ABSTRACT

EFFECTS OF SUBSOIL ASPHALT BARRIERS ON THE PRODUCTION OF PADDY RICE AND SUGARCANE ON SAND SOILS IN TAIWAN

by Alvin J. Marion Smucker

Asphalt barriers were installed in a deep fine sand soil in southern Taiwan at several depths below the soil surface. Paddy rice and sugarcane were the index crops used to evaluate the effects of the asphalt barrier on water consumption and crop production of tropical sand soils. A subsoil drainage system was installed in the asphalt lined paddies which provided a method for draining the asphalt paddies. Natural drainage occurred off the edge of the barriers in the sugarcane experiment.

The asphalt sand rice paddies required less irrigation water than most conventional clay paddies. A new drainage schedule was adapted to accommodate the fertilization and aeration requirements of the paddies.

Excellent rice yields were produced on all the barrier treatments of both the spring and summer crops. Asphalt barriers installed at a depth of 40 cm. proved most desirable for rice production on these soils. The sulfate nitrogen carrier had essentially no detrimental effects on rice production during this study.

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Asphalt barriers installed 75 cm. below the soil surface reduced the irrigation requirements of sugarcane by 70% or by 225 mm. water and doubled the production of sugarcane during the growing season. The 75 cm. barrier appeared to give the best water-air relationship in the root zone of the sugarcane.

Rice and sugarcane root penetration had essentially no effect upon the permeability of the asphalt barriers.

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By

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A THESIS

Submitted to
Michigan State University
in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE

Department of Soil Science

1969

TO BETTY

This thesis is dedicated to my wife for her encouragement and willing sacrifices during this investigation.

ACKNOWLEDGMENTS

The author would like to thank Dr. A. E. Erickson for his guidance and encouragement during the course of this study and for his constructive criticisms during the preparation of this manuscript.

The author also wishes to thank Dr. R. L. Cook, Dr. K. Lawton, Dr. C. M. Harrison and Dr. J. F. Davis for their helpful criticisms during the preparation of this manuscript.

A special note of appreciation is extended to Mr. K. Y. Li and the staff of the Taiwan Sugar Experiment Station for their assistance with the data collection.

The writer would also like to thank Mrs. Bess Quinlan for her assistance in the statistical analyses of the data.

Financial assistance by the Institute of International Agriculture and Nutrition, Michigan State University and the Joint Commission on Rural Reconstruction, Taipei, Taiwan are gratefully acknowledged.

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Chapter I

INTRODUCTION

Most of the water used by plants must be stored in the soil. The water storage capacity of a sand soil is very small and reduces the productivity of these soils unless supplemental irrigation is applied. However, the additional water applied to maintain optimal soil moisture conditions for plant growth is expensive. Therefore a combination of supplemental irrigation practices and a soil treatment similar to the asphalt moisture barrier developed by Erickson and Hansen of Michigan State University could be used to bring many of the deep well-drained sand soils of the world into production.

Taiwan, a small island country in the South China Sea, has greatly improved its agriculture during the last two decades. Recent land reforms, rural improvement programs and agricultural research, sponsored by the Joint Commission on Rural Reconstruction, have laid the foundations for maximum production of Taiwan's arable land. This nation's major problem, however, is that additional arable land is scarce. Hsi and Liao (30) indicated that land is in such demand that more than two-thirds of the marginal land in Taiwan is cultivated. As a result of this land shortage, many sand soil reclamation projects are in progress in the river bed and coastal areas of Taiwan.

This study resulted from the combined efforts of the Soil Science Department, Michigan State University (M.S.U.), the Institute of International Agriculture, M.S.U., the Joint Commission on Rural Reconstruction (J.C.R.R.) of Taiwan, and the Taiwan Sugar Corporation (T.S.C.). Both the author and his major professor traveled to Taiwan for this study. The author remained in Taiwan for six months while the major professor returned to M.S.U. shortly after the installation of the experiment and the first crops were planted. Staff members of the Soils and Agronomy Departments of the Taiwan Sugar Experiment Station (T.S.E.S.) harvested the second rice crop and the spring planted sugarcane crop.

Two experiments were conducted in this study. The first was conducted to evaluate the use of asphalt barriers for creating rice paddies on sand soils. The second was conducted to evaluate the effects of asphalt barriers upon soil water conservation and sugarcane production on tropical, deep, well-drained sand soils. The experiments were conducted on the Fusan farm of the T.S.C. Chekan Sugar Mill located five kilometers south of Tainan, Taiwan. Laboratory facilities and technicians were provided by T.S.E.S.

The primary objective of the rice experiment was to establish rice paddies on sand soils with subsurface asphalt barriers. Other objectives of this study included:

1. The determination of the minimum barrier depth which would assure maximum yield and protect the barrier from tillage.
2. The development of a method for periodically draining the asphalt paddy.
3. An evaluation of the effects of urea and ammonium sulfate nitrogen carriers on rice grown in asphalt-lined sand soil paddies.
4. An evaluation of the effects of rice roots on the asphalt barrier.
5. The determination of the water efficiency of the barrier.

The primary objective of the sugarcane experiment was to determine the quantity of water that could be conserved for sugarcane production by the installation of asphalt barriers below the root zone. Other objectives of this study included:

1. The determination of the effects of the asphalt barrier depth upon water storage, irrigation efficiency, and sugarcane production.

2. An evaluation of the effects of reduced soil oxygen on sugarcane production.
3. The determination of the sugarcane root-asphalt barrier relationships.

Chapter II

LITERATURE REVIEW

Many research workers have shown that the amount of water retained by sand soils is a function of soil texture, depth, and uniformity (7, 37, 8). Baver (8) showed that non-capillary pores in the root zone of sand soils are readily drained by the soil moisture tension created in the continuous capillaries of deep homogenous sand soils. Since a small quantity of available water is retained by these coarse soils, frequent additions of supplemental irrigation water are required in order to maintain optimum soil moisture conditions for plant growth. The higher costs resulting from frequent irrigations, to replenish water that is lost due to deep percolation, and additional fertilizers added to replenish those nutrients lost by leaching, greatly reduce the economic productivity of these soils.

Arable land is scarce in the small island country of Taiwan. Approximately 75% of the total land area of 35,760 square kilometers is mountains and thousands of hectares of land are covered with sand soils (36). Approximately 24% of the total land area is cropped leaving a very small area for expansion.

Rice is the chief food of the Orient where it sustains more than one-half the world's population (52). In Taiwan more than 60% of the arable land is cultivated for paddy rice, producing approximately two million metric tons of brown rice annually. More rice would be grown, however, if suitable paddy soils were available.

Sugarcane, the second most important crop in Taiwan, is grown in the alluvial soils. Many of these alluvial soils are coarsely textured and have a low water storage capacity. Yeh, et. al. (59) reported that the soil moisture contents of many unirrigated cane fields approach the permanent wilting percentage during the summer and autumn growing seasons. Preliminary studies by T.S.E.S. have indicated that the yield of sugarcane grown on sand soils may be tripled when an optimum available moisture content is maintained throughout the growing season (unpublished data). Therefore, steps must be taken to reduce the loss of natural and irrigation water from the root zone of these soils before maximum sugarcane yields can be economically obtained.

Recently, the irrigation facilities provided by the government have increased sugarcane yields in many of these sand soil areas. However, much of this valuable water is wasted as the irrigation frequency and water quantity are controlled by irrigation water availability rather than by crop demands. Crops are excessively irrigated when water is available reducing the efficiency of both water and nutrients. Consequently, when plant demands for soil moisture are high the remaining water supply is rapidly depleted.

Soil stratification increases the moisture holding capacity of sand soils. This phenomenon is especially true when the soil band is impermeable to water. Grant (26) reported beach sand soils that were underlined with boulders could be flooded and converted into rice paddies. Tremendous quantities of water and nutrients were required, however, to produce respectable rice yields on these sand soil paddies as the boulders did not form a water-tight moisture barrier. Hishomoto (29) showed an increased in rice yields of rain-fed sand soil paddies when vinyl sheets were installed below the root zone. Less water and fewer nutrients were lost by the vinyl treatment. Vinyl sheets are excellent moisture barriers although it is extremely difficult to produce an infinite moisture barrier of practical use for sand soil paddies as the joints between the vinyl sheets rupture during installation, reducing the efficiency of the moisture barrier (unpublished data). Erickson and Hansen at Michigan State University showed that the moisture holding capacity in the root zone of sand soils was doubled by installing a 3 mm. layer of asphalt 60 cm. below the soil surface (unpublished data). Asphalt moisture barriers limited the natural drainage of sand soils by disrupting the deep capillaries, thereby reducing the water tension in the root zone. Since the asphalt barrier is impermeable to water, low tension water can be stored above the barrier. They also showed that fewer irrigations were required to maintain available soil moisture conditions in the root zone above the asphalt barrier.

The above considerations suggest that if the subsoil asphalt barriers were continued to the soil surface, thereby stopping both the horizontal and vertical movement of the soil water, economically productive rice paddies could be constructed on sand soil.

The leaching of mobile nutrients through coarse soils is related to water movement. Bates (5) has shown that nitrate movement varies directly with the pore size distribution and the quantity of water moving through the porous soil. Other studies (54) have shown that large quantities of potassium are also removed from intensely irrigated sand soils. Therefore it seems feasible that the asphalt moisture barrier may also conserve soil nutrients.

Soil texture is also important in the retention and availability of nutrients. This is especially true for paddy culture where most nutrients are absorbed in the reduced form. The low exchange capacity of coarse textured soils reduce nutrient retention by these soils. The combined effects of high permeability and low exchange capacity allow for excess nutrient leaching.

Excessively irrigated sand soil paddies are not desirable for rice production because the soil in the root zone is not adequately reduced. Inadequately reduced soil does not allow iron to go into solution, anaerobic bacteria are not active, and the nitrification-denitrification cycle is not developed (40), consequently rice production decreases.

"Akiochi" (4), suffocation disease (16), and other rice physiology diseases often occur on "degraded" paddies, especially on soils low in iron. Mitsui and others (41, 17), suggest a heavy basal application of ammonium sulfate increases the incidence of this disease. For this reason an ammonium sulfate treatment was included with the 40 cm. barrier treatment.

Chapter III
MATERIALS AND METHODS

General Description

Soil type

The soil type of the Tiger Mountain section of the Fusan Farm was a fine sand which is representative of many droughty sugarcane soils in Taiwan. The physical properties of this very loose fine sand are recorded in table 1. These physical properties were analyzed by the commonly used methods outlined in the Agronomy Monographs No. 9 (1). The high permeability, the particle size distribution, and the low organic content indicate the beach-like properties of this sand soil. The uniform distribution of the separates throughout the soil profile also indicate the homogenicity of this soil. Soil core samples indicated this homogenicity continued to depths greater than three meters below the soil surface. Since this soil was relatively free of fine soil lenses it was described as an excessively drained soil. The soil was also analyzed for its nutrient content before the beginning of the experiment, table 2. The high pH, available phosphorous, and exchangeable calcium content in the Ap horizon probably resulted from the lime filter cake that

Table 1. Physical properties of the Fusan Farm sand soil*

Soil horizon depth-cm.	Percent partical size distribution-mm. diameter						Bulk density g/cc	Partical density g/cc	Total porosity %	Permeability cm./Ha.	Organic matter %
	2.0 - 1.0 V.C. sand	1.0- 0.5 C. sand	0.5 - 0.25 M. sand	0.25 - 0.1 F. sand	0.1 - 0.05 V.F. sand	0.05 silt and clay					
Ap(0-20)	0	3.1	14.3	67.3	6.6	8.7	1.3	2.7	51.7	5.8	1.2
B_{1t}(20-52)	0	6.5	22.8	59.3	5.1	6.3	1.4	2.7	47.6	3.1	0.8
B_{2t}(52-85)	0	0.7	19.2	69.0	5.1	6.0	1.4	2.7	49.6	3.4	0.5
BC_1(85-120)	0	0.2	15.0	73.8	5.3	5.7	1.4	2.7	48.5	5.4	0.1
BC_2(120-160)	0	0.5	22.0	68.2	4.6	4.7	1.4	2.7	48.7	5.6	0.1

*Analysis by C. C. Yang, T.S.E.S.

Table 2. Chemical properties of Fusan Farm sand soil++

Soil horizon depth -cm.	pH	Total nitrogen %	Available phosphorus ppm	Exchangeable potassium ppm	Exchangeable calcium ppm	Exchangeable magnesium ppm
Ap (0-20)*	8.4	0.16	192.0	54.9	22.1	2.9
B_{1t} (20-52)	7.9	0.13	36.5	51.3	3.8	2.2
B_{2t} (52-85)	6.6	0.14	25.0	72.5	1.5	1.7
BC_1 (85-120)	5.8	0.12	14.0	17.0	1.5	1.5
BC_2 (120-160)	5.5	0.12	9.0	22.6	1.4	1.0

* 15-20%, by volume, filter cake incorporated into surface horizon

++ Analysis by T.S.E.S.

was incorporated into the surface soil. These nutrients were also analyzed by the commonly used methods outlined in the Agronomy Monographs No. 9 (2).

The moisture retention curve in figure 1 was determined by the tension table and pressure plate methods commonly used in determining the effects of tension on soil water. This curve shows the greatest water loss occuring at tensions between 35 and 55 cm. of water. The data from this figure then, suggested the depths at which the asphalt barriers should be installed. The soil water content is approximately 19.6%, by volume, at field capacity while the soil moisture contents at 100, 75, and 50 cm. of water tension are 20.4, 25.9, and 34.5% by volume, respectively. Therefore as the asphalt barrier is brought closer to the surface a larger percent of the soil pore space will be filled with water. The moisture retention curves for the horizons from 12-120 cm., were similar to the Ap horizon reported in figure 1; See table 1 in appendix.

Climatic conditions

Taiwan's location astride the Tropic of Cancer gives it a subtropical climate with abundant rainfall during the monsoon season. Table 3 shows the 1967-1968 climate

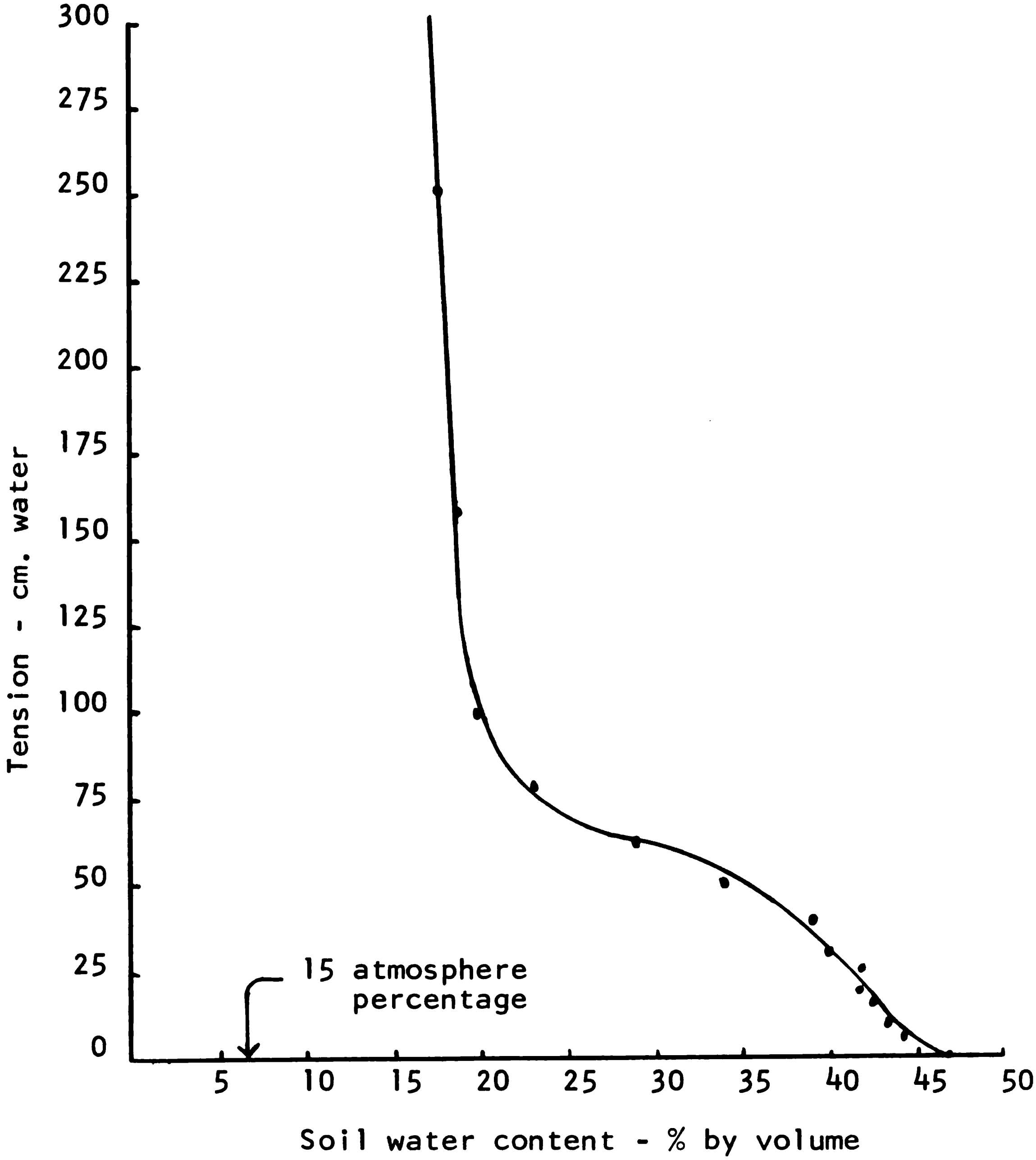


Figure 1. Soil water retention curve for the Ap horizon of the Fusan Farm fine sand - analysis by C.C. Yang of T.S.E.S.

