was 16% and that of No. 18 and 19 plots was 4% only. These findings show that the cracks of No. 16 and 17 plots were present in the 0~30cm zone as well as below a 30cm depth, and that most of the cracks of No. 18 and 19 plots were present within the 0~30cm zone. The field conditions during this investigation are shown in Table-8-2.

Table 8-1. Volume and depth of cracks in the field.

Point \ Depth	Volume of cracks (%)		Crack depth (cm)
	0cm	20cm	
16– 5	20.0	–	–
16–10	30.0	18.2	–
16–20	23.3	11.8	77
16–27	20.5	–	–
Average	23.5	15.0	
17– 5	27.1	21.0	–
17–10	27.9	14.9	–
17–20	28.0	14.3	60
17–27	31.1	20.2	–
Average	28.5	17.6	
18– 5	22.6	7.0	–
18–10	26.0	4.3	–
18–20	19.2	5.3	55
18–27	20.9	6.0	–
Average	22.2	5.7	
19–15	24.4	4.3	–
19–30	18.6	0.7	44
19–45	21.0	3.8	–
Average	21.3	2.9	

Note: 1) 0cm from surface of field: 60x60cm areas.
2) 20cm depth from surface of field: 50x50cm areas.
3) Date of survey: 16th to 26th March 1978.
4) Location of this investigation is the same as that of the sampling points.

Table 8-2. Soil physical characteristics.

Date of survey 20 ~ 22/3/1978

Plot No.	Depth (cm)	Moisture ratio (%)	Soil density (g/cm³) wet	dry	Three phases of soil (%) solid	liquid	gaseous
16	0–10	24.3	1.126	0.856	32.8	20.5	46.7
	10–20	25.2	1.254	1.004	38.4	25.1	36.6
	20–30	27.2	1.815	1.427	54.1	38.8	7.2
17	0–10	16.2	1.042	0.897	35.1	14.5	50.4
	10–20	25.7	1.198	0.952	36.9	24.5	38.6
	20–30	29.6	1.477	1.139	43.5	33.9	22.7
18	0–10	28.3	1.138	0.889	34.4	24.9	40.7
	10–20	32.9	1.422	1.070	41.1	35.2	23.7
	20–30	33.8	1.824	1.364	51.3	46.0	2.8
19	0–10	30.0	1.110	0.854	33.2	25.8	41.0
	10–20	34.3	1.401	1.045	40.2	35.7	24.1
	20–30	37.4	1.799	1.329	50.2	48.9	1.0

Soil hardness determined with Yamanaka's tester (unit: mm)

Depth (cm) \ Plot No.	16	17	18	19
1	26.3	26.3	26.6	26.5
5	29.1	29.3	28.2	27.2
10	29.6	28.3	26.8	25.9
15	28.9	28.2	26.4	25.0
20	29.3	28.1	24.0	23.1
25	27.6	27.2	22.5	19.6
30	27.8	25.7	21.7	17.8

Note:
1) The method applied in the survey consists of digging a cube (at a depth of 0 ~ 10cm and 10 ~ 20cm, the area measured 50×50×10cm and at a 20 ~ 30cm depth the area measured 30×30×10cm.)
Measuring method: scale and weight of cube volume of soil.
2) Yamanaka's tester was used to measure the soil hardness. The values express the distance of the penetration of the cone into soil.
3) Data of cylinder samples are shown Table 6-2.

VI. Evaluation Studies after the Construction of the Test Plots

The evaluation studies aimed at analysing the effectiveness of subsurface drainage, with regard to the improvement of the weak foundation of fields.

The investigations were carried out from July 1978 to August 1980 omitting the dry season of 1979 and 1980.

The location of the investigation points is shown in Figure-15. The investigations were carried out with the following objectives:

(1) To evaluate the relationship between the soil bearing capacity and surface and underground water level during the harvesting season.

(2) To evaluate the changes of the soil bearing capacity with the types of underdrain and distance between underdrains.

(3) To survey the field conditions.

* Surface and underground water level before and after drainage during the harvesting season.
* Water discharge from underground drainage.
* Measurement of soil physical properties.
* The level of field surface.
* Coefficient of permeability.

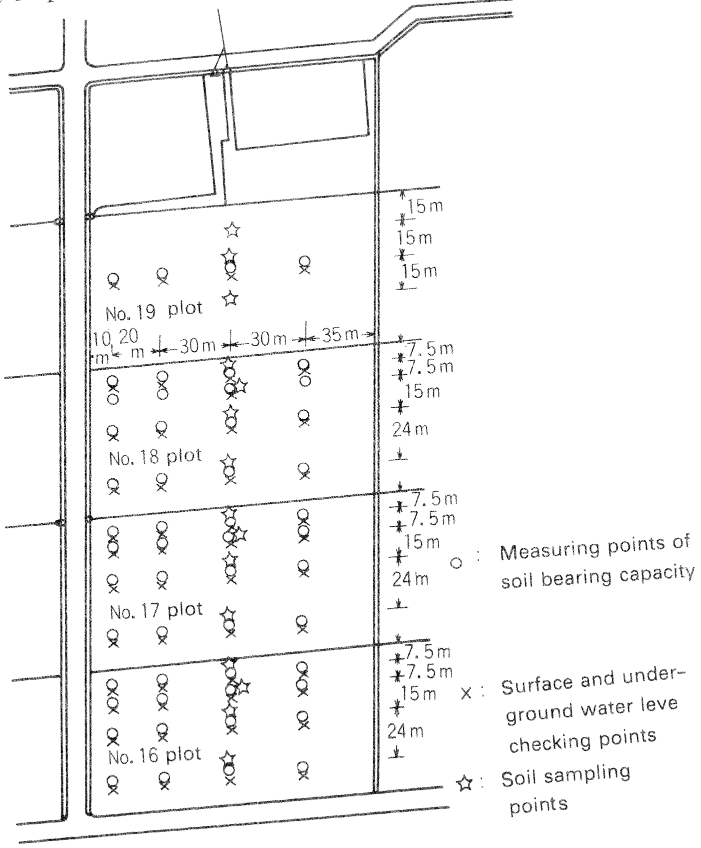


Fig 15. Location of measuring points after the construction of the test plots.

1. Evaluation of the relationship between the soil bearing capacity and surface and underground water level during the harvesting season

The weak foundation of the fields resulting in poor trafficability during the harvesting period (off-season) and puddling period (main-season) has been recognized as a serious problem delaying the development of mechanization in this area. Therefore, it is necessary to improve the weak foundation by drainage. Likewise, it is necessary to investigate the relationship between the soil bearing capacity and the field conditions.

The investigations during which the soil bearing capacity and water level in fields were determined were carried out three times, namely in November 1978, July 1979 and July and August 1980.

The results are shown in Figure-16. The methods applied were the same as those described in Chapter V. In November 1978 only the surface water level was measured and in July 1979 and July 1980 the surface and underground water level was measured.

(1) In the case of the investigation of November 1978, the field level was uneven and a weak foundation was observed in some parts of the fields due to the digging operations associated with the construction of underground drainage and disturbance of soil by the construction machines. Therefore, it was very difficult to drain the surface and residual water and to increase the soil bearing capacity.

The results showed that the soil bearing capacity was increased up to 2.0 kgf/cm^2 (average value within a depth of 25cm) after 14 days (No. 16 plot), 6 days (No. 17 plot), 15 days (No. 18 plot) and 20 days (No. 19 plot) of surface drainage, respectively.

In order to increase the soil bearing capacity, it is necessary to drain fast and uniformly the surface water. When the average surface water level in the field decreases below one centimeter, the soil bearing capacity increases rapidly. It was difficult to drain fast and uniformly the surface water.

(2) The author studied the soil bearing capacity during the off-season harvesting period

When the values of the soil bearing capacity during the harvesting period (three weeks before the off-season harvesting time) were compared it was found that the soil bearing capacity increased year after year, as illustrated in Table-9.

The soil bearing capacity recorded in 1980 in No. 16 and 17 plots increased by 43.3% and 29.6% from the values of 1977, and 20.4% and 10.2% from the values of 1978, respectively. The soil bearing capacity during the year 1980 in No. 18 and 19 plots decreased by 9.0% and 1.5% from the values of 1977, and increased by 30.2% and 15.6% from the values of 1978.

However, after the surface water had been drained, the soil bearing capacity increased rapidly, and it took from 3 to 10 days to reach a value of more than 2.0 kgf/cm^2 (average value within a depth of 25cm).

When the underground water level decreased to 7cm, the soil bearing capacity exceeded 2.0 kgf/cm^2. However, it took about 7 days to reach a value of −7cm which corresponds to a decrease of the underground water level from +5cm surface water level.

