DEVELOPMENT OF THE GARDEN TRACTOR (TILLER) IN JAPAN

By

Sakae TSUNEMATSU

Head Professor of Department of
Agricultural Machinery
Faculty of Agriculture, Hokkaido University, Japan

Introduction

The first "Tilling Machines" in Japan were imported form Switzerland with the commercial name "Utility" in 1910, and they were used in orange groves. They were good machines from the point of performance of the tillage machine itself, since they could do two kinds of jobs, plowing and harrowing in one operation. But these machines were not popular among farmers, because mechanical failure and because they werc too expensive. Several tilling machines have been made by co-operative study and efforts of farm implement and machinery makers and engine makers, and these machines have been getting spread among Japanese farmers since 1930. But these machines have had several weak points as follows:

1. The cost of these machines is rather high.
2. The operation of these machines is limited to tillage only.
3. The machines are quite heavy (300–400 kg), so it is not so easy to operate these machines on paddy fields.

Farmers want to obtain special tilling machines which are cheaper, lighter and easier to operate, and also which can be used for several operations.

The small garden tractor that was imported to Japan from the United States of America with the commercial name "Merry Tiller" in 1951 was a desirable machine for Japanese farms. But it was imported to adapt it to a situation of Japanese farms, since this machine was not made for paddy fields. Many improvements have been made on this new imported model, and more recently successful Japanese-made tilling machines have appeared in Japan.

The following description will show the several situations and performance of the present small tractors which are popular among Japanese paddy field farmers.

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1. Character and type of tillers for paddy fields

According to "Farm Engines and Tractors" by H. E. GULVIN (1953), popular small garden tractors in the United States of America are equipped with 1–2 HP engines. These amall garden tractors are called "Rotary Tillers", and were written that they are a kind of the garden tractor in "Farm Power" by B. D. MOSES and K. R. FROST (1952), but the horse-power of the mounted engine is not stated in this book. It is not certain but it is suposed that the name of "tiller" comes from "Rotary Tiller"

(1) Characters of Till.

The transmission of the power from the mounted engine to the wheel-shaft is very simple, and the power from the engine is transmitted to the wheel-shaft by chain and sprocket or pully and V-belt. When pulverizing blades, named "Rotor" are provided instead of the wheels, it is possible to till or pulverize soil by a rotation of the rotor. And when pneumatic tire wheels are provided on this shaft, this machine works the same as a garden tractor, and is able to trail several kinds of equipment. Early tillers had relatively small horse power 1–2 HP, but there are today powerufll tillers with a maximum 8 HP, and two kinds of engines, aircooled and water-cooled engines.

(2) Outline of the development of the tiller in Japan.

"Merry Tiller" imported from U. S. A. were used for plowing and cultivating with the pneumatic tire wheels, and for pulverizing of soil with rotors attached on the machine. One of the defects of the pneumatic tire wheel has not enough tractive force on paddy fields with the result that there is too much slippage of the wheels. On the other hand, some rotors have performed well enough in pulverizing soil to give farmers satisfaction.

There are hard soils, peat soils and wet soils where drainage is difficult in Japan. Numerous makers of "Tillers" in Japan have continued hard stud and effort to make wheels which suit the above mentioned paddy fields, and several new models of wheel have been sold widely in Japan, especially a new type of wheel that works as both a wheel and a kind of rotor at the same time. This was designed for, and been used among the paddy field farmers. All makers of tillers are continuing their study and design of new-models wheels with all their power.

(3) Outline of the spread of the Tiller in Japan.

The farmers interest in tilling machines have grown very much since about 20–30 years ago, but the use of tilling machines has not increased greatly until recently as noted in the Introduction. But the new kind of tiller is economical and has much better performance, so after being introduced among the paddy field farmers, its use has grown with amazing speed, and this is one of the memorable steps in the history of agricultural machinery in Japan.

According to a statistical investigation in 1958, the total number of tillers on farms was 144, 775, and this number represents a large increase during the previous seven years. It is very interesting to compare the numbers of garden tractors (5–6HP) and tillers in Japan. The number of garden tractors in 1958 was only 19,797, and it took about twelve years from 1946 to reach this number. This difference between the number of tillers and the number of garden tractors show that the tillers are suitable for farmers in Japan, depending on the size of farm and their utility. The number of farms in Japan was about six million in 1957 and also the total number of self-propelled small tractors (tilling machines) was 137,000 and the number of trailing type small tractors was 90,000. According to the statistics of the Ministry of Trade and Industry in 1957 the number of tilling machines (self-propelling type) poduced was 70,696, and the number of garden tractors produced was 57,708 (most of these garden tractors were tillers). These data show that the rate of increase in use of garden tractors has been tremendous. On the other hand, it can be predicted that the increase will continue in the furture, since the percent of farmers possessing garden tractors is only about 3.8%.

(4) Classification of the Tillers.

According to the construction of the tillers, they used in Japan may be divided into three types, as follows:

1. Tillers provided with the steering clutch and the change gears.
2. Tillers provided with the change gears only.
3. Tillers which do not have any steering clutch or change gears.

The tillers belong ed to "1" type are the most heavy tillers and they are easy to operatr in the fields or for the trailing of wagons. But they are too heavy operating in paddy fields, sometimes, especialy, in the too much soft fields. The simplest type is "3", and the machines of this type are the cheapest among three types. Handling of the machine, divided into "3", for the weeding operations in the soft paddy fields is very easy. On the other hand, they are not desirable for the common field operations, or for trailing operation of wagons, since it is difficult to reverse the tillers or to change the speed. The tillers used in Japan may be divided into three classes, as followa;

1. Heavy duty tillers — Engine-power is from 4 HP to 8 HP.
2. Ordinary duty tiller — Engine-power is about 3–4 HP.
3. Light duty tillers — Engine-power is less than 2.5 HP.

The heavy duty tillers are provided with the steering clutch and change gears, and the light duty tillers have not these mechanisms.

The specifications of the representative tillers are shown in Table 1.

TABLE 1-1. Specification of a heavy duty Tiller

	Item	Unit	Value
Specification	Length overall	mm	1610
	Width overall	mm	640
	Height overall	mm	1120
	Total weight (without ballast weight)	kg	116
	Height of handle	mm	940
	Tire size		4.00–9 2 ply pneumatic
	Wheel tread Max.-Min.	mm	445-645
	Road clearance	mm	145
	Ballast weight	kg	11.5×2
	Balancing weight	kg	6.0×2
	Height of hitch	mm	430
	Dia. of hitch pin	mm	22
	Dia. of wheel tube	mm	44
	Position of gravity	mm	Back from wheel shaft 14 Left from center 2 Above the wheel shaft 344
	Dia. of V belt Pulley	mm	263

	Item	Unit	Value
Engine	Rated	HP.	3
	Max.	HP.	4
	Type of engine		2 cycle vertical
	Number of cylinder		1
	Bore and Stroke	mm	56×50
	R. P. M.		3600
	Cooling system		Air-cooled
	Dia. of belt pulley	mm	74.75
Transmission	Engine—main shaft		V belt
	Main clutch		Belt clutch
	Change gear		Sliding-gear trance-mission Foward 3 steps Reverse 1 step
	Main shaft—wheel shaft		Gear and chain
	Steering clutch		Craw clutch

