韓國犁와 Plow의 發達過程 및 犁와 Plow의 各種土壤條件下에서의 耕深과 牽引抵抗에 關한 研究(Ⅱ)

A Study Of Development Processes Of Korean and Western Plows and Their Draft Resistances to A Various Plowing Depth and Soil Conditions(Ⅱ)

崔 在 甲*
Jae Kap Choi

Theoretical Analysis of the Draft Resistance

As the plow bottom advances through the soil layer, soil blocks (6) may be formed as shown in Fig. (16). Fig. (17) shows the shearing pattern of soil (a), the free-body diagrams of soil-block (b) and of tool (c), including forces being developed between the soil-block and the plow bottom (11) for the geometry given in Fig. (16).

The major forces included in this study are as follows:

1. Shearing force being developed between shearing forces of the soil-block.
2. Inertia force by the movement of plowed soil-block.
3. Sliding force developed on contacting surface between the soil-block and tool.
4. Friction force between the soil and the landside developed by the weight of soil-block and tool.
5. Total draft resistance against all of the resistant forces(34, 35).

As three-dimensional curved surface of plow bottom produces the complicate resistant forces, we have to identify the important factors involved in the soil-tool system as follows:

1. Coulumb's law, $S=C+P \tan \phi$, is used to calculate the shearing stresses of soil.
2. The slope angle of the plow bottom face is α, and the end of the plow bottom is a sharp wedge.
3. As mentioned above, plow bottom is formed by three dimensional curved surface, and thus the areas projected are on the mutually perpendicular three plans smaller than the real surface. Force acting on the projected area on the longitudinal plane develops the lateral force to turn over the soil-block.
4. The shearing angle, the angle between shearing plane of soil-block and horizontal plane, is $45-\frac{1}{2}\phi$ as shown in Fig. (16). The identical definition was given by M.L. Nichols.
5. $S=AC+P \tan \phi$ is used to calculate the shearing forces taking place on both sides of the sharp wedge.

* 서울大學校 農科大學

But, the pressure, P, is so negligible that the shearing forces acting on the tool side can be calculated by using the formula, $S=AC$.

The following is the nomenclature of the quantities to be used in developing the equation of motion for the soil and tool system:

W : Weight of the soil block. (kg)

B : Inertia force resulting from the velocity change of soil block. (kg)

D_f : Draft force. (kg)

G_1 : Weight of the Korean Janggi. (kg)

V : Vertical component of the force exerted on the bottom of the Korean Janggi. (kg)

C : Cohesion of the soil. (kg/cm²)

C_a : Tangential stress due to adhension of the soil on metal. (kg/cm²)

f_i : Coefficient of internal friction of the soil (tan ϕ)

ϕ : Angle of internal friction of the soil.

f_s : Coefficient of the friction between the soil and metal surface.

A_1 : Contact area between the soil and the bottom of the tool (Korean Janggi). (cm²)

A_2 : Projected area of the curved surface of the Korean Janngi to the horizontal plane. (cm²)

A_3 : Shearing area of the soil block. (cm²)

α : Slope angle of the tool.

β : Angle between the shearing plane of the soil block and horizontal plane.

N_0 : Normal component of the force exerted on the soil by the sloped face of the tool. (kg)

N_1 : Normal component of the force exerted on the soil block by the undisturbed mass of soil. (kg)

V_0 : Horizontal velocity of the tool. (m/sec) (Plowing velocity)

t : Plowing depth. (cm)

b : Width of the tool. (cm)

δ : Soil density. (gr/cm³)

V_s : Shearing velocity of the soil block. (cm/sec), the value of which can be determined by the relative velocity diagram.

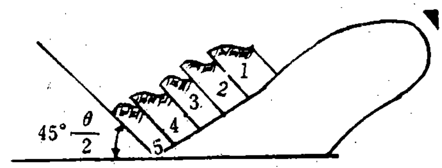
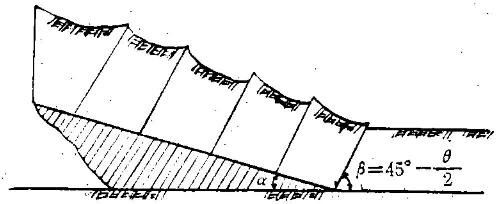
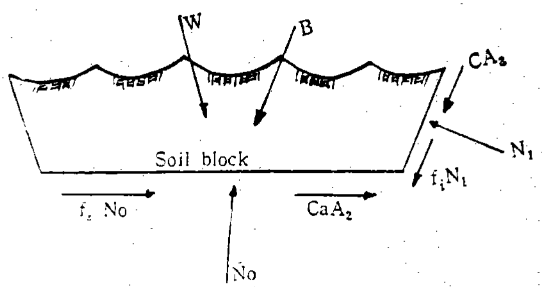


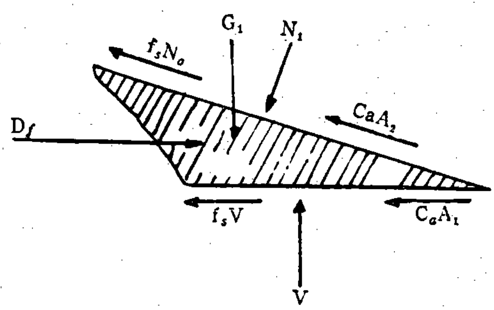
Fig. 16 Shearing pattern of soil block



(a) Shearing pattern of plowing



(b) Free body diagram of soil block



(c) Free body diagram of tool

Fig. 17 Free-body diagram of plowing soil block

Derivation of equation of motion

The equation of motion for the soil-tool system given in Fig. (17) can be derived by use of D'Alembelt's principle. It should be noticed that D_f is the function of the plowing depth, t, even when the other factors are constant.

For soil block given in Fig. (17), (6)

$\Sigma F_x=0;$

$$N_0(\sin\alpha+f_s\cos\alpha)-N_1(\sin\beta+f_i\cos\beta)-\cos\beta(CA_3+B)+C_aA_2\cos\alpha=0 \quad (1)$$

$\Sigma F_y=0;$

$$W-N_0(\cos\alpha-f_s\sin\alpha)-N_1(\cos\beta-f_i\sin\beta)+(B+CA_3)\sin\beta+C_aA_2\sin\alpha=0 \quad (2)$$

For tool given in Fig. (17), (C)

$\Sigma F_x=0;$

$$D_f=N_0(\sin\alpha+f_s\cos\alpha)+C_a(A_2\cos\alpha+A_1)+f_sV \quad (3)$$

$\Sigma F_y=0;$

$$V=G_1+N_0(\cos\alpha-f_s\sin\alpha)-C_aA_2\sin\alpha \quad (4)$$

Substituting equation(4) into(3), we obtain

$$D_f=N_0(2f_s\cos\alpha-f_s^2\sin\alpha+\sin\alpha)+C_aA_2\cos\alpha-f_sC_aA_2\sin\alpha+C_aA_1+f_sG_1 \quad (5)$$

Let us take the notations for the terms in Equations (1) and (2) as follows:

$$a_0=\sin\alpha+f_s\cos\alpha \qquad a_1=\cos\alpha-f_s\sin\alpha$$
$$b_0=\sin\beta+f_i\cos\beta \qquad b_1=\cos\beta-f_i\sin\beta$$
$$c_0=(B+CA_3)\cos\beta \qquad c_1=(B+CA_3)\sin\beta \quad (6)$$
$$d_0=C_aA_2\cos\alpha \qquad d_1=C_aA_2\sin\alpha$$
$$e_1=f_sV+C_aA_1$$

Substituting Equation (6) into Equations (1) and (2) gives:

$$a_0N_0-b_0N_1-c_0+d_0=0 \quad (1)'$$
$$W-a_1N_0-b_1N_1-b_1N_1+c_1+d_1=0 \quad (2)'$$

From these, we can write the Equation for N_0 as follow:

$$N_0=\frac{1}{b_1a_1+b_0a_1}\,b_0(W+c_1+d_1)+b_1(c_0-d_0) \quad (7)$$

It can be seen from the Fig. (19) that

$$l_1=\frac{t}{\sin\beta}\cos(\alpha+\beta)=\left(\frac{\cos\alpha}{\tan\beta}-\sin\alpha\right)t$$

$$l_2=\tan\alpha t$$

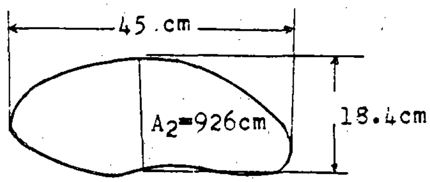


Fig. 18 Projected area of the bottom face of Korean plow on horizontal plane

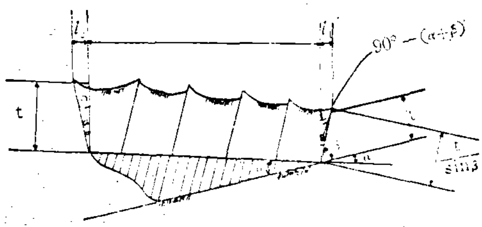


Fig. 19 Cross section of a tool in soil

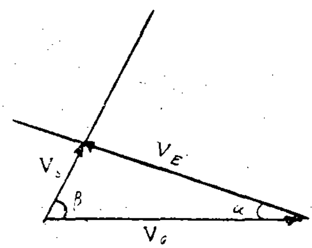


Fig. 20 Determination of relative velocity. Vs

$$\triangle(1)=\tfrac{1}{2}\left(\frac{\cos\alpha}{\tan\beta}-\sin\alpha\right)t^2$$

$$\triangle(2)=\tfrac{1}{2}\tan\alpha t^2$$

$$\triangle=\triangle(1)+\triangle(2)=\tfrac{1}{2}\left(\frac{\cos\alpha}{\tan\beta}-\sin\alpha+\tan\alpha\right)t^2$$

As the weight of the plowing soil, W and plowing depth, t, have a functional relationship, we can relate these as

$$W=A_2\delta t+\frac{b\delta}{2}\left(\frac{\cos\alpha}{\tan\beta}-\sin\alpha+\tan\alpha\right)t^2 \quad (8)$$

The inertia force can be written as

$$B=\frac{\delta}{g}(btv_0)\,(T)(a)=\frac{\delta}{g}(btv_0v_s) \quad (9)$$

Where; T = the time taken from the beginning to plow until the end of the first furrow slice turned over.

a = acceleration of unit soil block

$v_s=(a)(T)$

$\frac{\delta}{g}btv_0T$ = mass of soil block

Rewrite the Equation N_0 with full terms;

$$N_0=\left[\frac{1}{(\cos\beta-f_i\sin\beta)(\sin\alpha+f_s\cos\alpha)+(\sin\beta+f_i\cos\beta)(\cos\alpha-f_s\sin\alpha)}\right]$$
$$\times[(\sin\beta+f_i\cos\beta)\{W+(B+CA)\sin\beta+C_aA_2\sin\alpha\}+(\cos\beta-f_i\sin\beta)\{(B+CA_3)\cos\beta-C_aA_2\cos\alpha\}] \qquad (10)$$

Substituting B and W solved in Equation (9) and (8) into Equation (10) respectively, we obtain

$$N_0=\frac{1}{\sin(\alpha+\beta)(1-f_if_s)+\cos(\alpha+\beta)(f_i+f_s)}\times\tfrac{1}{2}(\sin\beta+f_i\cos\beta)\left(\frac{\cos\alpha}{\tan\beta}-\sin\alpha+\tan\alpha\right)$$
$$b\delta t^2+(\sin\beta+f_i\cos\beta)\left(A_2\delta+\frac{\delta}{g}b\ v_0\ v_s\ \sin\beta\right)+(\cos\beta-f_i\sin\beta)\ \cos\frac{\delta}{g}b\ v_0\ v_s\ t$$
$$+(\sin\beta+f_i\cos\beta)\times(CA_3\sin\beta+C_aA_2\sin\alpha)+(\cos\beta-f_i\sin\beta)\times(CA_3\cos\beta-C_aA_2\cos\alpha) \qquad (11)$$

Substituting N_0 into (5) :

$$D_f=\frac{\sin\alpha+2f_s\cos\alpha-f_s^2\sin\alpha}{\sin(\alpha+\beta)(1-f_if_s)+\cos(\alpha+\beta)(f_i+f_s)}\times\tfrac{1}{2}(\sin\beta+f_i\cos\beta)\left(\frac{\cos\alpha}{\tan\beta}-\sin\alpha+\tan\alpha\right)b\delta t^2$$
$$+(\sin\beta+f_i\cos\beta)\left(A_2\delta\frac{\delta}{g}bv_0v_s\sin\beta\right)+(\sin\beta+f_i\cos\beta)\times(CA_3\sin\beta+C_aA_2\sin\alpha)+(\cos\beta-f_i\sin\beta)\times(CA_3$$
$$\cos\beta-C_aA_3\cos\alpha)+C_a(A_2\cos\alpha+A_1)+f_s(G_1-C_aA_2\sin\alpha) \qquad (12)$$

Equation (12) is the theoretical Equation of motion to estimate the draft force on the Korean plow (Janggi).

Ⅳ. Experimental Design and Equipment

1. Experimental design and procedure

Under the natural conditions of the fields, it can be supposed that the draft of the Korean Janggi may depend upon the soil conditions, plowing depth and some other factors-soil type, its moisture content, and plowing depth. However, the three factors were taken as the major variables in this study.

As shown in table (1), the soil types were classified into six kinds, and the soil moisture contents into four different levels. The plowing depths were varied from 5 cm to 18 cm. Under the combinations of these conditions, the drafts were measured.

The experimental work was carried out during the three months from April to June. The draft of the Korean Janggi were measured on the dry fields and the rice paddies (in response to the variety of the soil moisture content under the natural conditions).

The measurements were taken in the dry field and paddies located in Suweon area where the soil properties are understood not to be quite different from those in the other area of the middle section of Korea. The physical and mechanical properties of soils to which the draft measurement were carried out, were analyzed and are summarized in Table (2).

2. Experimental equipment

1) Janggi and plow used in this experiment

The Korean Janggi and western plow used for this study are shown respectively in Fig. (21) and Fig. (22), the dimensions of which being summarized in Table (3). The following are the details of plow bottom configuration of the tillage tools used in this study.

Table (1) Experimental design and levels of variables

○ : used Janggi or plow
× : not used plow

Classification / Soil type	Moisture number	Soil moisture content (%)	Janggi	Plow	Plowing depth (cm)	Plowing width (cm) Janggi	Plowing width (cm) Plow	Plowing velocity (m/s)
F—Ⅰ (Clay'ey field)	1	26.4	0*	—	5-18	30	—	0.425
	2	27.1	0	—	〃	〃	—	〃
	3	24.4	0	0	〃	〃	22	〃
	4	12.4	0	0	〃	〃	〃	〃
F—Ⅱ (Loamy field)	1	30	0	—	3-18	〃	—	〃
F—Ⅲ (Sandy loamy field)	1	16.5	0	—	3-17	〃	—	〃
F—Ⅳ (Fine sandy loamy field)	1	11	0	—	11-13	〃	—	〃
P—Ⅴ (Clay'ey paddy)	1	35	0	—	5-6	〃	—	〃
	2	41	0	0	〃	〃	22	〃
P—Ⅵ (Sandy loamy paddy)	1	19.65	0	—	4-17	〃	—	〃
	2	23.9	0	0	〃	〃	22	〃
	3	29.5	0	0	〃	〃	〃	〃
	4	30	0	0	〃	〃	〃	〃

* 0 denotes that the tool was used for experiment.

Table (2) Physical and mechanical properties of soils to which the drafts were measured

Soilno. / Physical soil factors	F—*—Ⅰ				F—Ⅱ	F—Ⅲ	F—Ⅳ	P*—Ⅴ		P—Ⅵ			
	1	2	3	4	1	1	1	1	2	1	2	3	4
Soil moisture content(%)	26.4	27.1	24.4	18.4	30	16.5	11	35	41	19.7	24	29.5	30
Angle of internal friction(ϕ)	31′	30′	29′	17′	38′	32′	29′	19′	22′	22′	30′	40′	35′
f_i	0.6	0.6	0.56	0.3	0.77	0.62	0.55	0.35	0.4	0.4	0.58	0.8	0.7
c (kg/cm²)	0.15	0.21	0.22	0.16	0.08	0.14	0.02	0.18	0.5	0.21	0.22	0.14	0.18
δ (gr/cm)	1.56	1.78	1.53	1.6	1.65	1.78	1.56	1.82	1.84	1.79	1.85	1.85	1.8
f_s	0.3	0.3	0.3	0.4	0.4	0.3	0.3	0.2	0.1	0.3	0.3	0.3	0.3
Ca (kg/cm²)	0.01	0.01	0.015	0.01	0.01	0.01	0.015	0.12	0.01	0.01	0.01	0.01	0.01
Soil type	clay				loam	sandy loam	fine sandy loam	clay		sandy loam			
Clay content (%)	36				19	6	3	38		12			
Sand content (%)	16				49	74	78	18		59			
Silt content (%)	43				32	20	16	44		29			

* F denotes the upland field and P the paddy field.