(3) Improvement of field drainage associated with dry cultivation and shallow puddling in the off-season cropping of 1978 and 1979 resulted in the in-

crease in the soil bearing capacity year after year. In the case of the investigation of July 1980, the soil bearing capacity in No. 16, 17, 18 and 19 plots was 2.55, 2.10, 1.99 and 1.58 kgf/cm^2 respectively (average value within a depth of 25cm on 14th July 1980) about two weeks prior to harvesting time. The three values recorded in No. 16, 17 and 18 plots were close to the value of 2.0 kgf/cm^2. After the outlet of the drain of the test field had been opened, it rained several times and the surface water from No. 22, 23 and 24 plots was drained No. 17, 18 and 19 plots.

Therefore, the soil bearing capacity was hardly increased before harvesting. Due to the low amount of rainfall and since the surface water from other plots had been depleted during the harvesting time, the level of underground water decreased up to 10cm after 6 days and the soil bearing capacity slightly increased.

Table 9. Soil bearing capacity during the harvesting period.

Year	No. 16 (day/month)	No. 17 (day/month)	No. 18 (day/month)	No. 19 (day/month)	Note
1977	1.79 (14/7) 1.89 (30/7) 1.65 (13/9) ave=1.78	1.86 (14/7) 1.75 (30/7) 2.06 (13/9) ave=1.89	2.08 (14/7) 2.63 (30/7) 2.61 (13/9) ave=2.44	1.83 (14/7) 2.24 (30/7) 1.99 (13/9) ave=2.02	harvesting period = early September
1978	1.80 (16/11) 1.99 (26/11) 2.30 (2/12) ave=2.03	1.90 (3/11) 2.13 (10/11) 1.93 (20/11) 2.83 (26/11) ave=2.20	1.38 (26/10) 1.55 (31/10) 1.45 (4/11) 1.81 (11/11) ave=1.55	1.66 (10/11) 1.69 (20/11) ave=1.68	harvesting period= 16 (5~17/12) 17 (28/11) 18 (14~15/11) 19 (22~23/11)
1979	1.90 (21/6) 1.98 (1/7) 2.08 (7/7) 2.37 (11/7) ave=2.08	1.98 (21/6) 1.93 (1/7) 1.86 (7/7) 2.65 (11/7) ave=2.10	1.85 (22/6) 1.90 (2/7) 1.90 (8/7) 2.25 (12/7) ave=1.98	1.39 (22/7) 1.52 (2/7) 1.83 (8/7) 1.93 (12/7) ave=1.67	harvesting period= 16, 17 (15~17/7) 18 (19/7) 19 (20/7)
1980	2.55 (14/7) 2.39 (18/7) 2.71 (26/7) 2.56 (30/7) ave=2.55	2.10 (14/7) 2.55 (18/7) 2.56 (26/7) 2.59 (30/7) ave=2.45	1.99 (14/7) 1.86 (18/7) 2.54 (27/7) 2.49 (31/7) ave=2.22	1.58 (14/7) 1.91 (18/7) 2.36 (27/7) 2.10 (31/7) ave=1.99	harvesting period=16, 17, 18 and 19 (29/7~3/8)

Comparison of the 1977 values with 1980 values

No. 16	No. 17	No. 18	No. 19
$\frac{2.55-1.78}{1.78}$	$\frac{2.45-1.89}{1.89}$	$\frac{2.22-2.44}{2.44}$	$\frac{1.99-2.02}{2.02}$
=0.433	=0.296	=−0.09	=−0.015

Comparison of the 1978 values with 1980 values.

No. 16	No. 17	No. 18	No. 19
$\frac{2.55-2.03}{2.03}$	$\frac{2.45-2.20}{2.20}$	$\frac{2.22-1.55}{1.55}$	$\frac{1.99-1.68}{1.68}$
=0.204	=0.102	=0.302	=0.156

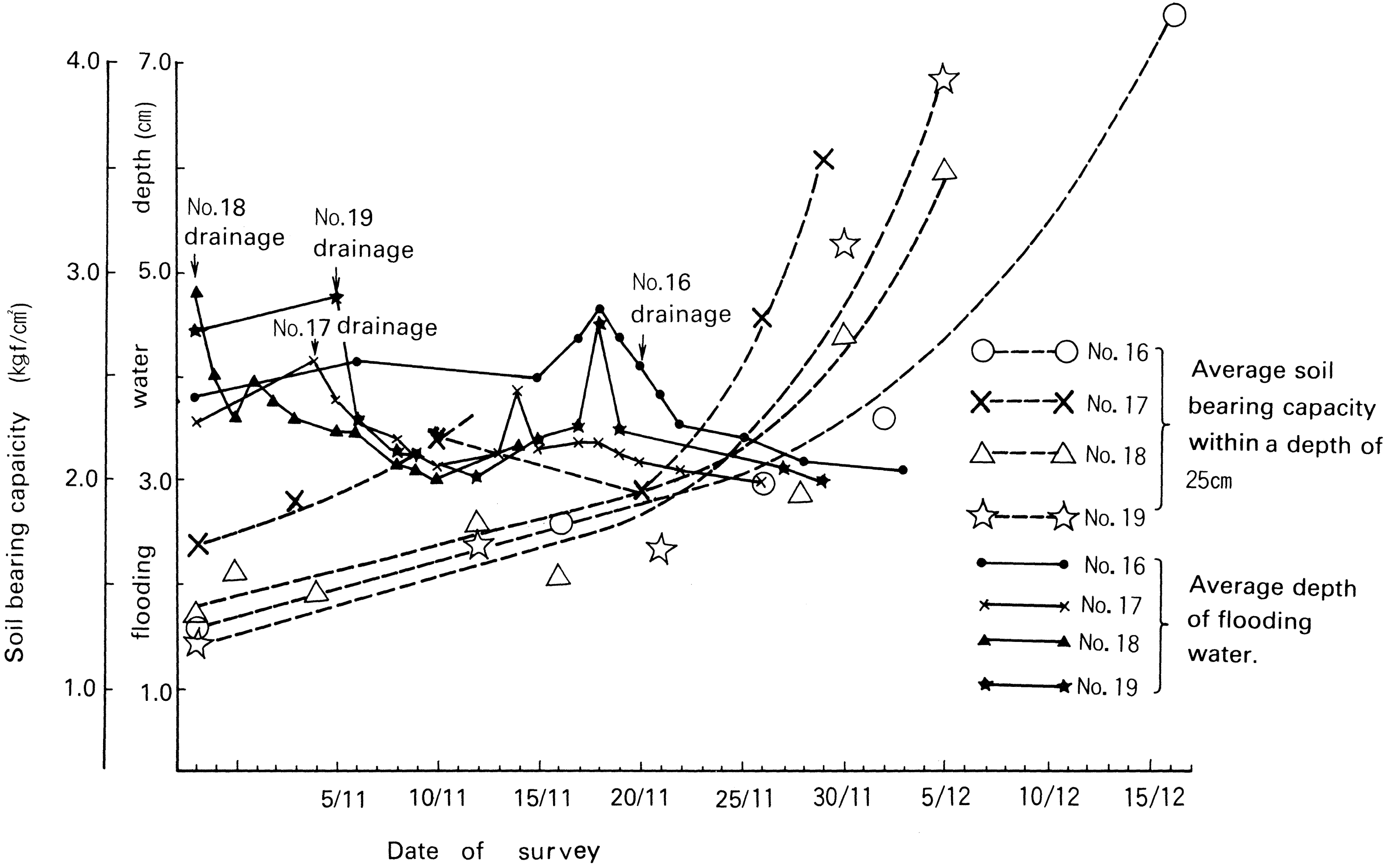


Fig 16–1. Soil bearing capacity and water level during the harvesting season (1978)