TABLE 1–2. Specification of a ordinary duty Tiller

Specification	Length overall mm	1545
	Width overall mm	705
	Height overall mm	1110
	Total weight (without ballast weight) kg	86
	Height of Handle mm	935–1000
	Tire size	4.00–8 2 ply pneumatic
	Wheel tread Max.–Min. mm	355–593
	Road clearance mm	135
	Ballast eight kg	9.3×2
	Balancing weight kg	8.0×3
	Height of hitch mm	367
	Dia. of hitch pin mm	16
	Dia. of wheel tube mm	3.9
	Position of gravity mm	Back from wheel shaft 22 Right from center 13 Above the wheel shaft 158
	Dia. of V belt pulley mm	316,295
Engine	Rated HP.	2
	Max. HP.	2.5
	Type of engine	2 cycle vertical
	Number of cylinder	1
	Bore and stroke mm	60×55
	R. P. M.	3000
	Cooling system	Air-cooled
	Dia. of belt pulley mm	48,80
Transmission	Engine—main shaft	V belt
	Main clutch	Belt clutch
	Change gear	Sliding-gear transmission Foward 2 steps Reverse 1 step
	Main shaft —wheel shaft	gears and chain
	Steering clutch	None

TABLE 1-3. Specification of a light duty Tiller

Specification	Length overall	mm	1560
	Width overall	mm	810
	Height overall	mm	1080
	Total weight (without ballast weight)	kg	85
	Height of Handle	mm	880-1000
	Tires size		4.00-8 2 ply pneumatic
	wheel tread Max.-Min.	mm	365-605
	Road clearance	mm	135
	Ballast weight	kg	16.6×2
	Balancing weight	kg	20.8 10.8
	Height of hitch	mm	365
	Dia. of hitch pin	mm	16
	Dia. of wheel tube	mm	39.5
	Position of gravity	mm	Back from wheel shaft 13 Right from center 13 Above the wheel shaft 222
	Dia. of V belt pulley	mm	307,294,130

Engien	Rated	HP.	3
	Max.	HP.	4
	Type of engine		4 cycle vertical
	Member of cylinder		1
	Bore and strocke	mm	65×55
	R. P. M.		3000
	Cooling system		Air-cooled
	Dia. of belt pulley	mm	80,60
Transmission	Engine—main shaft		V belt
	Main clutch		Belt clutch
	Change gear		None
	Main shaft —wheel shaft		Chain
	Steering clutch		None

TABLE 1–4. Specification of some attachments of tiller

Item	Dia. cm	Number of blade	Weight kg	Width of cut cm	Kind of Operation
Knife Rotor	35.6	4	10.0	80.0– 72.0	Purverlizing Tilling Cultivating
Cut-away Rotor	ε4.4	6	20.8	106.4–102.4	Cultivating Purverlizing

Item	Width of cut cm	Adjust mechanism of the width of cut	Distance from Tiller-wheel shaft		Weight kg
			point	tail	
Japanese plow: Ri (Reversible plow)	18.3	Pantagraphic mechanism	39.4	95.4	14.8

Item	Width of cut cm	Length of shar cm	Mold-board cm			Cutting angle	Wedge angle	Mold-board angle
			Width	Length	Height			
Plow	21.4	32.4	21.2	47.7	23.7	41.0°	20.5°	39.0°

Distance from tiller's wheel shaft cm		Dia. of coulter cm	Weight kg
point	tail		
62.0	116.5	28.5	32.5

2. Actual condition of utility and economical effects of the Tiller in paddy fieles

The following description is an interesting actual case to show the typical situation in which tillers are used by farmers in Hokkaido which is located in the north part of Japan, and is the second largest Island in Japan. In conventional paddy field farming in Hokkaido, horses are used, but the farmer in this case bought a tiller with the intention of replacing animal power with machine power, so he compared the two farming method, conventional use of horses and tiller farming. The tiller he has is a "Merry Tiller" with a 2.5 HP gasoline engine.

(1) Work-days comparison.

Table 2 shows the final results of all field operations except for operations in which neither tiller nor horse was used, such as fertilizing, harvesting and moving of the straw. The work-days were calculated for 3.5 hectares, on the bases of 10 hours of laber per day. Acording to Table 2, the total work-days

TABLE 2. Amount of work-hour per year

Type of working	Tiller work (days)	Conventional work (days)	Note
Plowing	8.75	8.75	—
Purverizing	3.50	4.40	—
Puddling	5.00	7.00	—
Weeding by machine	2.80	*8.80	total of 2 times weeding
Weeding around plants	14.00	14.00	total of 2 times
Mulching	2.90	*7.00	—
Weeding by hand	11.70	35.00	—
Total	48.65	84.95	—

*: Hand working.

required for one hectare were 19.7 days with the tiller, and 26.1 days with the horse, and the laber saving by the tiller to the horse is 24.4%. Several interesting things can be found in this table. One of them is the fact that weeding by tiller is possible, whereas weeding with the horse is very difficult, because when weeding by horse is done, the rice plants are injured by horses feet. For this reason, much advantage can be found in a tiller. A similar advantage is found in the case of the mulching operation. The second point is the fact that the results of weeding and mulching by tiller superior to the result obtained by using hand tools. This difference has much influence on the final weeding by hand. In most of case, the final weeding which is done just befor the sprouting the head is done by hand in Japan. There are two big problems involved in the mechanization in paddy fields in Japan. One of them is the mechanization of weeding, and the other is harvesting by machines. The appearance of tillers sheds a bright light on these problems, and the problem of weeding is almost solved. All makers of tillers are attempting to design of perfect weeding equipment, since the weeding equipment is not presently good enough to satisfy them under all conditions of the paddy dield, for instance under the soft and deep paddy conditions.

In the case reported here, the tiller was equipped with a Japanese plow "Ri" for the plowing operation, and the conventional paddy field plow was used for the horse plowing in Hokkaido. This farmer could not find much difference in efficiency, effect of the plowing and amount of personal fatigue. For the pulverizing operation, the "cutaway rotor" or mulching rotor was attached to the tiller, and a spike tooth harrow and rotary harrow were used in the conventional way. For the final preparation of the plant bed in the paddy field with water the so called "shirokaki" operation, a kind of harrowing

TABLE 3. Fuel Consumption of Tiller for each operation

Kind of working	Fuel consumption liter per hour		Required hours per ha	Fuel consumption liter per ha		Working area (ha)	Working hours	Total fuel consumption (1)	
	gasoline	mobile oil		gasoline	mobile oil			gasoline	mobile oil
Preparing seed bed	0.631	0.036	—	—	—	—	5.0	3.15	0.18
Irrigation	0.541	—	—	—	—	—	15.0	8.11	0.54
Tilling	0.721	—	2.5	0.803	0.090	35	87.5	63.00	3.16
Pulverizing	0.631	—	1.0	0.631	0.036	35	35.0	22.00	1.26
Paddling	0.721	—	1.4	1.01	0.051	35	49.0	35.30	1.76
Power weeding	0.541	—	0.4	0.217	0.014	70	28.0	15.15	1.01
Mulching	0.541	—	0.83	0.451	0.029	35	29.0	15.65	0.045
Trailing for rice straw	0.721	—	—	—	—	35	30.0	21.60	1.08
Trailing	0.721	—	—	—	—	—	30.0	21.60	1.08
Stationary working	0.631	—	—	—	—	—	10.0	6.31	0.361
Total	—	—	—	—	—	—	318.5	211.9	10.476

the tiller was equipped with a "Shirokaki rotor", a kind of combinated wheel and puddling device, and spike tooth harrow. This equipment will be described later.

