THE DRAFT RESISTANCE OF KOREAN JANGGI (PLOW) FOR VARIOUS SOIL CONDITIONS

土壤條件의 變化에 따른 한국 쟁기의 牽引抵抗에 關한 硏究

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要 旨

本硏究는 深耕의 必要性에 副應하여 自然狀態의 여러가지 土壤條件에서 한국쟁기의 견인 저항을 形成하는 諸要因 相互間의 關係를 究明하고 特히 새로 考案製作한 自記 耕深一測定計器를 使用하여 세밀한 경심變化에 따른 견인 저항을 分析함으로서 深耕할 수 있는 쟁기를 製作하는 데 必要한 基本資料를 얻기 爲하여 硏究하였다.

그 結果는

1) 견인저항과 경심과의 關係는 다음과 같은 二次 函數를 맺어졌다. $y=Ex^2+Fx+n$
2) 견인 저항의 理論値와 實測値는 그 차이가 적었다.
3) 含水比가 增加함에 따라 견인抵抗은 감소 하였고 粘土含量이 增加됨에 따라 견인 抵抗이 增加했다
4) 牽引抵抗을 지배하는 重要한 인자들은 β, φ, C, f_i, f_s, A_2, A_1, Ca, α 였다.

I. INTRODUCTION

Korean Janggi and Western Plow are the oldest farming tools in the world.

Regardless of the power source used for operating tillage tools, if we observe the cultivation process today, we find that the Janggi and Western Plow are the most important of many farming tools employed in the process of producing crops.

In the United States, many scholars-Reed, K. K. Barnes, C. W. Boek Hop and H. E. Meleod-have studied the mechanism of the Western Plow. They have used artificial soil bin in their studies.

But in Korea few persons have studied the improvement of the Korean Janggi by scientific means. Therefore, the authors undertook this experiment to find out the basic characteristic of the Korean Janggi.

The purpose of this study is to:

1) obtain the basic factors for the improvement of the Korean Janggi,
2) solve the problem of deep plowing,
3) investigate the functional relationship of the factors producing the draft resistance in deep plowing,
4) derive a theoretical equation for draft resistance,
5) compare the theoretical values to the experimental ones.

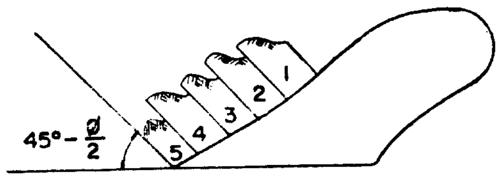
II. THEORETICAL ANALYSIS OF THE DRAFT RESISTANCE

As the plow bottom advances through the soil, soil blocks are formed as shown in Fig (1), and, as Fig(2) shows, reaction forces develope between the soil block and the plow bottom.

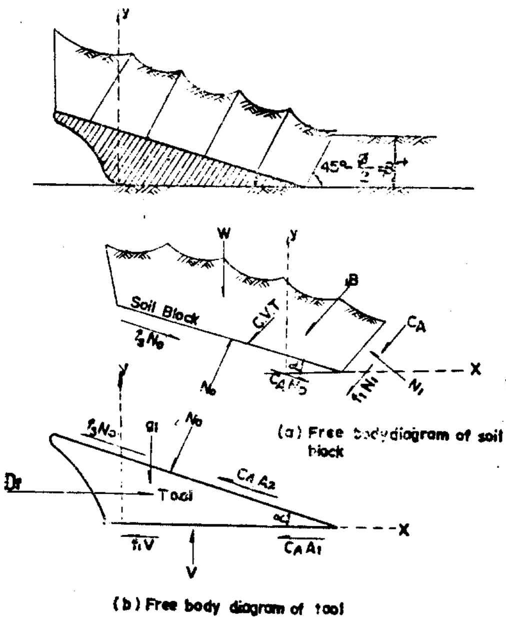
The author set up the following assumptions to derive the equation for the draft resistant force, by using the free body diagrams.

1) Assumptions

a) Coulumb's law, $S=C+S \tan \phi$, is used to



Fig(1) Shearing Pattenr of soil block



Fig(2) Free body diagram of the plowing soil block and the Korean plow bottom

calculate the shearing stresses.

b) The slope angle of the plow bottom face is α, and the end of the plow bottom is a sharp wedge.

c) Angle made between shearing plane of soil block and horizontal plane is $45-\frac{\phi}{2}$ as defined by M. L. Nichols. Fig(1) shows the shearing angle.

d) $S=AC+p \tan \phi$ is used to calculate the shearing forces taking place on both sides of the sharp wedge, but the sides pressure, P, is so negligible that the shearing forces can be calculated by using the [contracted formula, S=AC.