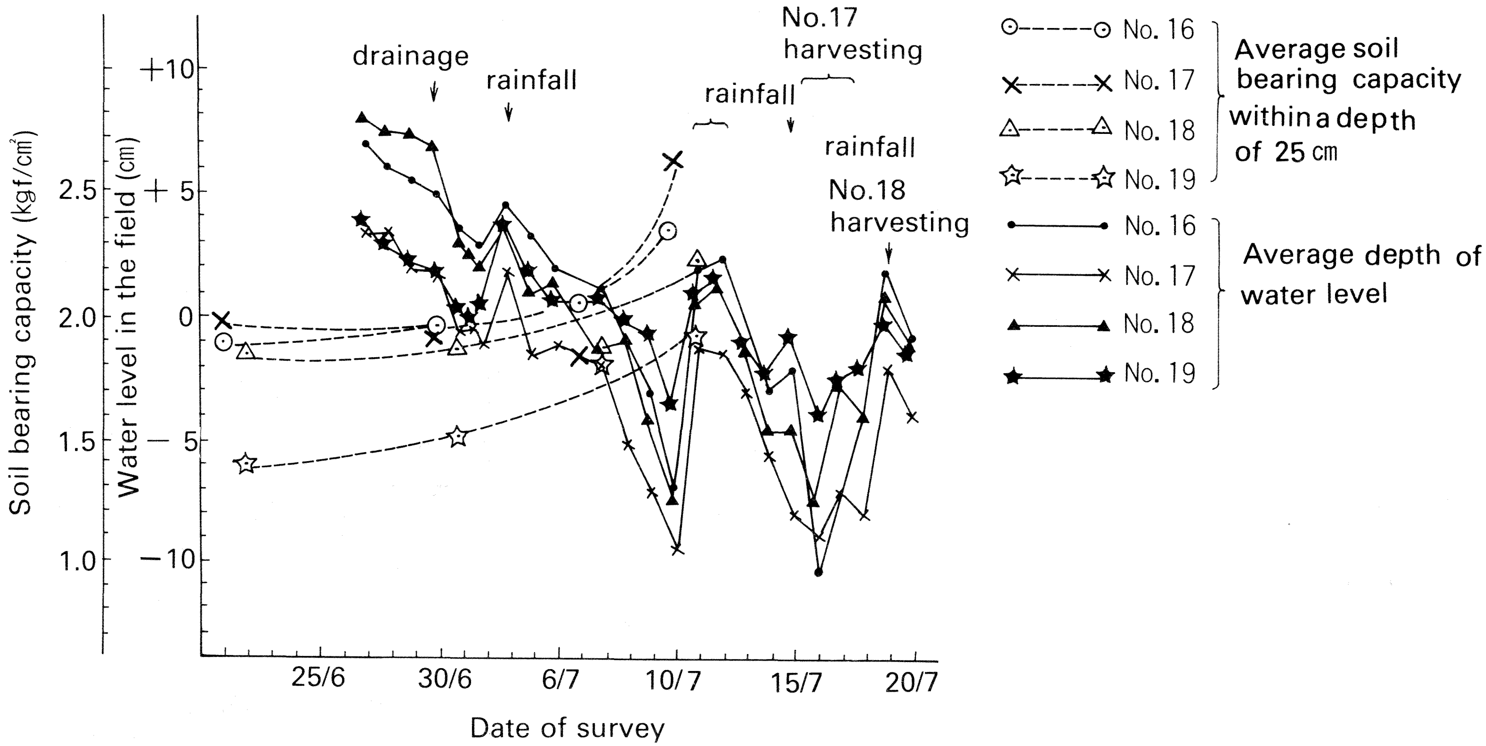


Fig 16–2 Relationship between soil bearing capacity and water level during harvesting season (1979).

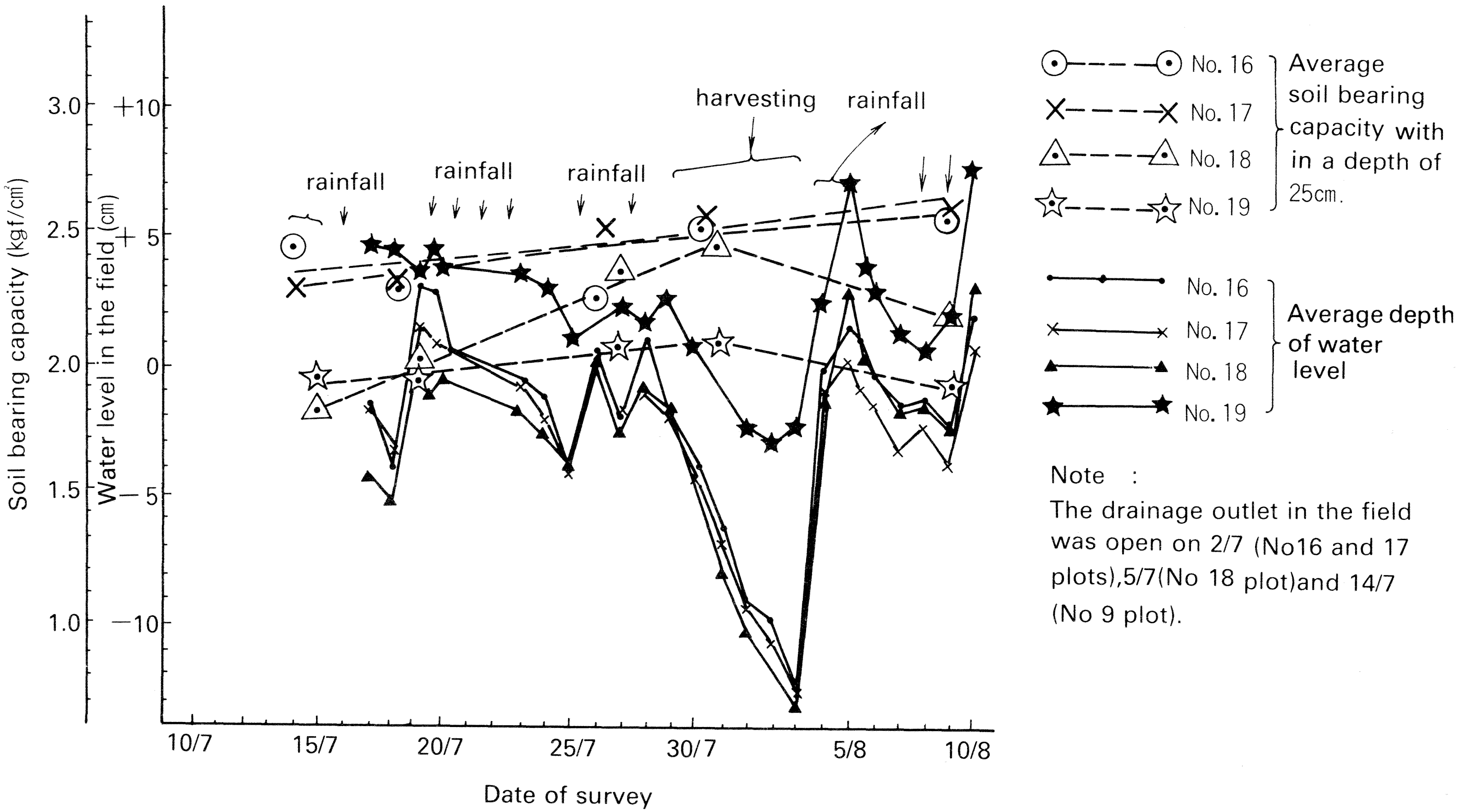


Fig 16–3. Soil bearing capacity and water level during the harvesting season (1980).

2. Changes in the soil bearing capacity with the type of underdrain and the distance between underdrains

In the test fields, four types of drain were built as follows.

(1) Plot with combination of complete underdrain and mole drain .... No. 16 plot
(2) Plot with complete underdrain............................ No. 17 plot
(3) Plot with blind drain.................................... No. 18 plot
(4) No drainage system in the .... No. 19 plot

The complete underdrains and the blind drains were constructed at different intervals, namely 5m, 9m, 20m and 27m.

The changes in the soil bearing capacity throughout the experimental period are illustrated in Figure-17. From the results obtained, it appears that the soil bearing capacity increased year after year, especially in No. 16 and 17 plots. Comparison of the types of underdrains and spacing of drain pipes, is illustrated in Table-10. The values of the soil bearing capacity which were adopted are those recorded three or two weeks prior to harvesting time since they were stable. When the values recorded before and after the construction of the sub-surface drainage were compared, the values of the complete underdrain plots increased by about 7 to 55%, whereas, the values of the blind drain plots showed little change, and the values of the plots without drains were slightly increased by about 7%.

The soil bearing capacity before and after the construction of the complete underdrains increased by 55%, 28%, 10% and 25% when the interval between the drain pipes was 5m, 9m, 20m and 27m (No. 16 and 17 plots), respectively. These results show the effectiveness of reducing the interval between the drain pipes when complete underdrains are constructed.

However, the soil bearing capacity of the blind drain plot increased in some points and decreased in others. On the other hand, the soil bearing capacity of the plots without drains increased by about 7%. The investigation enabled to demonstrate that the hole of the mole drain was completely filled with soil for nine months after its construction due to the slaking of the surface soil and the subsoil.