(2) Economic comparison.

Table 3 shows the fuel consumption, amount of lubricant and actual work hours for the tiller used for this farmer with the 3.5 ha. paddy field. It is reasonable that the fuel consumption per hour for heavy duty operations, such as plowing, puddling etc., was more than for the light duty operations, such as weeding, irrigating, pulverizing, etc. The longest hours was for preparing the plant bed (plowing, pulverizing and "Shirokaki"), and about 50% of all work hours. The next largest was trailing, and it accounted for 17.5%. And then weeding operation (included mulching) accounted for 16.6% of all work hours. One of the advantages of the tiller compared with the horse is that the tiller can be used for stationary work. The time for stationary work was only 10 hours in the case reported here, but when the farmer does not have any other prime motor, the tiller operating time will be increased more for threshing and hulling of rice. But animal power can not be used for these jobs. The total time used during the paddy field operation period from May to the middle of October, was about 343 hours, and this shows that the farmer made good use of his tiller. The fact that good results like this can be shown is due to the continuous efforts of the tiller makers to improve paddy field equipment. Table 4 shows the total expense of the tiller operation per year for the 3.5 ha. farmer, and expenses per ha. were about 11,700 Yen (about

TABLE 4. Anual cost required for Tiller operation

Item	Unit cost per ℓ (yen)	Amount (ℓ)	Cost (yen)	Note
Gasoline	41.70	227.00	9,450	—
Mobile	160.60	12.61	2,100	—
Repair	—	—	820	Piston ring etc.
Gear oil	—	—	200	—
Depreciation	—	—	28,000	—
Other	—	—	340	V belt etc.
Total	—	—	40,910	— .

$ 33). It is very interesting to compare Table 4 with Table 5, which shows the expense of horse operation per year. The cost of feed for the horse was very high, and was about 55% of all expenses. And this expense cannot be

TABLE 5. Cost of keeping a horse

Item	Cost per kg (yen)	Amount (kg)	Cost (yen)	Note
Feeding straw	2.67	2250	6,000	—
Hay	8.00	375	3,000	—
Oat	15.00	1500	22,500	—
Bedding material	2.13	2625	5,600	—
Green dentcorn	1.60	1875	3,000	—
Horse shoes	—	—	2,500	4 times
Injection	—	—	500	—
Premium	—	—	3,300	—
Depreciation of horse equipment and implements	—	—	7,800	—
Depreciation of horse	—	—	8,400	—
Total	—	—	62,600	—

reduced regardless of the area of the field and the number of work hours of the animal.

The above mentioned results represent only one case, so it is natural that somewhat different results might be found in other case, depending on such factors as size of farmer, soil conditions, technic of operation and type of tiller. But this case is a good one to illustrate the current use of tillers in rice farming in Hokkaido.

3. The kind of Equipment for the tillers for paddy field

The following description of equipment and its special features is limited to the main ones for paddy field use among the numerous kinds of equipment in Japan. It is certain that some items were introduced from overseas and were modified or reconstructed for paddy fields in Japan, and some of them were designed in Japan.

(1) Plow.

The bottom plow can be attached to the tiller sometimes, and its size is from 8 in. to 12 in.. But in most of cases the plow is not best equipment, because the drawing resistance is too great for the tiller in the paddy fields. The dried soil is very hard like brick, and when the soil is wet, it is too sticky for plowing. In these cases the plow does not cut into the soil, or the drawing resistance is too great for tiller. It is natural that there is a slat plow for tiller, too.

(2) Japanese plow.

We have had in Japan a special plow called "Ri" for use with animal power since ancient time. The performance of this plow (handling of plow, turning soiland flatness of furrow bottom) has been worse than for foreign plows past years. The defects of the "Ri" have been corrected recently, and a list of the excellent points of the "Ri" is as follows:

1. The drawing resistance is comparatively low.
2. The weight of Japanese plow is relatively small.
3. The suction into the soil is good even in hard dried soil.

The "Ri" is very good for use with tillers, because of the above mentioned reasons. Fig. 1 shows a two-way "Ri". The turning mechanism of the share and moldboard is not only very skillful but also very simple. When the turning lever is changed to the left side, the share and moldboard turns to the left and the curved surface of the moldboard is changed to opposite side by the link mechanism connected with the lever. It is certain that the tractive resistance is relatively low, since the moldboard is a kind of slat. The section of the beam of this plow is square and the beam is hollow, beeing made from four steel plates. Total weight of "Ri" for tiller is about 15 kg and the plowing width is 18–20 cm. Fig. 2 shows a type of jointer plow. A jointer of the "Ri" has the same advantage as a jointer of an ordinary plow. The turning of the soil and convering of the old rice stalks are improved by the jointer. The depth of the furrow can be adjusted by the depth adjusting lever, and also the width of the furrow can be adjusted by a special device, something like a pantagraphic mechanism, as shown in Fig. 1 and 2. This device may be also used for adjusting the position of the "Ri" relative to the tiller. One

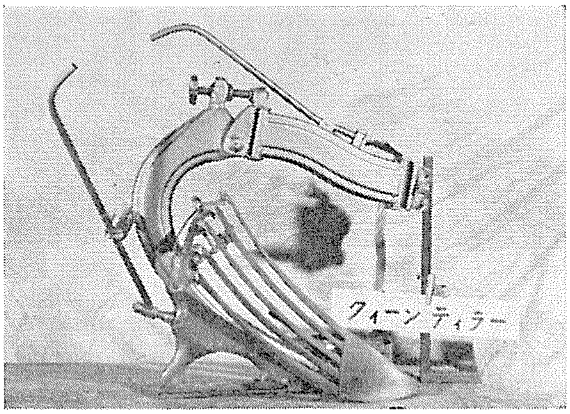

Fig. 1. Japanese Plow.

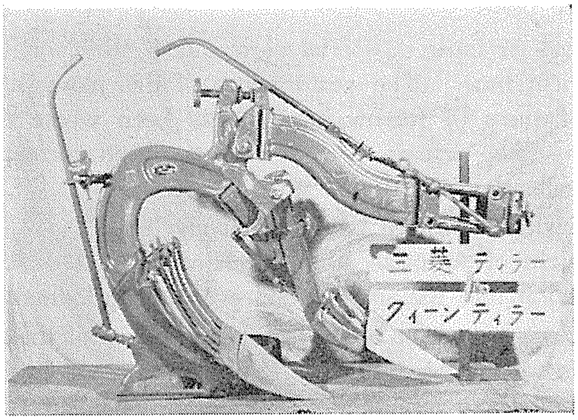

Fig. 2. Japanese Plow with Jointer.

of the reason that simple, light-duty tillers developed rapidly in Japan is the existence of the Japanese plow "Ri".

(3) Rotor.

