畓作의 效率的 耕耘整地 方法에 關한 研究

An Evaluation of Water Use Efficiency and Energy Requirements for Wetland Tillage

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摘 要

水資源과 에너지는 食糧生產에 直接 間接으로 큰 影響을 미치고 있으며 또한 1973年 에너지 危機 以後 農業에 使用된 에너지가 效率的으로 使用되었는가에 對한 研究는 農工學者들의 큰 關心이 되어왔다. 本 研究는 필리핀의 畓作農業에 있어서 耕耘整地時 灌漑에 따른 土壤硬度의 變化와, 土壤硬度와 燃料消耗率과의 關係를 究明하고, 에너지와 灌漑水의 效率的인 利用을 研究하고저 乾期와 雨期에 각각 遂行되었으며 그의 結果를 要約하면 다음과 같다.

가. 乾 期

1) 灌漑시작후 1~2日間 土壤의 水分含量이 增加함에 따라 土壤의 硬度는 급격히 減少하였으며, 灌漑 3日째는 緩慢한 減少를, 그리고 4日째 부터는 거의 變化가 없었다.

2) 土壤의 硬度에 따라 耗耘作業時 燃料消耗率, 機械의 作業性能에 큰 差가 있었으며, 灌漑 3日後 土壤의 水分含量과 土壤의 硬度가 安靜됨에 따라 각處理間의 燃料의 消耗率과 機械의 作業性能도 비슷하였다.

3) IRRI 5 Hp 耕耘機는 灌漑水로 인해 硬度가 낮아진 土壤에서도 移動性 問題가 없을 만큼 充分히 輕量이었다.

4) 灌漑水의 量에 따라 處理別로 耕耘前 土壤의 剪斷力에 큰 差가 있었으나, 耕耘整地作業後의 土壤剪斷力은 全處理에 있어서 거의 비슷하였다. 이는 耕耘整地作業時 處理間의 燃料消耗率, 機械의 作業性能의 差로 說明될 수 있다.

5) 耕耘整地時의 土壤狀態는 植物의 生育, 雜草의 發生率에 거의 影響을 미치지 않았다.

6) 本 實驗은 한가지 土壤型式에 對해 遂行되었으며 앞으로 여러 土壤型式에 對해 이와 같은 實驗을 遂行하여 土壤型式에 따른 水分含量, 土壤硬度, 에너지 消耗率등의 關係를 究明하여 灌漑水의 效率的인 利用이 可能하리라 思料된다.

나. 雨 期

1) 耕耘作業前에 이미 土壤이 水分으로 飽和되어 있는 狀態이었으므로, 追加의 灌漑水가 土壤의 硬度, 機械의 作業性能, 燃料消耗率에 影響을 미치지 않았다.

2) 耕耘整地期間이 가장 짧았던 處理區(3日)에 있어서 耕耘整地後 土壤剪斷力이 다른 3處理에 비해 크게 나타났다. 植物의 生育 또한 他處理에 비해 저조했으며 雜草發生率도 높았다.

3) 耕耘整地期間이 가장 짧았던 處理區(3일)를 除外한 3處理 間에는 燃料消耗率, 植物生育, 雜草發生率 등이 거의 비슷하였으며 雨期에는 위의 3處理中 11間의 耕耘整地 期間이 가장 效率的인 것으로 나타났다.

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I. Introduction

Computer simulations of crop production models indicate the most important loss in crop output results from lack of water. Other simulations show that crop yield is sensitive to energy, fertilizer and water input(D.W. Williams and W.J. Chancellor).

Land preparation requires much energy, time and labor. Energy efficiency during tillage is often very low. The most widely used energy transfer method is to pull the tillage implement through the soil. Therefore. the soil hardness (soil resistance) should be in a range suisable for such implements.

When an animal is used, the soil should be soft because of the low draft force available. When using a tractor the soil hardness should be in a range which makes most efficient use of the greater power of this machine. On occasions large tractors have mobility problems in soft wet land (Kuether, 1977).

Land preparation is the first of many operations in rice production. The timeliness and quality of land preparation strongly influences the growth and yield of rice crop. Also at this stage the demand for water is at its peak. The amount of water applied by irrigation during land preparation is often more than one-third of the total water supplied in growing a rice crop (Wickham, 1972).

In the Philippines, land preparation by traditional methods for irrigated rice usually requires about one month. Control of weeds, chemical reactions of decomposed organic matter, and water avaliability all contribute to this long land preparation duration. If we can reduce the land preparation period without sacrificing the quality of the puddling, water saving is a possible result.