2) Nomenclature

W: Weight of the soil block. (kg)

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

D_f: Draft force (kg)

G_1: Weight of the Korean Janggi. (kg)

V: $G_1+N_o \cos\alpha+fs\ N_o \sin \alpha+CA2 \sin \beta$ (Vertical component of the force exerted on the bottom of the Korean Janggi) (kg)

C: Cohesion of the soil (kg/cm²)

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

fi : Coefficient of internal friction of the soil ($\tan \phi$)

ϕ : Angle of internal friction of the soil.

fs : 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 : Projection area of the slope face of the Korean Janggi 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 slope 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_o : Horizontal velocity of the tool.(m/sec).

t : Plowing depth.(cm)

b : Width of the tool(cm)

δ : Soil density (gr/cm³)

V_f : Shearing velocity of the soil block (cm/sec)

(We can find the value of Vs by the rela tive velocity diagram)

3) Derivation of numerical equation

The equation of raft force D_f can be derived from the equations of dynamic equilibrium in the free body diagrams shown in Fig(2).

When the other factors are constant, D_f is the function of the plowing depth, t. :

The Equation is as follow:

$$D_f=Et^2+Ft+n$$

Where: $E=\left[\dfrac{(\sin\alpha+2f_s\cos\alpha-f_s^2\sin\alpha)}{\sin(\alpha+\beta)(1-f_if_s)+\cos(\alpha+\beta)(f_i+f_s)}\right]\left[\{(\sin\beta+f_i\cos\beta)\,b\delta\cos(\alpha+\beta)(1+\dfrac{v_s}{g}\sin\beta)+\dfrac{v_s}{g}(\cos\beta-f_i\sin\beta)\,b\delta\cot(\alpha+\beta)\cos\}\right]$

$F=\{(\sin\beta+f_i\cos\beta)(A_2\delta+\dfrac{v_s}{g}A\sin\beta+c_1v_s\sin\beta)+(\cos\beta-f_i\sin\beta)(\dfrac{v_s}{g}\delta A_2\cos\beta+c_1v_s\cos\beta)\}$

$n=(\sin\beta+f_i\cos\beta)(CA_3\sin\beta+C_aA_1\sin\alpha)+(\cos\beta-f_i\sin\beta)(CA_3\cos\beta-CaA_2\cos\alpha)+f_s(g_1-CaA_2\sin\alpha)+Ca(A_2\cos\alpha+A_1)$

These factors, E, F andn are determined by the factors oi the soil and the plow bottom.

III. EXPERIMENTAL DESIGN AND EQUIPMENT

1) Experimental design and procedure

Under the natural conditions of the fields, it can be supposed that the resistant force of the Korean Janggi depends upon the various soil and othe factorsr but the most important factors of them are soil type, moisture content and plowing depth. For this reason, the three factors were varied in this study.

As shown in table(1), the soil types were sepe-

Table(1) Control Factors

Soil-tyge	Number of soil moistur content	plowing depth	Plowing width	Plowing velocity
F—I	1	5～18cm	30cm	0.425m/sec
	2	〃	〃	〃
	3	〃	〃	〃
	4	〃	〃	〃
F—II	1	3～18cm	〃	〃
F—III	1	3～17cm	〃	〃
F—IV	1	11～18cm	〃	〃
P—V	1	5～6cm	〃	〃
	2	〃	〃	〃
P—VI	1	4～17cm	〃	〃
	2	〃	〃	〃
	3	〃	〃	〃
	4	〃	〃	〃

Table(2) Physical Soil factors

F : field
P : paddy

soil No / 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	24.0	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)	0.25	0.45	0.47	0.3	0.08	0.19	0.02	0.36	0.18	0.44	0.47	0.19	0.25
S(gr/cm)	1.56	1.78	1.58	1.6	1.65	1.78	1.56	1.82	1.84	1.79	1.85	1.85	1.8
fs	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
C_A(kg/cm²)	0.01	0.01	0.015	0.01	0.01	0.01	0.015	0.02	0.01	0.01	0.01	0.01	0.01
Soil type	clay				loam	sandy loam	sandy loam	clay		sandy loam			
clay content	36%				19%	6%	3%	38%		12%			
Sand content	16%				49%	74%	78%	18%		59%			
Silt content	48%				32%	20%	16%	44%		29%			

rated into 6 kinds, and the soil moisture contents into 4 steps. The plowing depths were varied from 5 cm to 18 cm.

In these above conditions, the draft forces were measured.

In order to control, carefully, the various factors, this experiment was carried out during the three months from April to June. In Korea, April and May are the draught season and June is the beginning of the rainy season.