Table 3. Climatic conditions at Taiwan Sugar Experiment Station (February 22, 1967 - February 19, 1968)

Month	Rainfall mm.	Evaporation mm.	Radiation g. cal. cm.$^{-2}$day^{-1}	Mean wind m/s	Mean relative humidity-%	Mean maximum temp.°C	Mean minimum temp.°C
February '67 (22-28)	10.6	138.9	8,009.5	3.5	82	22.2	11.8
March	5.4	184.5	10,150.2	2.7	83	25.8	15.1
April	117.8	162.1	9,288.5	2.6	86	28.3	19.3
May	204.3	218.8	11,440.3	1.7	85	31.0	22.9
June	339.8	181.8	11,017.5	1.8	88	30.4	24.1
July	156.3	203.5	12,053.0	1.7	86	33.3	24.0
August	285.6	169.1	7,592.7	1.6	88	31.9	24.7
September	6.7	171.4	9,186.6	1.7	86	30.9	22.4
October	21.2	164.7	9,090.7	2.6	82	29.3	18.9
November	11.7	124.2	6,846.8	1.4	83	27.7	17.5
December	0.3	115.5	6,763.9	1.7	80	22.6	10.2
January	4.9	127.9	7,802.2	2.8	81	23.4	11.3
February '68 (1-19)	63.1	50.3	3,624.7	3.7	88	17.7	10.3
Average or total	1227.7	2012.7	112,866.6	2.2	84	27.9	18.5
52 year avg. (Jan. 1-Dec. 31)	1884.7	1764.7	---	2.4	81	28.4	19.1

was very similar to the average climate during the past 52 years. Two medium velocity typhoons occurred during the sugarcane crop, one of which occurred during the summer rice crop. The subtropical climate allows for three rice crops or two rice crops and a vegetable crop or a 12 month sugarcane crop.

Irrigation water

Deep wells provided good quality irrigation water for both the rice and sugarcane experiments. For the rice experiment: the well water was warmed to ambient temperature during transport to and storage in a small open reservoir. A gasoline powered pump and a plastic hose were used to transfer the irrigation water from the reservoir to the individual paddies. Small flow meters, 2.5 cm. I.D., were used to measure the irrigation water. For the sugarcane experiments: The well water was applied directly to the individual plots by a concrete lined open irrigation ditch. Parshall flumes were used to record the irrigation rate, as high as 25 liters per second, and volume of water that was added to each plot.

Asphalt barrier installation

The subsurface asphalt barriers were installed by the cut and fill method using manual labor. The experimental sites were surveyed, cleared of plant debris, and leveled before excavation. During excavation the topsoil and subsoil were separately excavated and stored. The sides of each treatment were cut at a 1:1 slope while the "floor" was cut at the prescribed depth and parallel to the soil surface. Prior to asphalt application the newly exposed soil was treated with insecticide, leveled, and sprinkled with water.

Asphalt grade #50 was sprayed on the soil at the rate of 15 M.T./Ha., forming a thin, 3 mm., homogenous asphalt barrier. The asphalt, which was transported in 50 gal. barrels, was heated and then sprayed on the prepared soil. The three-man road surfacing asphalt sprayer illustrated in figure 2 was used to construct the asphalt barriers. Following solidification the barrier was inspected, repaired, and covered with soil.

Asphalt barrier installation expenses were much greater in Taiwan than in the United States. The additional expense arose from the tremendous quantity of manual labor employed to install the Taiwan barriers for a total cost of nearly U.S. $2,500 per hectare. Nearly 50% of the total installation costs arose from labor fees for excavating and refilling the soil while the cost of

Figure 2. Road surfacing asphalt applicator used to apply the barriers.

labor used to apply the asphalt was approximately 30% of the total expense. The remaining 20% of the total installation expense was spent for asphalt materials. Therefore the mechanical asphalt applicator, which will apply a subsurface asphalt barrier for approximately U.S. $500/Ha. including the asphalt materials, has a decided economical advantage.

Rice Experiment

Asphalt paddy construction

The subsurface asphalt barrier was continuous to the soil surface which essentially isolated the contents within the paddy from the surrounding soil. At the soil surface a brick wall, 20 cm. high, separated the flood water of adjacent paddies. However, further studies indicated that asphalt-lined soil dikes similar to that shown in figure 3 could be constructed to resist breakage during normal paddy manipulations. The isolated asphalt paddy also necessitated the installation of a drainage system. Perforated plastic pipe, 7.6 x 300 cm., were wrapped with palm sheaths and positioned in the center of the plot on the asphalt floor. This subdrainage system was covered with fine gravel and joined to an outlet in the wall. A short plastic pipe was also

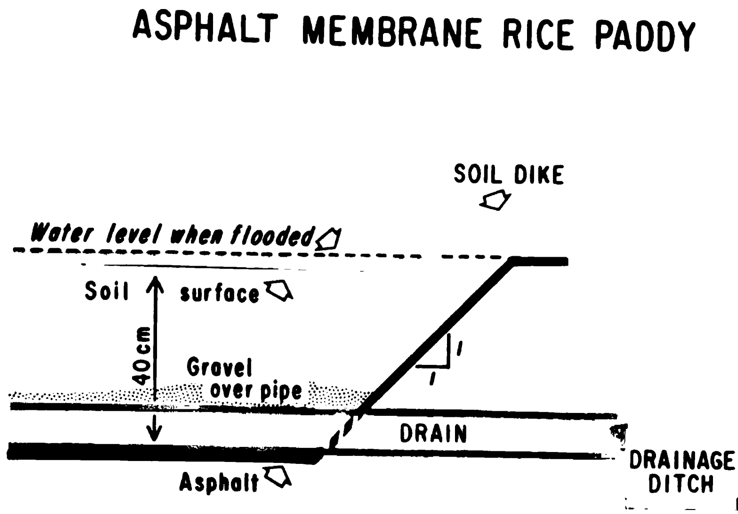


Figure 3. Diagrammatic illustration of asphalt rice paddy.

installed at the original soil surface in the same wall. Both outlets drained into an adjacent service drainage pit, figure 4. The drains were plugged during flooding and opened for draining and aerating the paddy soil.

Experimental design

The square asphalt rice paddies, four meters on a side, were arranged in the randomized block design shown in figure 5. There were four asphalt treatments and the control (A-E) fertilized with urea and one 40 cm. barrier treatment (F) fertilized with ammonium sulfate.

The five treatments were replicated four times. Concrete lined irrigation and surface drainage ditches were placed between the paddies according to the diagram in figure 5. Sand soil paddies were also constructed around the perimeter of the experiment as border plots. A three-meter bamboo windbreak was also placed along the north and west sides of the rice experiment.

The center 5.70 $m.^2$ of each paddy was evaluated for plant growth and production. The remaining rows, 4 per side, were designated as guard rows.

Cropping practices

Two rice crops were grown during this investigation. The spring crop was transplanted on

Figure 4. Service pit for surface and subsurface drains.

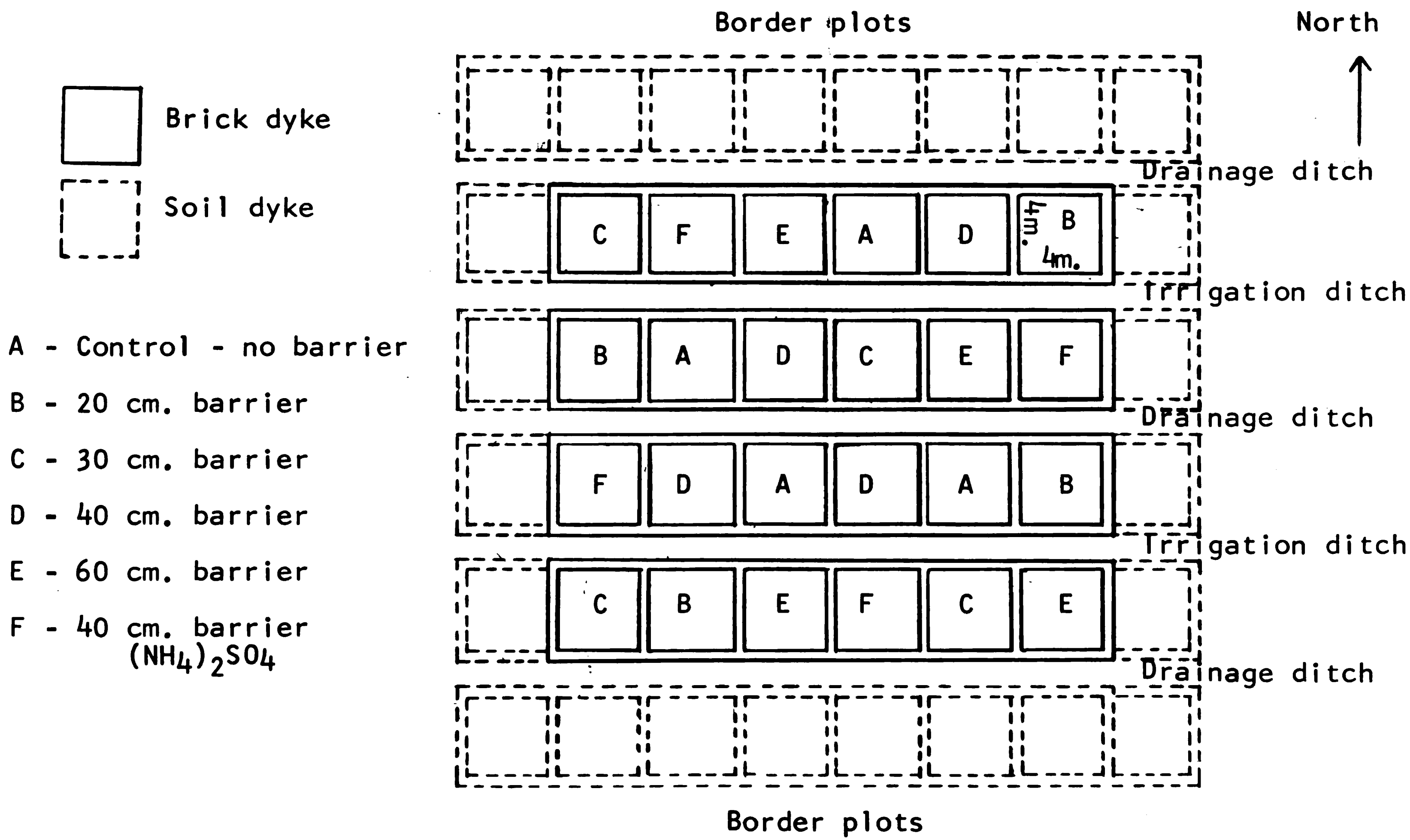


Figure 5. Field design of asphalt rice experiment

February 22, 1967 and the summer crop was transplanted on July 10, 1967. For the spring crop, the rice grown on the asphalt treatments was harvested on June 18 while the control treatments were harvested on July 3, 1967. The entire summer crop was harvested on October 16, 1967.

Rice variety Tainan #5 (Oryza sativa L.) was used for both crops. This short strawed variety was released in 1964 for high production by Taiwan plant breeders.

Nursery plants, 8-10 cm. tall, were transplanted in hills of six plants each. The hills were spaced at 15 cm. intervals within the row and 25 cm. between the rows.

Most of the cultural practices in this study were similar to those followed by Taiwan paddy rice farmers. Therefore the weeding, fertilizing, spraying, etc., were done by manual labor. However, additional fertilizer was required to maintain adequate fertility and a new fertilization schedule was developed, figure 6.

Fertilizer was applied to the paddies before the flooding and transplanting of both the spring and summer rice crops. Nitrogen was applied to all treatments of the spring crop at the rate of 113 Kg./Ha. While nitrogen

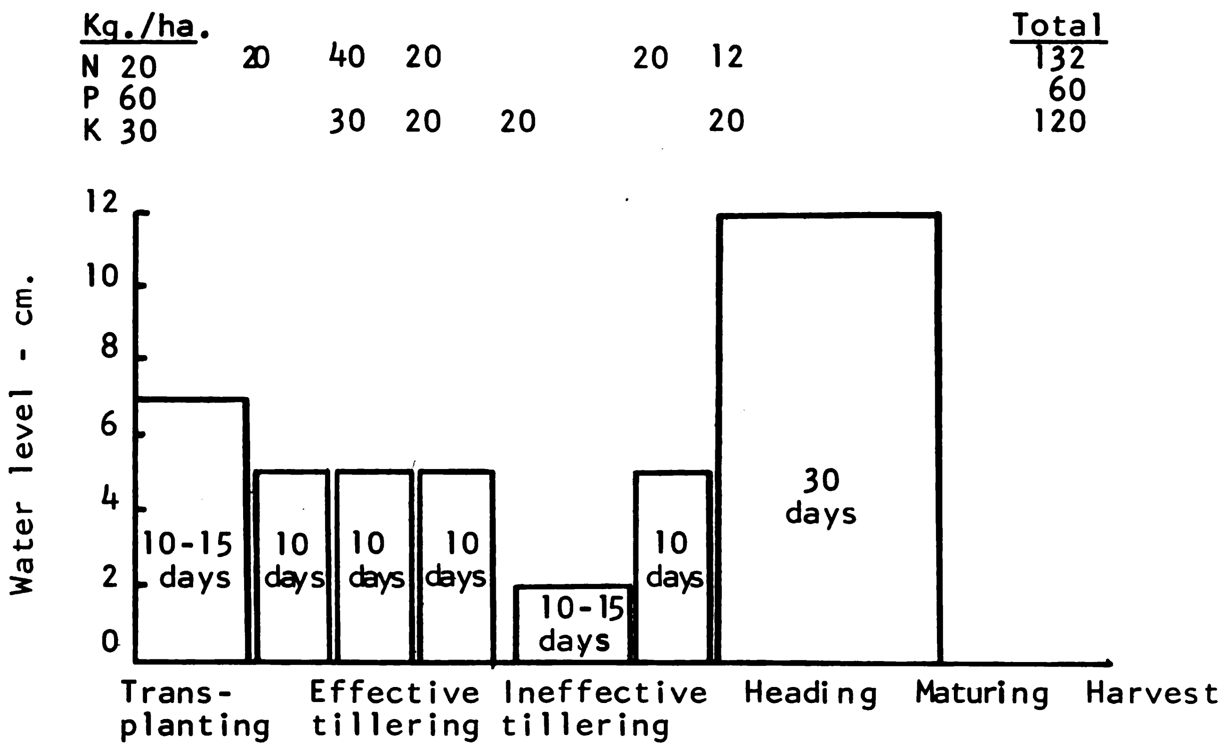


Figure 6. Drainage and fertilization schedule for asphalt rice paddy

was applied to the asphalt paddies of the summer crop at the rate of 132 Kg./Ha. Two additional side dressings of nitrogen were added to the control treatments 36 and 46 days after transplanting. Consequently, an additional 50 Kg./Ha. of nitrogen was applied to the control treatments of the summer crop. Phosphorus and potassium were applied to all the treatments of both crops in the forms of calcium superphosphate and potassium chloride. Phosphorus was added before transplanting while potassium was added according to the schedule in figure 6.

The water level on the asphalt paddies was maintained according to the schedule in figure 6. The asphalt paddies were drained and aerated five times for 48 hours and one time for 96 hours during the growing season, figure 6. Soils in the control paddies were flooded for 12 and 18 hours per day for the spring and summer crops, respectively.

Chemical pest control was similar to the methods followed by Taiwan rice farmers. Parathion, fumiron, α BHC and blasteiden S were used to control the leaf-hopper, weevil, stem borer, and the rice blast disease, respectively.

Plant growth and production measurements

The plant height and tiller quantity were determined at weekly intervals for the duration of both rice crops. Plant height was determined by measuring the aerial portion of the plant from the soil surface to the end of the longest plant part. Tillers were those branch stems, arising from the initial setting with more than one leaf. The average value of 20 hills per treatment was recorded for that treatment.

Brown rice and straw yields were harvested from the center, 5.70 square meters of each paddy. Dry grain yields were recorded at a 12% moisture content. The straw yield was the weight of the threshed plants which were dried in a 70 C forced air oven for three days. Plant height, panicle quantity and length, tillers, and grain quantity per panicle were determined by measuring the plants from 20 randomly selected hills per replication. Harvest data of the spring crop was taken from replications 2, 3, and 4 because replication 1 was destroyed by an overdose of fungicide. Four replications were used for all measurements of the summer crop.

Root distribution studies

Rice root distribution was determined by analyzing triplicated postharvest soil samples. A square metal frame, 15 x 25 cm. and open at both ends, was forced through the soil to the asphalt barrier or to a depth of 50 cm. in the control treatment. The surrounding soil was excavated and the soil volume containing the rice crown and roots was extracted. Then the soil was wetted, removed from the frame, and dissected at 5 cm. intervals parallel to the soil surface. The roots in each segment were washed, dried at 70 C for three days, and weighed. The asphalt barrier below each excavated plant was examined and the number of roots which penetrated a 100 $cm.^2$ area of the barrier was recorded.