II. Objectives

1. To determine the most efficient tillage procedure with respect to water use, energy and time requirements while maintaining puddling quality and weed control in wet and dry seasons.
2. To determine the relationships between water use, change in soil properties and tillage energy requirements.

III. Review of Literature

1. Energy requirements for soil failure

Tillage involves several physical actions but perhaps the most important of these is the breaking apart of the monolithic soil surface. Energy per unit volume may be interpreted directly as energy input in the field situation (16). Panwar and Siemens (15), using the unconfined compression and model tool method found that the energy requirement per unit volume of soil was greater for the higher bulk density of the soil and it was maximum at a moisture content of approximately 25% for the silt loam clay.

Bateman, Naik and Yoerger (1) using the impact and slow loading method of pulverizing the soil found that: 1) the energy requirement increased linearly with mean weight diameter for the coarsely pulverized condition and then at a more rapid rate for the finer degrees of pulverizing, 2) drying the low bulk density soil had little effect on the energy requirement but there were significant increases in the energy requirement to pulverize the higher bulk density soil by both method. Vomocil and Chancellor (16) found by evaluating the basic stress-strain characteristics for both the unconfined compression process and the wire loop cutting process that: 1) the amount of energy required to produce a unit failure surface is inversely proportional to efficiency of soil breaking efficiency, 2) and varies with the moisture content of the soil, and in the case of wire loop cutting, varies with changes in the coefficient of internal friction of the soil.

2. Effects of puddling on physical properties of paddy.

Naphade and Bodman(4, 14) defined puddling as change in soil properties such as aggregate size distribution, apparent specific volume, and hydraulic conductivity which was attributed to the reduction in noncapillary pore space and close packing of soil particles. With the increased level of pudding, the distribution of finer particles increases owing to the breakdown of the natural aggregate. Koenigs (11) studied the characteristics of puddled clay soils and reported the following changes in soil characteristics after puddling. The air filled pore volume is largely reduced, the permeability lowered, the suction raised, the resistance to rain drops lowered and deformability increased. The regeneration of puddled soil is only possible by drying.

3. Trafficability in rice paddy

The large tractor with rubber-tire wheel wh ch can generate high traction and floatation in hard, dry soils performs poorly in soft wet paddy(7). Although small machines are supported by the surface layer in paddy, large machines must be supported by the hard pan under the surface area. In that case the soft and sticky surface soil sticks to the tire and causes slippage. In such a condition, traction aids are attached to the tire to prevent slippage and these aids cut into the hard pan and break it(9). Kuether (12) reported that mobility problems with conventional 4-wheel tractors can occur after 2 to 3 years of continuous cropping. The use of 7 hp tiller, or equivalent machines, present little danger of bogging in the vast majority of rice paddy.

Choon (5) found that the bearing pressure of the soil had dropped at its lowest value at four days after the irrigation with 1. 4 kg/cm^2 to 2. 8 kg/cm^2 in cone index. In such soft soil conditions, conventional 4-wheel tractor is expected to have mobility problems. Thus he suggested, land preparation in the wet paddy by four-wheel tractors must be carried out immediately the irrigation water reaches the field.

Ⅳ. Materials and Methodology

A field of about 0. 25 ha on the IRRI experimental farm was divided into six plots by installing additional levees and lining each plot to a depth 70cm with polyethylene film of 0. 25mm thickness to control seepage of water between plots. Water inflow to each plot was measured for the entire period by a one-pen recorder which is calibrated to the height of water inflow from the hydrant (Fig. 1).

A cone penetrometer(ASAE R313. 1) with cone base area of 3. 2sq. cm was used to measure soil depth where soil resistance(cone index) of 2. 46kg/cm^2 and 4. 92kg/cm^2 were encountered, which can be considered as representing soft and firm soil conditions, respectively (IRRI, 1968). The cone index was also measured at soil depths of 5, 10, 15 and 20 cm. Soil shearing force was measured by a laboratory vane shearmeter (Fig. 2). Soil moisture content was determined by the oven-dried method.

After transplanting, sloping gauges (Fig. 3) were installed for measuring water losses from the field. Rainfall and evaporation were determined by a rain gauge and evaporation pan located in the plot. A 4-tube piezometer set with tube lengths of 70, 100, 130 and 160cm was installed in the middle of each plot for measuring the water table depth.

Evaporation, rainfall, water level in the piezometer, and sloping gauge readings were recorded daily. For 22 days after transplanting, plot water depth were maintained at about 3～5cm to control weeds except 2 or 3 days after transplanting.