Table (3) The size of Janggi and plow

Classification	Janggi	Plow
Beam length (cm)	155	100
Max bottom length (cm)	41	57
Handle length (cm)	121	124
Max bottom width (cm)	30	22
Length of landside (cm)	35	35
Total body weight+ (depth gauge) (kg)	27.1	27.1

The profile of the mouldboards (bottom)

The coordinate system was established to determine the profile of curved surface of Janggi-bottom, as shown in Fig. (23). The Janggi was placed on the horizontal plane in such a way that the bottom of the landside could contact perfectly on the plane. The y-axis was established along the center line of the landside which also passed through the share point. The share point was the origin of the coordinate system. The x and z axes

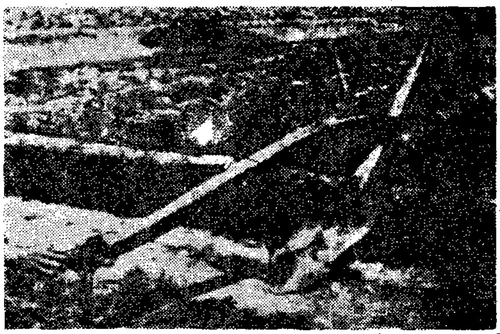


Fig. 21 Photograph of Korean Janggi used for this study

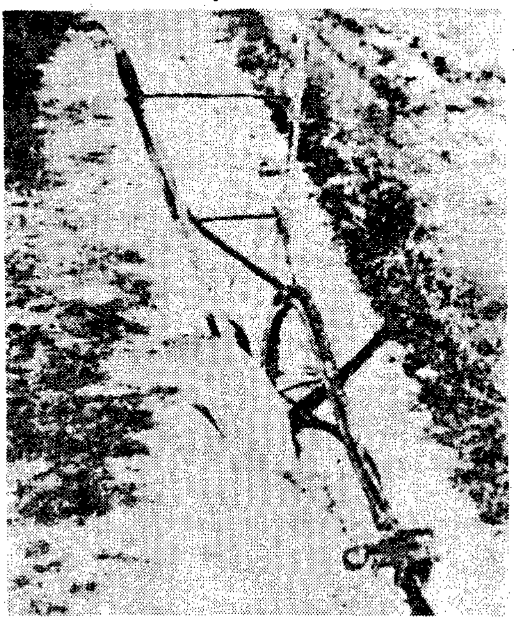
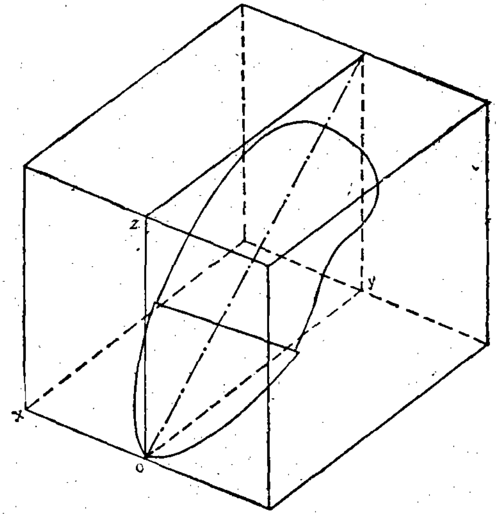
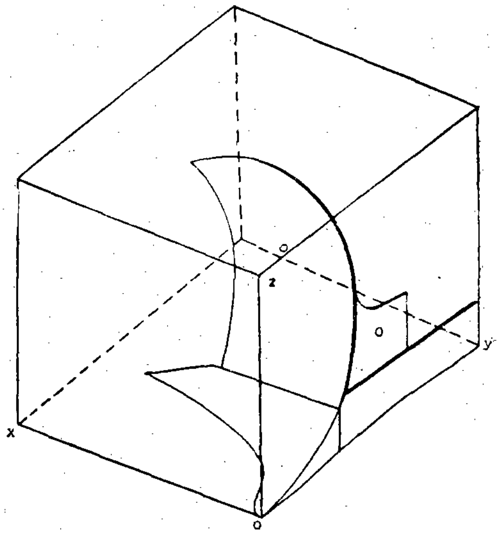


Fig. 22 Photograph of western plow used for this study



(a) Rectangular coordinate system established for Janggi



(b) Rectangular coordinate system established for western plow

Fig. 23 The coordinate system established to determine the bottom-face profile of tillage tools

for the rectangular coordinate system were established so as to be mutually perpendicular to y-axis, being taken z-axis as vertical.

The only difference of the coordinate system established for the western plow from that of the Janggi was the selection of y-axis. For the western plow the y-axis was elected to pass through the share point and was along the side of landside, while in the Janggi the y-axis was established along the center line of the landside. Accordingly, with this in mind, the bottom profiles for both type of tillage tools could be explained by adopting the same reference coordinate system.

To establish the reference points or lines on the surface of the share and moldboard, which may be necessary for defining the projection views of the surface, three axes divided into segments having 3 cm intervals.

The caplanar planer passing through these points on each three axes were established and their intersections with the bottom profile were marked off to define the side front, and top views.

Fig. (24) and (25) shows the projection views of the Janggi and western plow, respectively.

The horizontal lines appearing in side-view indicates the reference lines on the plow bottoms which have been formed by the xy planes perpendicular to z-axis.

These lines appear as the curves in the top-view, as seen from a bundle of curved lines in the top-view. In addition, a bundle of the curved lines in the longitudinal direction in the side-view show the surface line projected on yz-plane, the surface lines being formed by intersecting the bottom surface with the coplanar yz-planes which are perpendicular to the x-axis and passed through 3 cm segment points on the x-axis. A bundle of curved lines appearing in the front-view are

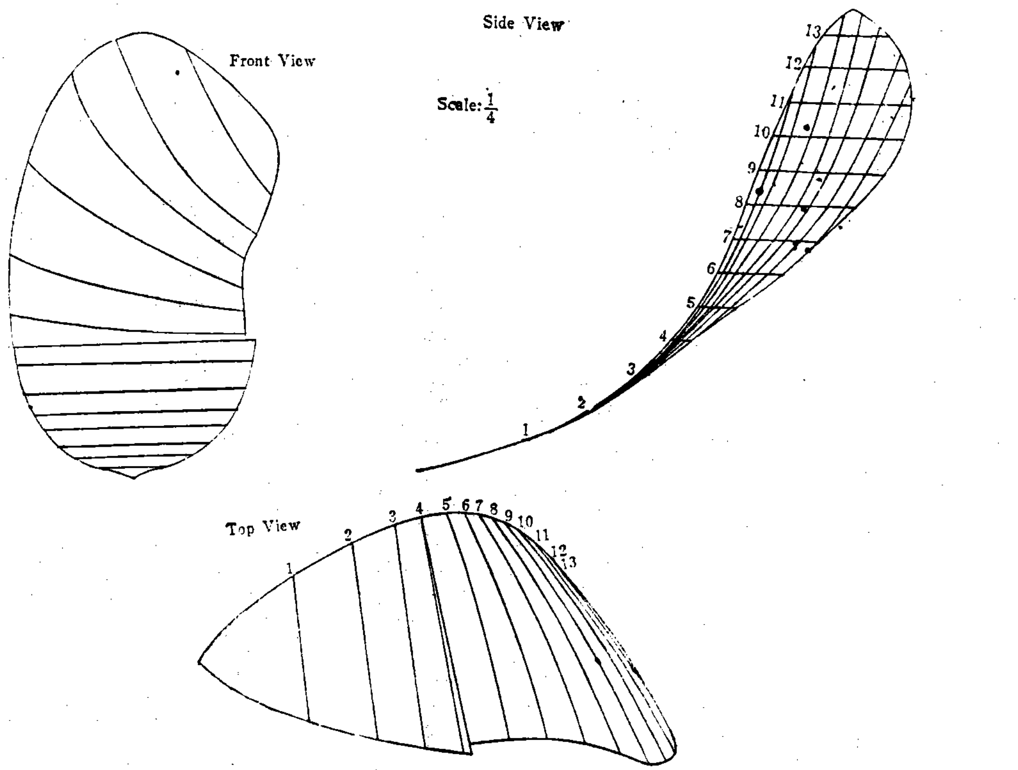


Fig. 24 Prtection views of bottom-face profile of Janggi

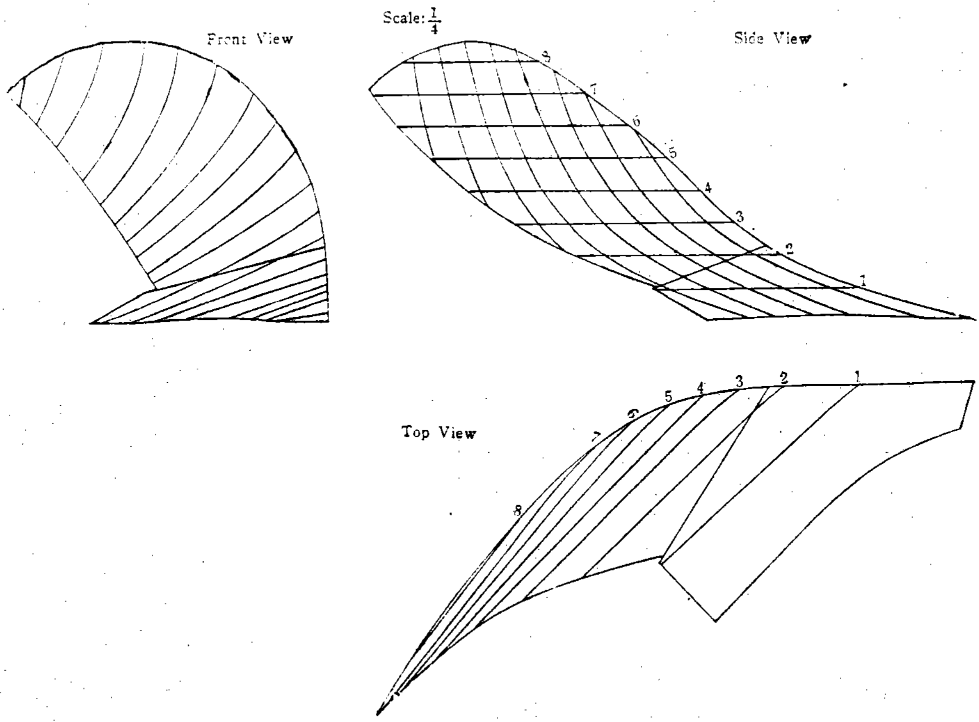


Fig. 25 Protection views of bottom-face profile of western plow

the surface lines projected on the xz-planes, the surface lines being the intersecting lines between the plow surface and the xz-planes which are formed on y-axis.

Characteristics of the projected views

The difference of the shape between the western plow and Janggi may be quite apparent from comparison of the corresponding projection views of Figs. (24) and (25). As a whole, the western plow has much sophisiticated bottom profile and its curvature is greater and smooth compared to the Janggi. It is expected that these overall differences of bottom and share profile may affect to a greater extent on the shearing, friction, and overturning forces.

Basic difference in the side-view between two tillage tools could be noticed from the shape of the share. The share of the western plow is extended widely in the lateral direction, while that of Janggi is of symmetry about the center line which passes through the share point and is comparatively narrow along the forward direction. Because of these, it may be easily justified that the western plow may be better in lateral stability, however, which may require inevitably an additional shearing and overturning forces compared to the Janggi.

In the top-view, Janggi has a relatively compact form and the area of share appears to be greater than that of the moldboard, while western plow has a much greater area of moldboard than that of share. It can be supposed from these results that the overturning action of soil-block in the western plow may be very smooth and complete compared to Janggi, the overturning action of which being controlled usually by the operator while plowing.

The area of the front-view may be very important to represent the overall resistance

Table (4) Dimensions of plow and Janggi bottoms

Description	Dimension		Unit
	Plow	Janggi	
Share width	220	232	mm
Share length	336	260	〃
Max height of share	70	128	〃
Min height of share	30	124	〃
Max slope length of share	308	276	〃
Min slo e length of share	200	260	〃
Width of waist	164	232	〃
Length of waist	132	232	〃
Proiection length of bottom to x-axis	300	320	〃
Projection length of bottom to y-axis	584	444	〃
Height of plow bottom	264	420	〃
Horizontal suction	3	—	〃
Down suction	2	—	〃
Share suction	3.5	—	〃
Share angle	45°	55°	degree
Wedging angle	26°	30°	〃
Reverse turn angle	55°	45°	〃
Landside	10×85×452	530×70×250	mm^3

of plow as it pulled forward. As seen from comparison of front-views for both tools, the Janggi appears to have a greater area of the front-view compared to the western plow.

The characteristics of plow-bottoms can be specified in detail by comparing the lengths or angles of the specified terms which are generally used in defining the configuration of the plow and Janggi bottoms. Table (4) shows the measured dimensions of the specified terms for two tillage tools being engaged in this study. It may be especially noticed that no suctions have been provided for Janggi, even though those for the western plow have been recognized as very important to make easier in maintaining the desired depth or width of cut.

2) Drawbar dynamometer

Draft force-measuring gauge being used in this experiment as shown in Fig. (26) was the spring-loaded drawbar dynamometer that can measure one directional drawbar pull. Spring constant for the dynamometer, K, is 26.2 kg/cm. The spring force with respect to displacement can be recorded continuously on the recording paper, 8 cm wide and 70cm length. The draft force has been calibrated as the function of spring displacement, which is related by the equation, $F=26.2S+35$, where F is the draft and S is the spring displacement.

Fig. 26 The draft measuring-gauge

3) Plowing depth gauge

In order to measure the draft forces for various conditions of plowing operations, the measuring device for the draft force and the plowing depth may be necessary.

For this purpose, the author designed and constructed a new self-recording depth gauge as shown in Fig. (27). The drawings of the design are shown in Appendix.

The major parts of the gauge corresponding to the indicated numbers are referred to as follows:

(1) Contact roller on the earth surface
(2) Plowing depth indicating slider
(3) Axis of slider
(4) Indicating rod
(5) Main paper-roller
(6) Following paper-roller
(7) Drive wheel of decrease-revolution-gear
(8) Drive axis of decrease-revolution-gear
(9) Indicating pen
(10) Case of the decrease-revolution-gear
(11) Frame of self-recording depth-gauge

The op rational principle of the self-recording depth gauge could be explained as the following.

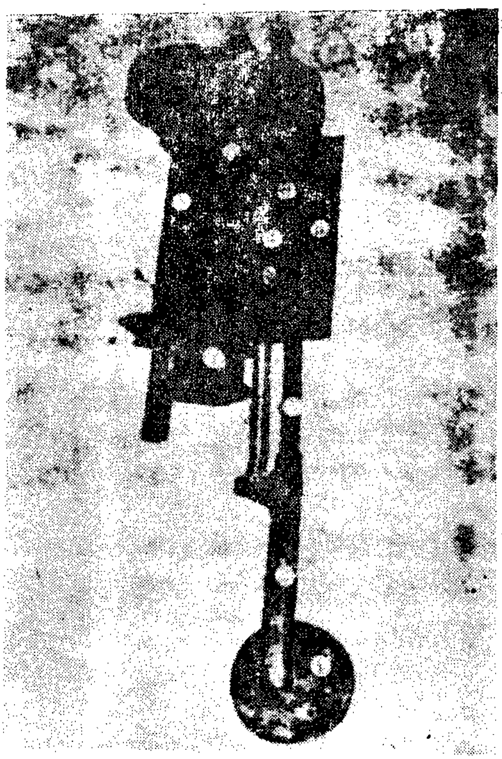


Fig. 27 Self-recording depth gauge

The recording paper, 20cm wide and 70cm length, is wound around the No. (6) part and one end of the paper is connected to the No. (5) part.