The rotors, as discussed here, have a special meaning. The rotors of a tiller are special devices with which the wheel-shaft is equipped instead of wheels. They work partly as pulverizers and partly as wheels. Several kinds of rotors have been deveroped in Japan. Fig. 3 shows a kind of rotor, named

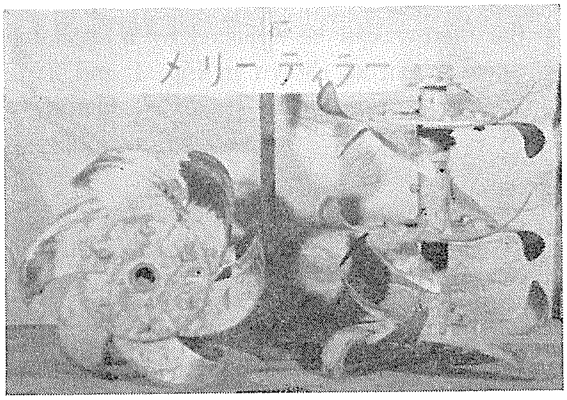

Fig. 3. Cutaway Rotor.

cutaway rotor, and Fig. 4 shows a knife rotor. The rotor will usually be used as 2 or 3 gangs on each side of the wheels, according to the size of the tiller or the soil condition. The specifications of several rotor are shown in Table 1–4. These rotors are useful for pulverizing the soil after plowing: but

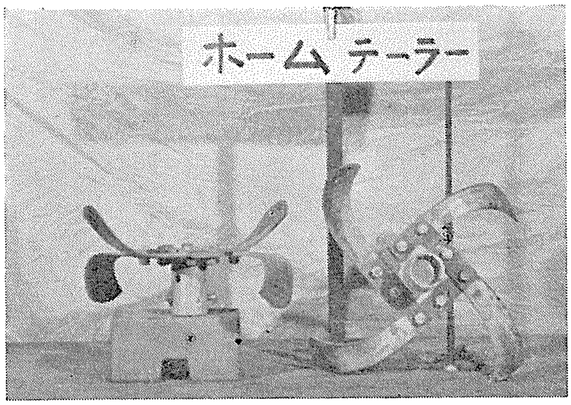

Fig. 4. Knife Rotor.

the working speed is very slow and the tiller is not so steady, so they should be used only when they are nessessary.

(4) Harrowing equipment used in paddy field covered with water.

The pulverizing of the soil in paddy flelds covered with water is the final stage in preparing the plant bed. The tiller is very useful for this work. Usualy the wheels are removed and the tiller equipped with a rotors, and also the spike tooth harrow (with one row) is connected just behind the tiller. The best rotor is a special rotor, called "Shirokaki rotor" or, another name of this rotor is a cage wheel. This rotor is qute wide and has several steel plates which are welded on both end rims. The shape of this rotor holds the tiller steady on the slippery soil covered with water and also works somewhat as pulverizer by compressing and mixing the soil in water. This job can be

Fig. 5-1. Paddling operation in Paddy field.

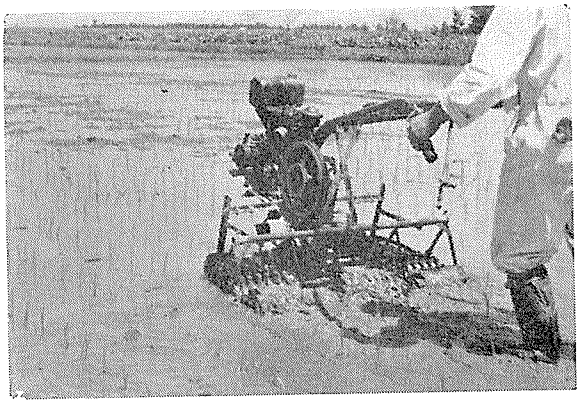

Fig. 5–2. Weeding operation in Paddy field.

finished completely in 2 or 3 circuits of the whole field. Fig. 5 show the "Shirokaki" operation and weeding operation.

4. Type and kind of wheels for tillers

The kinds of traveling part of tillers may be classified as follows:

A. Wheel type
  1. Pneumatic tire wheel
    a. Basic pneumatic tire wheel
    b. Pneumatic tire wheel with girdle
  2. Steel wheel
    a. Steel pipe tire
      i. narrow type with one pipe rim
        (i) common lugs
        (ii) high lugs
      ii. wide type with two pypes rim
      iii. special shape type such as cone shape (Fig. 6–6)
    b. Steel plate tire
B. Rotor type
C. Crawler

It may not be safe to say that all of these wheels will become popular in the market. Some of them will probably increase rapidly and some of them will disappear from the market. But these wheels are very interesting and useful for us as actual samples showing the efforts and study of tiller makers.

(1) Pneumatic tire wheel.

The basic wheels for tillers are the pneumatic tire Ths specifications of wheels are shown in Table 1. The diameter of the wheel is about 8 inches, and the width of the tire is 4 or 5 inches, and the tires are usually 2-ply. These pneumatic tire wheels useful on good condition such as dried field, hard roads, and paved roads. But the tractive force of the tillers with pneumatic tire is not sufficient to do good job under the bad conditions, such as too soft and too wet clay soil and paddy field work.

When field conditions are good enough to permit use of pneumatic tire wheels for plowing the fields, it is best to use pneumatic wheels. But if the soil is a little harder or wet enough to cause slippage of the tires, pneumatic tires should be equipped with girdles. But it should be kept in mind that the girdles have a tendency to injure the surface of the tires. In most cases the paddy fields are more moist and sticky than ordinary fields, and there are many cases in which one cannot use pneumatic tires. In such cases, the steel tires are very useful.

(2) Steel wheels.

The machine when imported from U. S. A. did not have steel wheels, but many steel wheels have been used, depending on soil conditions and object of the operations. One of the most important reasons for using steel wheels is to increas the tractive force, and the other reason is to increase the clearance of the machine above the earth. It is very important to remember, in considering steel wheels, that there are two different field conditions encountered. One of them is a ccondition on common field, and the other is a condition on field covered with water. The steel wheels for tillers should perform well in both cases. For this reason, the diameter of the wheels must be large enough to enable to operate in muddy fields. The diameter of the wheels is usually more than 450 mm. And a second problem is that the wheels should be open type as much as possible, because it is very, very important that the mud or water will be able to pass through all parts of the wheel. If the flow of water is poor, the mud will accumulate on the wheels and the resistance will increase and increase, until the operation of the machine must stop. For these reasons all tiller wheel are of the open type and simplified, as shown in Fig. 6. The problem of machine weight is also important. The tiller must be light, since the running of the machine in the paddy field is very hard. And also the area of most fields is small in Japan, so the farmer is obliged to go round and round the field. For these reasons, the wheel should be light. It is reasonable that there are many pipe tire wheels. Another specialty of the steel wheels is the fact that the height of the lugs is relatively great, and this point is important too when these wheels are used in watered fields. The differences in tractive forces of the machine equipped with each kind of wheel