Soil measurements

Various soil measurements were taken during the rice experiment. The density changes in the soil were periodically measured (1). Soil pH was measured by the glass electrode using a 1:1 soil-water ratio. During the drainage period oxygen diffusion rates were also determined by the platinum microelectrode according to the procedures outlined by Erickson, Van Doren, and Lemon (20, 35).

Sugarcane Experiment

Asphalt barrier construction

Both sides and one end of the subsurface asphalt barrier were continuous to the soil surface of the rectangular sugarcane plots. The remaining end was not sealed with asphalt allowing subsoil drainage, figure 7. This plot design created an infinite barrier in three directions and permitted good subsoil drainage.

Experimental design

This experiment was conducted in the same sugarcane field which was adjacent to the rice experiment. Sugarcane was grown on rectangular plots that were 8.75 x 25.0 m. The treatments consisted of three asphalt barriers placed at 50, 75, and 100 cm. below the soil surface henceforth refered to as the 50, 75, and 100 cm. treatments and two control treatments. One control was cut and filled to a depth of 100 cm., which will be referred to as the disturbed control, while the other control was undisturbed. Each treatment was replicated six times. The thirty plots were arranged in the randomized block design illustrated in figure 8. Border sugarcane plots, 10 m. wide, were placed around the perimeter of the experiment.

Two concrete lined irrigation laterals were installed in the middle two corridors of this experiment, figure 8.

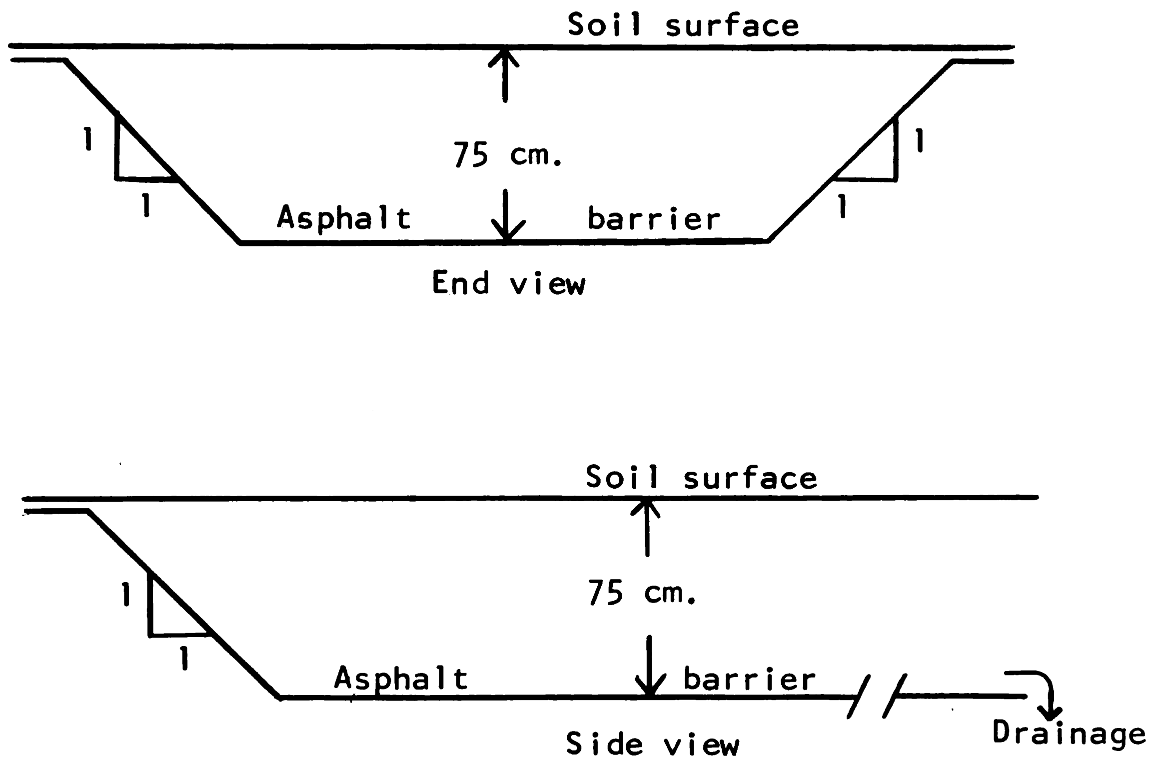
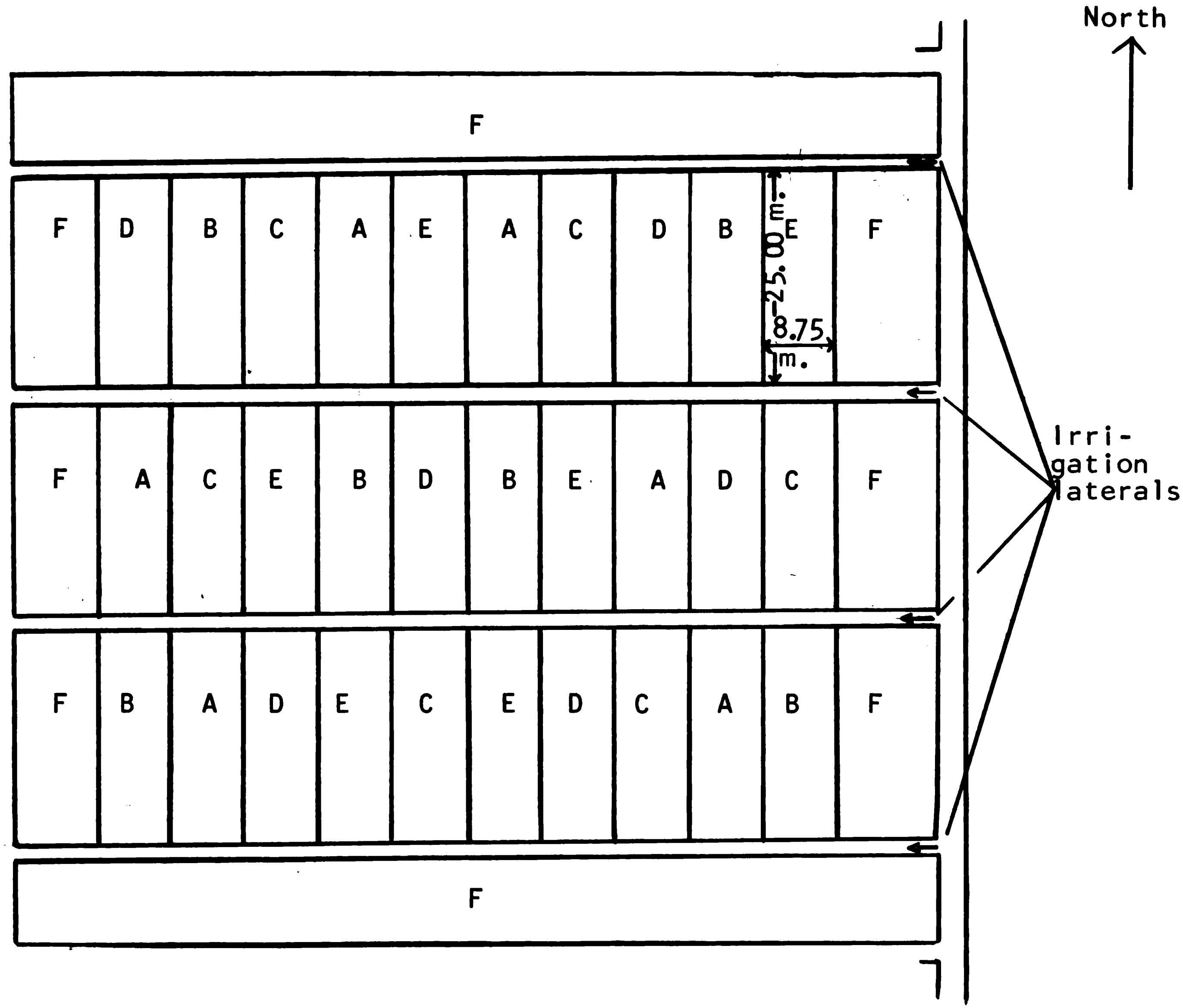


Figure 7. Asphalt barrier for sugarcane cultivation in fine sand soil



A- Control

B- 50 cm. barrier

C- 75 cm. barrier

D-100 cm. barrier

E- Disturbed control

F- Border plots

Figure 8. Field design of asphalt sugarcane experiment

Irrigation water was metered by a 7.6 cm. Parshall flume which was positioned at the junction of the irrigation main and each concrete lateral, figure 9. A system of exit gates, installed in each lateral, permitted independent irrigation of each plot.

Surface drainage ditches were also constructed of soil in each corridor of the sugarcane experiment, figure 8.

Cropping practices

A twelve-month sugarcane crop was grown for the asphalt sugarcane experiment. The sugarcane variety F-156 (Saccarum officinarum L.) was planted on March 5, 1967 and harvested February 26, 1968. This moderately drought resistant variety was released by T.S.E.S. plant breeders in 1965 and yields approximately 92.00 M.T. of sugarcane per hectare (T.S.E.S. Agronomy Department, unpublished data). Seedpieces, each having two nodes, were treated with calcium water and fungicide and planted in rows spaced at 1.25 m. and 0.30 m. within the row. Seedpieces were planted at a rate of 27,000 per hectare.

Gradulated inorganic fertilizer was the only source of nutrients added to the sugarcane experiment. Ammonium sulfate was applied to all treatments at the rate of 350 Kg. N per hectare. Superphosphate and potassium chloride were applied to all treatments at the rates of

Figure 9. Concrete irrigation lateral of sugarcane experiment showing the placement of the Parshall flume and the exit gates.

d 200 Kg. K_2O per hectare. The basal fer-
uded 125, 100, and 150 Kg. of N, P_2O_5, and
, respectively. The remaining nitrogen
7, 10, 13, and 20 weeks after planting at
, 65, 65, and 30 Kg. per hectare, respect-
ngle potassium side dressing was applied
planting.

vation and pest control practices used in
e similar to those followed by the other
f the Taiwan Sugar Company.

easurement

l water content in the root zone was determined
ron scattering method (39). A Nuclear Chicago
re probe and portable scaler, model 2800 were
termine the water content of each plot three
week. Aluminum access tubes, 5 cm. I.D. x 50 cm.,
talled in the soil to a depth of 30 cm. Two access
ere placed in each plot. The tubes were positioned
posite ends in row 3 and row 5 and were 8 m. from
end. The P-19 readings were taken at a depth of
cm. giving the average soil water content in the upper
0 cm. of the soil (33). Soil samples were taken to gravimetrically determine the soil water content throughout the profile. Porous cup water tensiometers were also

was applied to the asphalt paddies of the summer crop at the rate of 132 Kg./Ha. Two additional side dressings of nitrogen were added to the control treatments 36 and 46 days after transplanting. Consequently, an additional 50 Kg./Ha. of nitrogen was applied to the control treatments of the summer crop. Phosphorus and potassium were applied to all the treatments of both crops in the forms of calcium superphosphate and potassium chloride. Phosphorus was added before transplanting while potassium was added according to the schedule in figure 6.

The water level on the asphalt paddies was maintained according to the schedule in figure 6. The asphalt paddies were drained and aerated five times for 48 hours and one time for 96 hours during the growing season, figure 6. Soils in the control paddies were flooded for 12 and 18 hours per day for the spring and summer crops, respectively.

Chemical pest control was similar to the methods followed by Taiwan rice farmers. Parathion, fumiron, αBHC and blasteiden S were used to control the leafhopper, weevil, stem borer, and the rice blast disease, respectively.

Plant growth and production measurements

The plant height and tiller quantity were determined at weekly intervals for the duration of both rice crops. Plant height was determined by measuring the aerial portion of the plant from the soil surface to the end of the longest plant part. Tillers were those branch stems, arising from the initial setting with more than one leaf. The average value of 20 hills per treatment was recorded for that treatment.

Brown rice and straw yields were harvested from the center, 5.70 square meters of each paddy. Dry grain yields were recorded at a 12% moisture content. The straw yield was the weight of the threshed plants which were dried in a 70 C forced air oven for three days. Plant height, panicle quantity and length, tillers, and grain quantity per panicle were determined by measuring the plants from 20 randomly selected hills per replication. Harvest data of the spring crop was taken from replications 2, 3, and 4 because replication 1 was destroyed by an overdose of fungicide. Four replications were used for all measurements of the summer crop.

Root distribution studies

Rice root distribution was determined by analyzing triplicated postharvest soil samples. A square metal frame, 15 x 25 cm. and open at both ends, was forced through the soil to the asphalt barrier or to a depth of 50 cm. in the control treatment. The surrounding soil was excavated and the soil volume containing the rice crown and roots was extracted. Then the soil was wetted, removed from the frame, and dissected at 5 cm. intervals parallel to the soil surface. The roots in each segment were washed, dried at 70 C for three days, and weighed. The asphalt barrier below each excavated plant was examined and the number of roots which penetrated a 100 $cm.^2$ area of the barrier was recorded.

Soil measurements

Various soil measurements were taken during the rice experiment. The density changes in the soil were periodically measured (1). Soil pH was measured by the glass electrode using a 1:1 soil-water ratio. During the drainage period oxygen diffusion rates were also determined by the platinum microelectrode according to the procedures outlined by Erickson, Van Doren, and Lemon (20, 35).

Sugarcane Experiment

Asphalt barrier construction

Both sides and one end of the subsurface asphalt barrier were continuous to the soil surface of the rectangular sugarcane plots. The remaining end was not sealed with asphalt allowing subsoil drainage, figure 7. This plot design created an infinite barrier in three directions and permitted good subsoil drainage.

Experimental design

This experiment was conducted in the same sugarcane field which was adjacent to the rice experiment. Sugarcane was grown on rectangular plots that were 8.75 x 25.0 m. The treatments consisted of three asphalt barriers placed at 50, 75, and 100 cm. below the soil surface henceforth refered to as the 50, 75, and 100 cm. treatments and two control treatments. One control was cut and filled to a depth of 100 cm., which will be referred to as the disturbed control, while the other control was undisturbed. Each treatment was replicated six times. The thirty plots were arranged in the randomized block design illustrated in figure 8. Border sugarcane plots, 10 m. wide, were placed around the perimeter of the experiment.

Two concrete lined irrigation laterals were installed in the middle two corridors of this experiment, figure 8.