The revolving velocity of the No. (7) part is decreased by the decrease-revolution-gear, the gear ratio being 1 to 100. Therefore, the speed of recording paper is 1/100 to that of plow.

The roller (5) is driven by the decreasing gear and the No. (8) is driven by the rope being wound around the No. (7). The No. (1) part rolls on the earth surface and takes the reciprocating motion in the vertical direction, according to the depth of plowing.

Since the contact roller on the earth surface is the receiver of plowing depth, it must contact with the earth all the time as the plowing progresses. If the pressure of contact were too large, the plowing depth would not be measured correctly, because the natural condition of the field surface is too rough which would increase the side pressure. If the diameter were too small, the roller would penetrate into the earth which is very weak, and the side pressure on the roller would be increased. We have to compromise the size of the diameter with the various operation conditions, the resulting diameter so determined being 112mm.

The No. (4) part, fixed to the No. (1) part, has an indication pen which, by contacting with the No. (6) part, continuously records the various plowing depths on the recording paper.

The plowing depth gauge was fixed on the beam of the Janggi, then the contact roller has to take its position on near the end of the Janggi bottom, as shown in Fig. (28)

The draft force-measuring-gauge was fastened between the end of the beam and the drafting rope as shown in Fig.(26).

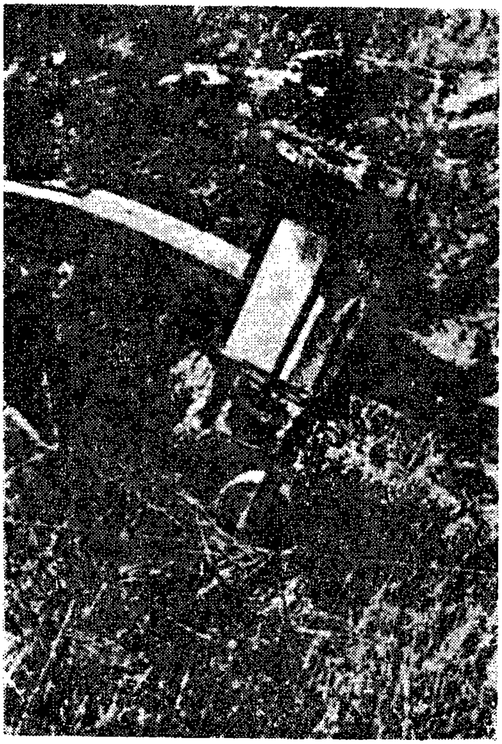


Fig. 28. Plowing depth gauge

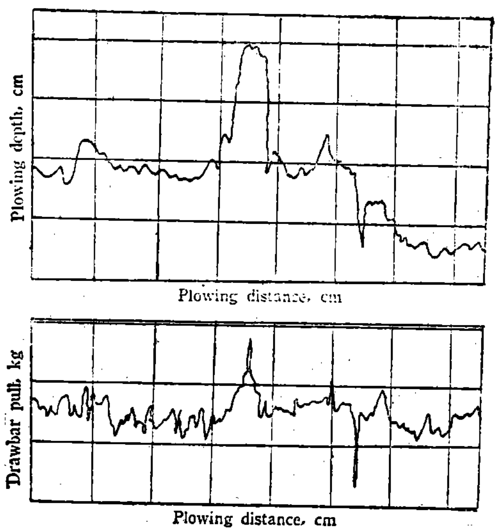


Fig. 29 A pair of osillograph for the plowing depth and the draft resistance

The plowing velocity was 0.425m/sec and the operation distance on the fields was limited to 60m, to fit in the recording paper, and the operation was repeated three times.

Since the depth-recording-paper's speed, passing under the indicating pen, was adjusted as fast as that of the draft force-recording-paper, the plowing depth and the draft could be recorded simultaneously on the recording papers, which formed many pairs of osillographs as shown in Fig. (29).

CHAPTER Ⅴ

ANALYSIS OF RESULT AND DISCUSSION

1. Analysis of results

The pair of the osillographs measured through the experiment shows the continuous values of the plowing depth and the drawbar pull for the varied moisture content of different soil types tested.

The data obtained from the analysis of osillographs are shown in Table (4). The relation between the draft forces and the plowing depth are plotted as shown in Fig. (31)-(a-s).

In order to compare the experimental value with the corresponding theoretical one, experimental equations, summarized in Table (6), were determined by use of the experimental data. The theoretical equations were analyzed by substituting the parameters of the soil factors given in Table (2) into the equation for D_f. The following assumptions are made in deriving the theoretical equations as summarized in Table (7).

(1) Assuming the value of the plowing velocity (V_0) as 0.425 m/sec, the value of the shearing velocity (V_s) was determined through the relative velocity analysis as shown in Fig. (20), the value of which being 0.25m/sec.

(2) The projected area of the plow-bottom face on the horizontal plane, A_2, was taken as 926 cm^2 by actual measurement.

Table (5) The measured arafts for various plowing depths

D_f : kg
Depth : cm

F-Ⅰ-1	Depth	5	6	7	8	9	10	11	12	13	14	15					
	D_f	61.0	87.0	87.0	76.9	113.6	121.0	113.6	95.0	126.3	113.6	166.6					
F-Ⅰ-2	Depth	3	4	5	6	7	3	9	10	11	12	13	14	15	16	17	18
	D_f	45.5	50.72	61.2	58.0	50.72	61.2	73.0	103.1	100.4	126.6	124.1	113.6	124.1	139.8	152.2	152.8
F-Ⅰ-3	Depth	3	4	5	6	7	8	9	10	11	12	13	14	15	16		
	D_f	48.0	56.0	61.2	77.0	63.7	87.4	89.9	74.0	105.6	110.9	118.8	124.1	134.6	175.0		
F-Ⅰ-4	Depth	4	5	6	7	8	9	10	11	12	13	14	15	16			
	D_f	61.2	56.0	58.7	74.0	103.1	113.6	108.4	166.0	166.0	166.0	152.8	166.0	166.0			
F-Ⅱ-1	Depth	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	
	D_f	50.72	42.7	71.5	66.4	61.2	87.4	66.4	124.1	150.2	155.5	100.4	152.8	126.6	139.8	160.8	
F-Ⅲ-1	Depth	3	4	5	6	7	8	9	10	11	12	13	14	15	16		
	D_f	42.7	55.86	55.96	74.0	69.0	48.0	69.0	50.72	74.0	108.4	100.4	87.4	113.6	147.5		
F-Ⅵ-1	Depth	11	12	13	14	15	16	17									
	D_f	40.2	61.2	74.0	74.0	105.6	92.6	118.8									
P-Ⅴ-1	Depth	5	6	7	8	9	10	11	12	13	14	15	16				
	D_f	66.4	63.7	76.9	87.9	113.6	126.6	152.8	137.0	152.8	166.0	168.0	166.0				
P-Ⅴ-2	Depth	8	8	9	10	10	10	10	10.5	10.5	11	12	12	13	13		
	D_f	66.4	79.4	105.7	82.2	87.4	92.6	100.4	61.2	97.9	87.4	97.9	103.1	113.6	115.0		
P-Ⅵ-2	Depth	4	5	6	7	8	9	10	11	12	13	14	15	16	17		
	D_f	50.7	53.5	61.2	73.0	59.0	92.6	97.9	87.4	131.8	139.8	129.3	150.3	157.0	163.5		
P-Ⅵ-3	Depth	4	5	6	7	8	9	10	11	12	13	14	15				
	D_f	48.0	53.0	50.7	58.0	74.0	82.2	113.6	103.1	113.6	124.1	129.3	139.8				
P-Ⅵ-4	Depth	6	7	8	9	10	11	12	13	14	15	16					
	D_f	58.6	56.0	53.2	97.9	126.6	118.8	113.6	116.1	139.8	131.8	158.0					

(3) Since the theoretical equation has been expressed by the draft force (D_f), the force was converted into the drawbar pull (D_p) to compare directly with the measured drawbar pull, the relationship between two forces being shown in Fig. (30).

$$D_p=\frac{D_f}{\cos\theta}$$

where, θ is draft angle.

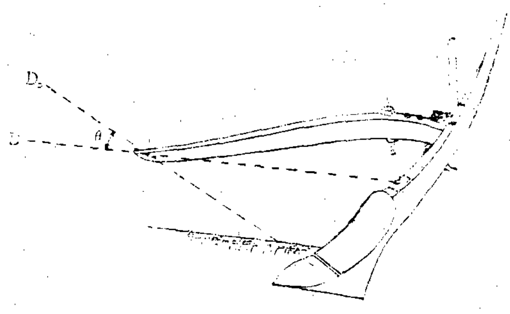


Fig. 30 Relation between the D_f and D_p

Table (6) Experimentally determined relations between drawbar pull (y) and plowing depth (x) for vairious soil conditions

Soil No.	Experimentally determined relation
F-Ⅰ-1	$y=0.143x^2+4.77x+31.63$
F-Ⅱ-1	$y=0.35x^2+x+40$
F-Ⅲ-1	$y=0.64x^2-6.7x+60.5$
F-Ⅳ-1	$y=x^2-17x-106$
P-Ⅴ-1	$y=0.75y^2+5x+65$
P-Ⅵ-1	$y=0.118x^2+8.7x+20.3$

Table (7) Theoretically analyzed relations between drawbar pull (y) and plowing depth for the identical conditions as given in Table (6)

Soil No.	Theoretical equations
F-Ⅰ-1	$y=0.041x^2+5.3x+35$
F-Ⅱ-1	$y=0.04x^2+8x+27.5$
F-Ⅲ-1	$y=0.031x^2+4.55x+30$
F-Ⅳ-1	$y=0.029x^2+2.74x+22.3$
P-Ⅴ-1	$y=0.018x^2+9.57x+15.2$
P-Ⅵ-1	$y=0.023x^2+7.34x+23.5$

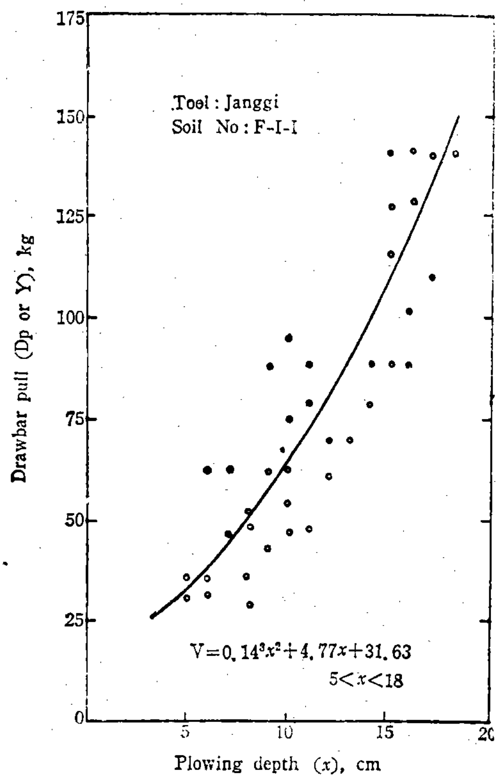


Fig. (31-(a)) The relationship between the measured plowing depth and drawbar pull

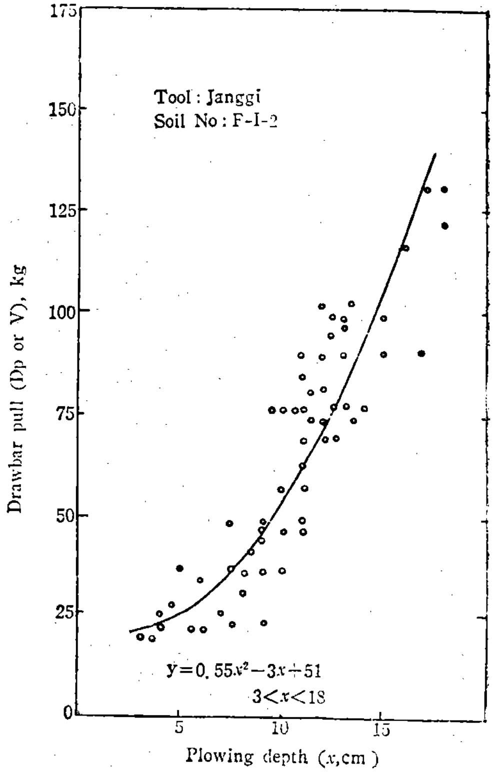


Fig. (31-(b)) The relationship between the measured plowing depth and drawbar pull

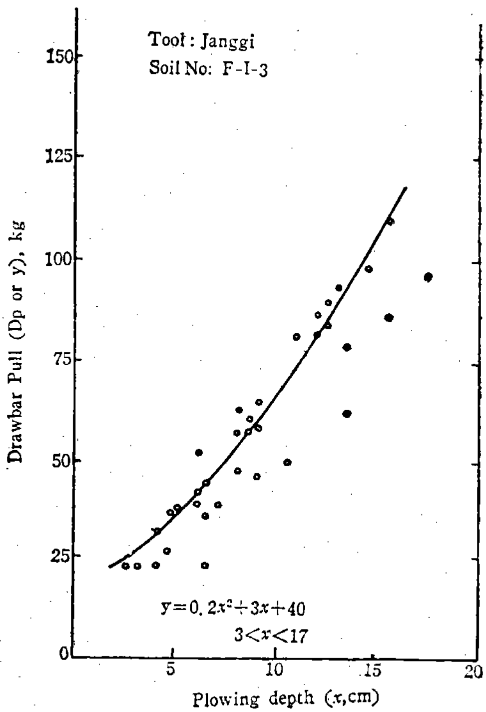


Fig. (31-(c)) The relationship between the measured plowing depth and drawbar pull

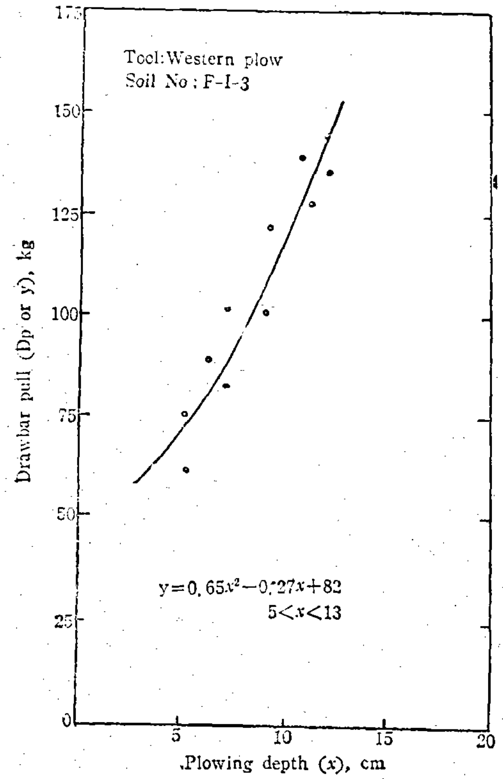


Fig. (31-(d)) The relationship between the measured plowing depth and drawbar pull

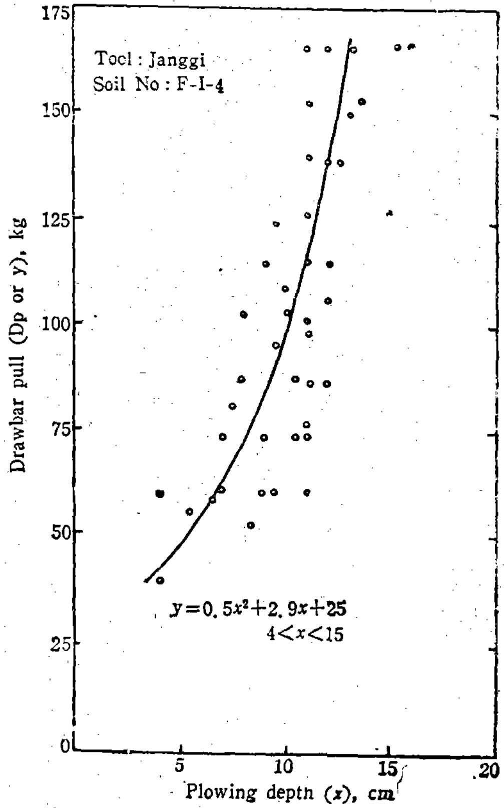


Fig. (31-(e)) The relationship between th measured plowing depth and drawbar pul

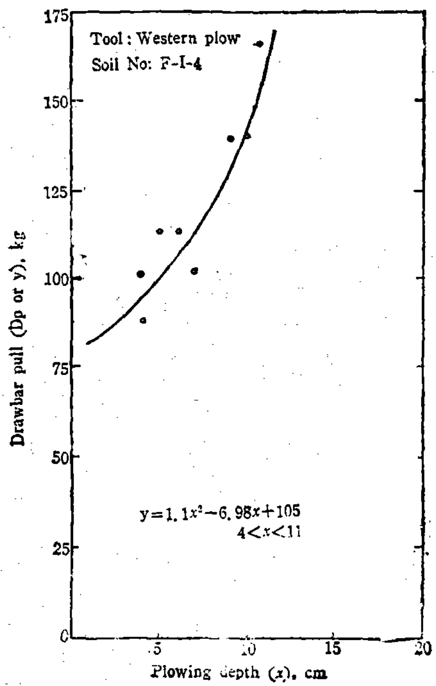


Fig. (31-(f)) The relationship between the meaured plowing depth and drawbar pull