An IRRI power tiller with 5 hp Kubota

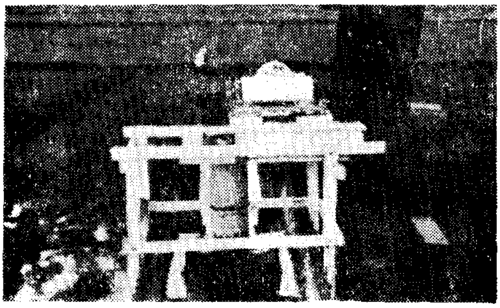

Fig. 1. One-pen recorder.

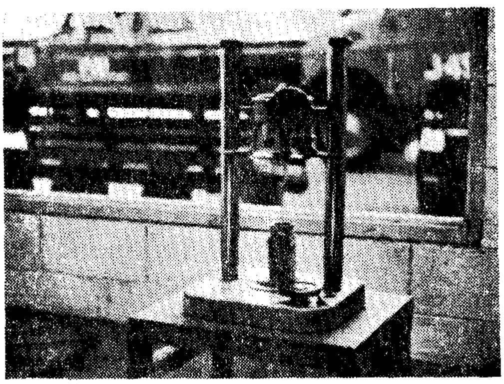

Fig. 2. Laboratory vane test equipment

engine(model 5KND) was used with a moldboard plow and comb harrow for all tillage operations. This power tiller weighed 230kg including cooling water, cagewheels and fuel.

Fig. 3. Sloping gauge

The weather and initial soil conditions differed greatly between the wet and dry season experiments; therefore, the tillage procedure differed with season as described below.

Dry season

For dry season experiment, the field was allowed to dry out before water was introduced. Change of soil moisture content, soil resistance, and soil shearing force were measured daily just before irrigating in all plots during the plowing period. After plowing was completed in all plots the harrowing operations were the same (Fig.4-a). Twenty-two to twenty-three-days seedlings (IR-42) were used in all plots. Only one trial of each tillage treatment could be completed because of the lack of land for replications.

Wet season

The soil was fully saturated before the wet season trials started, so soil characteristics did not change even after the application of water. The wet season experiments varied the duration of the tillage period only, with all operations within the periods remaining the same (Fig. 4-b).

Another levee was constructed without use of polyethylene to divide each of the six plots into two. The 12 plots allowed test of four treatments and three replications.

Ⅴ. Results and Discussion

1. Dry season

The field was dry before soaking with a soil moisture content of 26.4% in the upper 20cm, and 40.7% in the 20～40cm depth, on a dry basis. Soil bulk density averaged 1.65g/cc for all plots before soaking in the 0-40cm depth. Because the cone penetrometer could not penetrate the hard soil, cone index readings were not measured. A physical description of the soil is shown in Table 1.

Soil moisture content increased quickly during the first and second day of irrigation and slowed on the third day. After the third day there was no appreciable change. Atfer two days of irrigation, the field was fully saturated with a moisture content of 50%.

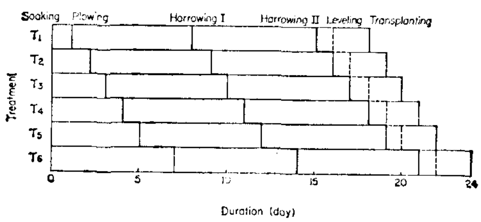

Fig. 4-a Duration of land preparation. (Dry Season, 1979)

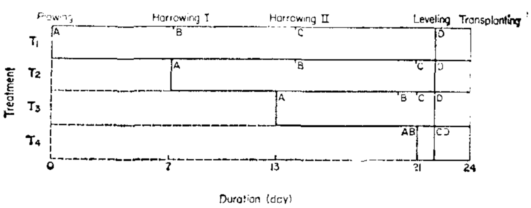

Fig. 4-b Duration of land preparation. (Wet Season, 1978)

Table 1. Soil properties of experimental field(Maahas clay).

Depth(cm)	0-30	30-60	60-90
Clay($<2\mu$)	40.9%	41.8%	37.2%
Silt($2\mu< <75\mu$)	44.1%	31.8%	32.0%
Sand($>75\mu$)	15.0%	26.4%	30.8%
Texture	clay	clcy	clay
Organic matter	1.28%	0.67%	0.59%
P.H.	7.4	6.4	6.5
Plastic limit	36.8%		
Liquid limit	52.5%		
Plastic index	15.7		

After saturation only minor changes in soil moisture content occurred during the first 7 days of irrigation (Fig. 5).