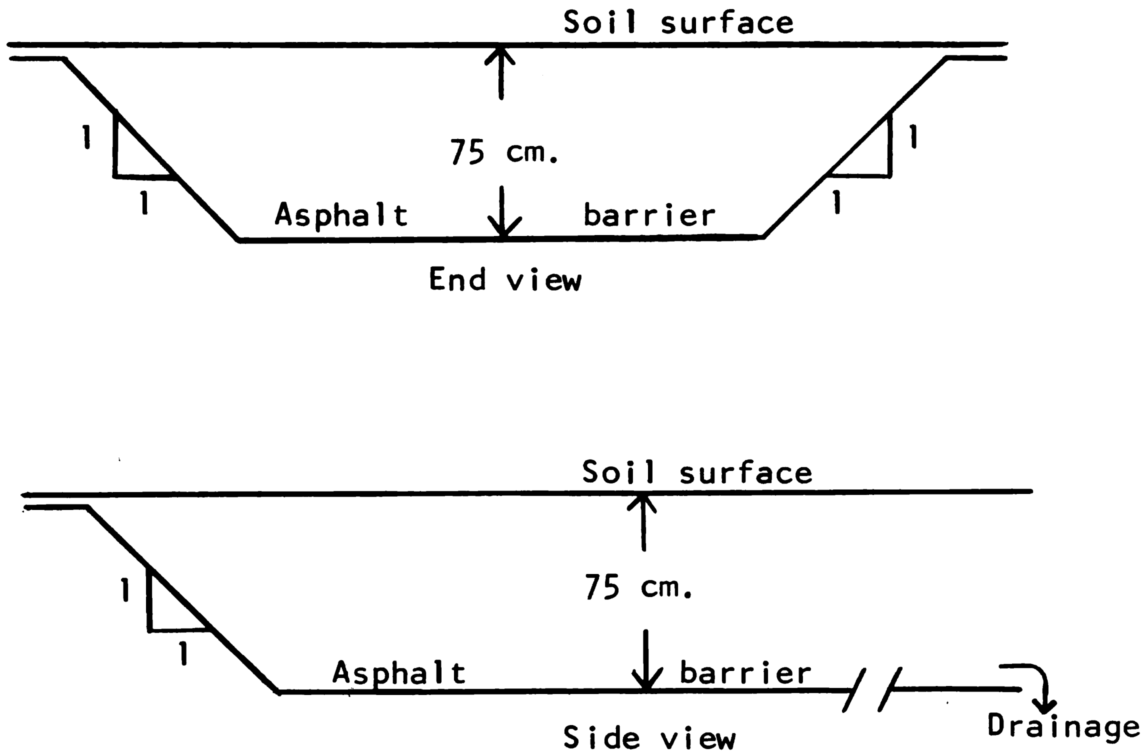
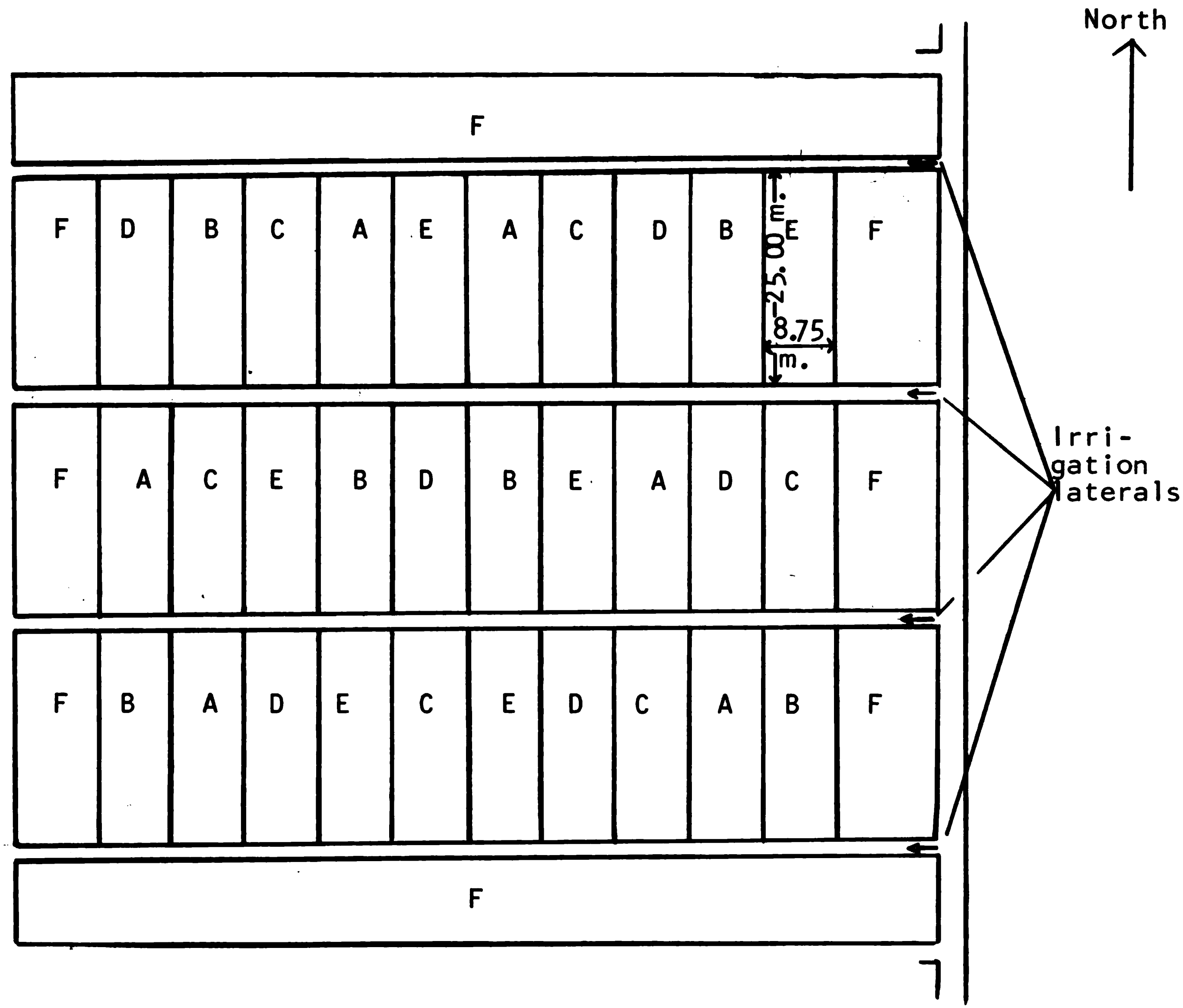


Figure 7. Asphalt barrier for sugarcane cultivation in fine sand soil



A- Control

B- 50 cm. barrier

C- 75 cm. barrier

D-100 cm. barrier

E- Disturbed control

F- Border plots

Figure 8. Field design of asphalt sugarcane experiment

Irrigation water was metered by a 7.6 cm. Parshall flume which was positioned at the junction of the irrigation main and each concrete lateral, figure 9. A system of exit gates, installed in each lateral, permitted independent irrigation of each plot.

Surface drainage ditches were also constructed of soil in each corridor of the sugarcane experiment, figure 8.

Cropping practices

A twelve-month sugarcane crop was grown for the asphalt sugarcane experiment. The sugarcane variety F-156 (*Saccarum officinarum* L.) was planted on March 5, 1967 and harvested February 26, 1968. This moderately drought resistant variety was released by T.S.E.S. plant breeders in 1965 and yields approximately 92.00 M.T. of sugarcane per hectare (T.S.E.S. Agronomy Department, unpublished data). Seedpieces, each having two nodes, were treated with calcium water and fungicide and planted in rows spaced at 1.25 m. and 0.30 m. within the row. Seedpieces were planted at a rate of 27,000 per hectare.

Gradulated inorganic fertilizer was the only source of nutrients added to the sugarcane experiment. Ammonium sulfate was applied to all treatments at the rate of 350 Kg. N per hectare. Superphosphate and potassium chloride were applied to all treatments at the rates of

Figure 9. Concrete irrigation lateral of sugarcane experiment showing the placement of the Parshall flume and the exit gates.

100 Kg. P_2O_5 and 200 Kg. K_2O per hectare. The basal fertilization included 125, 100, and 150 Kg. of N, P_2O_5, and K_2O per hectare, respectively. The remaining nitrogen was applied at 7, 10, 13, and 20 weeks after planting at the rates of 65, 65, 65, and 30 Kg. per hectare, respectively. The single potassium side dressing was applied 20 weeks after planting.

The cultivation and pest control practices used in this study were similar to those followed by the other plantations of the Taiwan Sugar Company.

Soil water measurement

The soil water content in the root zone was determined by the neutron scattering method (39). A Nuclear Chicago P-19 moisture probe and portable scaler, model 2800 were used to determine the water content of each plot three times per week. Aluminum access tubes, 5 cm. I.D. x 50 cm., were installed in the soil to a depth of 30 cm. Two access tubes were placed in each plot. The tubes were positioned at opposite ends in row 3 and row 5 and were 8 m. from each end. The P-19 readings were taken at a depth of 20 cm. giving the average soil water content in the upper 40 cm. of the soil (33). Soil samples were taken to gravimetrically determine the soil water content throughout the profile. Porous cup water tensiometers were also installed to determine the tension exerted upon the soil water above the barrier. Daily readings were recorded at 8:30 a.m.

The quantity of water required for each irrigation was determined by calculating the volume of water required to increase the soil water content to field capacity. First, the desired percent increase was determined by subtracting the current soil water content from the field capacity soil water content, figure 1. Second, the desired volume of soil to be irrigated was calculated. Then the soil volume to be irrigated was multiplied times the desired change in the soil water content. This product was expressed in liters of water measured by the irrigation system.

Plant growth and production measurements

Plant height and tillering were measured at 30 day intervals throughout the growing season. Ten randomly selected plants in rows 3, 4, and 5 of each plot were measured from the seedpiece to the dewlap of the first leaf below the apical whorl of the main stalk. The number of shoots which grew from the main stalk were recorded as the tiller number.

The production data was collected from replications III-VI while replications I and II were harvested sometime later. Yields were determined by weighing the millable stalks in rows 3, 4, and 5 of each plot. After measuring the final plant height, the sugarcane was cut at the seedpiece, topped, stripped of leaves, then weighed. The same plants that were measured during the growing season were evaluated for the final plant height, stalk diameter, and sugar content.

Root distribution studies

Triplicated sugarcane root samples were extracted at 136 days after planting and at harvest. Four randomly selected sugarcane stools were sampled per treatment. A thin metal frame, 25 x 25 x 25 cm. and open at both ends was placed over the cane stool and forced into the soil. An area 625 $cm.^2$ around the cane stool was extracted to the asphalt barrier or to a depth of 100 cm. in the treatments without barriers. Roots of each volume were washed, dried at 70 C. for three days and weighed. The asphalt barrier below each excavated plant was examined and the number of roots which penetrated an area 625 $cm.^2$ was recorded.

Chapter IV

EXPERIMENTAL RESULTS AND DISCUSSION

Rice Experiment

During this study, only a segment of the total effects of the asphalt barrier could be measured during the first two rice crops. Consequently the most convincing macro-parameters were selected for measurement. These measurements recorded and discussed below, show some of the effects of the asphalt barrier soil treatment on paddy rice growth and production on fine sand soils.

Efficiency of asphalt soil water barrier

During this study the asphalt lined sand soils were flooded and paddy-like soil conditions were maintained for a prolonged period of time. The quantity of irrigation water applied to the asphalt paddies was 1470 and 2397 mm. for the spring and summer crops, respectively, table 4. It was calculated that 570 mm. of water were discarded during the seven drainage periods, giving a net quantity of 900 mm. of irrigation water applied to the asphalt paddies of the spring crop. In comparison, approximately 1000 mm. of water are applied to the clay soil paddies in Taiwan. Therefore the above data suggests the asphalt barriers in this study reduced soil water loss in sand soil paddies to a level below that of clay soil paddies. In contrast, the unlined control paddies required 7 and 20 times more irrigation water to maintain flooded conditions for 12 and 18 hours per day during the spring and summer crops, respectively. The above results indicate that subsoil asphlat barriers continuous to the soil surface will discontinue the deep percolation of gravitational soil water and since these barriers are impermeable to water, large quantities of gravitational soil water can be stored by these asphalt lined sand soils. Therefore the asphalt barrier enabled the establishment of rice paddies on these highly permeable sand soils.

Table 4. Irrigation, pan evaporation, and precipitation during the 1967 spring and summer rice crops.

	Spring crop	Summer crop
	mm.	mm.
Irrigation		
Control treatment	10,387	42,388
Asphalt treatments	1,470	2,397
Pan evaporation	777	576
Precipitation	699	347

More than 40,000 m.m. of irrigation water were required to maintain flooded conditions for 18 hours per day on the control treatment of the summer crop, table 4. Table 5 shows that if this quantity of water was supplied by deep wells it would cost more than NT $62,000* per hectare for a paddy rice crop that was grown on sand soils without asphalt barriers. Since the installation cost of the asphalt barrier is approximately NT $100,000 per hectare, when manual labor is employed, the reduced irrigation costs brought about by the presence of the asphalt barrier would compensate for the initial investment during the first two crops.

Table 5. Irrigation water costs in central Taiwan

Water source	NT$ $mm.^{-1}$ $ha.^{-1}$
Natural	0.79
Shallow well	1.91
Deep well	1.56
Irrigation assn.	5.53

*The currency exchange rate of NT$ to U.S.$ was approximately 40:1 in 1967.

Table 6 shows the quantity of irrigation water applied to the sand paddies was nearly the same for all the asphalt treatments. Table 6 also shows that additional quantities of irrigation water were required by the asphalt paddies of the summer crop. This increased water requirement resulted from the weather changes during this study, table 3, and by soil drainage.

Table 6. Irrigation water applied to the spring and summer rice crops.

	Asphalt barrier depth-cm.					
Crop	20	30	40	60	40-$(NH_4)_2SO_4$	Average
	mm.	mm.	mm.	mm.	mm.	mm.
Spring	1477	1436	1551	1458	1429	1470
Summer	2335	2263	2464	2406	2519	2397

Soil drainage and aeration

The surface water of the asphalt paddies drained 8-10 hours after the paddy drains were opened. Within 48 hours a dry soil mulch had formed on the surface of the 60 cm. treatments. The surface soil dried more rapidly on the 60 cm. treatment than on the shallower barrier treatments because a greater tension was exerted on the water in the surface soil of the deepest barrier treatment, figure 1.

Little is known concerning the extent to which a paddy soil should be drained during the growing season. Consequently, measurements of the soil oxygen diffusion rate (ODR) were used as an index to determine the drainage time required for aeration of the rice root zone. Figure 10 shows the soil ODR of the asphalt paddies was 42×10^{-8} gm. cm.$^{-2}$ min^{-1} approximately 50 hours after the paddy drains were opened. Erickson (19) showed this ODR to be the critical level for normal growth of upland crops. In contrast, the ODR of clay soil rice paddies changed very little during the midseason "drainage" period, figure 10 . Since most of the clay paddies in Taiwan are "drained" for only five days during the rice crop, the above data suggest that the root zone of rice grown in clay soil is aerated very little during the "drainage" period. These studies suggest that sand paddies with asphalt barriers have a decided advantage over the fine textured paddies as they may be rapidly drained during the growing season for soil aeration, fertilization, and the removal of toxic soil materials. More information must be obtained, however, before the effects of periodic soil drainage and aeration can be established for paddy rice. Perhaps this phenomenon could be studied best on these asphalt sand paddies.

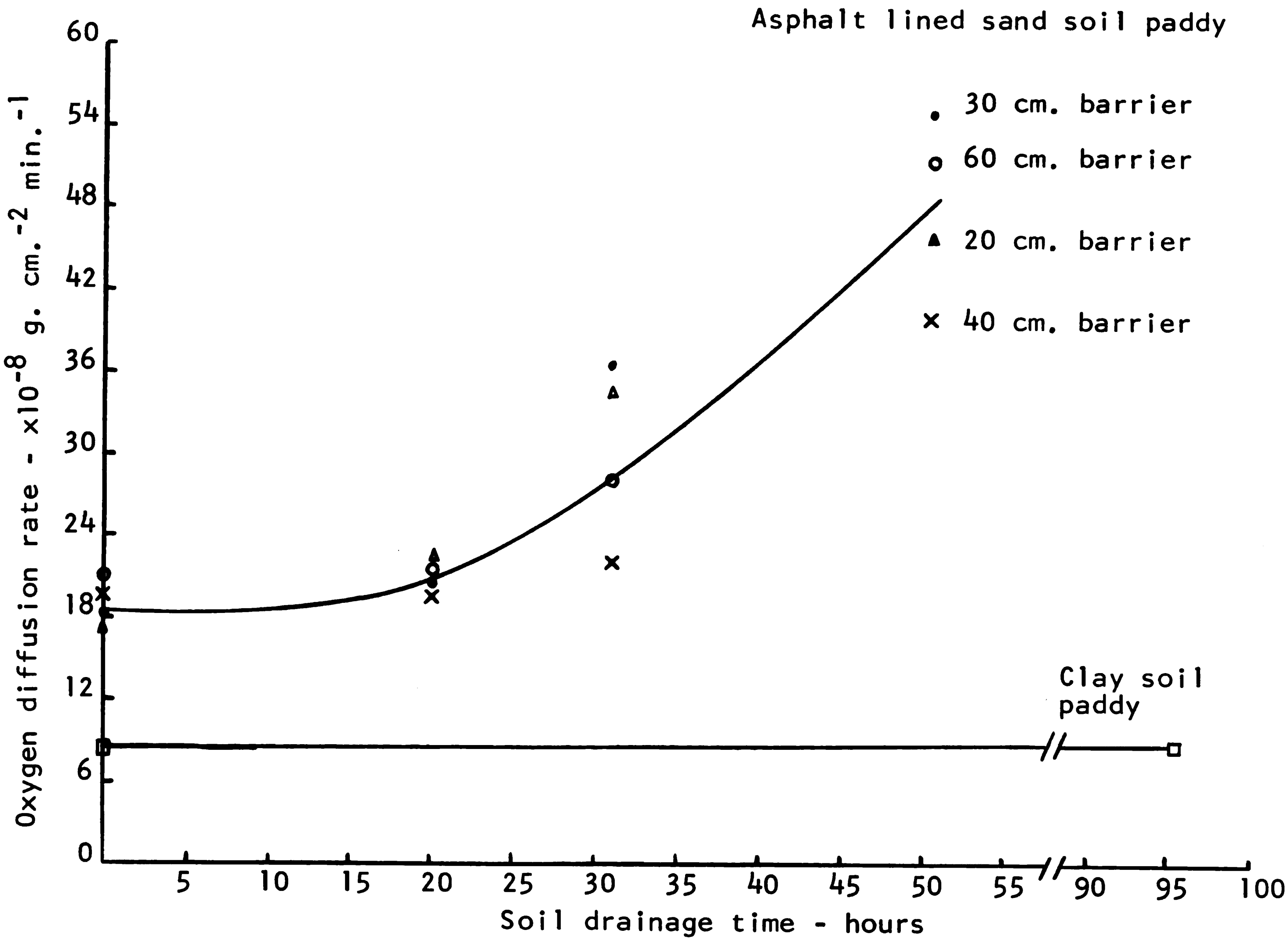


Figure 10. Oxygen diffusion rate at 10 cm. in sand and clay soil rice paddy

Preliminary pH studies indicated that soil flooding affected the hydrogen ion concentration of the Ap horizon very little as the pH changed from 8.4 to 8.2 during the first four months of flooding.

Replicated undisturbed soil core samples indicated that the density of these sand soils increased during flooding as the bulk density changed from 1.31 to 1.52 g./cc. sometime during the spring crop. There was essentially no change, however, during the summer crop as the bulk density was 1.57 g./cc. after the second rice crop had been harvested from these sand soils. It was also observed that the *in situ* water permeability rate on the control treatment was greatly reduced to 2.2 cm./hr. during the first few days of soil flooding. Therefore since the permeability rate was reduced soon after the soil had been puddled it appears that the above bulk density change may have occurred soon after the initial flooding of the spring crop.