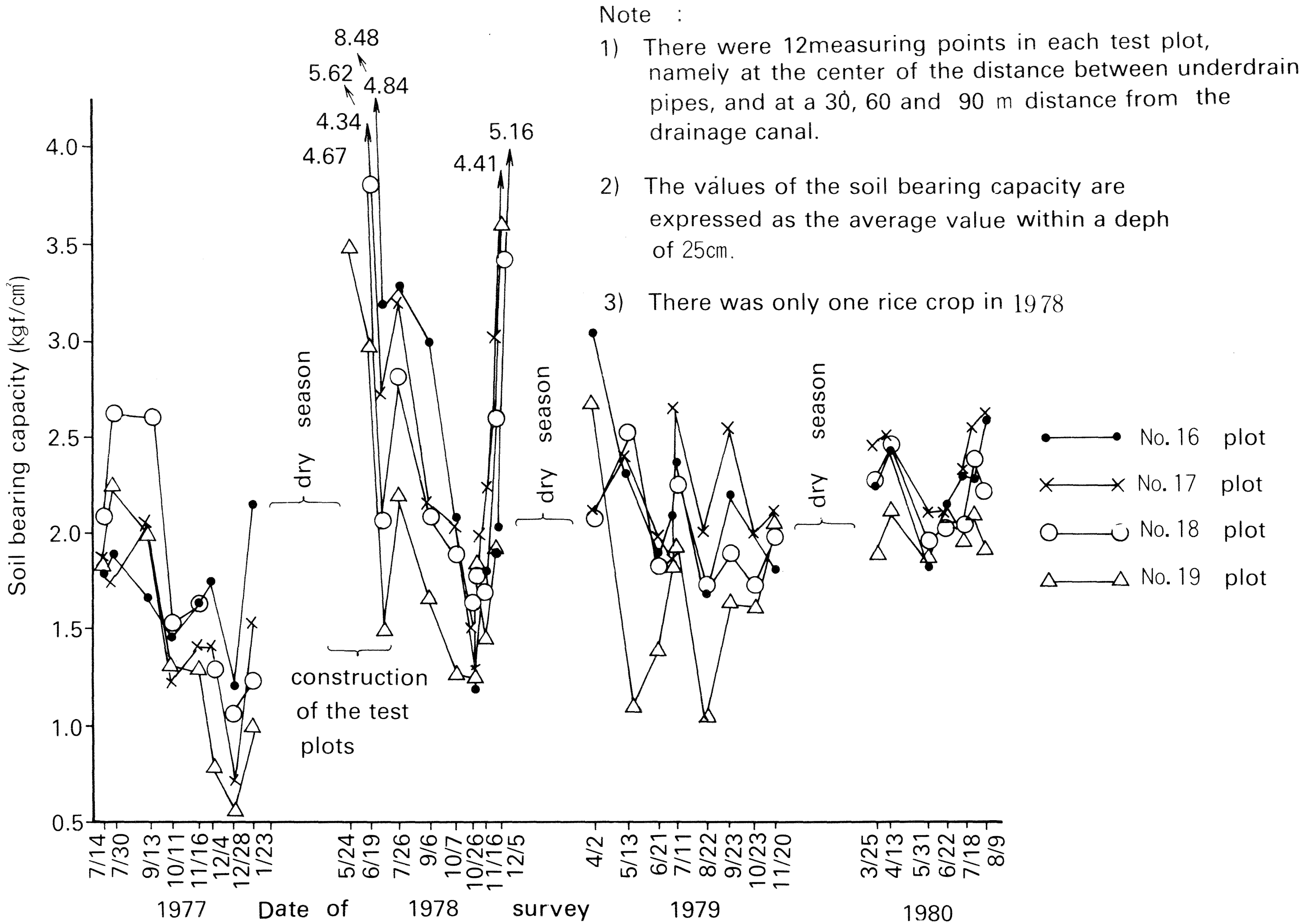


Fig 17. Soil bearing capacity in the test plots throughout the investigation period.

Table 10. Comparison of soil bearing capacity depending on the distance from the subsurface drainage pipe.

Plot No.	Date / Interval	15/7/1977	17/11/1978	Percentage	7/8/1979	Percentage	18/7/1980	Percentage	
16	5m	1.37	1.21	−12%	1.89	+38%	2.12	+55%	Combination of complete underdrain and mole drain
	10m	2,02	2.38	+18	1.95	− 3	2.57	+27	
	20m	1.93	1.72	−11	2.09	+ 8	2.07	+ 7	
	27m	1.87	1.89	+ 1	2.38	+27	2.49	+33	
17	5m	1.40	1.77	+26	1.95	+39	2.17	+55	Complete underdrain
	10m	1.58	2.88	+82	1.89	+20	2.04	+29	
	20m	2.18	1.98	− 9	1.76	−19	2.47	+13	
	27m	2.25	2.31	+ 3	1.76	−22	2.63	+17	
18	5m	2.40	1.86	−22	1.85	−23	1.91	−20	blind drain
	10m	1.83	1.91	+ 4	1.75	− 4	2.09	+14	
	20m	1.89	1.35	−29	1.81	− 4	2.18	+15	
	27m	2.18	1.62	−26	2.17	− 1	1.98	− 9	
19		1.83	1.44	−21	1.83	0	1.95	+ 7	no underdrain

Note:
1) Percentage values are obtained in dividing the value of 17/11/1978, 7/8/1979 and 18/7/1980 by the value of 15/7/1977.
2) The value is the average of three points, namely at the center of the distance between the underdrain pipe and a distance of 30m, 60m, and 90m from the drainage canal. Each value is the average value within a depth of 25cm.
3) 15/7/1977: Ten months before the construction of the underdrain.
17/11/1978, 7/8/1979 and 18/7/1980: Six months, 1.3 years and 2.2 years after the construction of the underdrain.
4) Unit: kgf/cm^2.

3. **Survey of the field conditions**

1) Surface and underground water level before and after drainage during the harvesting season

The survey was conducted three times, namely in November 1978, July 1979 and July 1980. For the determination of the surface and underground water level the height of the surface water level and water depth in the auger hole were measured with a scale once every or every other day at 24 (1978, 1979) and 35 points (1980), respectively.

The values shown in Figure-16 are the average data obtained from these points.

From the results illustrated in Figure-16, it appears that it was difficult to drain fast and uniformly the surface water and residual water, due to the uneven surface of the field, the presence of a small outlet and the difficulty in assessing the effectiveness of underdrains for drainage. The drainage of the surface water and residual water took about 6 to 20 days (1978) and 4 to 8 days (1979) during harvesting time, respectively. The determination of the underground water level took about 4 days (1979) and 6 days (1980) due to the lowering of the level to 8cm and 12cm below the field surface.

2) Water discharge from underground drainage

In order to determine the water discharge from underground drainage, the author used two methods, namely the determination of the water balance in the field and the direct measurement of the water discharge of the underdrain pipe.

The water balance in the field included the measurement of rainfall and evaporation by using a special tank attached to the water level gauge. The surface water discharge was measured by using a triangular weir and was calculated with the formula ($Q=1.4 \times h^{5/2}$ m^3/sec, where "Q" is the water discharge, "h" is the height of overflowing water). The flooding water levels were mesured in applying the same method as that described in clause 1).

The water discharge from underground drainage was calculated twice (1979, 1980) with a current meter.

The results are shown in Tables-11, 12 and Figure-18. From the results obtained, the author concluded that at these points the water discharge from subsurface drainage after the opening of the drain outlet was very small because were few drainage water paths in the soil. However, as the water paths developed with the drying of the field surface after the surface water was drained, the water dischage from the subsurface drainage during rainfall increased, especially in No. 16 and 17 plots. These observations indicate the effectiveness of the complete underground drainage.

Water discharge from the complete underdrain and the blind underdrain could be estimated to be about 3~4 m^3/day and 0.1 m^3/day (1979), based on Figure-18.

Since these values are very low, it is considered that the main water discharge from the paddy field is the surface drainage from the outlet of the field drain.

Table 11-1. Water balance after opening of drain outlet.

Plot No.	Date of opening of the outlet	Inflow		Outflow			
		(1)	(2)	(3)	(4)	(5)	(6)
16	20/11	487m³ (100%)	–	177m³ (36%)	184m³ (38%)	119m³ (25%)	7m³ (1%)
17	4/11	490m³ (100%)	–	59m³ (12%)	181m³ (37%)	232m³ (47%)	18m³ (4%)
18	29/10	762m³ (54%)	646m³ (46%)	8m³ (1%)	921m³ (65%)	387m³ (27%)	97m³ (7%)

Table 11-2. Water balance after rainfall.