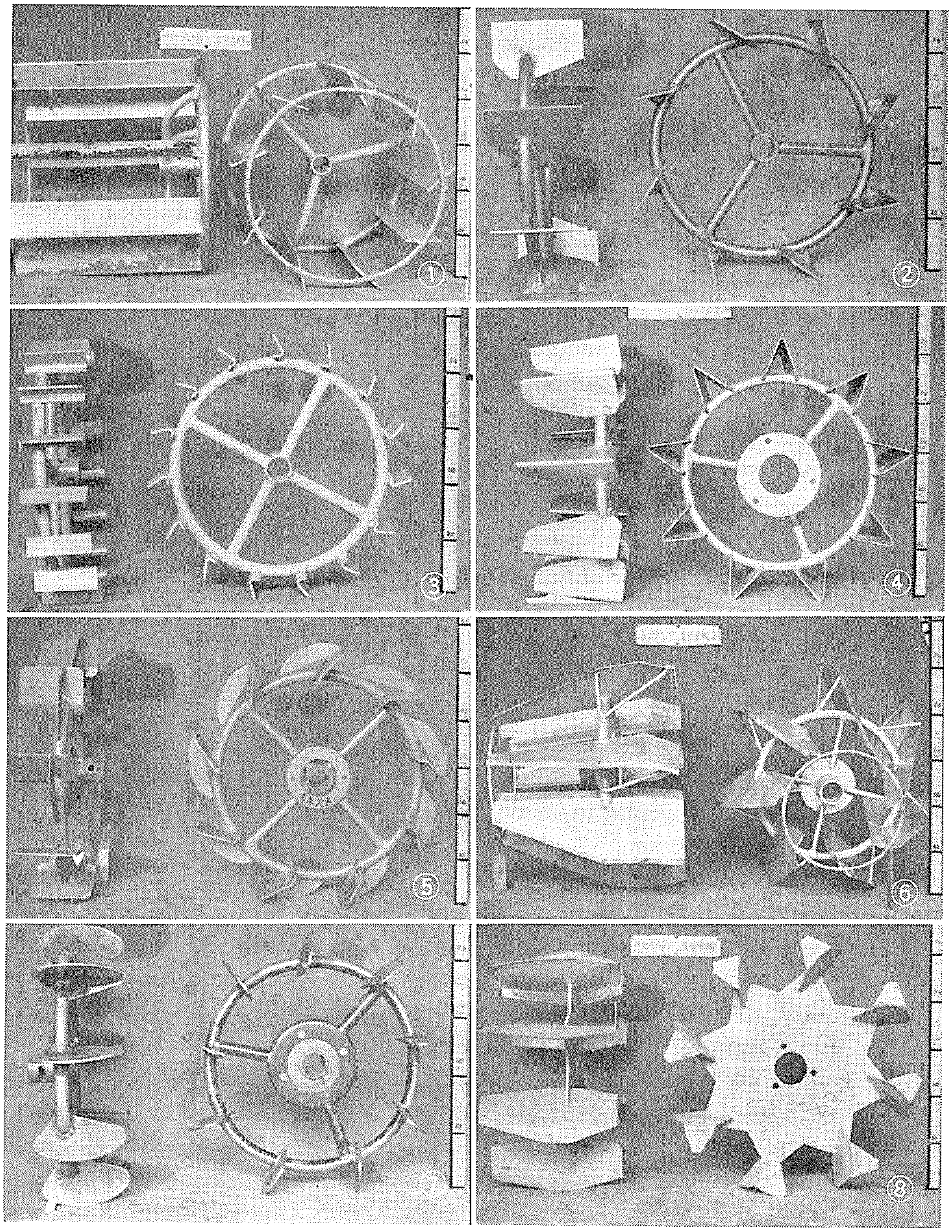

Fig. 6. Steel Wheels for Tiller (Scale···10cm)

will be discussed later. So an outline of special features for several wheels will be discussed here.
The pipe wheel shown in Fig. 6–5 is one of the plate-lug wheels, and, as shown in the picture, there are special plates something like the fins, around the tire just behind the lugs and perpendicular to it. These fins enter the soil and keep the machine steady, so they are very useful in increasing the tractive force.

Fig. 6–2 is the simplest type of a wheel for paddy fields. These two types are common types of steel wheels for general operations. These wheels can be used not only on watered fjelds, but also on moist soil. The wheel shwn in Fig. 6–3 has angle lugs, but the height of the lugs is much less than for the other wheels. The other wheels shown in Fig. 6, besides Fig. 6–1, are special wheels for use on fields covered with water, and they can be used for the harrowing operation in the paddy fields with a paddy field harrow.

For the harrowing operation, the special wheel, named the "Kagogata" wheel or "Shrokaki Rotor" in Fig. 6–1, is best one. This is a kind of Cage wheels, and it is the speciality that this device is not only partly a wheel, but also partly a pulverizer. It is wide enough (about 360 mm) for the pulverizing operation. And also the machines equipped with this wheel are very steady even in the field covered with wafer. It is certain that this wneel should be used together with the paddy field spike tooth harrow.

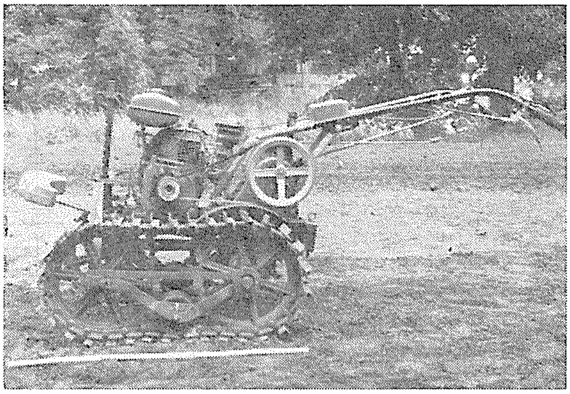

Fig. 7. Special Tiller equipped with Crawlers.

Although the crawler is not really a wheel, it will be descussed here. Fig. 7 is a special tiller equipped with crawlers. These crawlers are driven by the rear sprocket wheel (diameter 378 mm, teeth number 18). The links of the crawler are fixed on the front sprocket wheel, and the L-shape steel platrs with 30 mm width, 3 mm thickness, 240 mm length are rivetted on this links. The crawler is a little different from the crawler on tractors, i. e. the crawler plates are seprated from each other. This special design is made in consideration of utilization of this crawlers on accumlations of snow. They are made to prevent clogging of snow. This crawler is very usefull for the plowing operation, especially on dried hard paddy fields, since the tractive force is strong. The results of the tractive force tests will be shown later.

5. The tractive force of the Tillers

The important factors for good tillers operation are that their mechanism be simple that operating is easy and that the tillers are light in weight. A key point is to have the maximum tractive force consistent with tiller speciality. The following description shows the tractive force of the tillers and an outline of the factors, studied in our department, which influence tractive force.

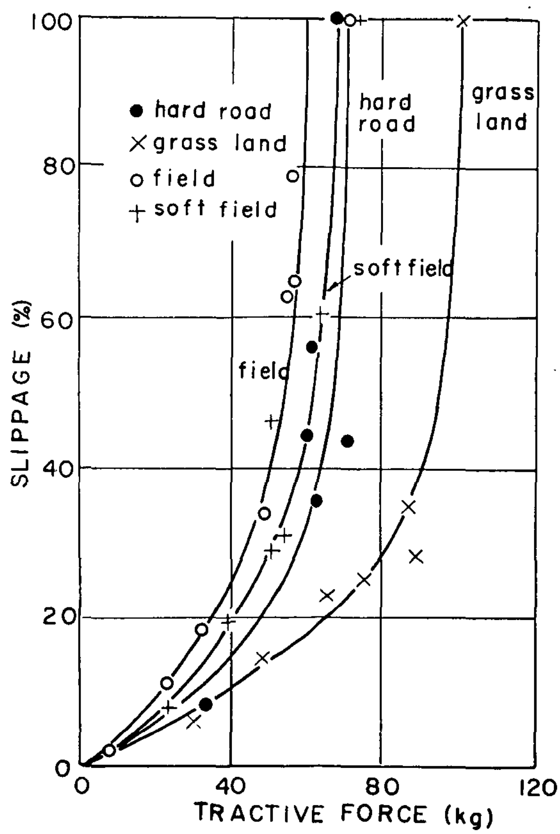

Fig. 8. Tractive force of tiller with pneumatic wheel. (Light duty tiller)

A. Tractive force of pneumatic tire.

Fig. 8 and 9 show the results of tractive force tested on several soil condition by electric strain gauge mater. These results show the following several problems.