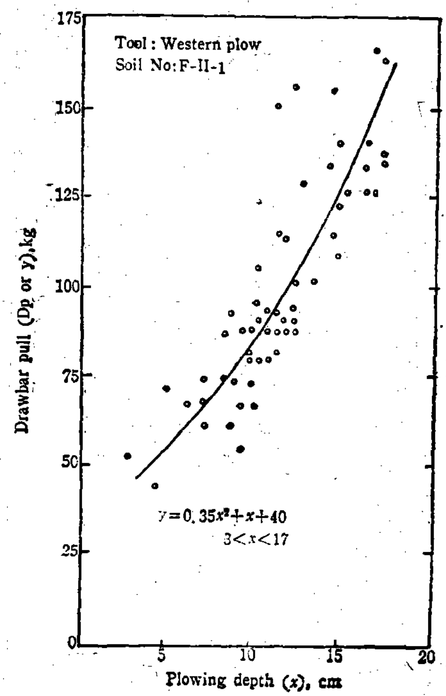


Fig. (31-(g)) The relationship between the measured plowing depth and drawbar pull

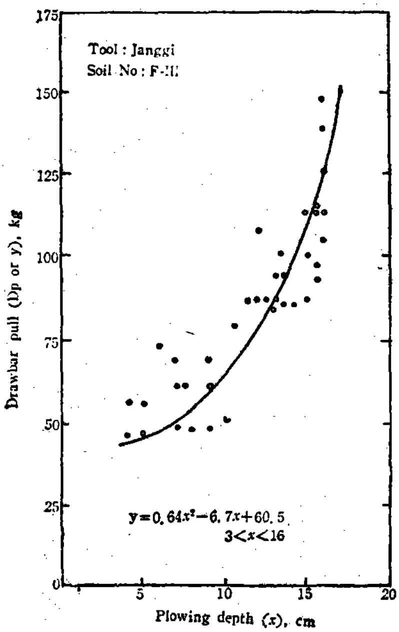


Fig. (31-(h)) The relationship between the measured plowing depth and drawbar pull

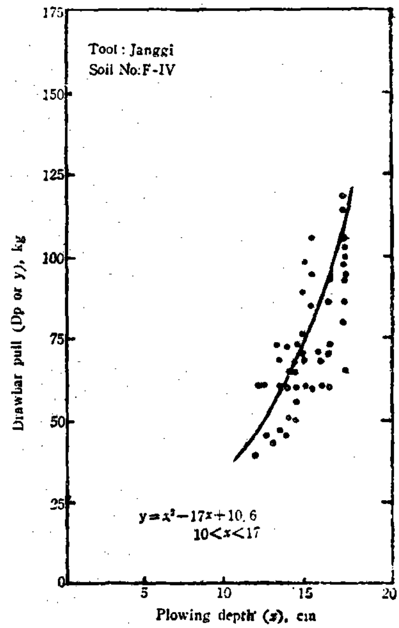


Fig. (31-(i)) The relationship between the measured plowing depth and drawbar pull

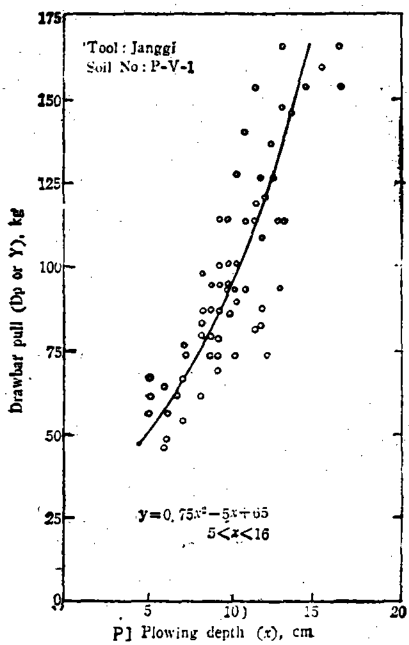


Fig. (31-(j)) The relationship between the measured plowing depth and drawbar pull

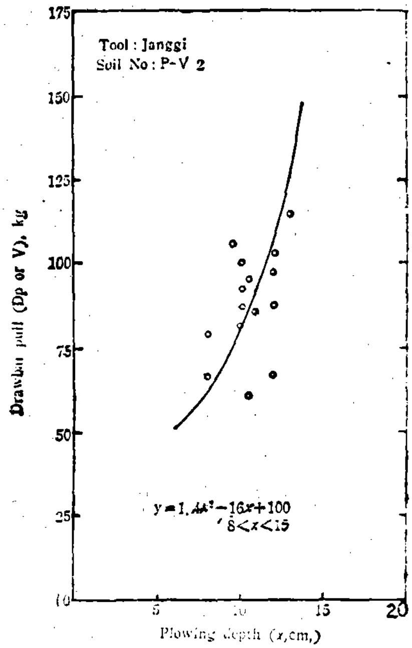


Fig. (31-(k)) The relationship between the measured plowing depth and drawbar pull

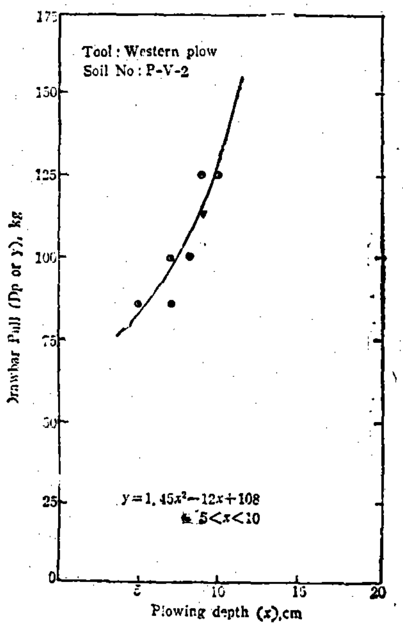


Fig. (31-(l)) The relationship between the measured plowing depth and drawbar pull

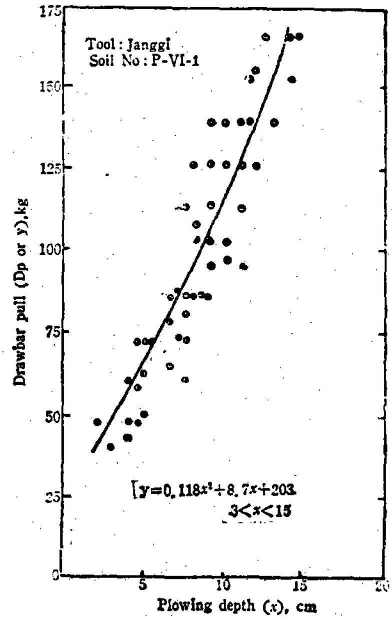


Fig. (31-(m)) The relationship between the measured plowing depth and drawbar pull

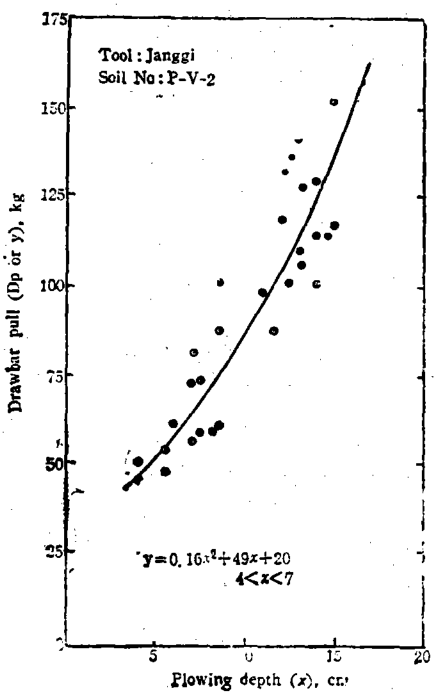


Fig. (31-(n)) The relationship between the measured plogwing depth and drawbar pull

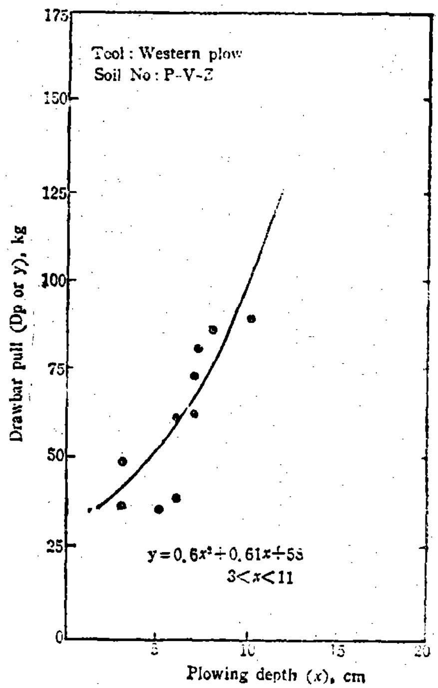


Fig. (31-(o)) The relationship between the measured plowing depth and drawbar pull

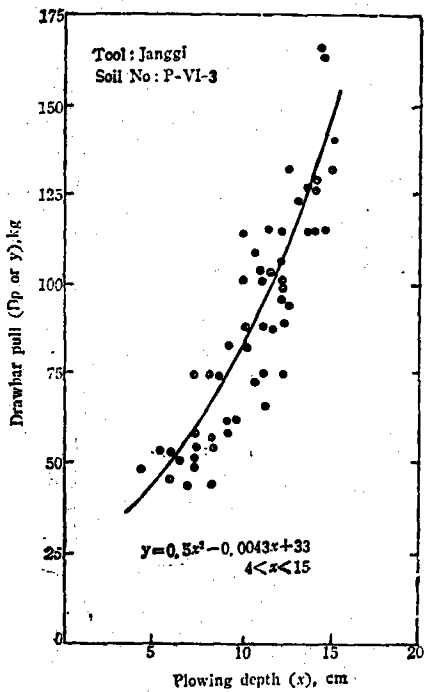


Fig. (31-(p)) The relationship betwen the measured plowing depth and drawbar pull

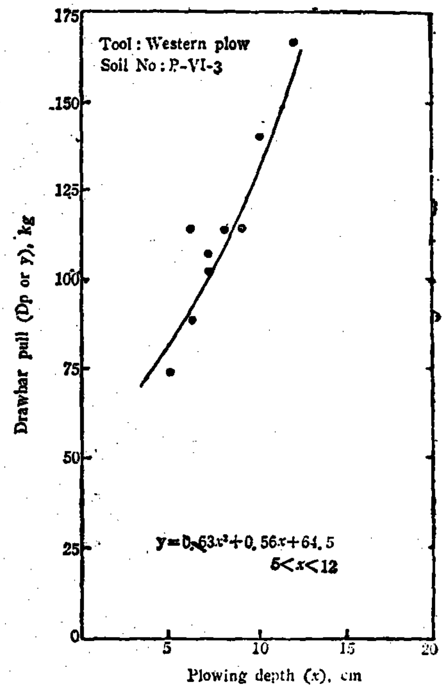


Fig. (31-(q)) The relationship between the measured plowing depth and drawbar pull

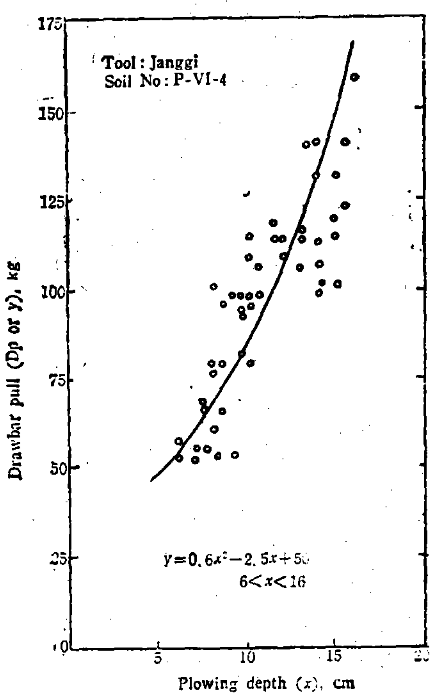


Fig. (31-(r)) The relationship between the measured plowing depth and drawbar pull

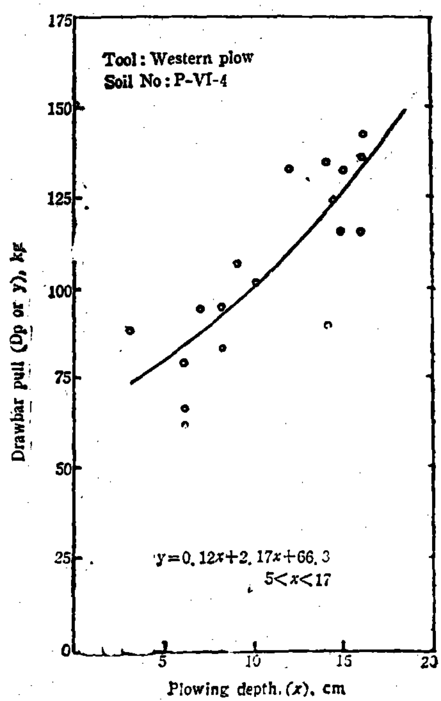


Fig. (31-(s)) The relationship between the measured plowing depth and drawbar pull

2. Discussion of result of analysis

The relationship between the draft resistance and the plowing depth

The relationship between the drawbar pull and the plowing depth for two types of plows and varied soil conditions was plotted and shown in Fig. (31-(a-s)).

Effect of the soil moisture content on the draft resistance

As the Fig. (32-(a-c) shows, the draft resistance increases generally as the moisture content decreases.

Such a result is explained by the fact that, when the moisture content goes over the plastic limit of the soil, the internal friction and cohesion of the soil decreases gradually[8], therefore the shearing stresses of the soil block decrease naturally.

Effect of soil type on the draft resistance

Besides the clay content, many other factors such as soil air content, moisture content, soil hardness, organic content and plant roots may control the draft forces, but only two factors, the moisture and the clay content, were controlled in the field experiment, and thus the effect of the soil type to the draft forces was observed in this experiment[7].

In this study, soil type was classified by the clay content or sand content.

For the high clay content and soil moisture as the cases of Fig.(33-(a-b)), the draft resistance increased. In this case, if the moisture content had been fixed at any point, the draft resistance would have been increased more than in the case mentioned above, because we previously learned that the draft resistance decreased correspondingly to the increase of the moisture content.