Plot No.	Date and month rainfall	Inflow		Outflow			
		(1)	(2)	(3)	(4)	(5)	(6)
31/10 ~ 1/11							
16	70.3mm	320m³ (36%)	569m³ (64%)	471m³ (53%)	30m³ (3%)	202m³ (23%)	185m³ (21%)
18		242m³ (30%)	564m³ (70%)	303m³ (38%)	358m³ (44%)	80m³ (10%)	65m³ (8%)
12/11 ~ 14/11							
17	46.2mm	56m³ (13%)	374m³ (87%)	128m³ (30%)	41m³ (10%)	162m³ (38%)	99m³ (23%)
19		16m³ (4%)	371m³ (96%)	168m³ (43%)	111m³ (29%)	120m³ (31%)	–12m³ (0)
16/11 ~ 17/11							
16	70.8mm	397m³ (41%)	573m³ (59%)	472m³ (49%)	93m³ (10%)	162m³ (17%)	243m³ (25%)
17		128m³ (18%)	573m³ (82%)	112m³ (16%)	469m³ (67%)	121m³ (17%)	–1m³ (0)

Note: (1) Flooding water before drainage. (2) Rainfall. (3) Flooding water after drainage.
(4) Drainage discharge of surface water. (5) Evapotranspiration (5mm/day).
(6) Water discharge from subsurface drainage.
Water balance (1) + (2) = (3) + (4) + (5) + (6).

Table 12. Water discharge from underground drainage.

Date	6th. June			18th. July	
Drain No.	Water discharge (m^3)	Drainage time (hour)	Percentage (%)	Water discharge (m^3)	Drainage time (hour)
16-1	8.06	24	13.7	3.78	1.8
3	9.79	24.5	8.3	–	–
4	5.58	23	3.01	1.67	3.85
5	–	–	–	0.72	0.2
Average	7.81			2.06	
17-1	4.26	25	17.26	1.5	1.0
2	3.38	25	5.76	2.64	2.0
3	13.85	25	11.71	2.15	1.15
4	24.19	26.5	13.05	0.98	1.0
5	–	–	–	4.73	1.0
Average	11.45			1.82	
18-1	2.7	30	4.6	–	–
2	6.17	24.5	10.51	0.001	0.1
3	1.64	29.5	1.39	0.001	0.1
4	4.50	36	2.43	0.013	1.0
5	0.53	29.5	0.50	–	–
Average	3.11			0.005	

Note:
1. Percentage of water discharge from underground drainage in relation to rainfall.
2. Paddy field conditions: flooding, before puddling on 6th June, and after puddling on 18th July 1978. Rainfall: 56.5mm on 5th June 1978.
3. The average values are the average of the total drainage water discharge in each drain pipe.

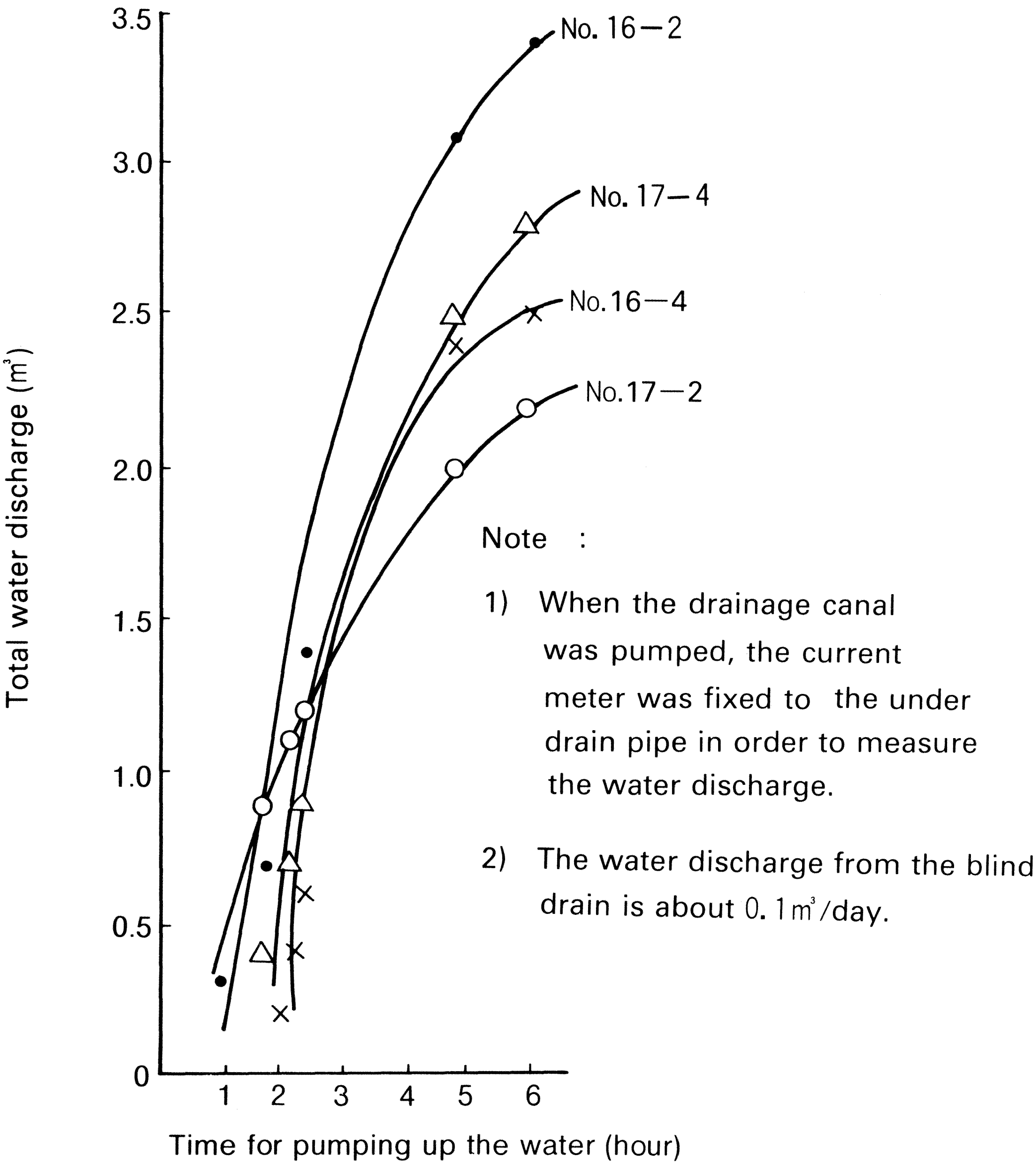


Fig 18. Water discharge from complete underdrain.

3) Determination of soil physical properties

In order to analyse the changes in the soil physical conditions after the construction of the subsurface drainage system, soil profiles were observed and undisturbed soil samples were collected from the test fields. Tests of the soil physical properties were carried out as described in Chapter V.

From the results illustrated in Table-13, the author drew the following conclusions.

(1) When the data on the soil physical properties recorded before and after the construction of the test fields were compared, the soil physical properties such as soil density and solid phase changed slightly. During the test period, the soil of the field was wet.

(2) However, the depth of the compacted layer (i.e. the hard pan layer) was shallower than at the time of the last harvesting period according to the determination of soil density and solid phase (Table-14). Namely, soil density and solid phase in the 10~20cm depth layer increased by about 6~14% and 4~18%. Especially, the values in No. 16 and 17 plots increased considerably.

Table 13-1. Soil physical characteristics. Sampling date 7/12, 21/12/1978

Plot No.	Depth (cm)	Moisture ratio (%)	Specific gravity	Soil density (g/cm^3)		Three phases of soil (%)			Atterberg limits (%)		
				wet	dry	solid	liquid	gaseous	L.L.	P.L.	P.I.
16	0–10	50.3	2.59	1.624	1.082	41.8	54.3	4.0	80.9	33.3	47.6
	10–20	44.3	2.59	1.738	1.207	46.7	53.1	0.4	76.8	32.6	44.2
	20–30	41.6	2.61	1.734	1.226	47.0	50.7	2.3	87.6	31.8	55.8
	30–40	40.1	2.66	1.747	1.247	46.3	49.9	3.1	94.9	32.4	62.5
17	0–10	57.5	2.57	1.586	1.015	39.5	57.2	3.4	84.3	38.4	45.9
	10–20	48.7	2.59	1.681	1.131	43.7	54.9	1.4	80.3	35.9	44.4
	20–30	43.4	2.61	1.712	1.194	45.8	51.8	2.3	82.3	32.5	49.8
	30–40	41.0	2.63	1.750	1.242	47.3	50.8	2.0	94.3	33.6	60.7
18	0–10	77.5	2.59	1.482	0.840	32.6	64.1	3.4	81.3	36.2	45.1
	10–20	59.1	2.60	1.604	1.013	39.1	59.1	1.9	78.4	35.6	42.8
	20–30	49.8	2.60	1.656	1.109	42.7	54.9	2.4	80.3	35.0	45.3
	30–40	44.4	2.64	1.725	1.196	45.5	52.8	1.8	80.9	33.0	47.9
19	0–10	68.4	2.59	1.524	0.908	35.2	61.6	3.2	88.5	38.4	50.1
	10–20	56.3	2.58	1.620	1.038	40.3	58.2	1.8	79.5	34.7	44.8
	20–30	43.4	2.57	1.772	1.234	48.0	53.8	0	79.7	32.0	47.7
	30–40	43.3	2.61	1.796	1.271	48.7	52.6	0	79.5	31.9	47.6

Table 13-2. Soil physical characteristics.