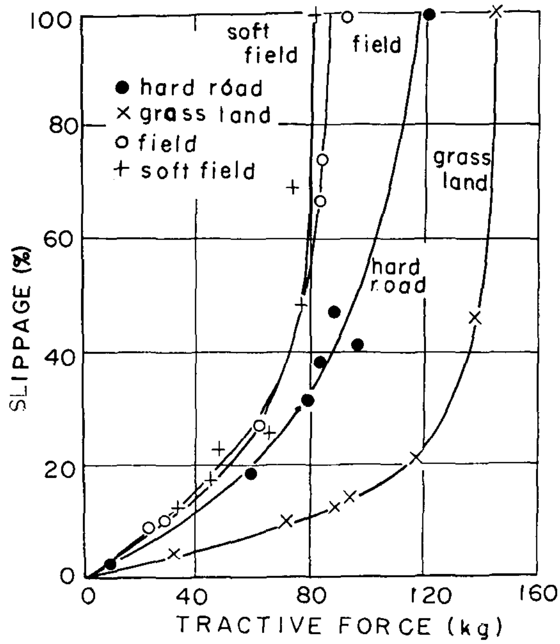

Fig. 9. Tractive force of tiller with pneumatic wheel. (Heavy duty tiller)

1. The tractive force is influenced by the weight of the machines
2. The soil condition should be considered.
3. The slippage of the wheels sharply increases, when the tractive force goes up beyond some limiting value.

Table 6 and Fig. 10 show the relation between the weight of tillers and the tractive force for seven popular tillers in Japan.

Table 6 shows that there are many difference in tiller-weight (includes the engine weight) among tillers. The most heavy tiller is 112 kg, and the lightest one is 80 kg. The tillers have two kinds of added weight, i, e. the ballast weight and the balancing weight mounted on the top of the tillers. The total weight of the tillers, including the added weight are also shown in table 6. The total weight ranges from 172 kg to 129 kg. Ballast weights mounted on large wheel tractors, and their effect are well known, but weights for tillers are more important and valuable than weights for large tractors, since the tillers are made as light as possible, in consideration of easy handling.

TABLE 6. Weight of Tillers and their tractive force

	Weight of Tiller	Total weight of machine	(%) *	On hard road (kg)		On grass-land (kg)		On ordinary field (kg)		On soft field (kg)	
				tractive force	coefficient of tractive force	tractive force	coefficient of tractive force	tractive force	coefficient of tractive force	tractive force	coefficient of tractive force
A	101	161	30	85	53	121	76	41	26	52	32
			100	103	64	142	89	67	42	72	45
B	116	172	30	76	48	113	72	48	30	64	36
			100	97	62	137	87	79	50	78	49
C	112	172	30	76	44	127	74	64	38	62	36
			100	120	68	146	85	89	52	83	48
D	86	129	30	56	44	84	66	44	35	52	40
			100	69	54	102	80	59	47	71	53
E	80	132	30	52	39	87	66	34	26	51	39
			100	72	54	108	83	56	42	71	52
F	109	161	30	90	56	121	76	52	32	55	34
			100	—	—	142	89	81	51	76	47
G	85	149	30	51	34	97	66	44	29	59	40
			100	57	52	116	78	70	47	79	54

*: Slippage of tiller wheels.

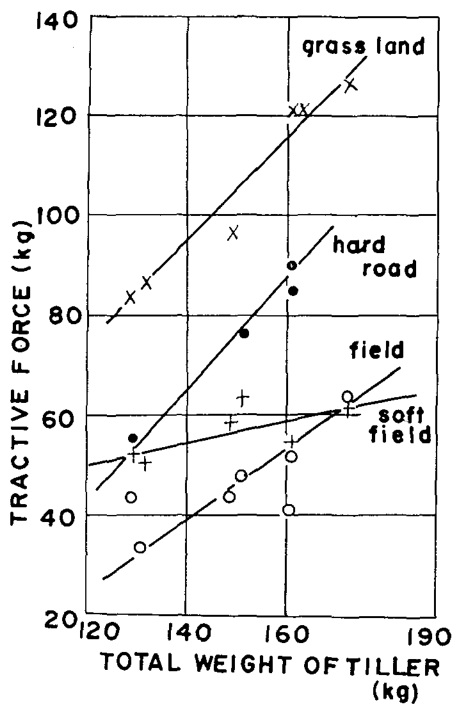

Fig. 10. Relation between tiller weight and tractive force. (at 30% slippage of wheel)

However the tractive force must be strong. The ratio of the total weight of the tillers is from 130%. Fig. 10 shows the relation between the total weight of the tillers and the tractive force in the case of 30% slippage of the wheels. It shows that the plowing condition in paddy fields is harder than in common fields because the tractive force in paddy fields is much less than in common fields or on hard roads. The tractive force in Fig. 10 were measured at 30% slippage of the wheels, but it is important to actually determie wheel slippage in such case in order to find out the practical available tractive force. There are many cases in which the tracting force of tillers is slightly helped by human power, so it will be presumed that the limit of drawbar ability can be determined at 50% slippage of the wheels for tillers. For this reason the actual tractive force will be assumed to be 10 or more kg greater than the tractive force at 30% slippage of the wheels. Fig. 10 shows the fact that the tractive force increases generally in proportion to the total weight.

The theoretical tractive force of the tiller is considered as follows;

(a) When the center of resistance of the attached equipment is lower than the soil surface.

(1) When the level of the two wheels is not the same (for plowing).

$$W_r = W + \frac{R_H h + Rva + \frac{1}{2}F_1 t + F_2 b - Kd}{l} \qquad (1)$$

W_1 : Reacting force of the wheel-load.
W_1^0 : Static load of the wheels.
R : Resistance of the implement.
R : Horizontal component of R.
Rw: Vertical component of R.
K : Rolling resistance.
F_1 : Frictional resistance by the vertical force of the implement.
F_2 : Frictional resistance by the lateral force to the landside of the plow.
A : Working point of resultant driving force.
a : Horizontal distance between the working point of R and the bearing point of the reactance of torque.
t : depth of the furrow.
d: : Height from the working point of the rolling resistance to the level plane, including point A.
b : Distance between F and the level plane, including point A.
l : Distance from A to the bearing point of reaction.
h : Height from the center of the resistance to the level; plane, including point A.

(2) When the lever of the wheels is the same.

$$W_1 = \frac{W_1^0 + R_H h + Rva + Ff - Kd}{l} \qquad (1)$$

$$D = KW \qquad (2)$$

K : Coefficient of tractive force.

From formulas 1 and 2, it is concluded tnat tractive force is in proportion to W, and W, is influenced by many factors. Following factors are important with tillers.

(i) The bearing position of the reacting force.

When the equipment (such as plow) is fixed on the tillers at the hitch, the equipment is not only the load of the tiller but is also the bearing part of the reacting force of the torque. And this bearing point can be determined by the distance from the wheel shaft (l) and the height from the center of the resistance to the level plane, including point A (h). In our experiments, the tractive force increased about 11% from $l=201$ cm to $l=81$ cm. These tests were done with $h=14$ cm, and with a determined value of 50% slippage of the wheels.