As shown in Table (2), in response to the variety of the soil moisture content under the natural conditions, the draft resistant forces of the Korean Janggi were measured on the fields and the rice paddies, respectively.

2) **Experimental equipment**

a) Plowing depth gauge

In order to measure the draft resistant forces for various plowing depths, the draft force-measuring gauge and the plowing depth-gauge are necessary in conducting the field experiment.

Because there was no plowing depth gauge in our laboratory, the author deviced and constructed a new self-recording depth gauge as shown in Fig(3).

The names of every part of the gauge corresponding to the numbers and the operation process are as follows:

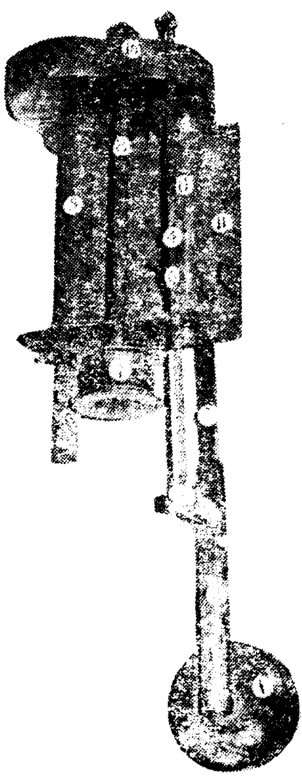
Names of every part

(1) Contact roller on the earthsurface
(2) Ploving 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

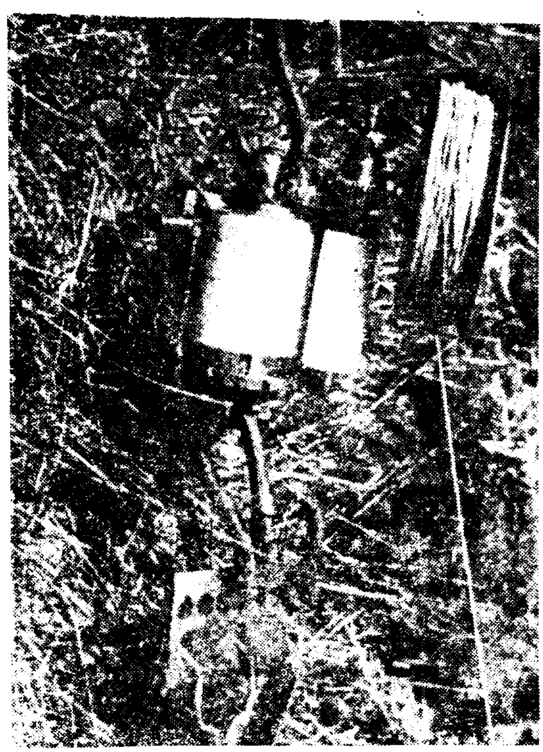
Operation process

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

The revolution velocity of the No. (7) part is decreased by the decrease-revolution-gear,



Fig(3) self-recording-depth gauge



Fig(4) The plowing depth gauge

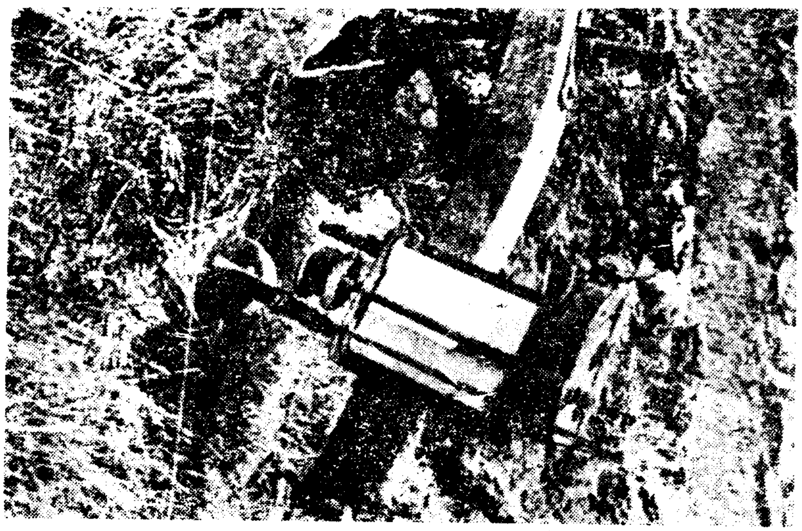
the decrease rate of the gear is 100:1.

The No. (5) roller is driven by the decreasing gear and the No (8) is driven by the rope wound around the No (7).