Sampling date 4~6/7/1979

Plot No.	Depth (cm)	Moisture ratio (%)	Soil density (g/cm³)		Three phases of soil (%)		
			wet	dry	solid	liquid	gaseous
16	0–10	74.2	1.510	0.869	33.5	64.1	2.4
	10–20	51.5	1.641	1.088	42.0	55.3	2.7
	20–30	39.8	1.727	1.233	47.3	49.2	3.5
	30–40	39.8	1.730	1.239	46.7	49.1	4.4
	40–45	40.3	1.728	1.232	45.5	49.1	4.9
17	0–10	62.4	1.547	0.955	37.2	58.9	3.9
	10–20	50.1	1.621	1.098	41.9	53.6	4.6
	20–30	38.3	1.718	1.243	47.6	47.5	4.9
	30–40	36.6	1.759	1.286	48.9	47.4	3.7
	40–45	41.7	1.730	1.221	45.0	50.9	4.2
18	0–10	67.9	1.499	0.897	34.7	60.3	5.2
	10–20	47.5	1.640	1.119	43.1	52.2	4.9
	20–30	36.3	1.768	1.283	50.0	46.9	3.1
	30–40	35.4	1.784	1.320	50.1	46.5	3.8
	40–45	36.2	1.755	1.290	47.2	46.6	6.3
19	0–10	67.9	1.538	0.919	35.6	61.9	2.5
	10–20	42.3	1.636	1.163	44.9	47.3	7.8
	20–30	42.1	1.707	1.201	46.6	50.6	2.9
	30–40	28.1	1.753	1.369	52.1	38.4	9.5
	40–45	37.0	1.741	1.271	48.5	47.0	4.5

Table 13-3. Soil physical characteristics.

Sampling date 2~5/8/1980

Plot No.	Depth (cm)	Moisture ratio (%)	Soil density (g/cm³)		Three phases of soil (%)		
			wet	dry	solid	liquid	gaseous
16	0–10	67.4	1.520	0.910	35.1	61.1	3.9
	10–20	48.2	1.663	1.128	48.2	53.5	3.0
	20–25	46.1	1.716	1.204	46.1	51.2	2.7
17	0–10	64.0	1.559	0.954	37.1	60.4	2.6
	10–20	48.0	1.674	1.134	43.8	54.0	2.2
	20–25	41.7	1.735	1.230	47.5	50.6	2.0
18	0–10	62.7	1.526	0.941	36.4	58.5	5.1
	10–20	46.2	1.698	1.167	45.1	51.3	2.0
	20–25	44.7	1.705	1.179	45.4	52.6	2.0
19	0–10	67.4	1.565	0.935	36.2	63.0	1.8
	10–20	51.0	1.678	1.116	43.1	56.3	0.7
	20–25	42.0	1.727	1.216	47.1	51.1	1.8

Table 14-1. Comparison of soil density during the four years.

Plot No.	Depth (cm)	9/1977	12/1978	7/1979	8/1980	Percentage (%)
16	0–10	0.925	1.082	0.869	0.910	98.4
	10–20	1.063	1.207	1.088	1.128	106.1
	20–30	1.138	1.226	1.233	1.204	105.8
17	0–10	0.855	1.015	0.955	0.954	111.6
	10–20	0.998	1.131	1.098	1.134	113.6
	20–30	1.120	1.194	1.243	1.230	109.8
18	0–10	0.925	0.840	0.897	0.941	101.7
	10–20	1.088	1.013	1.119	1.167	107.3
	20–30	1.210	1.234	1.201	1.216	100.8
19	0–10	0.924	0.908	0.919	0.935	101.2
	10–20	1.075	1.038	1.163	1.116	103.8
	20–30	1.210	1.234	1.201	1.216	100.5

Note: Percentage value: value of 8/1980 divided by the value of 9/1977
Unit: g/cm^3

Table 14-2. Comparison of solid phase during the four years.

Plot No.	Depth (cm)	9/1977 (%)	12/1978 (%)	7/1979 (%)	8/1980 (%)	Percentage (%)
16	0–10	35.9	41.8	33.5	35.1	97.8
	10–20	41.0	46.7	42.0	48.2	117.6
	20–30	43.8	47.0	47.3	46.1	105.3
17	0–10	32.9	39.5	37.2	37.1	112.8
	10–20	38.6	43.7	41.9	43.8	113.5
	20–30	42.9	45.8	47.6	47.5	110.7
18	0–10	35.7	32.6	34.7	36.4	102.0
	10–20	42.2	39.1	43.1	45.1	106.9
	20–30	45.1	42.7	50.0	45.4	100.7
19	0–10	36.0	35.2	35.6	36.2	100.6
	10–20	41.6	40.3	44.9	43.1	103.6
	20–30	46.0	48.0	46.6	47.1	102.4

Note: Percentage value: value of 8/1980 divided by the value of 9/1977.

(3) Coefficient of permeability

It is important to determine the permeability of the field soil in order to analyse the characteristics of soils.

Permeability tests were conducted three times in December 1978, July 1979 and July 1980 From the results obtained (Table-15), the coefficient of permeability increased about 10 fold, suggesting that the permeability pro perties of soilimproved.

Table 15. Coefficient of permeability (cm/sec) of soil after the construction of the test fields.

Plot No. / Test period	16		17		18		19		Method
	Depth (cm)	C.P.	Depth (cm)	C.P.	Depth (cm)	C.P.	Depth (cm)	C.P.	
17–28/12/1978 (after harvesting)	0–10	1.14×10^{-4}	0–10	1.30×10^{-3}	0–10	3.20×10^{-4}	0–10	3.77×10^{-6}	auger hole method
	10–20	4.34×10^{-7}	10–20	1.28×10^{-5}	10–20	2.93×10^{-6}	10–20	5.42×10^{-7}	
	20–30	3.39×10^{-7}	20–30	7.64×10^{-7}	20–30	7.39×10^{-7}	20–30	6.42×10^{-7}	
			30–35	9.52×10^{-7}	30–35	7.84×10^{-7}	30–35	8.30×10^{-7}	
21–25/7/1979 (after off-season harvesting)	0–10	8.80×10^{-6}	0–10	3.14×10^{-6}	0–10	1.33×10^{-5}	0–10	9.55×10^{-6}	tube method
	11–22	5.39×10^{-7}	12–22	1.76×10^{-7}	12–21	3.95×10^{-7}	13–23	4.66×10^{-7}	
10–15/8/1980 (after off-season harvesting)	0–10	5.60×10^{-5}	0–10	2.69×10^{-5}	0–10	1.78×10^{-4}	0–10	1.96×10^{-5}	tube method
	10–20	1.20×10^{-6}	10–22	4.68×10^{-6}	11–25	1.86×10^{-6}	17–25	2.07×10^{-6}	
	20–33	1.80×10^{-6}	27–38	3.40×10^{-6}	30–40	1.50×10^{-6}	29–37	3.80×10^{-6}	

(4) Level of field surface

As it is difficult to improve the soil bearing capacity during the flooding period, it is preferable to drain fast and uniformly the surface water. Thus, the level of the field surface was surveyed twice after the construction of the test plots.

Based on the results obtained (Table-16) the level of the field surface after the construction of the test plots was above ±7cm, and the zone with the lowest elevation was found in the center of the field. Therefore, it appears that it is difficult to drain the surface water with only one outlet in the field drain.

Table 16-1. Percentage of class frequency distribution of land level height (%).