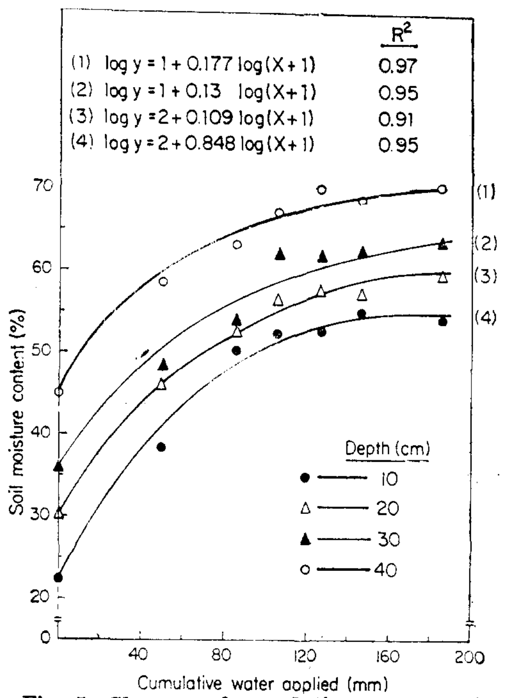

Fig. 5. Changes of cumulative water applied and soil moisture content. (Dry Season, 1979)

Soil resistance as measured by the cone penetrometer, decreased markedly after the first day of irrigation. The soil depth at 4.92 kg/cm² cone index increased from zero to 9cm, but at 2.46kg/cm² almost no change was found. The soil depth continued to increase until after the third day of irrigation (Fig. 6).

Change of soil shearing force after irrigation shows similar trend with the cone index change. But the value (kg/m²) was much lower than cone index. Soil shearing force decreased quickly until the third day of irrigation. The soil shearing force increased with depth (Fig. 7). Large fluctuations in the soil shearing force were found even in readings taken on same day and from the same plot, which may be due to the sensitivity of the vane test equipment.

From the cone index and soil shearing force results, it was found that upon irrigating, the soil resistance decreased quickly due to the increasing of the pore water pressure, which has the effect of reducing the effective stress when soil is stressed. The lower the effective stress, the lower would be the expected soil resistance. Before irrigation, water table levels were about 55cm below the soil surface as an average of three long piezometer tubes. No water was found in the 70cm piezometer tube, which was only 40cm below the soil surface. One day after irrigation of 50mm water, the water level rose to 20cm below the soil surface. In the three long piezomeer tubes, the water level rose slowly during the first 6 days of irrigation. But the water level in the shortest tube went up quickly and stabilized after 2 days of irrigation. The water level stopped rising after it reached around 10cm below the soil surface during land preparation even though there was standing water on the field (Fig. 8). After transplanting, the water level rose 1-5cm depending upon the different piezometer tube.

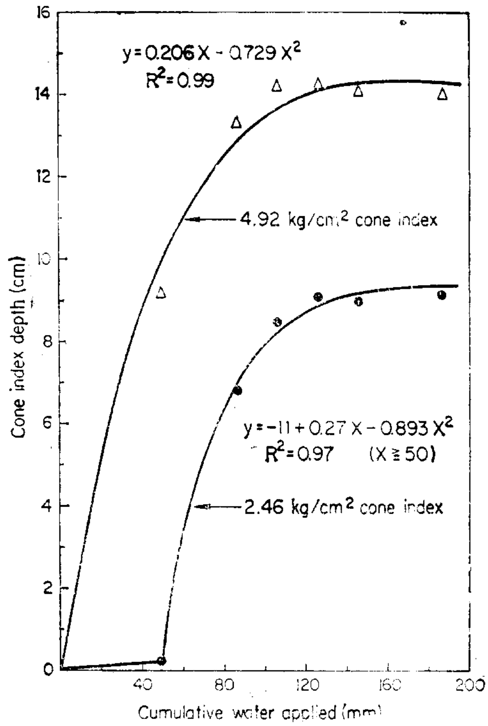

Fig. 6. Changes of cumulative water applied and cone index depth. (Dry Season 1979)

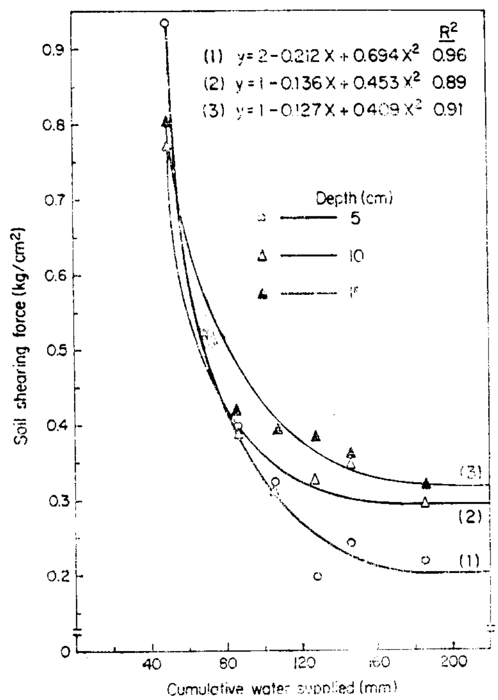

Fig. 7. Changes of soil shearing force in relation, to irrigation. (Dry season 1979)