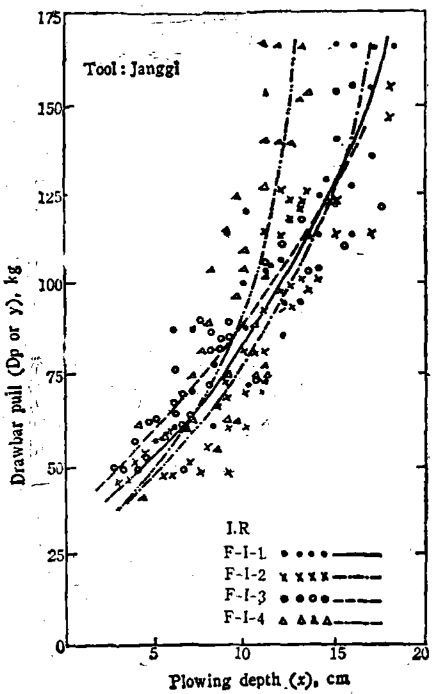


Fig. (32-(a)) Relationship between the measured drawbar pull and plowing depth for different moisture level of soils

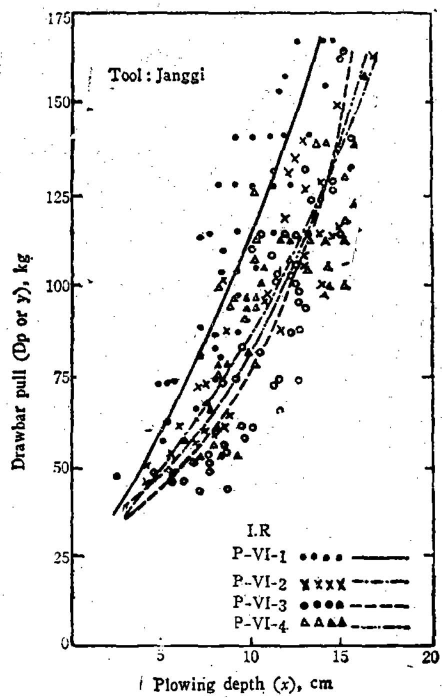


Fig. (32-(b)) Relationship between the measured drawbar pull and plowing depth for different moisture level of soils

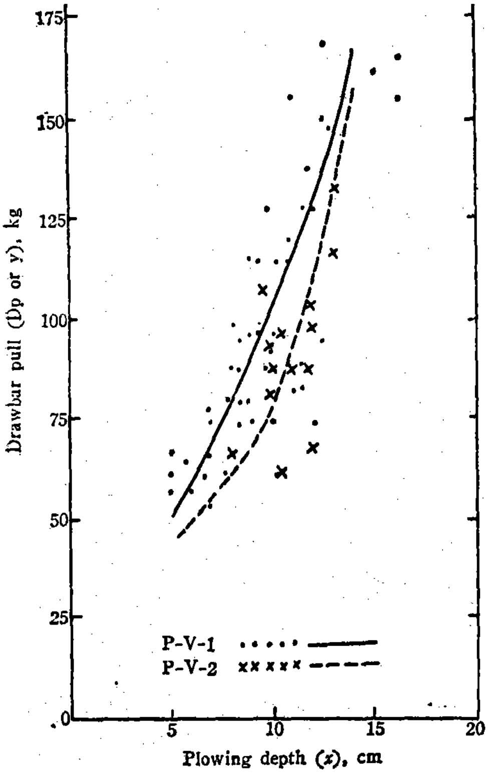


Fig. (32-(c)) Relationship between the measured drawbar pull and plowing depth for different moisture level of soils

Analyzing this result, we concluded that the effect of soil type on the draft force is larger than that of the moisture content.

Comparison of the draft resistance on the dry field and the rice paddy for the same soil type

As shown in Fig. (34-(a-b)), the draft resistance on the rice paddy was greater than that of the field for the same soil type. This result may come from the reason that the rice paddy has been seaken with the water for long time and so was hardened by the water, and the paddy was dry condition when the experiment was operated.

Comparison of Janggi and plow in draft resistance

Under the field containing 36% of moisture content of soil, the draft resistance of Janggi increased with the decrease of moisture content of the soil and the increase of plowing depth as shown in Fig.(34-(a-c)).

But the draft resistance of plow due to the

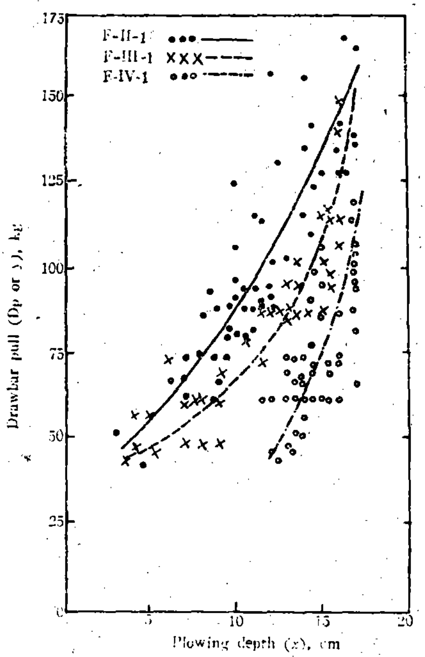


Fig. (33-(a)) Relationship between the measured drawbar pull and plowing depth for different type of soils

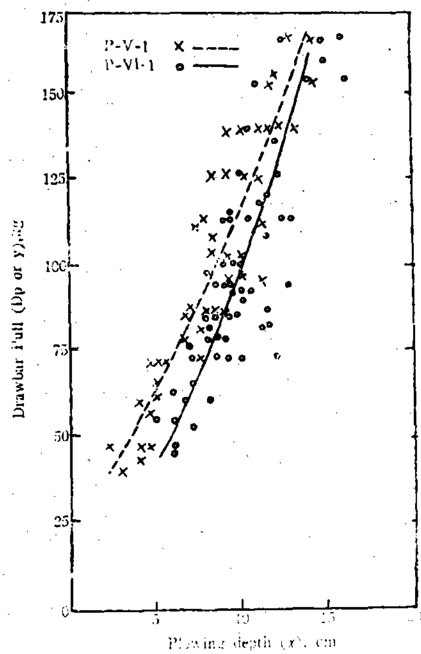


Fig. (33-(b)) Relationship between the measured drawbar pull andplowing depth for different type of soils

decrease of moisture content of the soil showed little variation, because the slope angle of the tool, cutting angle, angle of internal friction of the soil are smaller than those of Janggi and thus the plow may be less influenced by moisture content than in Janggi.

In the rice paddies containing 38% of clay content and 41% of moisture content of soil, total draft resistance of Janggi was far less than that of plow.

The increase rate of total draft resistance in accordance with the increase of plowing depth was shown only a little differences each other.

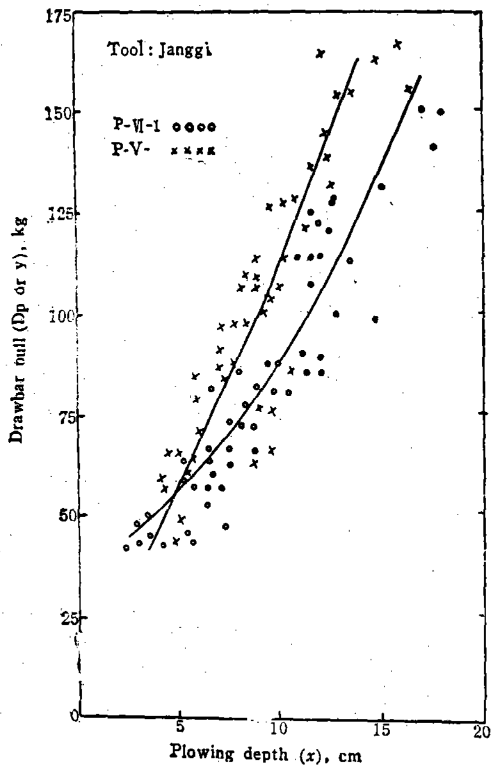


Fig. (34-(a)) **Relationship between the measured drawbar pull and plowing depth for the field and rice addy having the same soil type**

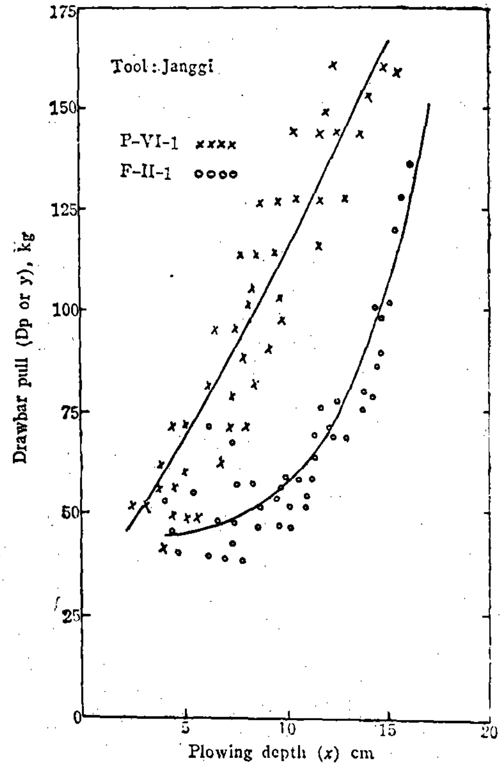


Fig. (34-(b)) **Relationship between the measured drawbar pull and plowing depth for the field and rice paddy having the same soil type**

As shown in Fig. (35-(a-f)), draft resistance of plow was larger than that of Janggi, it is considered the reason why the friction force on the landside that is oonstructed with two surface, vertical and horizontal, and contacted broadly with uncultivated soil is larger than that of Janggi. On the other hand, the landside of Janggi is so narrow that the friction resistance is small.

Operation stability of the western plow was higher than that of Janggi, because the plow landside area contacting the soil is broader than that of Janggi, therefore the plow does not require special technique on the field work, the operation of plow is easier than in Janggi.

Comparison of the theoretical drawbar pulls with the experimental ones

As shown in Fig. (36-(a-f)), the increasing tendency of the experimental values, resulting from the increase of the plowing depth, could be related by a quadratic curve,

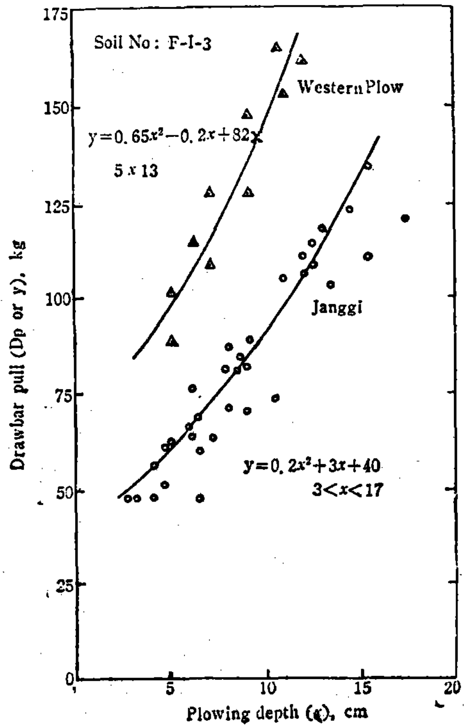


Fig. (35-(a)) Relationship between the measured drawbar pull and plowing depth for different tillage tools

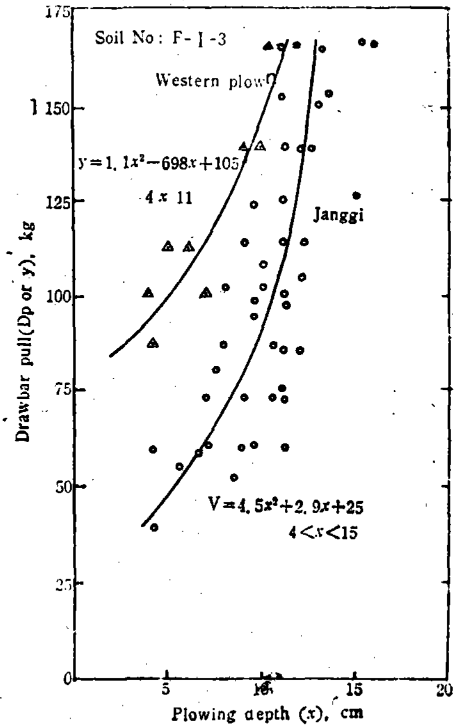


Fig. (35-(b)) Relationship between the measured drawbar pull and plowing depth for different tillage tools

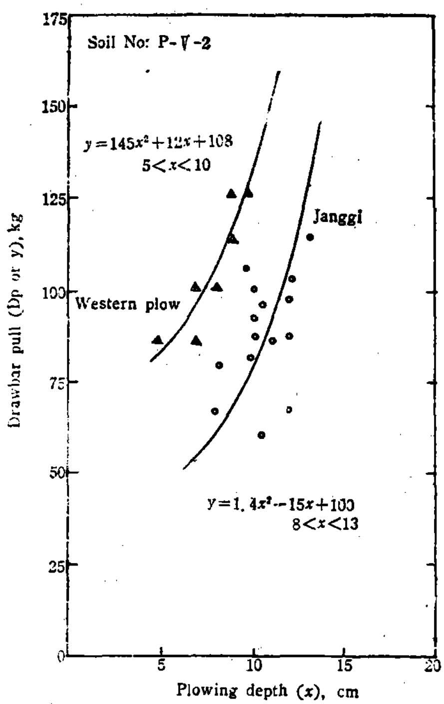


Fig. (35-(c)) Relationship between the measured drawbar pull and plowing depth for different tillage tools

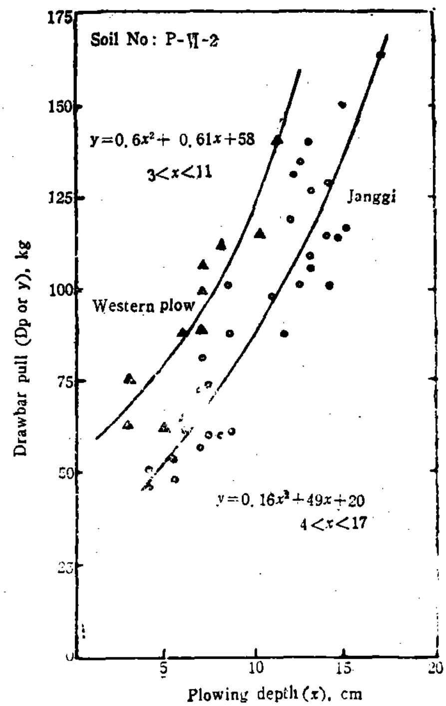


Fig. (35-(d)) Relationship between the measured drawbar pull and plowing depth for different tillage tools

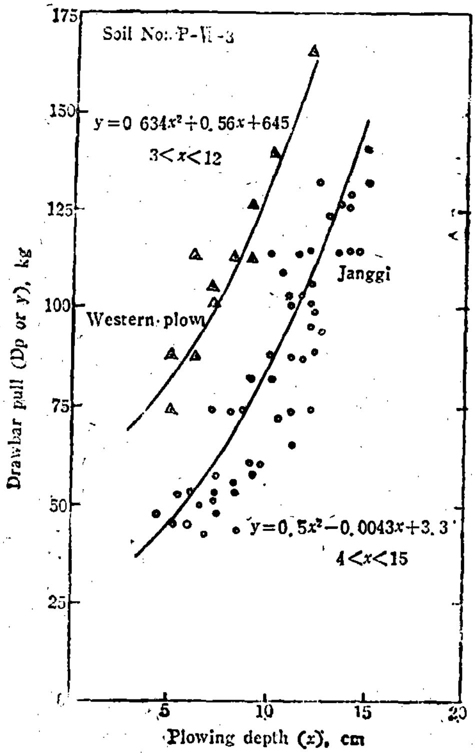


Fig. (35-(e)) Relationship between the measured drawbar pull and plowing depth for different tillage tools

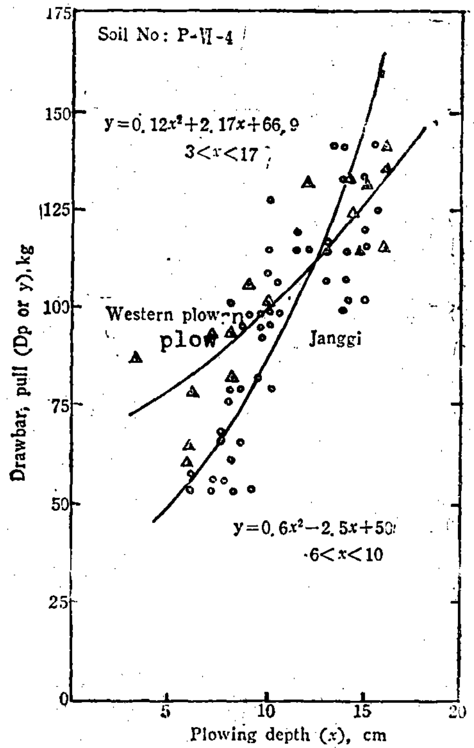


Fig. (35-(f)) Relationship between the measured drawbar pull and plowing depth for different tillage tools