Date of survey 17, 24/6, 1/7/1970

Class \ Plot No.	16	17	18	19
±. 0	6.6	9.9	5.5	4.8
± 1.0	18.7	11.0	8.8	9.6
± 2.0	13.2	17.0	12.1	7.7
± 3.0	13.2	2.2	9.9	6.7
± 4.0	9.9	13.2	9.9	8.7
± 5.0	7.7	7.7	6.6	7.7
± 6.0	5.5	15.4	16.5	8.7
± 7.0	7.7	4.4	6.6	5.8
± 8.0	3.3	7.7	6.6	11.5
± 9.0	7.7	2.2	3.3	3.8
± 10.0	2.2	5.5	2.2	2.9
± 11.0	1.1	2.2	2.2	8.7
± 12.0	0	0	3.3	3.8
± 13.0	2.2	0	3.3	1.0
± 14.0	0	1.1	1.1	1.9
± 15.0	1.1	0	1.1	1.9
± 16.0	0	0	0	1.0
± 17.0	0	0	0	0
± 18.0	0	0	1.1	1.0
± 19.0	0	0	0	1.0
± 20.0	0	0	0	0
± 21.0	0	0	0	0
± 22.0	0	0	0	1.0
± 23.0	0	0	0	0
± 24.0	0	0	0	1.0
80% of class	±7.0	±7.0	±8.0	±11.0

Table 16-2. Percentage of class frequency distribution of land level height.(%)

Date of survey 3-4/8/1980

Class (cm) \ Plot No.	16	17	18
± 0	0	0	0
± 1	11.4	14.3	17.1
± 2	11.4	11.4	8.6
± 3	14.3	5.7	20.0
± 4	5.7	14.3	14.3
± 5	11.4	14.3	8.6
± 6	8.6	5.7	5.7
± 7	5.7	2.9	8.6
± 8	5.7	2.9	8.6
± 9	5.7	0	5.7
±10	8.6	8.6	2.9
±11	0	0	0
±12	2.9	0	0
±13	2.9	0	0
±14	0	2.9	0
±17	0	2.9	0
±19	0	2.9	0
±20	0	2.9	0
±22	2.9	0	0
±24	0	2.9	0
±25	0	2.9	0
±29	2.9	0	0
±31	0	2.9	0
80% of class	±9	±10	±7

VII. Conclusion

The studies were conducted as a technological approach to the improvement of the weak foundation of the paddy fields in the Muda Area. In order to imporve the weak foundation, only engineering methods were applied including subsurface drainage system under farming conditions with a view to achieving the following objectives.

1) To use middle-or large-sized type of tractors and combines in order to alleviate the labour shortage for farm operations.
2) To enable the establishment of double cropping of paddy in the Muda Area: Harvesting was performed in July (off-season), and puddling and transplanting in August (main-season).

This study was based on the findings of Anyoji[1] who demonstrated that to achieve good trafficability the soil bearing capacity within a depth of 25cm should exceed 2.0 kgf/cm^2 on the average for the use of the experimental medium-sized combine harvester.

From the results of the investigations and analyses carried out, the author would like to outline the following aspects.

1) Soil conditions in the test plots
   (1) Heavy clay soil (clay percentage of about 70%).
   (2) When the values of the soil physical properties were compared before and after the construction of the subsurface drainage system, the values of the soil density and solid phase at a depth ranging from 10cm to 20cm were increased, suggesting that the compacted layer was near the field surface.
   (3) There was very little vertical percolation (coefficient of permeability during the wet season in the field was about $10^{-6} \sim 10^{-7}$ cm/sec) because of the absence of water paths.
   (4) The soil readily underwent slaking when the moisture content was less than 20%. The mole drain and subsoiler did not enable to achieve effective drainage because the mole drain hole or soil crakcs tended to be blocked depending on the time interval after the supply of water to the paddy fields.
2) When the construction speed of the components of the subsurface drainage system in the test plots was compared, the results were as follows (i) mole drain = 7 ha/day, (ii) blind underdrain = 2 ha/day, (iii) complete underdrain = 0.3 ha/day. The spacing of both the blind drain and complete underdrain was 10m. Working time for the three components was 7 hour/day.
3) The experimental results are summarized as follows

   The soil bearing capacity was found to increase up to 2.0 kgf/cm^2 with evaporation and desiccation below a 60% moisture level and a continuous period of 9 to 17 fine days was required. On the basis of the relationship between underground water level and soil bearing capacity (average value within a depth of 25cm), it appears necessary to lower the underground water level to a depth of more than 30cm.

   From the results of the permeability tests of the surface soil in the fields, it appears that the coefficient of permeability does not decrease by weak puddling, but that the permeability quickly decreases by cultivation on fine soil and by strong puddling. Therefore, it is preferable to perform light puddling and to proceed to cultivation on dry condition.
4) The soil bearing capacity showed a high value (cone index: about 10 kgf/cm^2) during the dry season and thereafter it decreased during the period of flooding and puddling. It remained almost constant until harvesting and increased after drainage at harvesting time. Such a pattern of soil bearing capacity was observed twice a year.

   During the test period (about three years), it could thus be expected that the soil bearing capacity might increase year after year, especially in the plots with complete underdrain.

   The soil bearing capacity in the plots with complete underdrain increased by about 7 to 55%, before and the construction of the construction of the subsurface dr ainage system.

   The soil bearing capacity in the plots with underdrain exceeded 2 kgf/cm^2 during the present harvesting season. However since it is difficult to increase rapidly the soil bearing capacity with this type of underdrain during the harvesting season, a simple ditch type drain can be used.

   At the time of introducing the transplanter in future, a flat plow layer (until

15cm depth) will have to be developed in order to transplant the seedlings. Therefore, the soil hardness of the field foundation will have to be increased.

5) In order to increase the soil bearing capacity, the surface and the gravitation water in the soil layer should be drained quickly and uniformly.

Problem of drainage was due to the difficulty in removing the surface water in the plots because of the uneven surface of the field, the large size of the plots, the presence of a small outlet, and the absence of percolation in soil.

After drainage of the surface water, the soil bearing capacity increased rapidly. However, it was difficult to dry the field by evaporation alone during the rainy season.

The results obtained emphasize the effectiveness of the subsurface drainage system and the need to adopt new cultivation methods (e.g. dry cultivation, light puddling).

However, the soil bearing capacity showed a small increase during the period from drainage to harvest, suggesting that the effectiveness of drainage to increase the soil bearing capacity was minimal during the three-week period from the opening of the drain outlet to harvest. Such a small increase may be ascribed to the following factors: the depth of the soil covering the underdrains exceeded that which had been planned and the soil zone became impermeable due to the run of the machines, the outlet of the field drain was small and the center of the field had the lowest elevation in the plots.

Since the drainage of the surface is difficult to achieve during a short period, the soil cannot become readily dry. Therefore, it is necessary to drain fast and uniformly the surface water and to drain the excess water in the soil zone by underground drainage.

Subsoil in clayey paddy fields can be improved as follows. Cracks are prepared in the impermeable soil layer and when these cracks are connected to underdrains, it becomes possible to drain the surface and gravitational water rapidly even in impermeable paddy fields. Rational drainage system should combine the use of absorbing underdrain pipes (lateral underdrain pipes) covered with high permeable filter materials and shallow supplementary mole drains crossing the permeable filter at right angle.

The shallower underdrains, which are called supplementary underdrains, are aimed at removing rapidly the water over the surface layer and water in surface layer voids through drying cracks and mechanically-formed water paths. These can be installed in great numbers and near the surface. The permeability of the surface soil can be improved by adequate drainage. Therefore, the shallower drains should be constructed so as to be readily renewed since they are short-lived and may undulate with land drying or be broken by the machines running over the fields.

This method which is often applied in the paddy fields of Japan which consist of heavy clay appears to be useful under tropical conditions judging from the results of the current field studies.

The author thus recommends the combination of the use of a complete underdrain and supplementary underdrain, the former and the latter being constructed at about 10m and 2~4m intervals, as illustrated in Figure-19.

It is desirable that the supplementary underdrains be packed with permeable materials such as husks in order to prevent slaking of the soil. However, the improvement of the durability of the husks requires further testing.