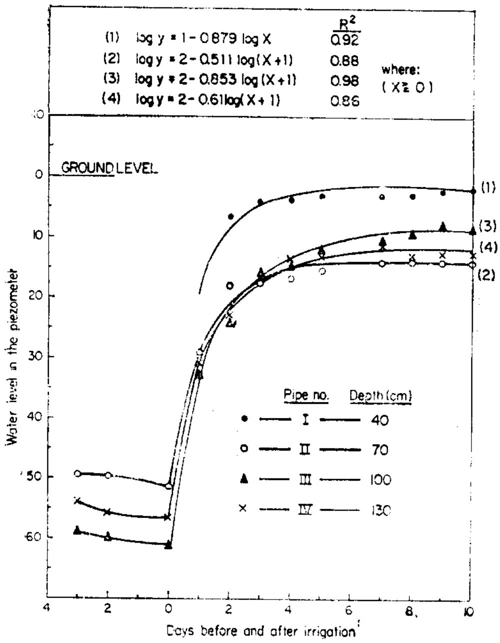

Fig. 8. Daily changes of water level before and after irrigation. (Dry Season, 1979)

When the power tiller was operated at full throttle having a speed of 68.81 meter per minute in firm soil without draftpull, a high travel reduction of 32.3% was measured during the plowing operation of the plot which had been soaked only one day (Fig. 9). During this operation, power tiller speed was reduced to 43.1 meter per minute and its field capacity was 0.055ha/hr. As the machine performance decreased, its energy requirement to finish one hectare increased. During the first plowing, the fuel consumption was 17.21 liters/ha (Table 2). When plowing subsequent plots, travel reduction decreased markedly until the fourth plot after which further decreases in travel reduction were not noted.

During harrowing and leveling, large differences in fuel consumption or machine field capacity were not found (Fig. 10). The level of input and soil condition during land preparation is shown in Table 2.

Fig. 11 shows the linear relationship between soil resistance (cone index) before plowing and total fuel consumption. The differences in fuel consumptions for complete land preparation is primarily due to plowing not subsequent operations.

Table 2. Level of input and soil condition in land preparation, 1979 dry season.

Operation	Treat-ment	Labor input (man-hour/ha)	Fuel consumption (1/ha)	Cumulative water applied (mm)	Initial cone index depth (cm) 2.46kg/cm²	4.92kg/cm²
Plowing	1	18.24	17.21	85.7	0.3	9.2
	2	15.97	14.56	106.9	6.8	13.3
	3	15.27	14.02	126.9	8.5	14.2
	4	14.13	13.08	147.3	9.1	14.2
	5	15.03	13.38	167.3	9.0	14.1
	6	14.24	12.77	210.3	9.1	14.0
Harrowing[a/]	1	26.32	21.93	355.0		
	2	27.00	20.74	375.5		
	3	26.11	20.41	395.8		
	4	24.39	19.84	446.7		
	5	26.49	20.43	451.5		
	6	26.33	20.03	479.9		

Total	1	44.56	39.14
	2	42.97	35.30
	3	41.38	34.43
	4	38.52	32.92
	5	41.52	33.81
	6	40.57	33.07

a/Consists of two harrowing and one leveling operations.

There are several methods for defining the physical properties of the puddled soil, such as aggregate size distribution, apparent specific volume, hydraulic conductivity, and soil shearing force under different degree of puddling. Among these factors effected by puddling quality, soil shearing force was measured to define the soil puddling in wet land preparation.

Almost no shearing force was found in the depth of 0—5cm after puddling, thus soil shearing force was measured only in the 10 and 15cm depth. The force at this depth was almost the same for all plots even though there were large differences before plowing.