The above mentioned result means that equipment should be attached as near as possible to the wheel shaft, taking into consideration that the performance of the equipment should not be hampered, such as by clogging of the soil while plowing.

The actual distance from the shaft to the point of the Japanese plow "Ri" is about 40 cm, and it is 50～60 cm for ordinary plow.

(ii) The position of the balancing weight.

That the weight of the tiller is a very important factor was mentioned already. And in common fields the tractive force can be increased 50–60% by the addition of a balancing weight in front of the tiller.

But the positioin of the balancing weight influences the tractive force. The further the weight is from the wheels, the stronger the tractive force is. But the most important problem of the balancing weight is to keep the whole balance of the tiller and its equipment.

(b) For the trailing of wagons.

In this case the formula is shown as follow;

$$W_1 = W - \frac{Rh}{l} - \frac{Kd}{l} \quad \dots\dots\dots\dots\dots\dots \quad (3)$$

According to Fomula (3), the value of W_1 (tractive force) is influenced by not only W_1^0, but also l.

In the case of trailing a load, when l was 201 cm the drawbar ability increased about 20% compared with the case when was 81 cm at 16% slippage of the wheels. This result shows that the longer the distance from the tiller to the wheels of the trailer is, the bigger the tractive force will be. But it should be considered that there is an important relation between this distance and the radius of turn of the tiller. The longer the distance is, the more difficult the turnning of the tiller is.

B. Effect of a girdle.

The amount of increase in the tractive force by the attachment of girdles to the wheel is inflienced by the soil condition. On dried fields or on fields where moisture exists only on the surface of the soil, the increase in tractive force was 50%; and on wet fields on which one could obtain a large tractive force by using pneumatic tire wheels, the increase in the tractive force was about 25%. And then on soft fields it was only 15%.

The effect of the girdles was striking. But it should be kept in mind that the girdles have a weak point; that the soil clogs between the girdles on sticky paddy soil, and then the girdles do not work.

Steel wheels are better than girdles, in the above mentioned case.

C. Tractive force of tillers with crawlers.

In the tests of tractive force and resistance of traveling with tillers equipped with pneumatic tire wheels and with crawlers the available maximum tractive force with crawler was 2.5 times as high as the tractive force of the pneumatic wheels on the hard loam fields and 3.2 times as great as for pneumatic wheels on soft fields. The increase of the coefficient of tractive force were 46% and 87%, respectively. In the plowing test 50% slippage of the wheels occured at 11.6 cm plowing depth for the pneumatic wheels, and for the crawler the slippage was only 23.5% at about 21 cm plowing depth. The crawler requires much horse power for running itself and the traveling resistance of the'crawler was 4.5～5.1 times as high as for pneumatic wheels on herd fields and 3.0～3.5 times as high on soft fields. For this reason, tillers equipped with crawler should have engines stronger than 4.5 HP at least.

D. The tractive force of tillers with steel wheels.

Tillers are small and light machines that operate easily in paddy fields covered with water. This is one of the most important factors, but it is also very important that the tiller has as strong tractive force as possible, in spite of its small size. But there are many case in which to operate the tillers is very difficult, when they are heavy or have addedweight; so one of the ways to increase the tractive force is to attach steel wheels. For this object many kinds of steel wheels have been studied by manufacturers.

Our drawbar tests were carried out using nine tillers that were equipped with nineteen different kinds of steel wheels. The following description is just outline of the results.

(1) The tractive force of tillers with steel tires on common fields. According to the results of the tests, coefficient of tractive force of steel wheels was 73～79% on wet fields and 60～70% on soft fields, and the differences in coefficients were not very large among the various kinds of wheels. The coefficient of the steel wheels was the highest compared with the values for pneumatic wheels and pneumatic wheels with girdles. This is shown in Fig. 11.

Further considerations for each kind of steel wheel showed that the wheels which were too light and had small diameter or too many lugs did not have high coefficients of tractive force; and also when the area of the lugs was too small, the results were not favorable. On sticky paddy fields, the best results were obtained with pipe steel wheels.

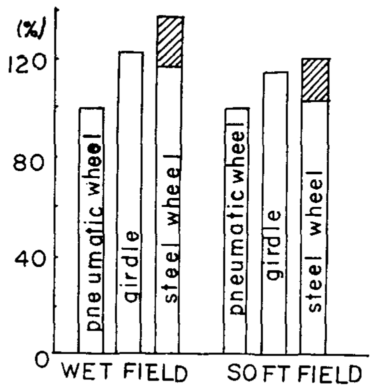

Fig. 11. Comparison of tractive force among three types of wheels.

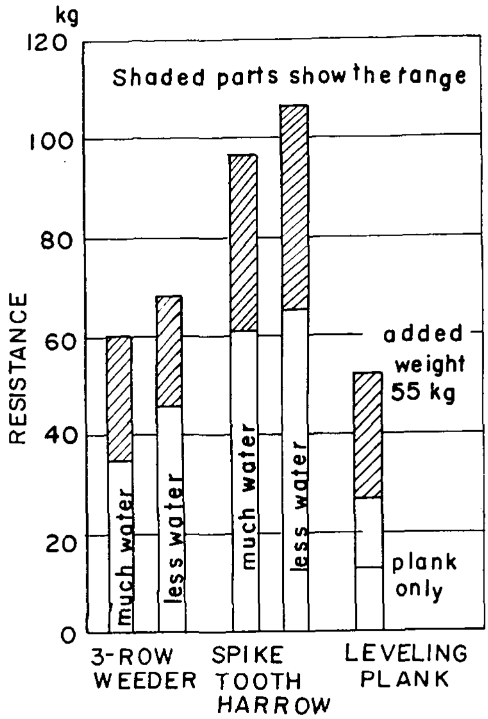

Fig. 12. Tractive resistance of some implements on paddy field.

(2) The tractive force of tillers with steel wheels on paddy fields covered with water.

Tee main operations of the tiller in paddy field covered with water are "Shirokaki", harrowing in water to make the final preparation of the rice bed, and weeding or cultivating. In paddy fields covered with water, pneumatic wheels can not used, since it is too slippery. Many interesting results were obtained in the tests for many types of steel wheels.

But only the results for the special wheels will be discussed here. It will be interesting to show the resistance of several implements in paddy fields covered with water. (Fig. 12). The shaded parts in Fig. 12 show the range of the resistance. The resistance of the implements in mud were greatly influenced by such factors as the holding angle of the implements, the angle of drawing, etc, since the holding or clogging of the mud among the member of implements, and the depth into the soil of implements, were much influenced by the operating factors. The most difficult operation was "Shirokaki", harrowing in water and the resistance was from about 100 kg to 60 kg.

Leveling and smoothing by plank is the lightest operation, and the resistance was from 50 kg~30 kg.

(a) Steel pipe wheels.

Fig. 13 shows one of the results of the tests. The tractive force of the steel pipe wheels was about 80 kg at 50% slippage of the wheels.