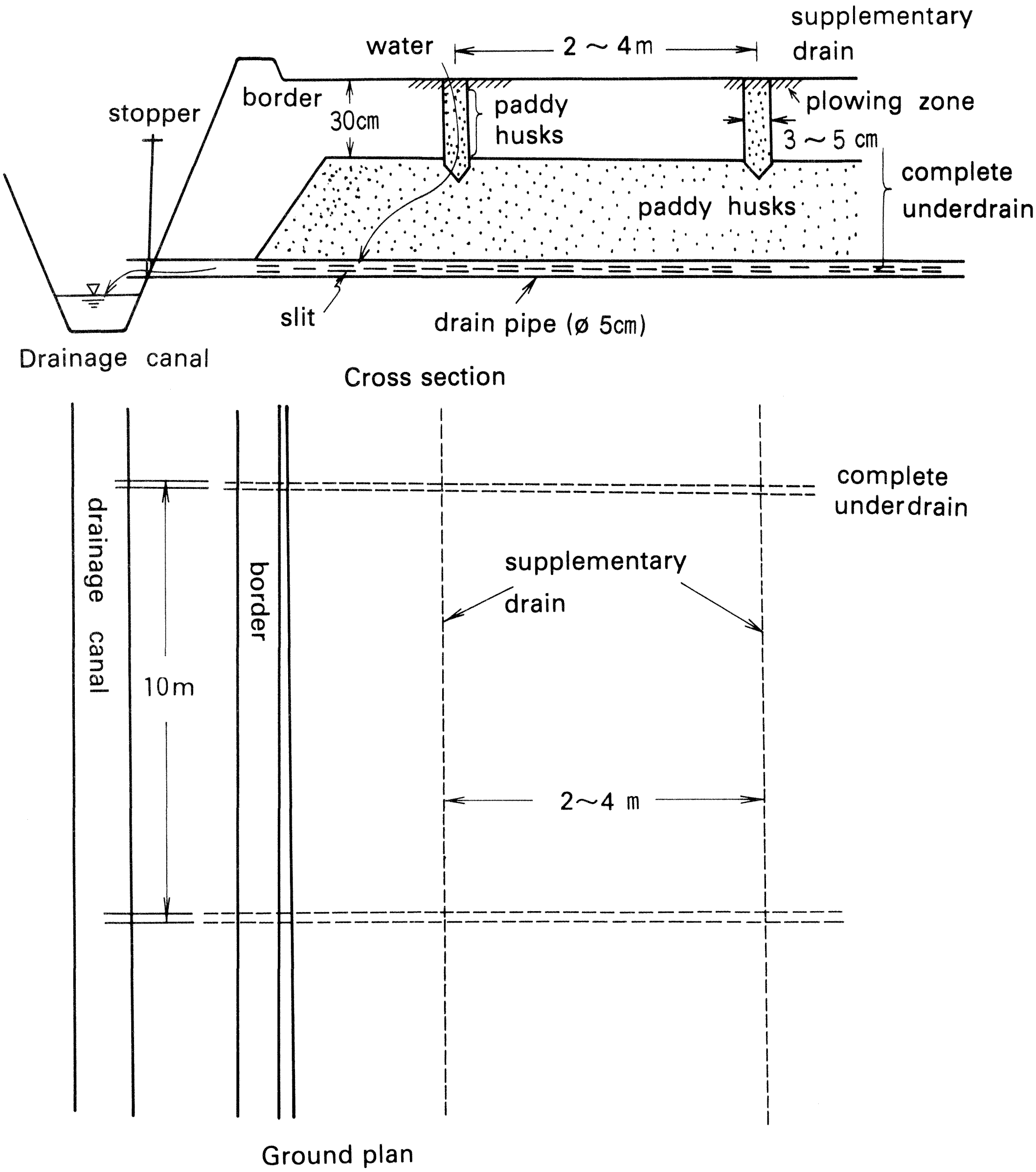


Fig 19. Combination of underdrains.

Table 17-1. Rainfall record (Telok Chengai Experimental Station).

(July. 1977 ~ December. 1977)   Unit: mm

Month/day	Rainfall record	Month/day	Rainfall record	Month/day	Rainfall record
1977 year		8/27	11.3	10/14	15.3
7/4	11.7	8/29	27.0	10/15	1.7
7/5	4.5	8/30	23.3	10/8	0.6
7/6	0.6	8/31	20.0	10/19	2.0
7/7	64.3	Total	438.6	10/21	13.0
7/9	2.5	9/1	5.4	10/22	15.5
7/11	46.8	9/2	13.5	10/23	7.5
7/12	1.1	9/3	11.9	10/24	5.3
7/13	8.9	9/5	37.0	10/25	2.4
7/16	25.3	9/6	17.0	10/26	0.4
7/19	0.7	9/7	2.0	10/27	4.8
7/20	1.0	9/14	4.5	10/28	27.6
7/26	2.1	9/15	62.5	10/29	33.4
7/29	12.8	9/16	40.9	10/30	1.4
Total	182.3	9/17	16.5	10/31	3.3
8/3	2.8	9/18	0.5	Total	315.8
8/5	9.7	9/23	37.5	11/1	5.7
8/6	23.5	9/24	27.2	11/4	25.0
8/7	1.6	9/25	19.5	11/5	14.0
8/8	10.9	9/26	14.0	11/6	6.6
8/9	2.6	9/27	94.0	11/8	16.2
8/10	4.1	9/29	52.9	11/12	2.0
8/11	34.3	9/30	4.7	11/13	1.0
8/12	0.5	Total	479.5	11/23	0.5
8/13	11.3	10/1	7.6	Total	71.0
8/16	46.5	10/2	11.5	12/4	0.3
8/17	35.0	10/4	22.5	12/7	79.1
8/18	59.6	10/5	2.6	12/9	1.9
8/19	71.8	10/6	32.5	12/10	1.4
8/20	17.2	10/7	0.5	12/16	13.7
8/21	2.0	10/8	15.5	12/20	1.3
8/23	21.1	10/9	57.0	Total	97.7
8/24	2.5	10/10	31.9		

Table 17-2. Rainfall record (Telok Chengai Experimental Station).

(January. 1978 ~ July. 1978) Unit: mm

Month/day	Rainfall record	Month/day	Rainfall record	Month/day	Rainfall record
1978 year		5/4	24.2	6/23	1.3
1/9	1.5	5/6	3.2	6/26	50.0
1/16	9.3	5/7	9.8	6/27	3.3
1/17	4.5	5/8	31.9	6/28	61.0
1/19	6.5	5/9	0.3	6/29	17.7
1/29	2.2	5/10	58.7	6/30	13.9
Total	24.0	5/11	3.7	Total	415.6
February	0	5/12	3.2	7/1	89.4
3/5	2.3	5/13	136.6	7/2	2.1
3/11	17.6	5/14	0.1	7/4	44.0
3/18	7.7	5/16	20.5	7/8	15.0
3/19	26.4	5/17	1.8	7/10	26.0
3/21	10.6	5/19	4.2	7/11	2.0
3/26	21.5	5/21	0.4	7/13	6.0
3/28	23.2	5/22	3.0	7/14	7.2
Total	109.3	5/28	0.5	7/15	3.1
4/3	1.6	5/29	2.6	7/18	42.5
4/4	86.4	5/30	2.7	7/19	23.4
4/5	0.3	Total	365.9	7/21	10.4
4/8	2.8	6/1	24.4	7/24	0.3
4/11	4.0	6/2	9.1	7/26	24.0
4/12	1.3	6/3	3.0	7/27	15.0
4/13	40.8	6/4	2.9	7/28	24.5
4/16	0.4	6/5	70.6	7/29	2.7
4/17	49.6	6/7	54.8	Total	337.6
4/18	0.3	6/9	5.5		
4/19	3.1	6/10	64.4		
4/22	0.5	6/12	0.5		
4/25	96.2	6/14	15.6		
4/26	34.4	6/15	1.4		
Total	323.7	6/16	0.8		
5/2	46.7	6/17	5.8		
5/3	11.8	6/20	6.2		

Table 17-3. Rainfall record (Telok Chengai Experimental Station).

(August. 1978 ~ December. 1978) Unit: mm

Month/day	Rainfall record	Month/day	Rainfall record	Month/day	Rainfall record
8/3	38.8	9/25	0.2	Total	140.7
8/5	0.5	Total	350.2	12/2	0.7
8/9	57.5	10/2	4.0	12/5	3.5
8/10	5.6	10/6	3.2	12/6	24.2
8/14	27.0	10/7	0.3	Total	28.4
8/15	3.1	10/8	1.1		
8/17	62.8	10/9	2.2		
8/18	27.0	10/10	31.3		
8/19	4.6	10/11	35.5		
8/22	1.5	10/12	37.4		
8/25	15.6	10/13	25.7		
8/28	1.0	10/15	5.6		
8/29	4.3	10/16	19.7		
8/30	16.2	10/17	31.7		
8/31	47.9	10/18	0.3		
Total	313.4	10/20	5.6		
9/1	4.8	10/22	0.4		
9/2	4.3	10/24	5.4		
9/4	14.2	10/26	2.1		
9/5	61.9	10/28	3.3		
9/7	23.7	10/31	44.9		
9/8	18.1	Total	259.7		
9/9	79.0	11/1	23.8		
9/10	5.7	11/3	7.6		
9/13	7.5	11/7	1.0		
9/15	39.7	11/12	25.8		
9/17	1.7	11/13	11.4		
9/19	0.7	11/14	5.8		
9/20	25.2	11/15	0.7		
9/22	53.6	11/16	32.9		
9/23	6.6	11/17	31.4		
9/24	3.3	11/18	0.3		

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