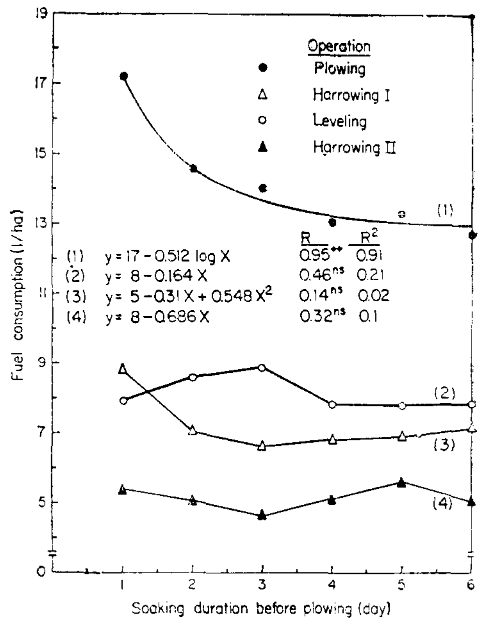

Fig. 10. Relationship between different soaking duration and fuel consumption for each power tiller operation. (Dry Season, 1979)

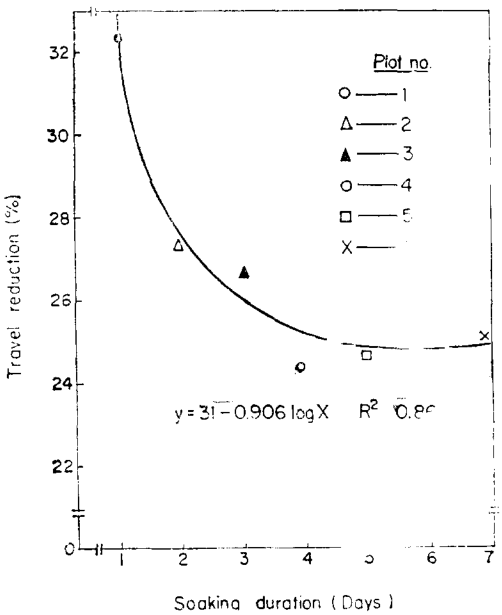

Fig. 9. Relationship between soaking duration before plowing and travel reduction during plowing (dry season 1979)

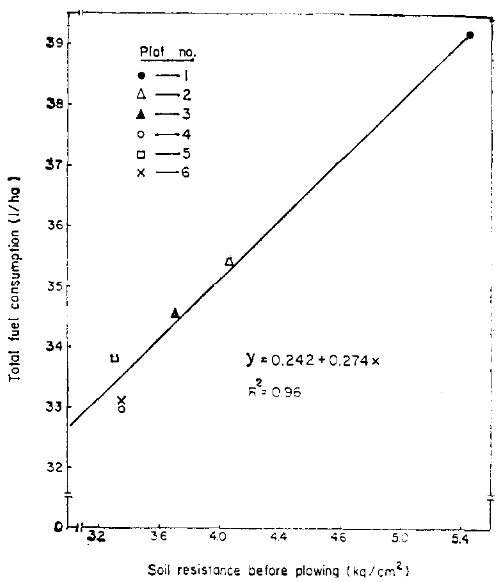

Fig. 11. Relationship between cone index before plowing and total fuel consumption during land preparation (dry season 1979)

These results may represent the differences in energy used for land preparation between the plots which received different amount of water before plowing operation (Fig. 12).

The greater the change in soil strength, the greater was the total fuel consumption of the power tiller during land preparation. This relationship is shown to be linear in Fig. 13.

After transplanting, the gravity water loss was about 10mm per day. This is higher than during the wet season experiment which was 5mm per day. This water loss cannot be considered as pure percolation because the polyethylene did not completely control lateral water movement.

No significant differences were found in plant growth. Twenty-two days after trans planting, weed samples were taken to determine weed dried weight. Plot 3 produced more weeds in comparison to the other plots, but differences were not large (Table 3),

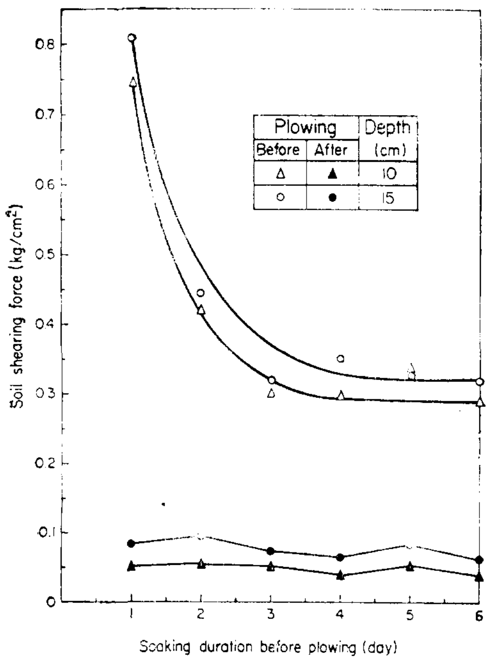

Fig. 12. Changes of soil shearing force during land preparation(Dry Season, 1979)