According to the results of all tests, the tractive force was from about 100 kg to about 50 kg. But when the coefficient of tractive force are compared among wheels which have different diameter and width of lugs, but have the same angle of lugs (30°), they show almost the same value, 50~51% at 50% slippage of the wheels. This fact shows that the width of lugs and diameter

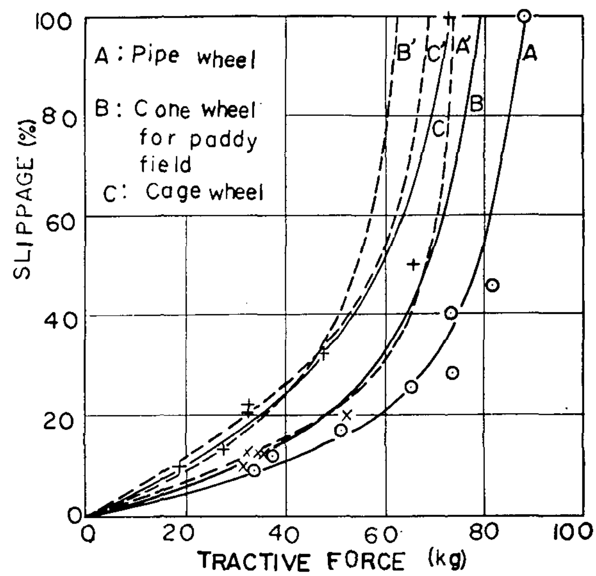

Fig. 13. Relation between tractive force and slippages of wheels for paddy field.

of wheels did not influence the tractive force. On the other hands, the angle of lugs to the wheels did influence the coefficient of tractive force. When the angle was 45°, the coefficient of tractive force was only 35%, but the coefficient increased to 80% at an angle of 20°. And then if the angle was smaller than 20°, the coefficient decreased. It is concluded that the best angle of lugs is about 20°.

The wheel shown in Fig. 6–7 has the commercial name "clam wheel"; The shape of the lugs is something like that of shell of a clam. This wheel has the characteristic that this shape of the lugs is useful for hard paddy fields, because the penetration into the soil is rather easy. The result of the test for the tractive force is shown in Fig. 14. Another type of pipe wheel is shown in Fig. 6–2. The fins which are around the tire work to keep machine from slippage from side to side, so the handling of machine is rather easy. But

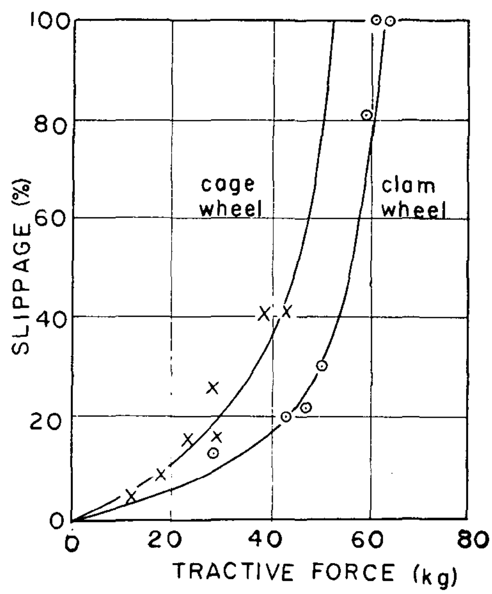

Fig. 14. Relation between tractive forces and slippages of wheels. ("Clam" wheel & Cage wheel)

there is a weak point in that the mud will clog in the fins and lugs, sometimes. The tractive force is not sufficient for "Shirokaki" operation, under some bad field condition. Making the fields condition good is very important. Too deep paddy fields and too little or too much water, etc, is not desirable for "Shirokaki" operation.

(b) Cage wheel.

This wheel is effective equipment for the "Shirokaki" operation and is used to-gether with a harrow in paddy field. The tractive force of this wheel is shown in Fig. 13. The tractive force is about 60 kg at 50% slippage of the wheels, and the coefficient tractive force is about 50%, according to tests with six tillers equipped with this type of wheel. This wheel works partly as pulverizing equipment, so the slippage of the wheels has special significance. This point should be kept in mind when considering these wheels.

6. Conclusion

Since the first tilling machines were imported from Switzerland, thirty years have passed, and during this thirty years there were three stages in the history of tilling machines. The first stage was the cradle period of the "Japanese type tillage machine", during this period many manufacturers designed and remodeled these machines, but it was difficult to increase their use among farmers. The second stage was the period during which Japanese tilling machines were getting spread among the farmers, and it could be said that this stage was from about 1940 to 1950. These machines were quite satesfactory and they were very useful for tilling operations in both common fields and paddy fields. The third stage began in 1951. This was the year include the "Merry tiller" was imported from the United States of America. This model was a kind of garden tractors, but it had a very simple mechanism and the weight of the weight of the machine was less than that of the common garden tractor, and also it had the characteristic that special tilling devices could be attached on the wheel-shaft in spite of the wheels. An another imprrtant characteristic was that the tillers was very cheap.

But there were lots of problems in satisfying the farmers in Japan, since this machine was not designed for the usual type of farming. It was designed for gardening, road-side working and other special purposes for farmers and others in foreign countries. But in Japan these machines were used not only in common fields, but also in paddy fields.

To make satisfactory tillers, all tiller makers continued their efforts. And also farmers offered many good suggestion to the manufactures. Most farm operations can be done by these machines today.

To-day's individual farmer's situation does not permit to use of large tracters, i. e. the area of the fields is not great enough, so small tractors are better suited farms of several hectares. In most case the paddy fields do not permit use of heavy machines and ordinary garden tractors are too heavy for easy operation. For this reason the tillers are the best machines for paddy fields, at least.

But there are many technical problems with tillers, as follows;

1. The tiller must be powerful enough to do paddy field operations and on the other hand, the weight of the tiller must be as small as possible.

2. Since the economical condition of all farmers is not good enough to allow purchase of the machines, the machines must be cheap.

3. Dust and water proofing on the main parts is important for the heavy work in water.

4. The attachments are as important as the tillers itself. All kinds of

good equipment must be provided as soon as possible. Harvesting equipment is one of the problems to be faced in the future, and there are some problems which should be solved in connection with weeding.

5. Problems of mounted engine are weighty, also.

6. The study of the technics to be used under various field condition is another important problems.

The wheel of the tiller is one of the important parts related to the tractive force, so the several results of our tests on wheels were introduced in this report.

Steel wheels are useful in increasing the tractive force of tillers in paddy fields. Many kinds of steel wheels have been designed by the tiller makers, and some of these wheels are described. The most interesting wheel is the "Kagogata wheel" Cage wheel, and this wheels work partly as wheels partly as kind of pulverizer in paddy fields covered with water.

The tractive force of tillers is influenced by the kind of wheels, the total weight of the machines, the bearing portion of the torque reaction of the machines, the field condition, etc. These problems must be resolved by the future studies, but some results can be shown as follows:

1. The weight of tillers is about 80 kg～120 kg, and the total weight including the ballast and balancing weights is about 130～180 kg.

2. The tractive force of machines with pneumatic tire is about 80～90 kg at 50% slippage on dried fields. And the coefficient of tractive force is about 50～60%.

3. The available maximum tractive force should be considered at 50% slippage of wheels on the tiller, since the tractive force of the machine is helped by human power.

4. To increase the tracting force the equipment should be attached as near as possible to the wheel shaft.

5. For trailing operations the wheels of the wagon should be far the wheel-shaft of the tiller to increase the trailing force.

6. The tractive force of tillers equipped with common steel wheels (pipe steel wheels) is about 90～105 kg on wet fields.

7. The angle of the lug is closely related to the tractive force, and the best angle is about 20 degress.

8. The tractive force and coefficient of the "Shirokaki rotor" are about 70 kg and 50%, respectively.

9. The tracting force and the coefficient of the crawler are about 175～200 kg and 70～80%, respectively.