Rice growth and production

Good plant growth occurred on the asphalt lined sand paddies that were constructed for this investigation. The growth curves in figure 11 indicate that a normal plant growth pattern occurred on the 40 cm. asphalt treatment throughout the growing seasons of both the spring

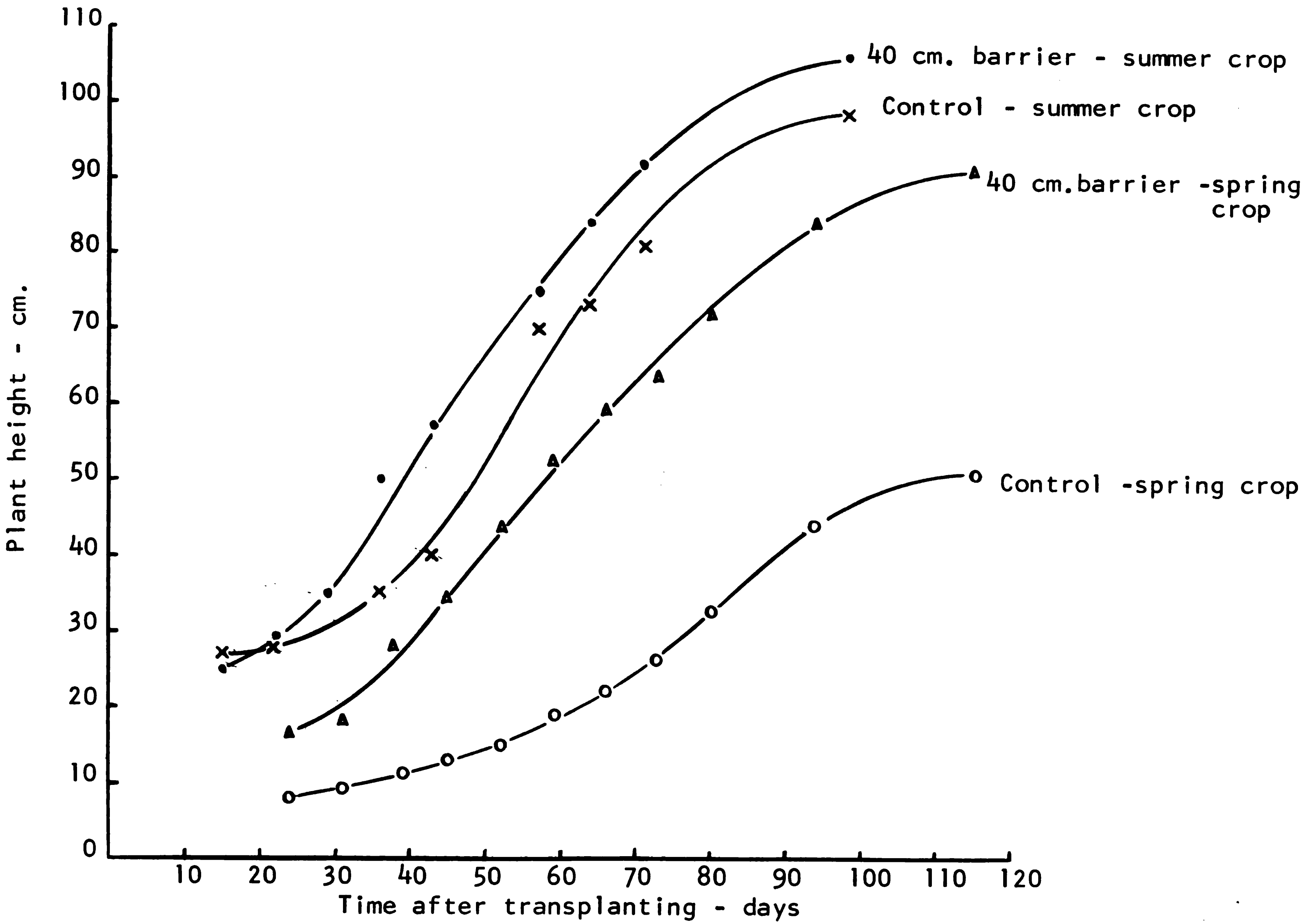


Figure 11. Growth rates of the 1967 spring and summer asphalt rice crops

and summer crops. The rice plants from the summer crop grew taller than those from the spring crop. This phenomenon generally occurs in Taiwan as a result of the higher temperature and longer photoperiod during the summer growing season. Growth measurements of the other asphalt treatments indicated that barrier depth had essentially no affect upon plant growth in either crop, tables 7 and 8. In contrast, plant growth was reduced on the control treatments of both rice crops, figure 11. During the spring crop the drastic reduction of plant growth on the control treatment appeared to have resulted from the short 12 hour flooding period as plants became chlorotic soon after transplanting. As these deficiency symptoms progressively intensified plant growth on the control treatment was obviously reduced, figure 12. At a later stage of the growing season plants developed symptoms similar to those of the "Akiochi" disease (40), a physiological disease that frequently occurs in rice grown on degraded paddy soils in Japan. Consequently, maturation of plants on the control treatment of the spring crop was delayed, table 9. However, by increasing the flooding time and the nitrogen side dressings, plants on the control treatment of the summer crop grew at a rate similar, although somewhat depressed, to the rate of plant growth on the

Table 7. Plant growth rates of spring rice crop

Time after transplanting	Treatment					
		Asphalt barrier depth - cm.				
days	Control	20	30	40	60	$40(NH_4)_2SO_4$
24	8.0	16.0	15.2	16.1	16.2	18.3
31	9.0	18.1	20.2	18.1	19.3	20.0
38	10.8	29.8	29.1	27.6	27.0	31.3
45	13.1	35.4	34.7	33.7	32.0	37.5
52	15.2	45.2	44.5	44.3	41.7	47.5
59	18.8	52.1	52.2	53.2	51.9	53.7
66	22.2	56.5	58.5	58.7	55.8	60.5
73	26.2	63.9	62.2	62.4	62.0	64.0
80	33.2	68.0	69.8	72.3	70.6	73.4
116	51.0	87.8	93.7	94.1	100.3	93.1

Table 8. Plant growth rates of summer rice crop

Time after transplanting	Treatment					
		Asphalt barrier depth - cm.				
days	Control	20	30	40	60	$40(NH_4)_2SO_4$
15	26.7	31.7	30.4	27.3	27.3	29.3
22	29.1	30.4	28.7	27.9	28.4	28.9
29	35.2	42.2	38.0	39.5	37.2	40.2
36	40.6	50.8	48.1	49.7	45.4	47.6
43	49.1	58.1	56.8	56.8	53.4	57.2
50	52.4	68.2	--	61.5	58.0	60.5
57	63.6	74.0	68.3	71.0	67.8	69.1
64	73.0	87.2	84.3	84.3	80.9	84.0
71	81.6	91.4	88.6	92.0	88.9	90.6
98	98.3	103.6	104.4	106.1	102.2	103.9

Table 9. Visual observations of experimental rice plants during spring crop.

Time after transplanting days	Plants on barrier	Plants on control
15	Began tillering, 10 cm. new root growth, green plants	3 cm. new root growth, chlorotic plants
48	K deficiency symptoms	Chlorotic plants
50	Maximum tillering	Began tillering
61	Rust-colored roots	White-colored roots
76	Inflorescence	Degraded plants
92	Grain in milk stage	Inflorescence
116	Harvest	Grain in milk stage
131	- - - -	Harvest

Figure 12. Rice growth 96 days after transplanting of control (upper center) and surrounding asphalt treatments.

asphalt paddies of this crop. Therefore it appears that the reduced plant growth on the control treatments resulted from the incomplete flooding and severe leaching of these treatments.

Seven weeks after transplanting rust-colored rectangular spots appeared on the older leaves of rice plants across the entire experiment. A comparative tissue analysis indicated that lower concentrations of N, P, and K existed in the spotted leaves. The results showed concentrations of N, P_2O_5, and K_2O to be 3.75, 0.61, and 1.34% by weight, respectively, in the spotted leaves. While green leaves from the same relative position of other plants, which did not have spots, had 3.97, 0.55, and 1.83% of N, P_2O_5, and K_2O respectively. From the above data it was concluded that the potassium concentration was too low in the leaf tissue of the spotted plants. Therefore additional KCl was added to the experiment thereby eliminating the deficiency symptoms. Higher concentrations of plant nitrogen are also necessary during the effective tillering stage and 2 to 3 weeks before inflorescence (21). Therefore, since most of the available soil nutrients are stored in solution the above information indicates the importance of periodic side dressings of both nitrogen and potassium during the growing season. Additional studies are needed, however, before fertilizer recommendations can be made for these sand paddies.

This study also shows more tillers were produced on the asphalt treatments. Figure 13 shows many more tillers were produced on the asphalt treatments of both crops as compared to the controls of these crops. This difference reaffirms the reductive effects of unflooded soil conditions upon paddy rice tillering. The number of tillers on the 40 cm. treatment of the spring crop appears to be greater than for the summer crop. This trend suggests that the tillering of this rice variety is inversely related to both temperature and solar energy. Tables 10 and 11 show that rice tillering was also unaffected by the depth of the asphalt barrier.

Respectable yields of brown rice were harvested from the asphalt paddies of both the spring and summer rice crops, table 12. The crop failure on the control treatment in the spring crop resulted from the unflooded and leached soil conditions. However, despite the applications of additional water and nutrients, brown rice production was also lower on the control treatment of the summer crop.

Yields also increased with barrier depth during the spring crop as yields on the 20 and 30 cm. treatments were significantly less than the yield on the 60 cm.

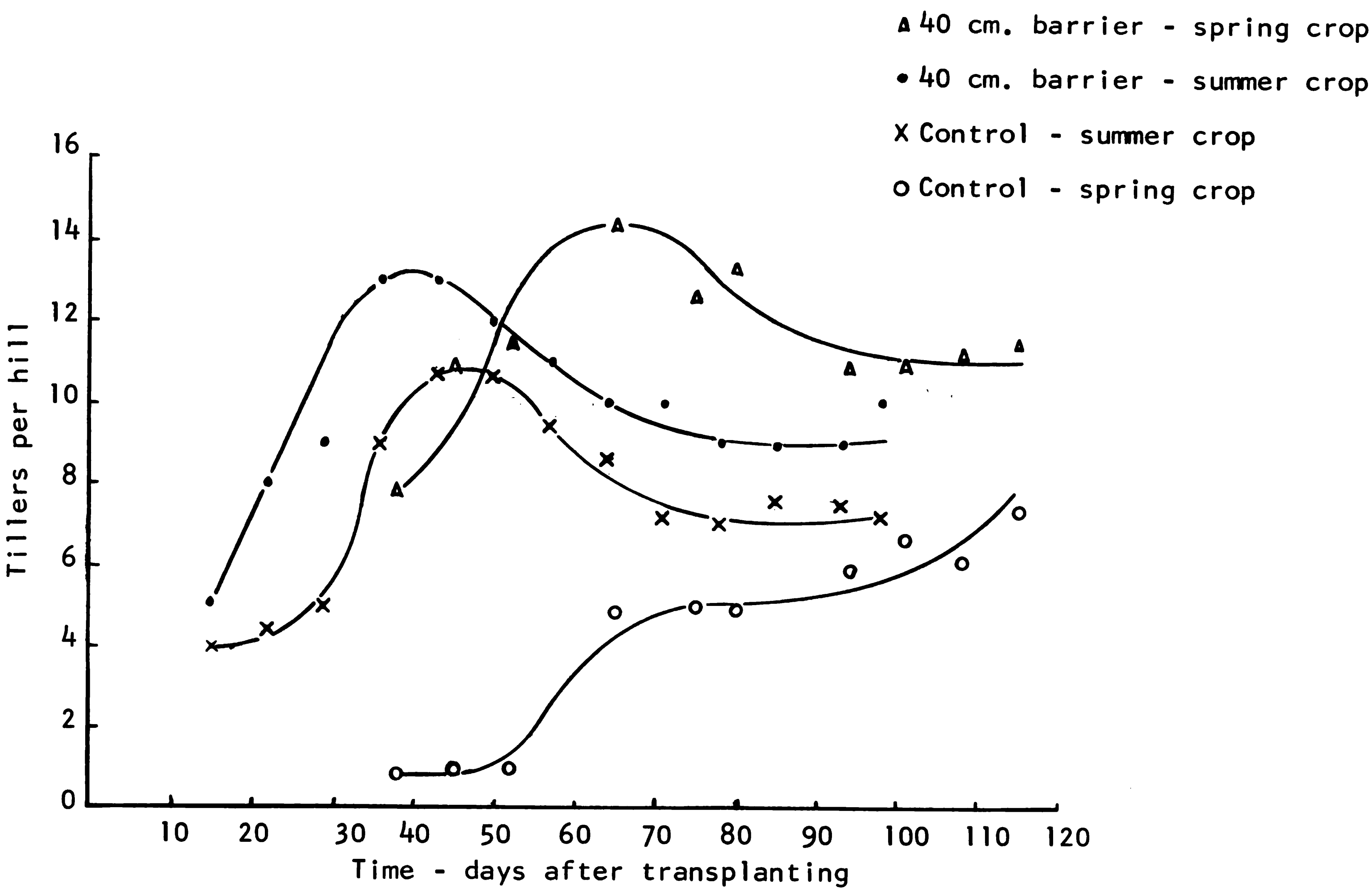


Figure 13. Tillering rates of the 1967 spring and summer asphalt rice crops

Table 10. Tillering of spring rice crop

Time after transplanting	Treatment					
		Asphalt barrier depth - cm.				
days	Control	20	30	40	60	40$(NH_4)_2SO_4$
38	0.9	10.8	9.7	7.8	7.8	8.3
45	1.0	12.9	12.5	10.9	11.1	14.1
52	1.0	13.4	13.5	11.5	12.0	16.9
66	4.9	13.2	14.6	14.4	14.8	16.8
73	5.0	14.1	15.4	12.7	14.9	16.3
80	4.9	14.4	14.9	13.3	14.8	16.3
94	5.9	12.5	12.7	10.9	11.2	11.0
101	6.6	12.0	12.7	10.9	11.4	11.6
108	6.1	12.5	12.8	11.2	11.4	11.7
115	7.4	12.2	11.8	11.5	11.9	11.1

Table 11. Tillering of summer rice crop

Time after transplanting	Treatment					
		Asphalt barrier depth - cm.				
days	Control	20	30	40	60	40$(NH_4)_2SO_4$
15	4.4	5.8	5.5	5.6	5.5	5.9
22	4.4	8.8	8.0	7.8	6.7	7.2
29	5.5	9.6	9.9	9.3	8.9	8.7
36	9.5	13.5	13.7	13.3	13.8	13.1
43	10.7	12.0	13.0	13.1	13.1	12.7
50	10.6	10.9	11.4	12.0	11.8	10.6
57	9.5	9.9	10.4	10.6	10.4	10.3
64	8.7	9.4	10.5	10.2	9.7	11.9
71	7.3	9.6	9.7	9.8	9.4	9.1
98	7.2	10.6	9.6	10.6	--	9.7

Table 12. Brown rice yields of spring and summer rice crops

Treatments	Spring crop	Summer crop
	M.T./Ha.	M.T./Ha.
Control - no barrier	0.4	3.4
20 cm. barrier	4.5	4.8
30 cm. barrier	4.9	4.6
40 cm. barrier	5.2	4.8
60 cm. barrier	5.6	4.8
L.S.D. at 0.01 level	0.7	N.S.

treatment, while the yield on the 20 cm. treatment was significantly less than the yield on the 40 cm. treatment, table 12. This trend did not occur during the summer crop. Therefore it appears that the phenomena affecting the yields in this experiment were similar to those reported by the International Rice Research Institute (32) who showed that unless additional nutrients were added to paddy rice during the growing season rice yields could be reduced by barriers placed at depths less than 40 cm. below the soil surface.

The plant characteristics which were measured at harvest were greatly improved by the presence of the asphalt barriers. Table 13 shows the straw production, tiller number, and grain density were significantly higher on the asphalt treatments of the spring crop. Straw

Table 13. Plant characteristics at harvest of the spring and summer rice crops.

Treatment	Crop	Plant height (cm.)	Dry straw yield (M.T./Ha.)	Productive tillers per hill	1000 grain wt. (gm.)	Milling ratio (%grain)	Grain/straw ratio
Control (no barrier)	Spring	51.1	1.8	6.5	16.9	75.4	0.2
	Summer	98.3	3.7	7.2	24.0	79.9	0.9
20 cm. barrier	Spring	87.8	5.4	11.7	26.7	83.3	0.8
	Summer	103.6	5.1	10.6	26.6	83.4	1.0
30 cm. barrier	Spring	93.7	5.6	12.0	25.5	83.9	0.9
	Summer	104.4	4.8	9.6	26.3	81.7	1.0
40 cm. barrier	Spring	94.1	5.9	11.8	26.1	83.2	0.9
	Summer	106.1	4.8	10.6	26.3	81.8	1.0
60 cm. barrier	Spring	100.3	5.9	11.6	25.7	83.0	0.9
	Summer	102.2	4.8	---	26.6	81.6	1.0
Barrier average	Spring	94.0	5.7	11.8	26.0	83.4	0.9
	Summer	104.1	4.9	10.3	26.5	82.1	1.0
LSD	Spring	7.6**	0.4**	1.5**	2.0**	---	---
	Summer	N.S.	0.5*	1.4**	N.S.	---	---

**Significant at 0.01 level
* Significant at 0.05 level

production and tillering were also increased in the summer crop by the asphalt barriers. The grain size was much more uniform on the asphalt treatments of both crops. As a result the superior plant and grain characteristics accounted for the greater rice yields on the asphalt treatments.