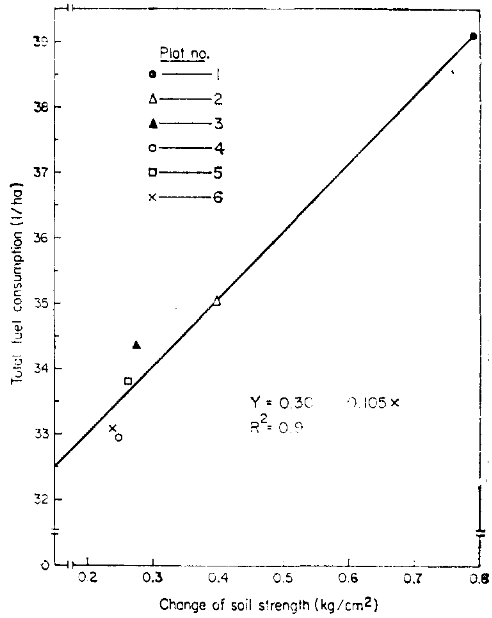

Fig. 13. Changes of soil shearing force during land preparation and total fuel consumption.(dry season 1979)

Table 3. Plant and weed growth, 1979 dry season.

Treat-ment	Height (cm)	Plant No. of tiller per hill	Dried weight (g/hill)	Weed Dried weight (g/0.25m)
1	35.6	15.9	2.29	3.92
2	34.9	14.4	2.44	3.96
3	35.1	14.4	2.34	4.82
4	37.1	17.8	2.70	3.74
5	35.0	16.0	2.46	4.48
6	34.7	14.5	2.31	3.80

Note : Sampled 22 days after transplanting.

2. Wet season

Before starting the first wet season expe-

Table 4-a. Level of input and soil condition in land preparation, 1978. First wet season experiment.

Operation	Treat-ment	Labor input (man-hour/ha)	Fuel consumption (l/ha)	Cumulative water applied (mm)	Initial cone index depth (cm)	
					2.46kg/cm²	4.92kg/cm²
Plowing	1	16.83	14.02		B/ 8.2a	A/ 14.9
	2	16.21	13.68	4.8	2.3b	14.7
	3	16.22	13.13	21.13	7.0a	15.3
	4	16.04	12.89	36.8	7.8a	15.3
Harrowing a/	1	26.19	17.58	422.93		
	2	25.33	17.02	312.75		
	3	26.19	17.90	170.26		
	4	28.38	20.31	41.88		
Total	1	A/ 43.02	A/ 31.60			
	2	41.54	30.70			
	3	42.41	31.03			
	4	44.42	33.20			

a/ Consists of two harrowing and one leveling operations.
A/ Not significant at 5% level
B/ Significantly different at 5% level by L.S.D.

Table 4-b. Level of input and soil condition in land preparation, 1978. Second wet season experiment.

Operation	Treat-ment	Labor input (man-hour/ha)	Fuel consumption (l/ha)	Cumulative water applied (mm)	Initial cone index depth (cm)	
					2.46kg/cm²	4.92kg/cm²
Plowing	1	14.93	11.95	39.0	A/ 15.0	A/ 17.5
	2	15.36	12.09		14.0	17.5
	3	15.21	12.51		15.3	17.8
	4	15.88	12.56		14.5	16.2
Harrowing a/	1	22.40	17.58	272.4		
	2	23.98	18.65	154.2		
	3	22.96	18.06	86.6		
	4	25.37	19.60	10.3		
Total	1	A/ 37.33	A/ 29.53			
	2	39.24	30.74			
	3	38.17	30.57			
	4	41.25	32.16			

a/ Consists of two harrowing and one leveling operations.
A/ Not significant at 5% level.

riment, the plots were fallow for 2 months. Soil was somewhat compacted but fully saturated (Table 4-a). Soil moisture content was 60—67% in the upper 40cm for all the plots.

The plots were fallow for 1 month between the first and second wet season experiment. Thus the soil was not so compacted with a soil moisture content of 75～80% in the top 10cm, and 60～73% in the 10～40cm depth (Table 4-b).

During the first wet season the depth at a cone index of 2.46 kg/cm² averaged 6.3cm and was 15.1cm at the cone index 4.92kg/cm² for all the plots. Soil resistance at depths of 5, 10, 15 and 20cm were also measured. Drastic change in soil resistance was found at the depth of 15cm.