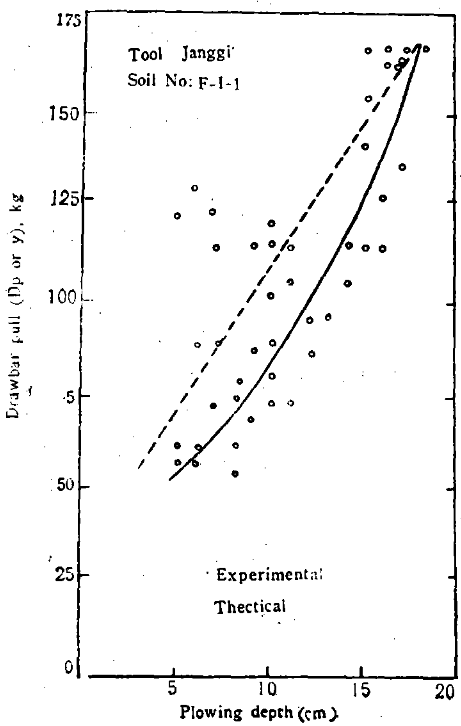


Fig. (36-(a)) The comparison of the measured and theoretical drawbar pulls

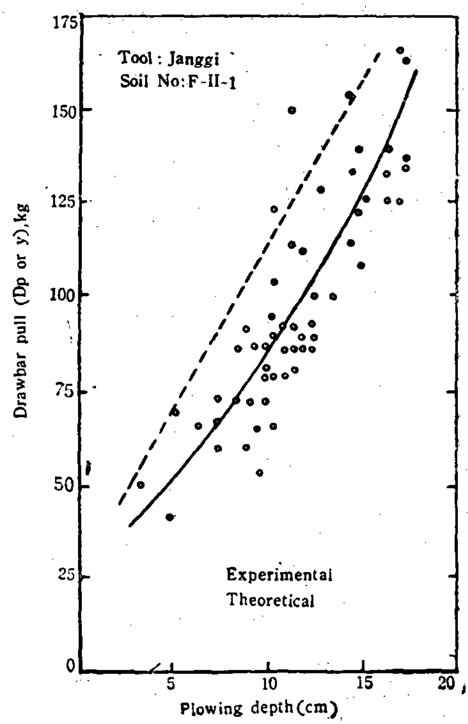


Fig. (36-(b)) The comparison of the measured and theoretical drawbar pulls

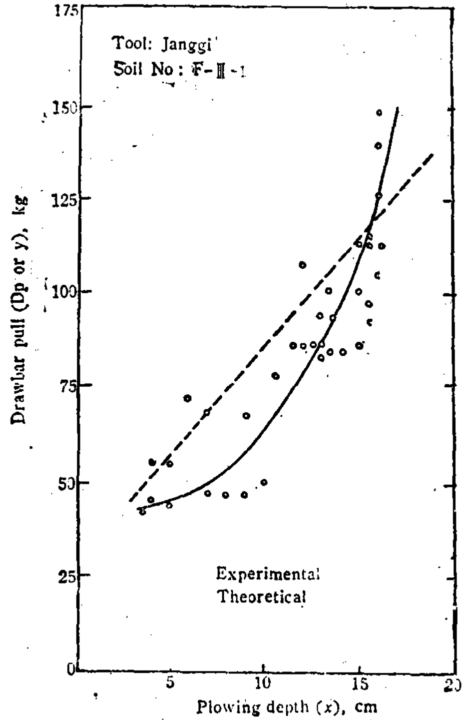


Fig. (36-(c)) The comparison of the measured and theoretical drawbar pulls

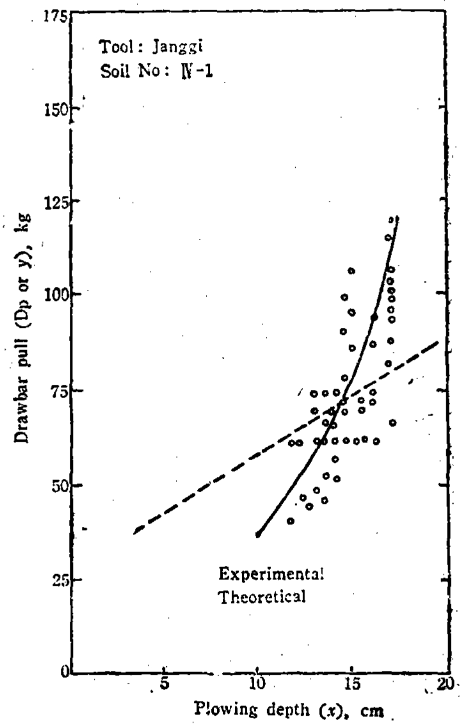


Fig. (36-(d)) The comparison of the measured and theoretical drawbar pulls

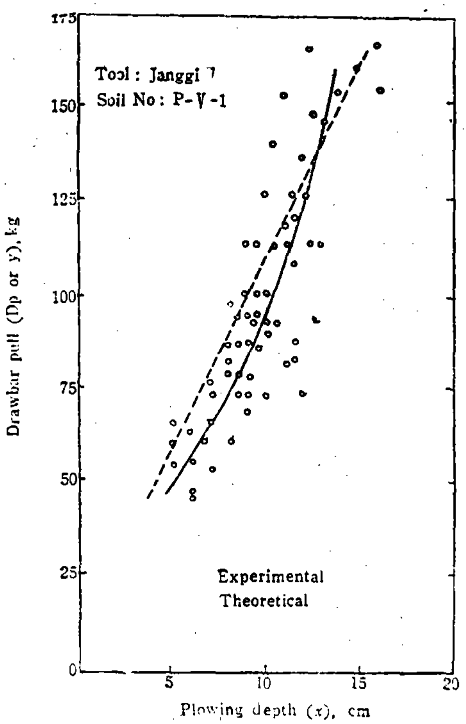


Fig. (36-(e)) The Comparison of the measured and theoretical drawbar pulls

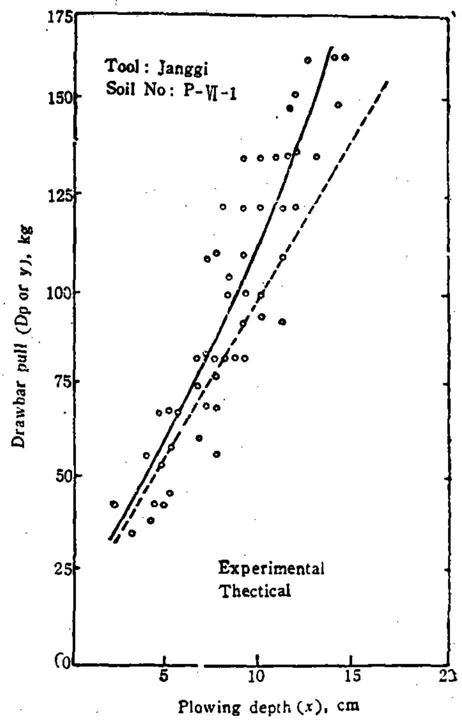


Fig. (36-(f)) The compari son of the measured theoretical drawbar pulls but that of the theoretical ones showed the quadratic curve which may be much closer to a linear curve. In many cases, the difference between the experimental and theoretical drawbar pull was not so large.

The more clay content in the soil, the less difference between them. On the other hand, the greater the sand content, the larger the difference between them.

The fact that the experimental and theoretical values of drawbar pull were coincided fairly well may be an indication that the factors c, t, V_s, V_0, A_1, A_2, A_2, θ, S, C, C_a, f_s, and f_i related to derive the theoretical equations may be justiable for practical purpose.

The relationship of the specific draft resistance and plowing depth

The specific draft resistance K (g/cm²) is the drawbar pull per shearing area of the soil block, we can calculate this value by dividing the drawbar pull by shearing area of the soil block[5(7)].

The shearing area of the soil block depends upon plowing depth, X, because the plowing width is approximately constant.

Since the specific draft resistance[(52)], K, is a function of X, we can write these equations by dividing the experimental equations as shown in Table (6) with the shearing area of the soil block, bx (cm²). These equations so determined are summarized in Table (8) and are plotted as shown in Fig. (37-(a-s)).

The effect of soil moisture content on the specific draft resistance

On the field of clay soil having the range of the moisture content of 27% to 18%, the least specific draft resistance were found in the range of the plowing depth of 10 cm to 7 cm as shown in Fig. (38-a).

At the medium moisture content from 26% to 24%, the minimum range of specific resistance was found in the plowing depth between 15 cm and 14 cm.

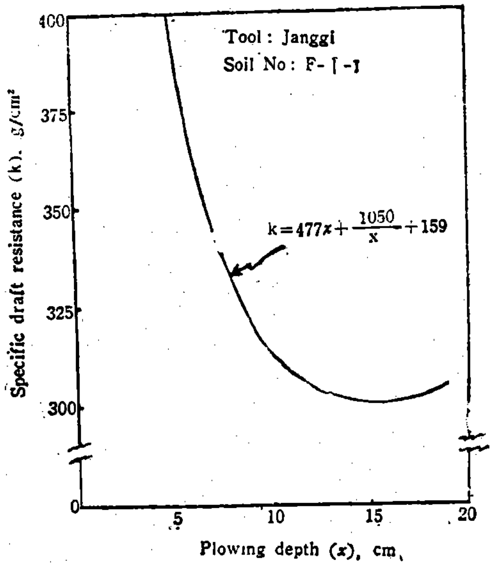


Fig. (37-(a)) Relationship between specific draft resistance and plowing depth

As in the case of totale draft resistance, the specific draft resistance was decrased as the moisture content increased.

As shown in Fig. (38-b), on the rice paddy of sandy loam soil, the relationship between the specific resistance and the moisture content is different from that of dry field. The minimum point of specific resistance was found at the same plowing depth, in spite of the variation of the moisture content. In the range of moisture content from 24% to 19%, the decreasing and increasing rates of the specific resistance from the minimum point were larger than that of the moisture content from 30% to 29%. The increase of the specific resistance due to the decrease of the moisture content was about the same as that of the field.

As shown in Fig. (38-c), the relationship

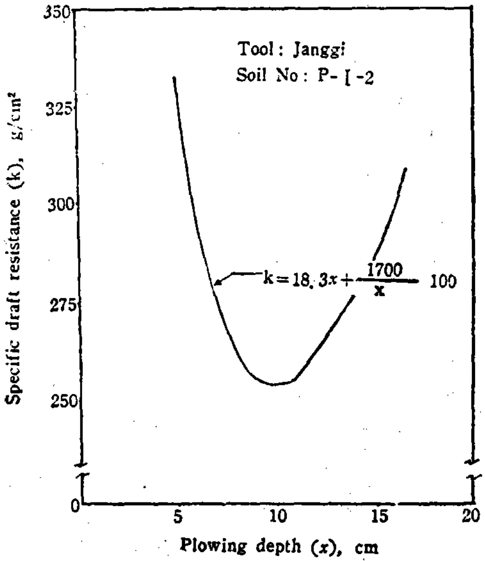


Fig. (37-(b)) Relationship between specific draft resistance and plowing depth

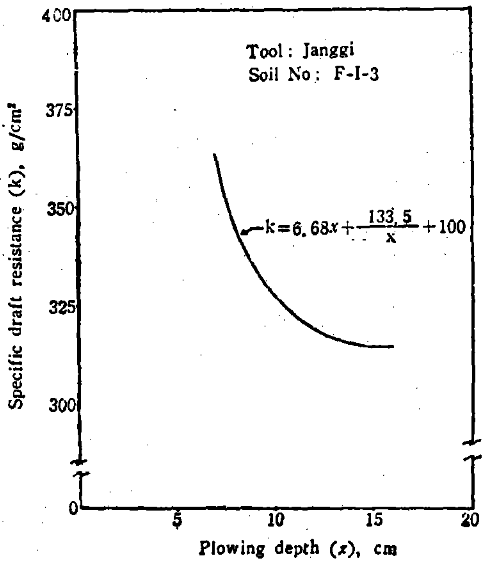


Fig. (37-(c)) Relationship between specific draft resistance and plowing dept

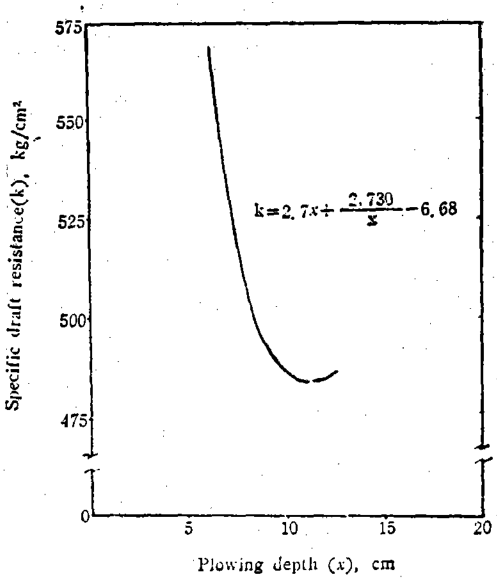


Fig. (37-(d)) Relationship between specific draft resistance and plowing depth

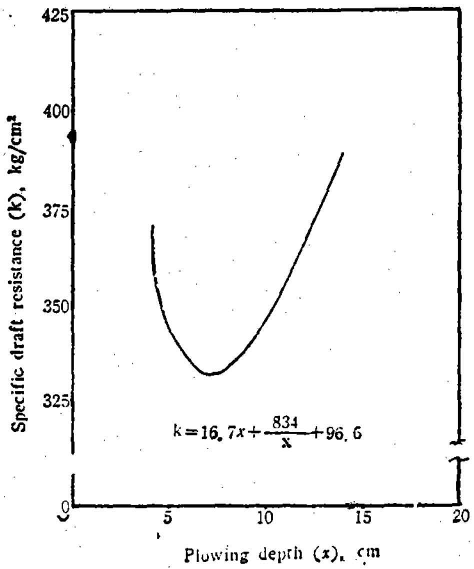


Fig. (37-(e)) Relationship between specific draft resistance and plowing depth

between the moisture content and the specific resistance on rice paddy of clay soil was about the same as the other cases, as mentioned previously. The minimum specific draft resistance was found in the range fo plowing depth from 9.5 cm to 8.5 cm, and the increasing and decreasing rates of specific resistance were comparatively large.

The effect of soil type on the specific draft resistance

As shown in Fig. (39-a), the specific resistance on the dry field increased nearly in proportion to the increase of clay content,

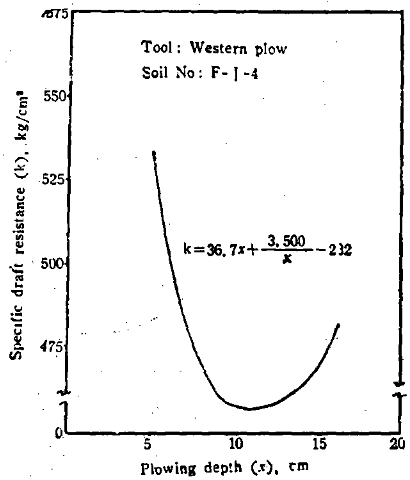


Fig. (37-(f)) Relationship between specific draft resistance and plowing depth

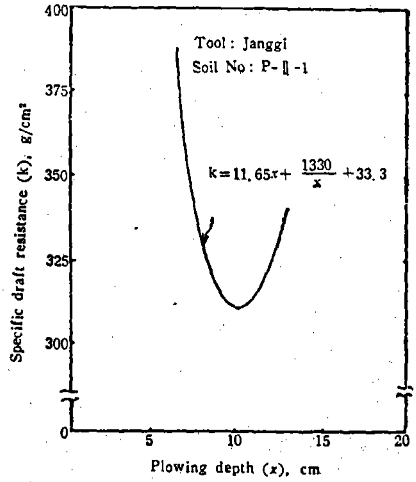


Fig. (37-(g)) Relationship between specific draft resistance and plowing depth

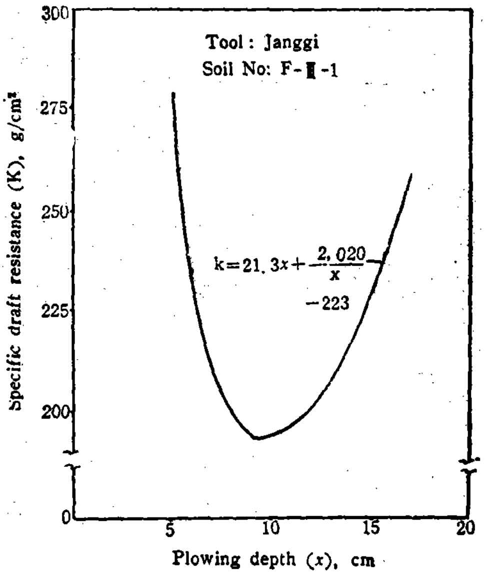


Fig. (37-(h)) Relationship between specific draft resistance and plowing depth

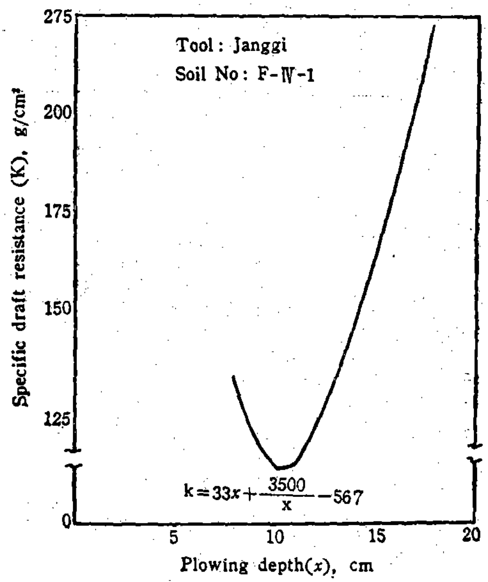


Fig. (37-(i)) Relationship between specific draft resistance and plowing depth

and the minimum points were found at the almost same plowing depth. The increasing and decreasing rates were very sensitive due to the variation of the plowing depth.