Asphalt barrier depth appeared to have more influence upon plant growth during the spring than during the summer crop. The height of plants and the production of straw tended to increase with the depth of the barrier in the spring crop, since plants on the 60 cm. treatment of the spring crop were significantly taller than those on the 20 cm. treatment and more straw was produced on the 40 to 60 cm. treatments than on the 20 cm. treatment. The plant characteristics measured at harvest were essentially uniform on the asphalt treatments of the summer crop.

This data suggests that the minimum depth for the asphalt barrier is 40 cm. below the soil surface as shallower 20 and 30 cm. barriers will reduce rice production unless additional nutrients are applied, and rice production was essentially unchanged by increasing the barrier depth from 40 to 60 cm. The additional cost required for the installation of the 60 cm. barrier does not warrant the placement of a barrier at this depth.

The production and plant characteristics of rice grown in this experiment corresponded very closely to those of rice grown on the conventional clay paddies in Taiwan, table 14.

Table 14. Plant characteristics at harvest of the rice variety Tainan #5 grown on asphalt lined sand paddies and clay paddies

Characteristic	Spring planting		Summer planting	
	Sand paddy+	Clay paddy**	Sand paddy+	Clay paddy**
Growing season (days*)	116	119	98	95
Brown rice (M.T./ha.)	5.2	5.9	4.8	4.6
1000 grain wt. (g.)	26.1	26.1	26.3	27.0
Plant height (cm)	94.1	101.7	106.1	109.4
Milling ratio (% grain)	83.2	82.1	81.8	82.6

*Time from transplanting to harvest
+Data taken from 40 cm. barrier treatment
**Data obtained through personal correspondence with Chiayi Agricultural Experiment Station, Chaiyi, Taiwan

Nitrogen carriers

This study showed that the ammonium sulfate had no injurious effects on either the rice production or the plant characteristics of the first two rice crops grown on these sand paddies, table 15. This table also shows less roots were produced on the ammonium sulfate treatment. The above data also suggests that hydrogen sulfide problems, which frequently reduce the growth and yield of rice grown on paddysoils fertilized with sulfate fertilizers (16 and 17), were nonexistent in the asphalt sand paddies. This phenomena most probably resulted from the periodic draining of these sand paddies which leached and/or oxidized any reduced compounds that accumulated in the rhizosphere.

Root growth and distribution

Rice root growth was enhanced on the barrier treatments soon after transplanting. At ten days some preliminary observations indicated that root growth was 2-3 times greater on the asphalt paddies. Nine weeks after transplanting, replicated core samples taken in the row midway between the plants indicated that the roots in the barrier treatments had completely explored the soil above the respective barriers while only traces

Table 15. Effects of nitrogen carrier upon paddy rice grown on sand soils lined with 40 cm. asphalt barrier (each value is the average of the 1967 spring and summer crops).

Nitrogen carrier	Rice yield M.T./Ha.	Plant height cm.	1000 grain wt.-g.	Milling ratio % grain	Tillers per hill	Dry straw yield M.T./Ha.	Root wt. per hill g.
Urea	5.0	100.1	26.2	82.5	11.2	5.0	3.3
Ammonium sulfate	5.0	98.5	26.3	82.1	10.6	5.2	2.9

Table 16. Root distribution of spring rice crop 64 days after transplanting in asphalt lined sand soil (each figure represents the average value of three samples).

Sample depth cm.	Control %	Asphalt barrier depth - cm. 20 %	30 %	40 %	60 %
0-10	99.0	79.4	87.7	69.6	55.0
10-20	Tr	20.6	11.0	18.3	13.2
20-30	0	---	1.3	7.0	12.7
30-40	0	---	---	5.1	8.7
40-50	0	---	---	---	3.4
50-60	0	---	---	---	7.0

of roots were found at a similar depth in the control treatment, table 16. By harvest, root growth on the control treatments of the spring crop had been reduced to 30% of that on the asphalt treatments, table 17. Root growth on the control treatments of the summer crop were also reduced in spite of the application of additional water and nutrients, table 18. These reductions were similar to and may have accounted for the reduced plant growth and yields on the control treatments of both crops.

Post harvest root studies confirmed that most of the paddy rice roots are located near the soil surface. More than 80% of the roots were located in the upper 10 cm. in all treatments except for the 60 cm. treatment where the greatest accumulation was in the surface 5 cm. of soil. The root weights and consequently the root distribution of both crops are different as the crown was included in the 0-5 cm. sample for the spring crop while only the roots were included in this sample for the summer crop.

Rice roots explored the entire soil profile above the barrier in all the treatments of both crops. During the spring crop roots accumulated on the barrier of the 20 cm. treatment forming a mat-like mass parallel

Table 17. Root weight per hill at harvest of spring planted paddy rice variety Tainan #5 grown on asphalt sand paddies.

Soil depth cm.	Control		Asphalt barrier depth - cm. 20		30		40		60		40-$(NH_4)_2SO_4$	
	(gm.)	(%)	(gm.)	(%)	(gm.)	(%)	(gm.)	(%)	(gm.)	(%)	(gm.)	(%)
0-5	1.153	81.5	3.839	75.7	2.874	75.9	3.591	74.3	3.128	61.4	3.074	72.6
5-10	0.118	8.3	0.466	9.2	0.340	9.0	0.351	7.3	0.567	11.1	0.442	10.4
10-15	0.094	6.6	0.164	3.3	0.273	7.2	0.199	4.1	0.373	7.3	0.205	4.8
15-20	0.033	2.4	0.600	11.8	0.102	2.7	0.160	3.3	0.211	4.1	0.143	3.4
20-25	0.016	1.2	---	---	0.100	2.6	0.261	5.4	0.181	3.6	0.180	4.2
25-30	---	---	---	---	0.098	2.6	0.078	1.6	0.140	2.7	0.092	2.2
30-35	---	---	---	---	---	---	0.120	2.5	0.139	2.7	0.070	1.7
35-40	---	---	---	---	---	---	0.074	1.5	0.110	2.2	0.030	0.7
40-45	---	---	---	---	---	---	---	---	0.076	1.5	---	---
45-50	---	---	---	---	---	---	---	---	0.081	1.6	---	---
50-55	---	---	---	---	---	---	---	---	0.080	1.6	---	---
55-60	---	---	---	---	---	---	---	---	0.011	0.2	---	---
Total	1.414	100.0	5.069	100.0	3.787	100.0	4.834	100.0	5.097	100.0	4.236	100.0

Table 18. Root weight per hill at harvest of summer planted paddy rice variety Tainan #5 grown on asphalt sand paddies.

Soil depth cm.	Control		Asphalt barrier depth - cm. 20		30		40		60		40-$(NH_4)_2SO_4$	
	(gm.)	(%)	(gm.)	(%)	(gm.)	(%)	(gm.)	(%)	(gm.)	(%)	(gm.)	(%)
0-5	0.921	74.0	1.078	57.2	0.868	65.4	1.373	75.2	1.126	33.4	1.095	70.9
5-10	0.194	15.6	0.700	37.1	0.276	20.7	0.141	7.7	1.007	29.9	0.175	11.3
10-15	0.058	4.6	0.064	3.4	0.094	7.1	0.085	4.7	0.803	23.8	0.063	4.1
15-20	0.038	3.0	0.042	2.3	0.057	4.3	0.080	4.4	0.094	2.8	0.085	5.5
20-25	0.034	2.8	---	---	0.021	1.6	0.065	3.6	0.091	2.7	0.047	3.1
25-30	---	---	---	---	0.012	0.9	0.037	2.0	0.056	1.6	0.023	1.5
30-35	---	---	---	---	---	---	0.033	1.8	0.038	1.2	0.041	2.6
35-40	---	---	---	---	---	---	0.011	0.6	0.036	1.1	0.015	1.0
40-45	---	---	---	---	---	---	---	---	0.051	1.5	---	---
45-50	---	---	---	---	---	---	---	---	0.031	0.9	---	---
50-55	---	---	---	---	---	---	---	---	0.031	0.9	---	---
55-60	---	---	---	---	---	---	---	---	0.005	0.2	---	---
Total	1.245	100.0	1.884	100.0	1.329	100.0	1.825	100.0	3.369	100.0	1.544	100.0

and adjacent to the upper surface of the barrier. In contrast, the barriers at depths of 30 cm. and greater appeared to provide ample space for root development as roots did not accumulate at these barriers. Roots did not accumulate at the barrier of any treatment during the summer crop. Approximately 14, 8, and 4% of the roots in the 60 cm. treatments explored soil depths greater than 20, 30, and 40 cm., respectively. Tables 17 and 18 also show that approximately 12 and 3% of the roots in the 40 cm. treatments explored soil depths greater than 20 and 30 cm., respectively. These findings suggest that the optimum depth for these barriers is 30 to 40 cm. below the soil surface. However, since the rice yield on the 30 cm. treatment was lower and since animal power is often used for paddy cultivation, it appears that the minimum depth for the asphalt barrier in sand soils is 40 cm. below the soil surface.

The 3 mm. asphalt barriers used in this experiment did not physically impede rice root growth very much as most of the roots which contacted the barrier traversed and grew below it, table 19. In theory, after the moisture barrier has been installed the sand soil below the barrier should continue to drain becoming quite dry thereby retarding root growth. Consequently, roots which penetrate the barrier will be aborted by the dry soil below the barrier. However, during this experiment the lateral movement of water from the heavily irrigated control and surrounding border paddies supplied enough water for rice root growth below the barrier.

Post harvest studies of the asphalt barrier showed root penetration of the barrier to be inversely related to the depth of the barrier. Roots penetrated the shallow 20 and 30 cm. barriers 8.5 times more frequently than the 60 cm. barrier. Root penetration was decreased by 65% when the barrier depth increased from 30 to 40 cm. It was observed that both fibrous and filamentous roots penetrated the shallow 20 and 30 cm. barriers while only the thinner more filamentous roots penetrated the deeper 40 and 60 cm. barriers.

Table 19. Root penetration of 3 mm. asphalt barrier during spring rice crop.

Number of roots contacting 100 cm.^{2} area of asphalt barrier	Asphalt barrier depth-cm.			
	20	30	40	60
Above barrier	mat	72	22	10
Below barrier	59	60	20	7

In conclusion, this experiment showed that sand soils which are lined with asphalt barriers provide an excellent medium for root growth. These sand paddies are low in organic matter, hence fewer toxic compounds are generated (52), there is less impedence of root growth (24) and the root zone may be rapidly drained and aerated providing a medium for maximum rice plant growth during a minimum period of time. It was also shown that the most favorable asphalt barrier depth was 40 cm. below the soil surface.

Sugarcane Experiment

Soil water retention

Asphalt barriers doubled the moisture holding capacity of these fine sand soils. Triplicated gravimetric samples showed that the soils of the asphalt treatments retained an average soil water content of nearly 28% while approximately 13% was retained by the natural soil, table 20. The asphalt barrier reduced soil water loss by discontinuing the soil capillaries below the root zone thereby reducing the tension exerted on the soil water in the root zone. Since the barrier is impermeable to water low tension water was stored above the barrier thereby increasing the quantity of water held by the sand soil.

Table 20. Soil water content of sand soil five days after 134 mm. rainfall - expressed as volume percent.

Soil sample depth - cm.	Treatments			
	Disturbed control	50 cm. barrier	75 cm. barrier	100 cm. barrier
0-20	11.6	25.9	24.7	21.2
20-40	14.7	31.9	32.2	31.5

The low tension water is transported by the soil capillaries to the root zone at a rate dependent upon the potential gradient in the soil.

During the course of this study the additional water storage capacity above the barrier was maintained by rainfall and irrigation. The moisture magazine above the barrier was filled at monthly intervals from April 20 to November 19 except for three fillings by rainfall in June and no filling in October. Obviously the asphalt barrier is most effective when the moisture magazine is filled as more low tension water is stored in the root zone but as the soil water was deleted the soil water tension increased reducing the effectiveness of the barrier. Figure 14 shows the soil water content in the root zone of the barrier treatment was nearly twice that of the control when the moisture magazine was

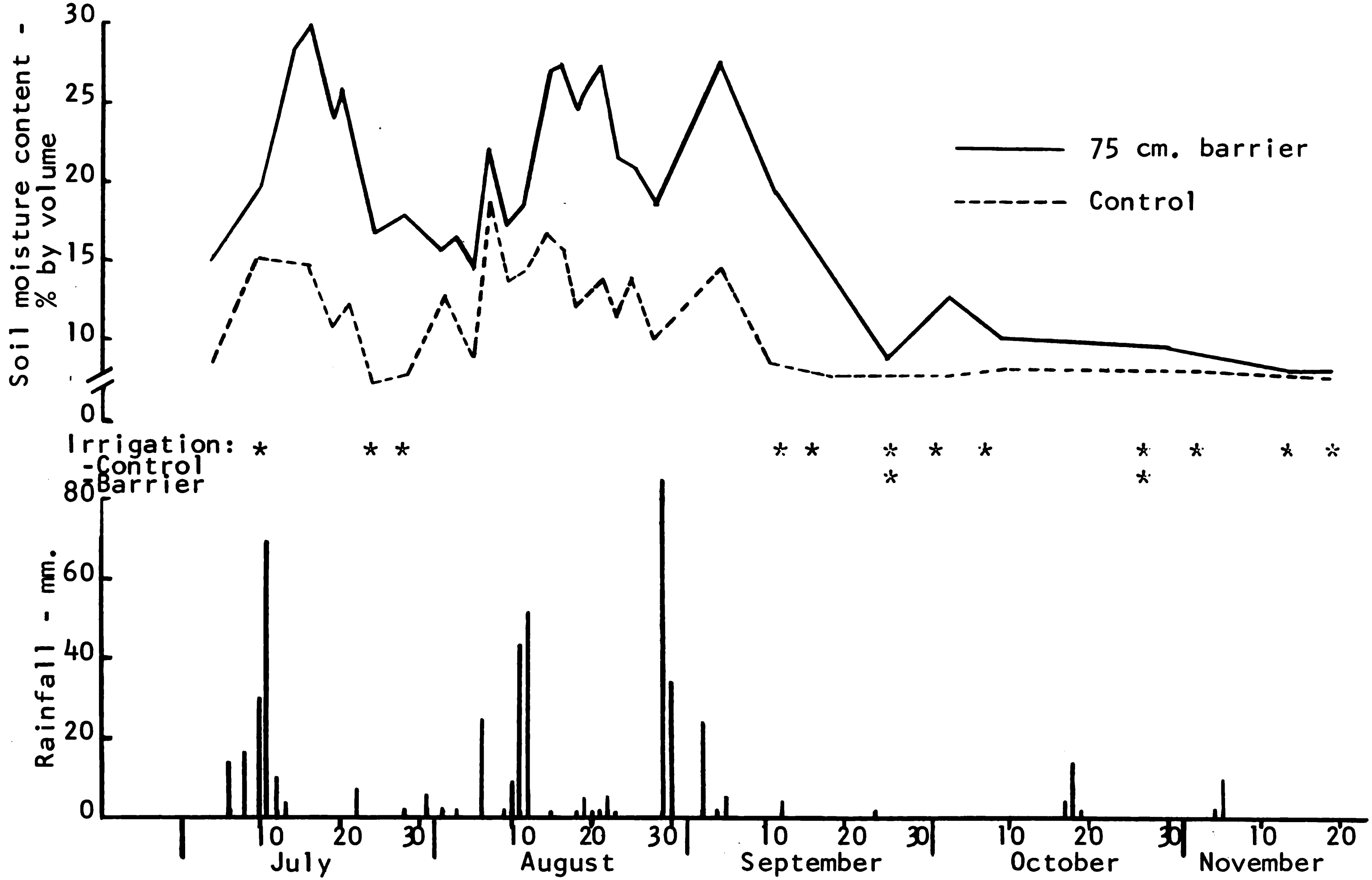


Figure 14. Soil moisture regime in 0-40 cm. and rainfall on asphalt sugarcane experiment

periodically filled. However, in October when the water content above the barrier was too low the barrier had essentially no effect on the soil moisture content in the root zone. This figure also shows that in September, when very little water was added to the experiment, the barrier delayed irrigation for nearly two weeks. Table 21 shows the soil moisture regimes of the remaining asphalt and disturbed control treatments were similar to those reported in figure 14.

Figure 15 shows that the water content at a given soil depth was inversely related to the depth of the barrier. As expected the soil moisture also increased with soil depth. The lower soil water content of the deep samples of the 75 and 100 cm. treatments, recorded in figure 15, appear to be the result of a sampling error as it was difficult to sample the saturated sand soil in the neighborhood above the barrier. The high water content in the soil of the 50 cm. treatment during the monsoon season suggested that soil aeration may fall below the critical level, described by Erickson (19). Platinum microelectrode measurements showed low soil oxygen diffusion rates on the 50 cm. treatment for 24 hours after a heavy rainfall, table 22. Since more water was stored in the deeper horizons it is

Table 21. Soil moisture regime of asphalt sugarcane experiment - expressed as percent moisture by volume.