Soil was very soft at the start of the second trial, especially in the upper portion from the soil. The depth at a cone index of 2.46kg/cm² was about 15cm and it was 17.5cm at a cone index of 4.92 kg/cm². This depth was much greater than first wet season experiment. Soil resistance during first wet season experiment was much higher than second experiment.

Before land preparation, vegetation was about the same in all plots which consisted of weeds and rice stubble.

In the wet season, no relationship was found between fuel consumption and amount of water applied during land preparation. Fuel consumption and machine field capacity were also similar between plots for both experiments(Table 4-a, 4-b).

Table 5 shows soil shearing force after puddling at different depths. Soil shearing force was almost the same, except for treatment 4, which has the shortest land preparation duration. Treatment 4 represents a little higher soil shearing force but the difference was not large.

Gravity water loss during the second trial was about 5mm per day(Table 6). Some differences were found between plots, but these were considered to be affected by surrounding fields No measurements were taken during the first experiment.

Table 5. Soil shearing force after puddling in g/cm².

Treatment	Soil depth(cm) 9—11	Soil depth(cm) 14—16
First wet season experiment	A/	B/
1	36.68	56.46a
2	35.01	67.18ab
3	44.45	63.55a
4	48.83	77.52b
Second wet season experiment	A/	A/
1	37.09	70.60
2	36.31	75.96
3	36.73	68.71
4	47.74	86.78

Note: Measurement were taken one day after leveling operation.
A/ Not significant at 5% level
B/ Significantly different at 5% Level by L.S.D.

Table 6. Gravity water loss per day after puddling in mm. Second wet season experiment

Treatment	1	2	3	4
	A/ 5.63	6.17	6.57	7.3

Note: Measurement were taken for 22 days after transplanting.
A/ Not significant at 5% level.

Table 7 shows the plant and weed growth for both wet season experiments. No large differences were found between treatments.

Table 7. Plant and weed growth

Treat-ment	Height (cm)	Plant A/ No. of tiller per hill	Plant A/ Dried weight (g/hill)	Weed A/ Dried weight (g/0.25m²)
1	38.93	11.73	1.72	4.82
2	39.39	12.55	1.73	4.22
3	40.05	12.65	1.88	4.42
4	39.52	12.47	1.69	5.28

Note : First wet season experiment, 1978. Measurements were taken 22 days after transplanting.
A/ Not significant at 5% level.

Treat-ment	Height (cm)	Plant A/ No. of tiller	Plant A/ Dried weight (g/hill)	Weed B/ Dried weight (g/0.25m²)
1	38.03	11.9	1.11	1.06a
2	36.63	12.13	1.27	1.00a
3	37.00	11.2	1.17	1.22a
4	36.27	10.8	1.01	2.32b

Note: Second wet season experiment, 1978. Measurement were taken 20 days after transplanting.
A/ Not significant at 5% level.
B/ Significantly different at 5% level byL.S.D.

Ⅳ. Conclusions

1. Dry season

1) As soil moisture content increased during the first 1 or 2 days of irrigation, soil resistance decreased quickly. Irrigation after the second day resulted in slow changes in soil resistance and after 3 days no more changes were found.

2) Fuel consumption and machine field capacity varied with treatments. This was mainly due to the changing soil resistance.

3) The 5 hp power tiller is light enough to be operated in the comparably soft soil without mobility problems.

4) Soil resistance after 3 days of irrigation stabilized, so differences in fuel consumption and machine field capacity were similar in those treaments tilled after three days of soaking.

5. No differences were found in soil shearing force after puddling even though soil conditions were different before land preparation.

6) No significant differences in weed and plant growth were found between treatments.

7) Additional research is required to determine relationships between soil strength and machine performance including energy requirements for several soil types used for paddy production. If soil strength parameters can be related to machine performance and soil strength parameters in turn are related to soil moisture content, irrigation recommendation by soil type could be given to the farmer.

2. Wet season

1) No relationships were found between fuel consumption, machine field capacity and water applied primarily because soil was saturated before the start of land preparation.

2) In the tillage treatment which had the shortest land preparation duration (3 days) soil shearing force and fuel consumption was a ittle higher in comparison to the other plots. This plot also produced a higher weed dried matter weight than other plots, but plant growth were almost the same with other plots.

3) In the first three treatments no differences in fuel consumption, machine field capacity, plant and weed growth were found.

4) In the wet season, treatment 3 which involved 11 days of land preparation appears to be the most efficient tillage procedure. No advantage was detected in land preparation of longer duration.

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