Comparison of the specific resistance between the field and rice paddy at the same soil type

As shown in Fig.(40-(a-b)), the minimum specific draft resistances on both field and paddy were found at the almost same plowing depth, and the increasing and decreasing rates of the specific resistance from the minimum point was larger on the dry field and paddy of clay soil than that of sandy loam field and paddy.

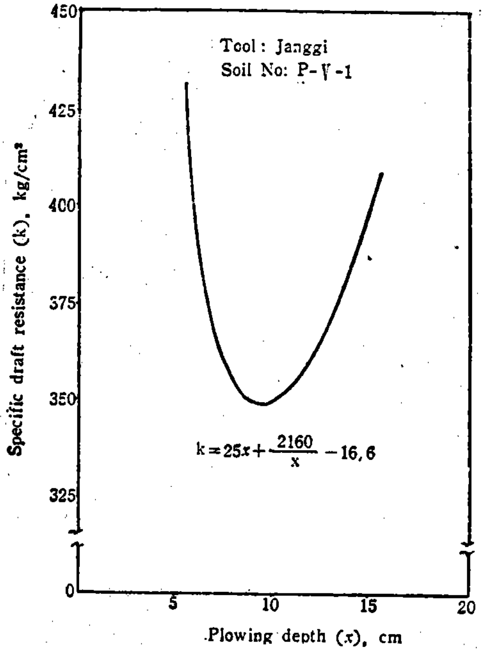


Fig. (37-(j)) **Relationship between specific draft resistance and plowing depth**

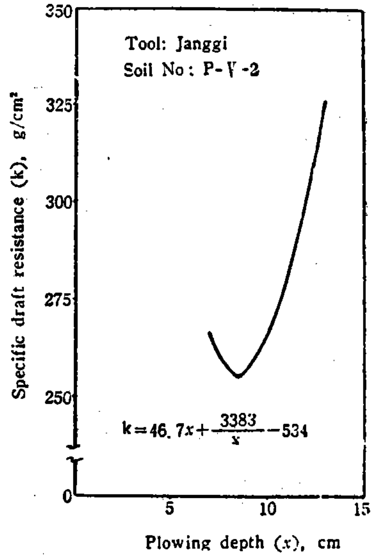


Fig. (37-(k)) **Relationship between specific draft resistance and plowing depth**

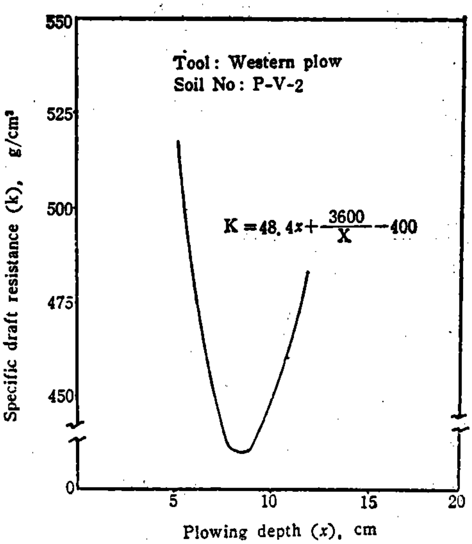


Fig. (37-(l)) **Relationship between specific draft resistance and plowing depth**

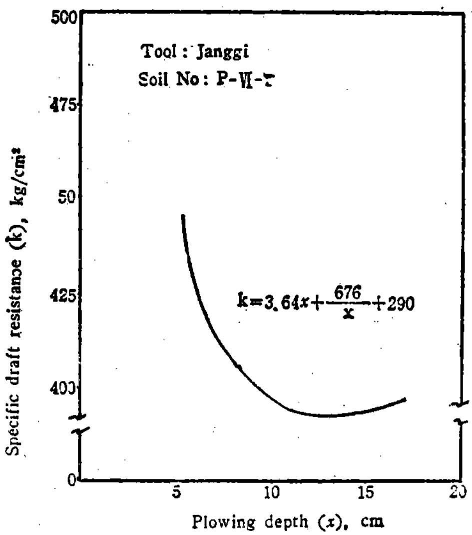


Fig. (37-(m) **Relationship between specific dract resistance and plowing depth**

Comparison of Janggi and plow in specific draft resistance

The equations as shown in Table (8) are shown in Fig. (37-(a-s)). These relationships between the plowing depth and the specific draft desistance were represented by the equation in thefollowing type: $K=AX+\frac{B}{X}+C$, which are shown in Fig.(41-a).

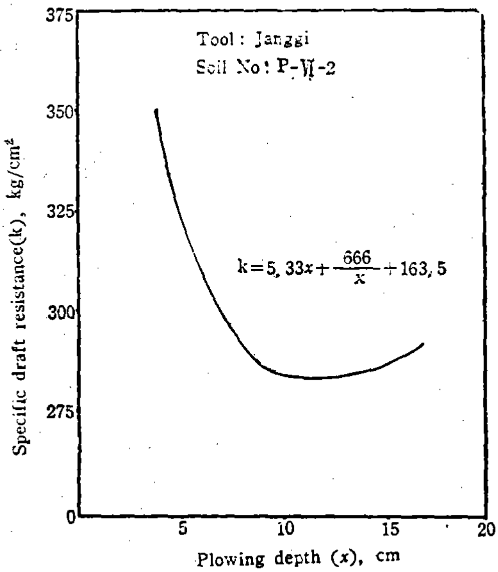


Fig. (37-(n)) **Relationship between specifc draft resistance and plowing depth**

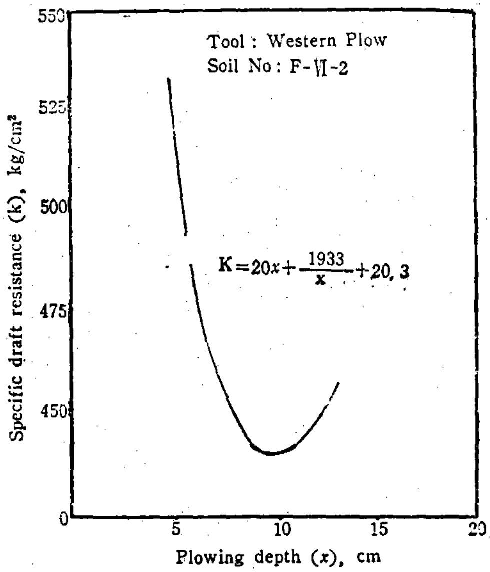


Fig. (37-(o)) **Relationship between specific draft resistance and plowing depth**

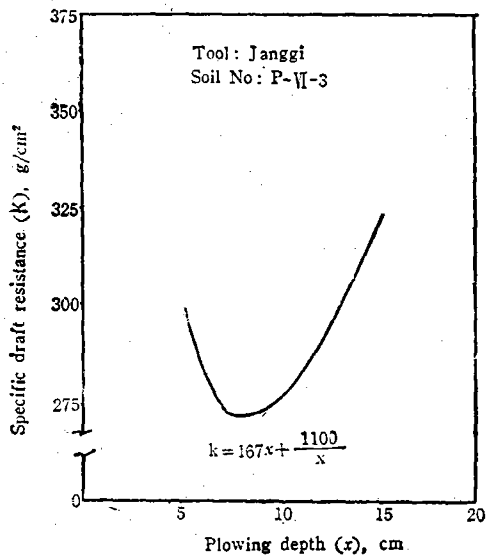


Fig. (37-(p)) **Relationship between specific draft resistance and plowing depth**

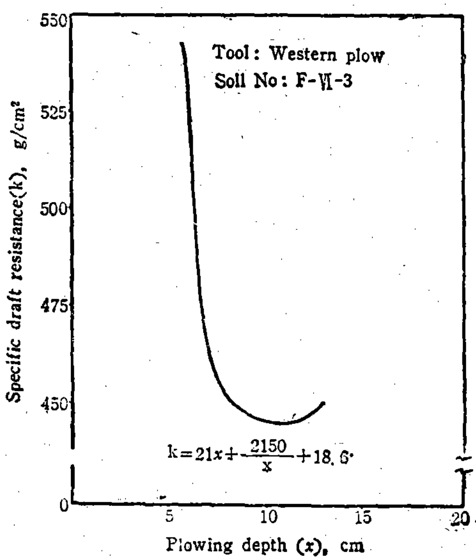


Fig. (37-(q)) **Relationship between specific draft resistance and plowing depth**

On the field of adhesion soil conaining 24% of moisture content of soil, the specific draft resistance of Janggi was about 287 gr/cm² when the plowing depth was kept at 14 cm. and that of plow was about 480 gr/cm² with 12 cm of plowing depth.

The results given above are very similar to those of those of the study that carried out in Japan and America. In th case of plow studied in America, the specific resistance was measured at 11.3 cm of plowing depth and 22.3 cm of the plowing width. In the

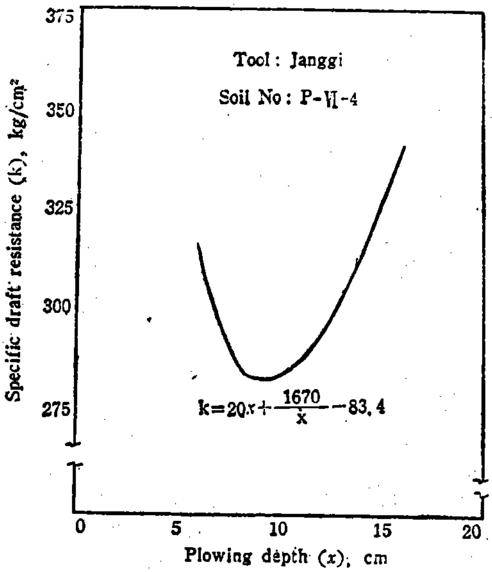


Fig. (37-(r)) Relationship between specific draft resistance and plowing depth

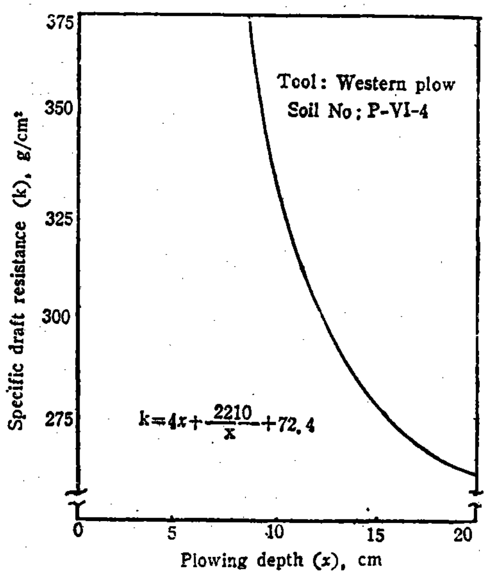


Fig. (37-(s)) Relationship between specific draft resistance and plowing depth

Table (8) Equations of specific resistance in the dry field (F) and rice paddy (P) for the Korean Janggi (K.P) and western plow (W.P)

No.	Tillage tool	Soil no	Soil moisture content (%)	Equation of specific resistance (gr)
1	K.P	F—Ⅰ	26.4	y=477x+1050/x+159 (gr)
2	〃	〃	27.1	y=18.3x+1700/x−100
3	〃	〃	24.4	y=6.68x+1335/x+100
4	〃	〃	24.4	y=21.7x+2730/x−6.68
5	〃	〃	18.4	y=16.7x+834/x+96.6
6	W.P	〃	18.4	y=36.7x+3500/x−232
7	K.P	F—Ⅱ	30	y=11.65x+3500/x+33.3
8	〃	F—Ⅲ	16.5	y=21.3x+2020/x−223
9	〃	F—Ⅳ	11	y=33x+3500/x−56.7
10	〃	P—Ⅴ	35	y=25x+2160/x−166
11	〃	〃	41	y=46.7x+3333/x−534
12	W.P	〃	41	y=48.4x+3600/x−400
13	K.P	P—Ⅵ	19.65	y=3.94x+676/x+290
14	〃	〃	23.9	y=5.33x+666/x+163.5
15	W.P	〃	23.9	y=20x+1933/x+20.3
16	K.P	〃	29.5	y=16.7x+1100/x
17	W.P	〃	19.5	y=21x+2150/x+18.6
18	K.P	〃	30	y=20x+1670/x−83.4
19	W.P	〃	30	y=4x+2210/x+72.4

case of Janggi studied in Japan, the specific resitance was measured at 14 cm of prowing depth and 26 cm of prowing width.

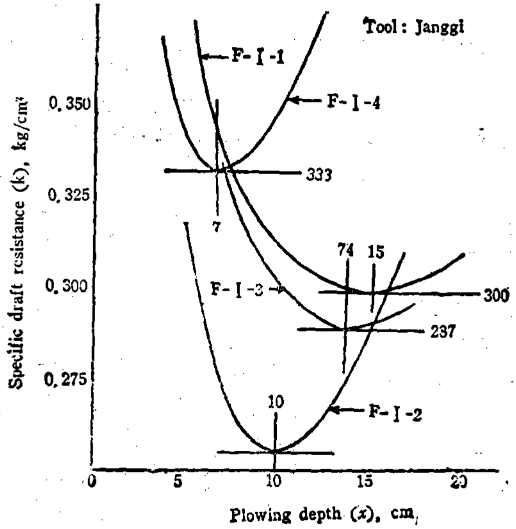


Fig. (38-(a)) Relationship betfween specific draft resistance and plowing depth or a varied moisure

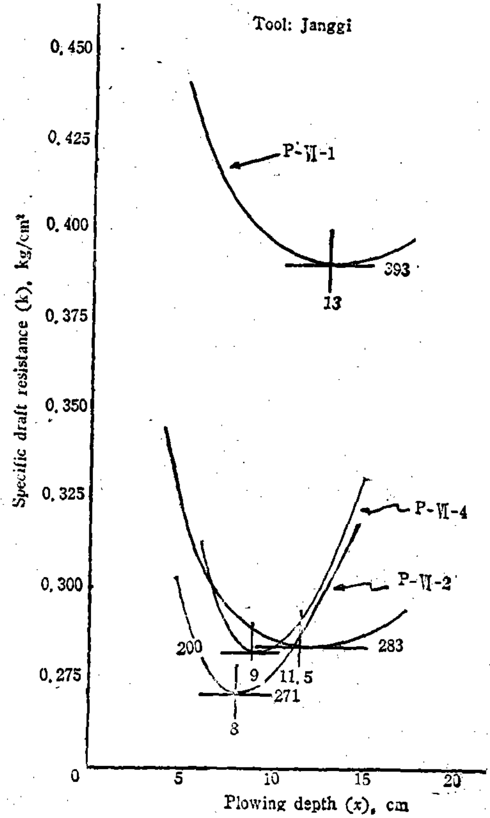


Fig. (38-(b)) Relationship between specific draft resistance and plowing depth for a varied moisure content of soils