Date	Control	Disturbed control	Treatment 50 cm. barrier	75 cm. barrier	100 cm. barrier
July 4	8.7	9.3	16.0	15.0	13.2
July 10	15.3	16.2	19.0	19.8	19.8
July 14	15.0	15.7	29.9	28.5	28.1
July 17	14.8	14.7	23.0	30.1	26.0
July 19	11.0	11.4	26.0	24.0	21.9
July 21	12.3	11.5	23.5	26.0	21.5
July 24	7.5	7.8	18.0	16.7	15.2
July 28	7.8	8.3	16.0	18.0	15.8
Aug. 1	13.0	12.2	14.9	15.6	14.7
Aug. 3	10.7	11.7	14.3	16.6	14.3
Aug. 5	8.9	9.6	11.9	14.6	13.6
Aug. 7	19.0	17.8	21.5	22.1	20.1
Aug. 9	13.8	13.7	18.3	17.4	17.0
Aug. 11	14.4	14.6	17.8	18.7	16.5
Aug. 14	16.9	18.2	30.0	27.0	23.5
Aug. 16	15.8	14.8	25.3	27.5	23.5
Aug. 18	12.2	12.6	25.8	24.5	20.1
Aug. 21	13.9	12.7	24.0	27.6	21.8
Aug. 23	11.8	11.9	23.5	21.6	18.6
Aug. 25	14.3	13.4	24.3	25.2	23.9
Aug. 28	10.2	10.2	20.0	18.5	12.2
Sept. 4	14.9	14.3	25.4	27.9	24.1
Sept. 11	8.8	11.4	19.8	19.5	19.3
Sept. 18	8.0	8.2	12.2	14.3	14.7
Sept. 25	8.0	8.0	8.4	8.7	10.8
Oct. 2	8.1	8.4	9.7	12.9	11.5
Oct. 9	8.4	8.4	9.8	10.2	9.8
Oct. 30	8.4	8.5	9.1	9.6	10.7
Nov. 13	8.0	8.2	8.7	8.4	8.2
Nov. 19	7.9	8.2	8.8	8.3	9.5

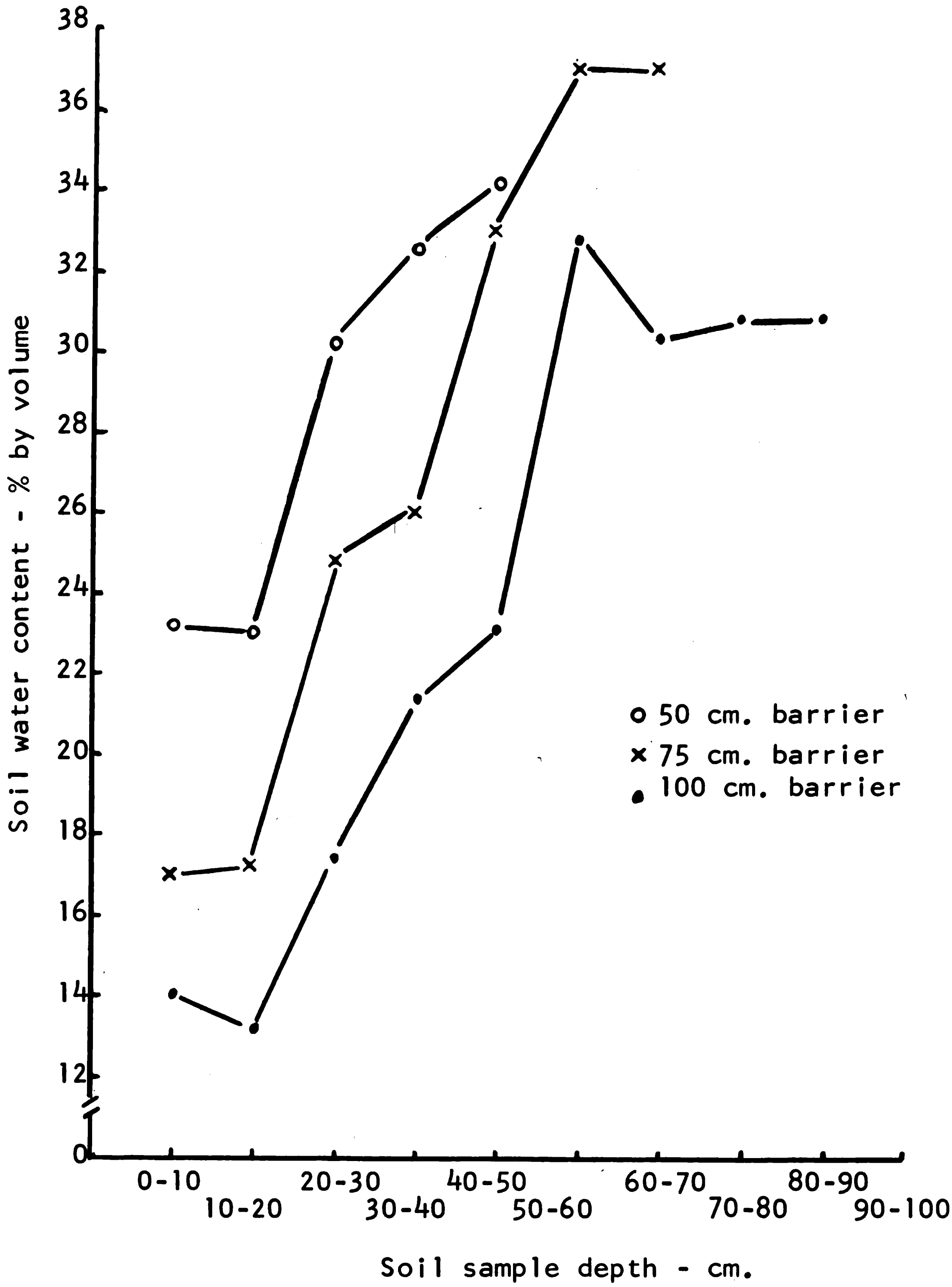


Figure 15. Effects of asphalt barrier depth on soil water content

conceivable that a portion of or the entire root zone of the 50 cm. treatment was oxygen deficient throughout the monsoon season. These low oxygen diffusion rates were not observed on the 75 and 100 cm. treatments. However, it is very likely lower rates did occur at soil depths near the barriers (23). Since these depths were below the root zone of the young sugarcane there were essentially no aeration problems in the root zone of the 75 and 100 cm. treatments during the monsoon season. The decline in the ODR on the control and later on the asphalt treatments resulted from the decreasing soil water content to a point below that for which the platinum microelectrode instrument was designed (20).

The thin asphalt barriers used in this investigation proved to be excellent water barriers.as the soils above the asphalt barrier retained gravitational water for nearly three days while those without barriers were drained immediately, figure 16. This figure also shows that low tension water was stored above the asphalt barrier for nearly a month which suggests that very little water was lost through the barrier. The gradual increase in water tension from December 12 to January 5 probably resulted from evapotranspirative water loss.

Table 22. Oxygen diffusion rates at a soil depth of 10 cm. as measured by the platinum microelectrode - diffusion rates are expressed in $g. \times 10^{-8}\ cm.^{-2}\ min.^{-1}$

Hours after cessation of rainfall	Treatment				
	Control	50 cm. barrier	75 cm. barrier	100 cm. barrier	Disturbed control
6	60.9	31.4	61.5	57.3	62.1
18	---	52.5	---	69.3	---
24	56.7	54.3	63.9	63.3	55.5
36	54.9	63.9	69.3	63.3	51.9
48	54.9	71.8	70.6	68.1	52.5
60	53.7	78.4	74.2	73.6	49.4
72	47.6	81.4	72.4	65.7	42.8
84	47.0	79.6	71.2	66.9	45.8
96	41.0	76.6	69.3	60.3	39.2

As expected the soil water tension gradient between the barrier and near the surface soil was much smaller on the 50 cm. treatment than on the 75 cm. treatment, table 23. This phenomenon shows the importance of soil water hydraulics for determining the proper depth of the asphalt barrier. In this study the 50 cm. barrier was too shallow. For both the tension measurements reported in table 23 and observations during the growing season indicated that the soil capillaries conducted low tension

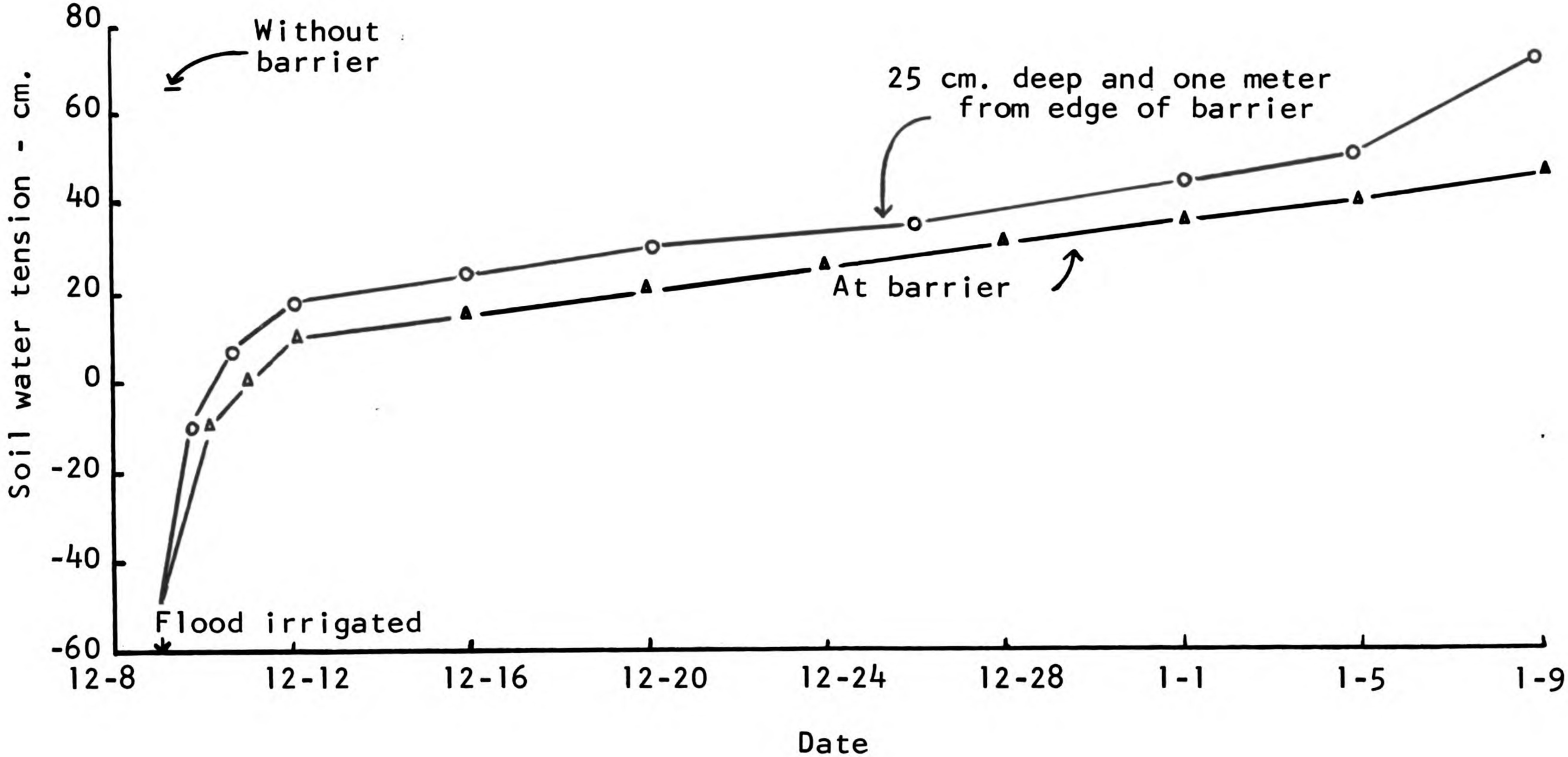


Figure 16. Soil water tension in 50 cm. barrier treatment of asphalt sugarcane experiment

Table 23. Effect of asphalt barrier depth upon the soil water tension gradient - values are expressed in centibars of water

	50 cm treatment								75 cm. treatment									
Date:	6/24	6/28	7/3	7/5	7/7	7/10	7/11	7/13	7/14	7/19	7/20	7/23	7/28	7/29	7/31	8/1	8/3	8/6
Tensiometer depth - cm.																		
15	0	6	10	13	0	0	7	0	0	0	0	0	4	5	5	6	2	0
30	0	9	17	21	6	7	10	0	0	4	6	-	19	25	34	15	42	0
barrier	0	10	29	31	9	7	13	0	0	12	16	48	84	84	84	53	58	6
Rainfall	19.4	--	--	--	31.2	29.3	70.4	13.2	--	--	--	--	--	--	--	--	--	25.2

water from the barrier to the soil surface causing excessive water loss by evaporation greatly reducing the efficiency of this barrier. In contrast, the treatments at 75 and 100 cm. lost very little soil water by evaporation. The large gradient between the soil water tension at the barrier and near the soil surface, table 23, suggests that essentially no low tension water was transported to the surface of the 75 cm. treatment. Observations of the 75 and 100 cm. treatments also indicated that there was essentially no evaporation from the soil surface as a dry soil mulch formed soon after each application of water.

Water retained by the barrier appeared to be affected very little by the soil water gradient along the edge of the barrier. Figure 16 shows that water, stored one meter on the edge of the barrier is partially drained. Table 24 shows soil drainage occurs from 1.0 to 1.5 meters onto the barrier. However, very little water is drained from the soil above the barrier. Water in the soil surrounding the barrier was rapidly drained discontinuing the horizontal capilaries thereby reducing the loss of water from above the barrier.

Table 24. Effect of distance upon soil water at edge of barrier - soil water content expressed in volume percent.

	Distance from edge of barrier - m.			
Sample depth - cm.	0.5	1.0	1.5	2.0
0-10	6.5	6.8	7.3	8.3
10-20	9.4	9.6	10.7	11.8
20-30	11.9	12.2	15.3	15.4
30-40	13.6	15.1	18.9	17.5
40-50	15.7	17.4	20.6	22.3
50-60	19.6	19.9	26.5	25.8
60-70	21.6	26.9	28.8	28.6
70-80	26.0	29.4	30.1	30.6

Tremendous quantities of water were conserved by the asphalt moisture barriers during the sugarcane growing season. Table 25 shows that the asphalt treatments required 80% fewer irrigations reducing the quantity of irrigation water from 327 mm. for the control of 109 mm. for the asphalt treatments. From September through February, Taiwan's dry season, irrigation water was applied to the control and asphalt treatments at 30 and 7 day intervals, respectively. It appears that the interirrigation period could have been extended for the asphalt treatments if the entire moisture magazine had been filled at each irrigation, figure 14. This reasoning led to the heavy irrigation of the entire experiment, on November 19, which provided enough water until harvest. Therefore the asphalt barriers reduced both water and the labor costs of sugarcane production.

Table 25 shows that the depth of the barrier had essentially no effect upon the water requirements of sugarcane. The 11.8% less irrigation water that was added to the 50 cm. treatment resulted from the small quantity of water that was added to this treatment at the final irrigation. Further discussion concerning the effects of the final irrigation upon sugar production will be discussed in a later section.

Table 25. Supplemental irrigation added to sugarcane experiment

Date	Control (mm)	Asphalt barrier depth cm. 50 (mm)	75 (mm)	100 (mm)	Disturbed control (mm)
March 9	.8	.8	.8	.8	.8
June 26	28.2	---	---	---	29.6
July 5	22.5	---	---	13.5	18.0
July 24	22.5	---	---	---	21.6
July 28	21.0	---	---	---	22.2
September 11	18.6	---	---	---	---
September 18	21.0	---	---	---	20.4
September 25	21.0	19.8	18.9	---	21.0
October 2	20.7	---	---	---	19.8
October 9	19.8	---	---	---	19.8
October 23	19.5	19.5	19.5	19.5	19.5
October 30	19.8	---	---	---	19.5
November 13	21.0	19.8	20.3	20.4	20.4
November 19	71.0	34.0	50.3	55.0	68.0
Total	327.4	93.9	109.8	109.2	300.6

The 8.2% less water that was applied to the disturbed control suggests that soil tillage has essentially no affect upon the water holding capacity of sand soil.

It is well known that the frequency of sugarcane irrigation is dependent upon the soil type and the season. During this study the time between irrigations was reduced as a result of the experimental design. However, the results from this experiment indicate that when sugarcane is spring-planted on these asphalt sand soils, a general wetting of the surface soil immediately after planting and two or three heavy applications of water during the dry season would maintain optimum soil moisture conditions throughout the growing season. For the fall-planted sugarcane the moisture magazine should be filled after planting and maintained until the maturation stage of the growing period.

The more mobile nitrogen and potassium appeared to be conserved by the asphalt barriers (9 and 10), as greater quantities of these elements were found in the tissue of plants growing on the barrier treatments, table 26. The logical explanation for this phenomenon is that the moisture barrier decreased the loss of water and the loss of the more mobile nutrients

Table 26. Leaf analysis of 127 day-old sugarcane

Treatment	Nutrient		
	N-%	P-%	K-%
Control	2.14	0.67	1.35
50 cm. barrier	2.45	0.71	1.64
75 cm. barrier	2.32	0.70	1.58
100 cm. barrier	2.36	0.79	1.67
Disturbed control	2.07	0.71	1.33
L.S.D. at 0.05 level	0.20	N.S.	0.26

from the root zone. Consequently more nutrients were absorbed. The higher nitrogen content in plants on the 50 cm. treatment appears to have resulted from the upward movement of soil water resulting in greater concentrations of nitrogen in the upper portion of the root zone (55). The plant nutrient content was lower on the 75 cm. treatment as a result of the greater growth of plants on this treatment.

Sugarcane growth

Sugarcane growth on the asphalt treatments was superior to the controls throughout the growing season. One month after planting, plant counts indicated that germination was uniform throughout the experiment, table 27. By 14 weeks, plants on the asphalt treaments were visibly taller than the control, figure 17. This difference increased throughout the remainder of the growing season,

Table 27. Germination of sugarcane variety F-156 grown on Taiwan fine sand-expressed as percent

Plant age	Treatment				
	Control	50 cm. barrier	75 cm. barrier	100 cm. barrier	Disturbed control
30 days	91.4	92.1	93.0	92.6	91.1
Index	1.00	1.01	1.02	1.02	1.00

Figure 17. Sugarcane growth on asphalt barrier treatment (right) and on control (left).

figure 18. Although plants were taller on the treatment at 75 cm. the sugarcane growth rates on the treatments at 75 cm. and 100 cm. were similar during the last eight months of the growing season. The reduced growth on the treatment at 100 cm. appears to have resulted from the lower soil moisture content in the root zone of this treatment during the first few months of the growing season. Plant growth on the 50 cm. treatment was similar to the other asphalt treatments during the first half of the growing season. But growth on this treatment was severely retarded during the last half of the season. Since the plants in this treatment were visibly taller during the early stages of the growing season and the slope of the curve for this treatment decreased with time, the 50 cm. barrier may have been too shallow for maximum sugarcane growth. There are at least two reasons why the 50 cm. barrier reduced sugarcane growth. First, as discussed earlier, this shallow barrier maintained very high moisture conditions in the root zone during the monsoon season thereby reducing soil air which inevitably reduced plant growth. Second, the 50 cm. barrier restricted root growth directly, by physical forces, and/or indirectly by providing

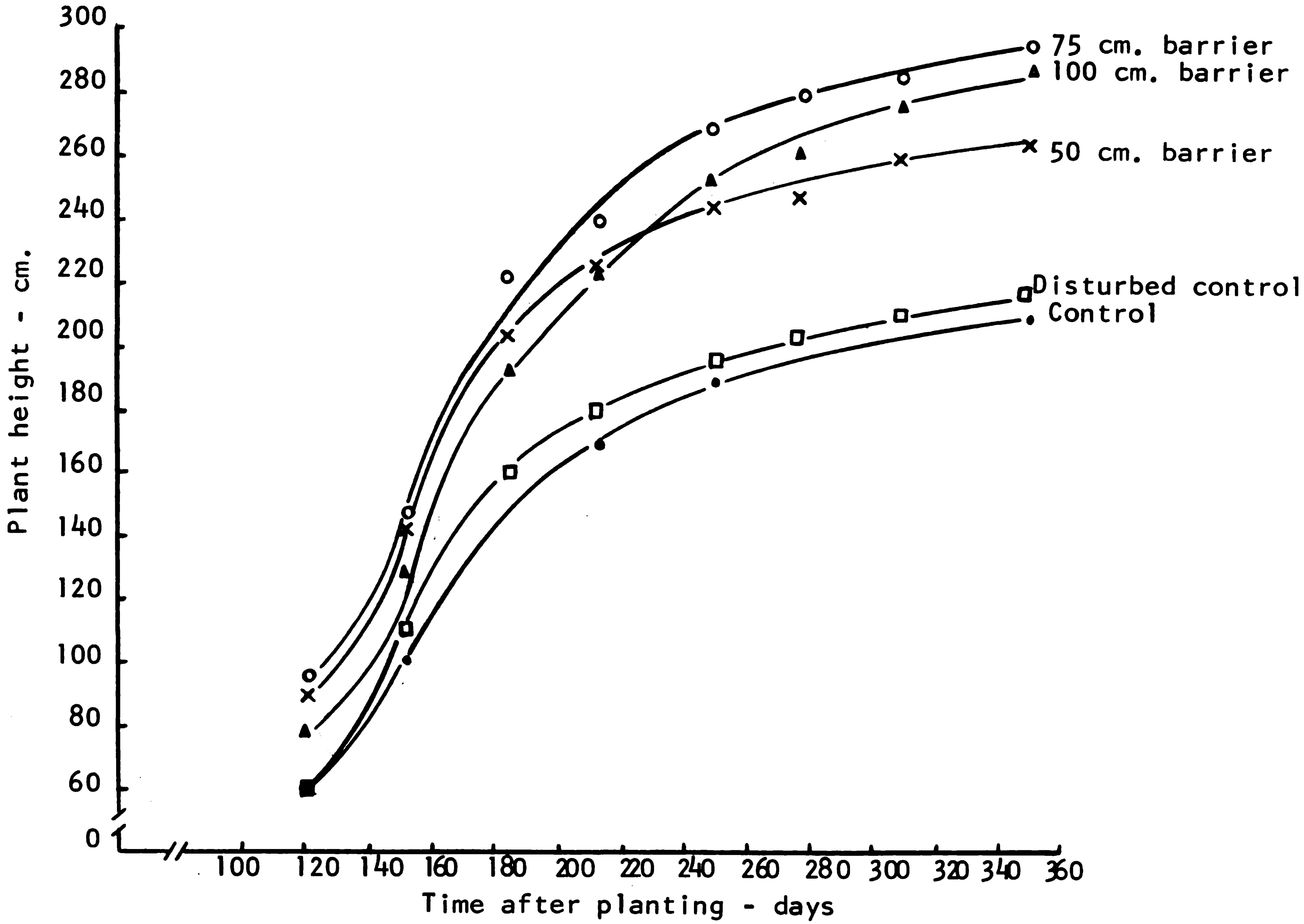


Figure 18. Plant growth rates of asphalt sugarcane experiment

abundant quantities of low tension water in the root zone. Consequently, the root system was underdeveloped and did not support the plant during the dry season. Consequently, plant growth on the 50 cm. treatment was drastically reduced during the last five months of the growing season.

The continuously higher soil water content in the root zone of the asphalt treatments obviously promoted sugarcane growth. Low tension soil water, which resulted from the greater water content in the root zone, appears to explain the reason for better plant growth on the asphalt treatments. Many (48, 57, 58, 29) have studied this phenomenon without positive results. This study, however, agrees with Taylor (53) in that plant growth was inversely related to the soil moisture tension gradient throughout the root zone. As was previously discussed the asphalt treatments of this investigation created different tensions upon soil water at a given depth in the root zone. On the 50 cm. treatment, which had the lowest soil water tension gradient, plant growth was superior to the deeper asphalt treatments until the monsoon season when soil aeration problems were encountered in the root zone. Since equal quantities of water were added to the 75 cm. and 100 cm. treatments, more water was added per unit volume to the 75 cm. treatment causing a lower soil water tension gradient in the root zone of the shallower treatment. Therefore, greater plant growth occurred on the 75 cm. treatment as a result of the lower soil water tension gradient throughout the root zone.

Sugarcane growth was considerably less on the treatments without asphalt barriers as plants on the control treatment were nearly 30% shorter than those grown where the barrier was at 75 cm. There was very little difference, however, in plant growth between the two treatments without barriers. Therefore, it appears that plant growth on sand soils is affected very little by deep cultivation. An explanation for the smaller plants on these two treatments is that soil water was stored at higher tensions and plants frequently encountered severely dry soil conditions in the upper portion of the root zone.

Sugarcane root growth

Sugarcane root growth was inversely related to the available soil water content in the root zone for the duration of the crop. During the first 135 days roots of the deepest barrier treatment and of the control treatment had penetrated to soil depths of 75 cm. while the roots of the 50 and 75 cm. barrier treatments had penetrated the upper 50 cm. of soil, table 28. The total quantity of roots produced was smaller for the 50 and 75 cm. treatments. The restricted root zone of the 50 cm. treatment may have reduced root growth. It was believed, however, that the negative effects of low soil oxygen upon root growth which are discussed by Scott and Erickson (45) and Gill and Miller (24) greatly reduced the production of roots in the 50 cm. treatment. A higher percentage of roots (81.1%) which were located in the surface 25 cm. of the 50 cm. treatment suggests that the adverse soil conditions created by the shallow barrier also affected the distribution of roots in this treatment.

Post harvest observations of the asphalt barrier indicated that many roots had contacted the upper surface of the barrier. Triplicated samples showed 4120, 3453, and 2157 sugarcane roots penetrated the upper surface of a one-meter-square section of the 50, 75, and 100 cm. barriers, respectively. These studies also showed that roots would not grow below the barrier as the soil water content below the barrier was too low to

Table 28. Root distribution of asphalt sugarcane - expressed as percent dry weight

Sample depth cm.	Control		Asphalt barrier depth - cm. 50		75		100		Disturbed Control	
	135 da.	Harvest	135 da.	Harvest	135 da.	Harvest	135 da.	Harvest	135 da.	Harvest
0-25	89.4	71.2	91.0	81.8	92.9	71.1	75.2	70.7	---	69.2
25-50	6.3	16.0	9.0	18.2	7.1	18.4	12.4	19.0	---	19.9
50-75	4.4	8.3	---	---	0	10.5	12.4	7.2	---	6.9
75-100	0	4.5	---	---	---	---	0	3.1	---	4.0
Dry root weight g.	37.9	270.1	17.9	174.2	21.8	215.0	27.5	329.5	---	465.5

support root growth. Therefore roots which penetrated the barrier were aborted forming a static physical plug. Consequently, roots which penetrated the barrier had essentially no effect upon the water retention properties of the asphalt barrier.

Root growth appeared to be greatly enhanced on the treatment which was disturbed to a depth of 100 cm. Also, the quantity of roots was much smaller on the control treatment. This phenomenon may account for the somewhat taller plants on the 100 cm. disturbed treatment.

Sugarcane production

Sugarcane yields were much higher on all the asphalt barrier treatments, table 29. The 75 cm. barrier produced the greatest quantity of sugarcane, 100 M.T./Ha., which essentially doubled the yield of the treatments without barriers. The remaining production characteristics recorded in table 29 were also much better on the asphalt treatments. Both the production of millable stalks and the final plant height were significantly greater on all the asphalt treatments. Plant height as well as stalk diameter were also significantly greater on the 75 and 100 cm. barrier treatments. Again plant size as well as sugar production were the highest on the 75 cm.

Table 29. Effects of asphalt barriers on sugarcane production

Treatment	Sugar-cane yield M.T./Ha.	Sucrose %	Sugar M.T./Ha.	Mill-able stalks /Ha. $\times 10^3$	Dead stalks /Ha. $\times 10^3$	Stalk height cm. $\times 10^2$	Stalk diameter cm.
Control	54.27	13.22	7.17	71.81	4.42	2.10	2.20
50 cm.barrier	83.28	12.49	10.40	86.69	7.04	2.66	2.28
75 cm.barrier	104.35	11.56	12.06	90.53	7.35	2.96	2.45
100 cm.barrier	97.07	11.38	11.46	80.85	6.04	2.87	2.40
Disturbed control	48.88	12.82	6.27	63.41	4.55	2.19	2.20
L.S.D.	13.01**	0.51**	---	8.65**	1.54**	.16*	.15*

**Significant at 0.01 level
*Significant at 0.05 level

treatment. The number of dead stalks was proportional to the plant population. Therefore, more dead stalks were recorded for the asphalt treatments.

The available sugar content was lowest in the harvested plants from the 75 and 100 cm. barriers. This appears to have resulted from the effects of high soil moisture upon plants during the maturation period. Lin (37) reported sugarcane maturation was delayed and the sugar content reduced when a high soil moisture content was maintained during cane maturation. He also showed a 10% increase in the available sugar content of cane grown in soils containing less than 20% available soil moisture during maturation. The higher percent available sugar content in the plants grown on sand soils without barriers resulted from the lower soil moisture content during maturation. The sugar content is significantly higher on the 50 cm. barrier as the moisture reserved in this treatement was more rapidly depleted by evapotranspiration. During the maturation period of the sugarcane in this experiment the soil moisture content was certainly higher in the 75 and 100 cm. barrier treatments as 65% more water was added to these treatments at the final irrigation.

Disturbing the soil to a depth of 100 cm. did not significantly affect the sugarcane production in this experiment. Since the enhanced root growth, reported in an earlier section, affected neither plant growth nor production, the increased growth and production of sugarcane on the asphalt barriers was not enhanced by the manipulations of the soil during the installation of the barrier.

Chapter V

CONCLUSIONS

A thin asphalt barrier can be used to construct rice paddies on fine sand soils. This procedure appears to be a practical method for reclaiming excessively drained soils for paddy rice production. These barriers retained free water in the root zone which resulted in the conservation of both water and nutrients while concurrently enabling the production of 5.2 and 4.8 M.T. of rice per hectare during the 1967 spring and summer crops. The adverse soil conditions of the control treatments caused a crop failure during the spring crop while 3.4 M.T. of rice were produced per hectare during the summer crop.

This experiment showed that barriers at less than 40 cm., below the soil surface, reduce plant growth and production and are also penetrated more frequently by the rice roots. Since rice grown on the 60 cm. barrier did not produce more than the treatment at 40 cm. it was concluded that the 40 cm. barrier provided adequate space for paddy rice root growth.

Subsoil drains installed on the surface of the asphalt barrier allowed rapid drainage of the paddy soil. Because of the speed and ease of drainage these paddies can be easily manipulated for soil aeration and fertilization. However, additional fertility studies are needed to develop a system which will give maximum production.

Rice roots appear to affect the water retaining properties of the barrier very little unless large numbers of roots penetrate and continue to grow through the asphalt barrier.

The type of nitrogen carrier had no effect upon rice growth or production in these sand paddies although this hydroponic-like paddy culture does require more frequent applications of both nitrogen and potassium.

Asphalt barriers can be successfully installed below the root zone of sugarcane grown on Taiwan fine sand soils. These barriers reduced the soil water tension in the root zone by halting the deep percolation of water. These alterations of the soil hydraulic properties doubled the water holding capacity of this soil thereby increasing sugarcane plant growth and production while concurrently reducing the irrigation requirements of a spring planted crop by 66%. This study showed at least 104 M.T. of sugarcane could be produced per hectare and approximately 215 mm. of irrigation water could be saved by using the asphalt barriers.

Soil texture is the primary factor to consider when selecting an optimum depth for the asphalt barrier. This study demonstrated the barrier should be installed 75 cm. below the surface of fine sand soils used for sugarcane production. The 50 cm. barrier increased the water holding capacity of the soil providing an abundant supply of water to the young plants. But the very high soil water content throughout the root zone of the 50 cm. treatment reduced soil aeration which retarded plant growth when the roots penetrated into the deeper soil horizons. The 100 cm. barrier increased the soil water content in the root zone very little as the texture of this soil was too coarse to retain water at this tension. Therefore the additional cost required for the 100 cm. barrier is unprofitable. The deep tilling of the sand soil had essentially no effect on sugarcane production.

During this study preliminary soil aeration studies indicated that short term soil oxygen deficiencies reduced sugarcane growth and production.

The root zone at the 50 cm. barrier remained very wet after each heavy rainfall causing soil aeration problems. Consequently, plant growth was severely retarded during the monsoon season.

Sugarcane roots which penetrated the barrier stopped growing when they encountered the dry soil below the barrier. Consequently the water retention properties of the asphalt barrier are affected very little by the root action at the surface of the barrier.

The two experiments reported herein show that sub-surface asphalt barriers will allow the production of satisfactory yields of both rice and sugarcane on subtropical fine sand soils. The asphalt barriers will also greatly reduce the quantities of irrigation water that are normally required for satisfactory yields of both of the above crops if they are grown on sand soils. The asphalt barrier procedures outlined in this investigation could be used to ameliorate thousands of hectares of subtropicsl sand soils while concurrently saving tremendous quantities of valuable irrigation water and at the same time increasing the yields of these deep well-drained coarse soils.

APPENDIX

Table 1. Soil moisture retention of Chekan fine sand.

Moisture tension cm. of H_2O	pF	Horizon Ap (0-20 cm.) Vol.-%	Bt1 (20-52 cm.) Vol. - %	Bt2 (52-85 cm.) Vol. - %	BC1 (85-120 cm.) Vol. - %
1.0	0	46.5	44.5	45.7	40.5
1.6	0.2	46.0	44.1	45.7	40.4
2.5	0.4	45.5	43.5	45.3	40.3
4.0	0.6	44.6	43.8	43.9	40.2
6.3	0.8	44.4	43.2	44.0	39.4
10.0	1.0	43.4	41.9	42.3	39.3
12.6	1.1	42.7	41.0	42.7	39.9
15.8	1.2	42.7	40.0	42.2	38.9
20.0	1.3	41.7	39.1	42.5	39.3
25.1	1.4	41.8	38.7	40.7	38.7
31.6	1.5	40.4	38.1	38.9	38.3
39.8	1.6	38.4	37.4	37.3	36.4
50.1	1.7	34.2	36.8	31.2	33.5
63.1	1.8	29.0	35.3	26.6	23.3
79.4	1.9	23.2	29.0	22.4	17.8
100.0	2.0	20.2	24.9	18.6	16.5
158.0	2.2	19.0	20.8	16.6	12.7
251.0	2.4	17.9	19.2	15.3	11.8
398.0	2.6	15.7	17.9	14.7	10.9
631.0	2.8	14.1	16.1	12.9	9.0
1000.0	3.0	13.4	15.8	12.0	8.2
1585.0	3.2	12.1	12.9	10.4	7.3
2512.0	3.4	11.3	12.4	10.1	6.5
3981.0	3.6	9.6	11.2	9.7	6.4
6310.0	3.8	8.3	10.7	9.2	6.1
10000.0	4.0	7.5	8.8	7.2	5.2
15849.0	4.2	6.3	7.8	6.6	4.2

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