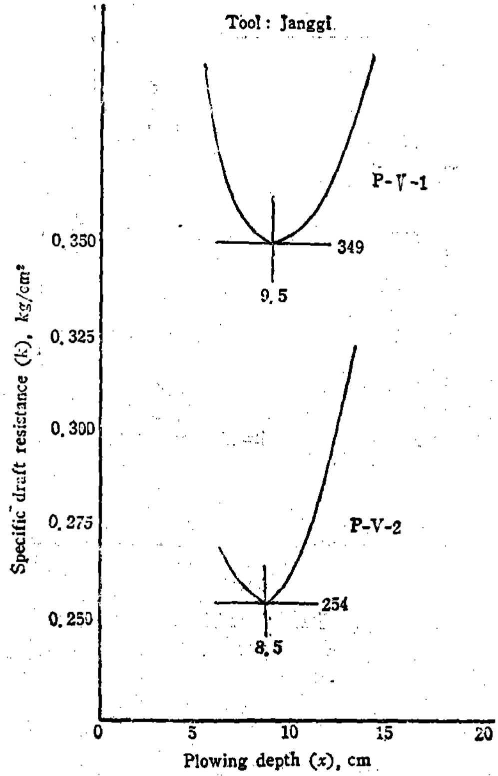


Fig. (38-(c)) Relationship between specific draft resistance and plowing depth for a varied moisure content of soils

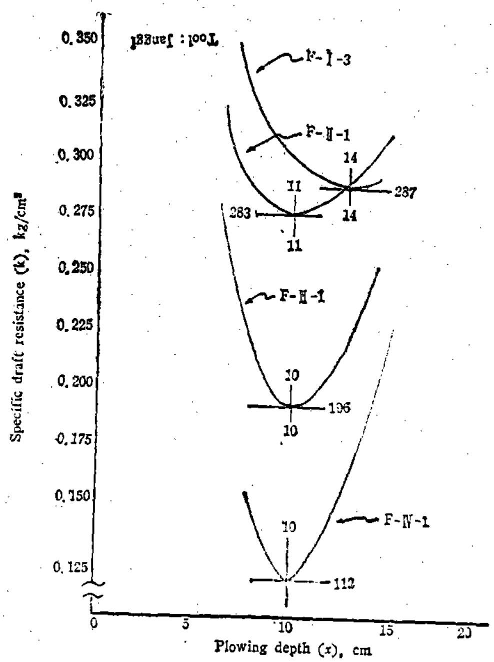


Fig. (39-(a)) Effect of soil type on the specific draft resistance

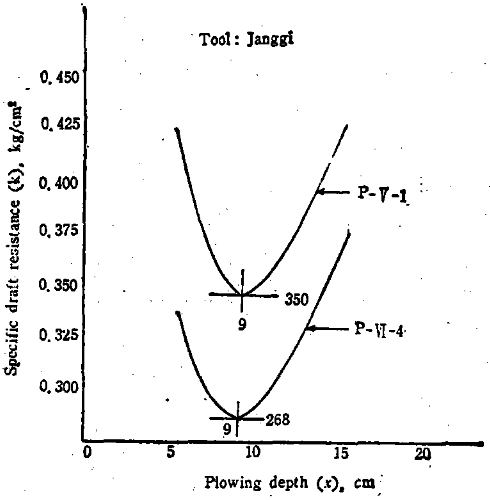


Fig. (39-(b)) Effect of soil type on the specific draft resistance

On some dry field containing 18.4% of moisture content, the minimum specific draft resistance, far Janggi was about 330 gr/cm² at 8 cm of plowing depth and 30 cm of plo-

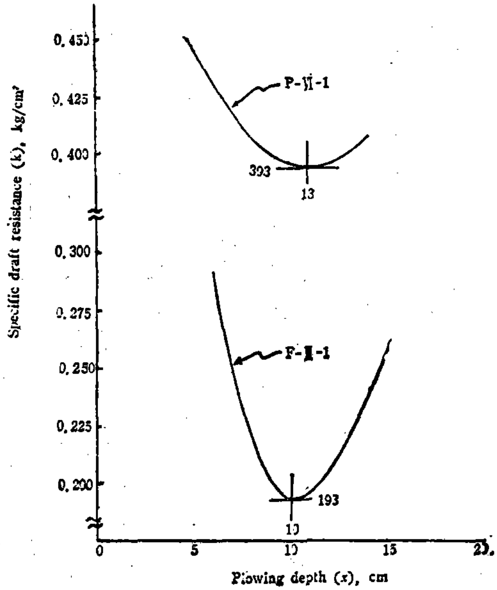


Fig. (40-(b)) Comparison of the specific resistance between the field and rice paddy for the same soil type

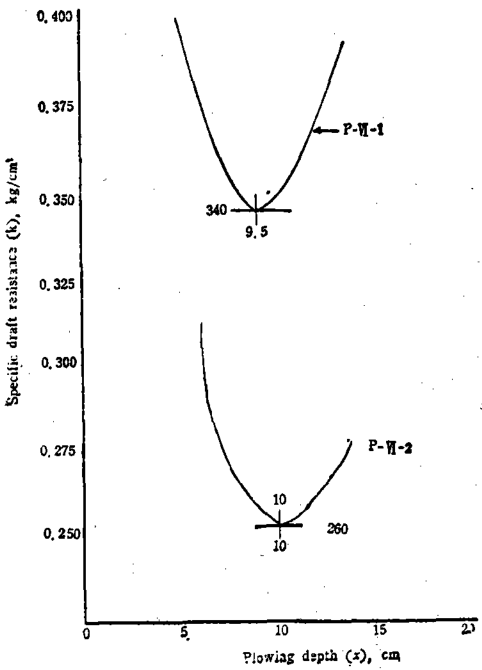


Fig. (40-(a)) Comparison of the specific resistance between the field and rice paddy for the same soil type

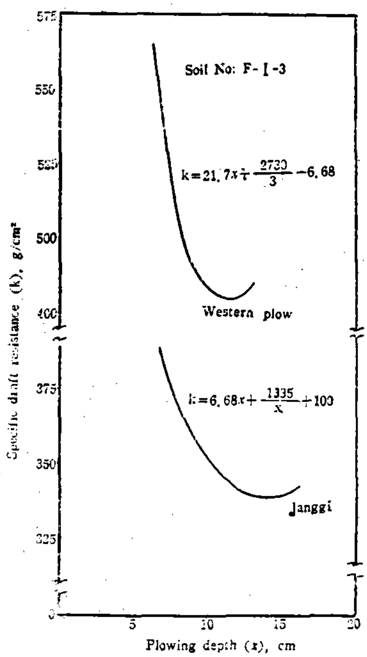


Fig. (41-(a)) Comparsion of Jannggi and plow in specific draft resistance

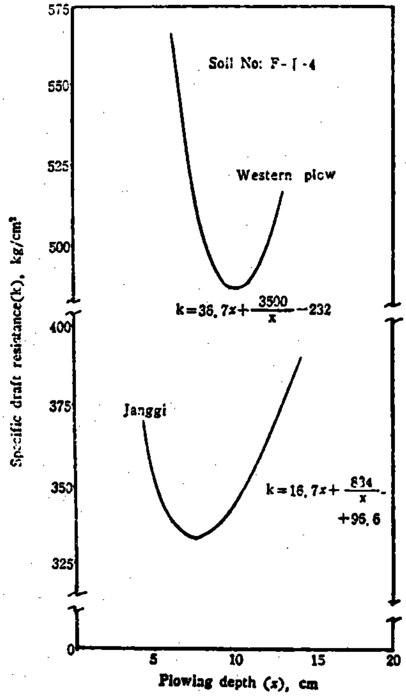


Fig. 41-(b)) **Comparison of Janggi and plow in specific draft resistance**

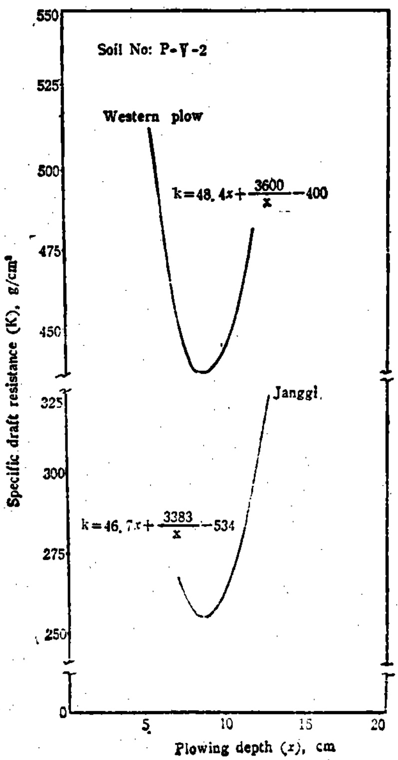


Fig. (41-(c)) Comparison of Janggi and plow in specific draft resistance

wing width and for western plow was 480 gr/cm² at 10 cm plowing depth and 22 cm of plowing width.

As mentioned above, the specific resistance of Janggi was smaller than that of the western plow, and the less moisture content of the soil, the more the variation of specific resistance due to the variation of the plowing depth.

On the rice paddies containing much clay and moisture content, the minimum specific resistance of plow was found in the range of 8∼10 cm of plowing depth, and its minimum value for Janggi was found at shallower plowing depth than that of plow. Ths results may come from the influence of the soil adhesion force and the shape of the overturning curved-surface of moldboard of Janggi, which is not a well-defined curve for overturning action compared to that of the western plow.

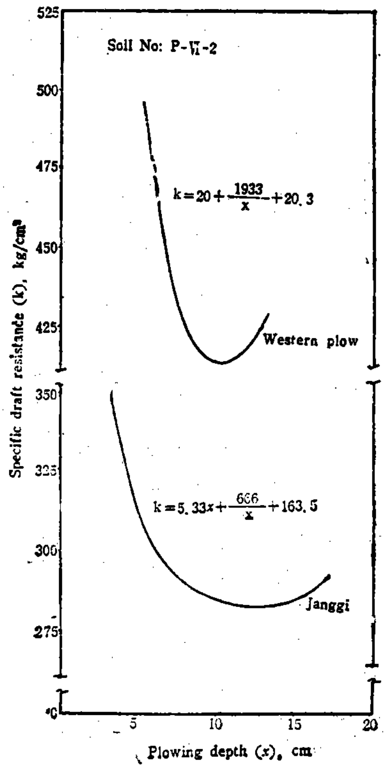


Fig. (41-(d)) Comparison of Janggi and plow in specific draft resistance

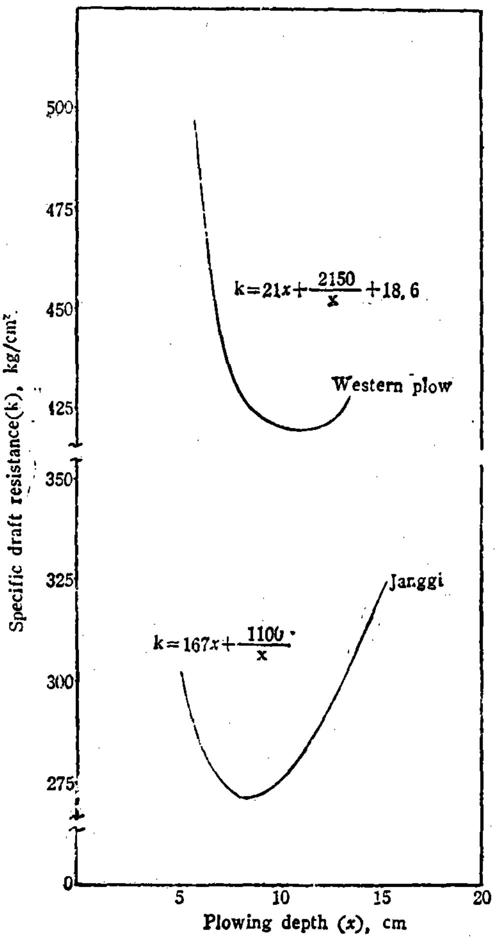


Fig. (41-e)) **Comparison of Janggi and plow in specific draft resistance**

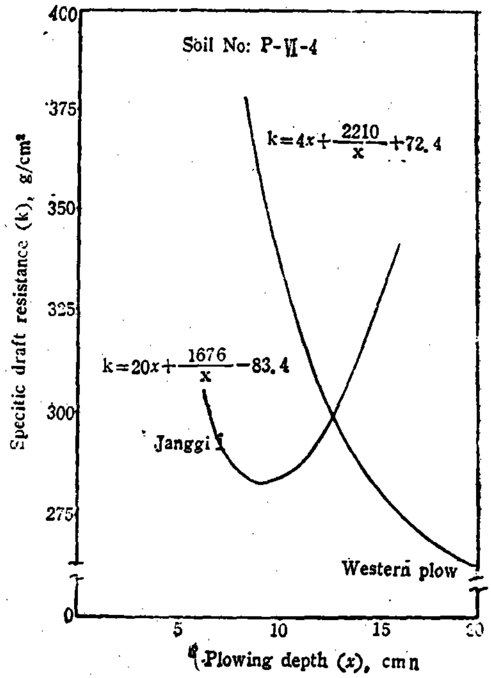


Fig. (41-(f)) **Comparison of Janggi and plow in specific draft resistance**

The specific resistance increased particularly in accordance with the increase of moisture and clay content of the other physical characteristics of soil. In this experiment, the specific resistance was the smallest at the moisture content of 25%. Therefore, we can say that the Janggi and the plow used for this experiment was more suitable on the field than on the paddy.

Ⅵ. Summary and Conclusions

This study was conducted to review the development of Korean Janggi, to identify the difference of shapes of plow-bottoms between the western plow and Korean Janggi, to develop the mathematical model for predicting the drawbar pull for different soil conditions and plowing depth, and to compare the theoretical drawbar pull with the experimentally measured one. In conducting the field experiment, the continuous plowing depth and the corresponding drawbar pull were measured by making use of the newly developed plowing depth-recorder and the drawbar dynamometer.

The results of the study are summarized as follows:

1. A great difference of development, linkage of plow and shape of plow-bottom between the western plow and Korean Janggi was justified through the literature survey and analyses of plow-bottoms. The western plow has a complete and smooth curvature for the share and moldboard profiles with three suctions, while the Korean Janggi has a very narrow and symmetrical share and no such suctions.

2. The draft resistance was increased as plowing depth, the functional relationship between the depth and draft being expressed by the equation: $Y=EX^2+FX+n$

where, Y : the draft resistance

X : the plowing depth

E and F : parameters which may depend upon the soil conditions

n : tool parameter

3. When the moisture content decreased, the draft resistance generally increased.

4. The more clay content in the soil, the larger the draft resistance and the higher the increasing rate of the draft resistance, the effect of the clay content on the draft resistance being much pronounced than that of the moisture content.

5. In many cases, theoretical drawbar pull was greater than the experimental one, but the difference between them was small. The difference between them was smaller for soils with high clay content.

6. The important factor which controlled the draft resistance were plowing velocity (V_0), contact area between soil and the plus bottom(A_1), and projected area of the curved surface on the horizontal plane (A_2), for the Korean Janggi and internal friction angle (θ), cohesion of soil (c), coefficient of friction between soil and metal surface (f_s), and targential stress due to adhesion of soil on metal (C_a) for the soil. Therefore, the most important factor that we could control in order to design an effective Korean Janggi may be A_1, A_2, C_a, and f_s.

7. On the dry field the draft resistance of Korean Janggi was far less than that of the western plow, the influence of moisture content of the soil to the total draft resistance being larger in Janggi than in plow. On the paddy, however, there was little difference between them.

8. The relationship between the specific draft resistance and plowing depth may be expressed by the equation

$$K=AX+\frac{B}{X}+C$$

where K : the specific resistance (gr/cm^2)

X : plowing depth (cm)

C : constant

9. The stability of plowing operation was higher in plow than in Janggi.

10. Minimum value of the specific draft resistance was given for different soils and tools, which are estimated as

(1) On the field: Janggi:

$K=280$-330 gr/cm^2 for $X=8$-14 cm,

Plow : $K=480$-490 gr/cm^2 for $X=10$-12cm.

(2) On the paddy: Janggi:

$K=255$-280 gr/cm^2 for $X=8$-12 cm,

Plow : $K=415$-420 gr/cm^2 for $X=7$-10 cm.

11. Korean Janggi and western plow were more suitable on the field with the less moisture content than on the paddy, and the total draft resistance and specific resistance of Janggi were far less than those of plow.