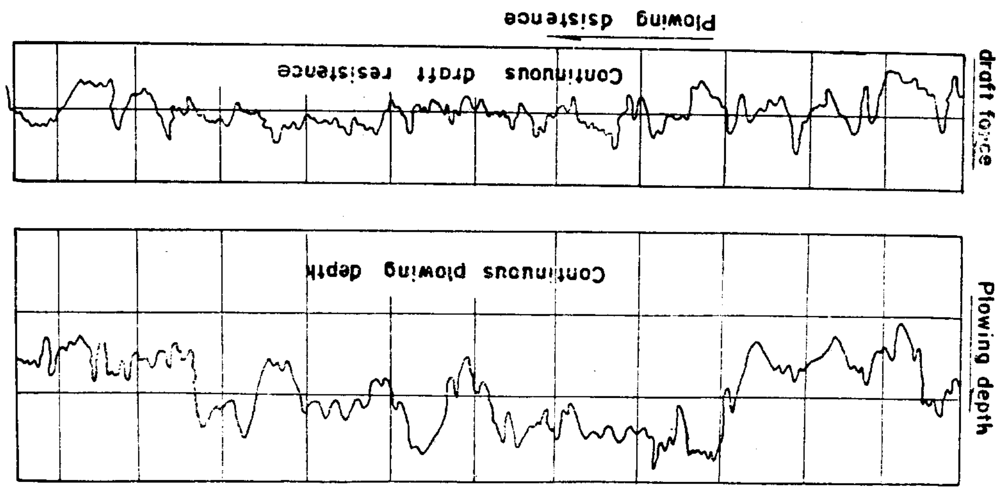
The No (1) part rolls on the earth surface and takes the reciprocating motion up and down, corresponding to the various plowing depths.

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

The plowing depth gauge was fixed on the central part of the beam of the Janggi as shown in Fig(4), and the draft force-measuring-gauge was fastened between the end of the beam and



Fig(5) The draft force-measuring-gauge



Fig(6) A pair of osillograph for the plowing depth and the draft resistance.

the drafting rope shown in Fig(5).

The draft 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 val-ues of the plowing depth and the draft resis-tance recorded simultaneously on these recording papers formed many pairs of osillographs as shown in Fig(6).

IV. ANALYSIS OF RESULTS AND DISCUSSION

1) Analysis of results

The pairs of the osillographs measured through the experiment show the continuous values of the plowing depth and the draft force for various soil moisture contents of each soil type.

The data obtained from the analysis of the osillographs is shown in the table(3).

In order to compare the experimental value with the theoretical one, the experimental equations as shown in Table(4), were derived from the data, and the theoretical equations, as shown in table(5) were obtained through substituting the constant value of the soil factors, as shown in Table(2), into the equation (Df).

Table(3) Draft resistance for various plowing depths (Df : kg, Depth : cm)

F-I-1	Depth	5	6	7	8	9	10	11	12	13	14	15
	Df	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	8	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_e	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-IV-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-1	Depth	3	4	5	6	7	8	9	10	11	12	13	14
	D_f	40.24	61.2	74.0	100.0	113.6	126.6	139.8	139.8	166.0	155.5	166.0	136.0

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

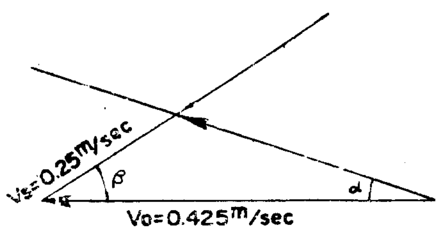
P-VI-4	Depth	6	7	8	9	10	11	12	13	14	15	16
	D_f	58.6	56.0	53.2	97.9	126.6	118.8	113.6	116.1	139.8	131.8	158.0

Table(4) Experiment Equations
y: draft resistance
x: plowing depth

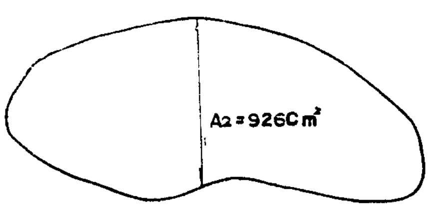
Soil No	Expenmental Aquationis
F-1-1	$y=0.143x^2+4.77x+31.63$
F-II-1	$y=0.35x^2+x+40$
F-III-1	$y=0.64x^2-6.7x+60.5$
F-IV-1	$y=x^2-17x-106$
P-v-1	$y=0.75y^2+5x+65$
P-VI-1	$y=0.118x^2+8.7x+20.3$

Table(5) Theoretical Equations

Soil No	Theoretical Equations
F-1-1	$y=0.041x^2+5.3x+35$
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(7) Relative velocity diagram

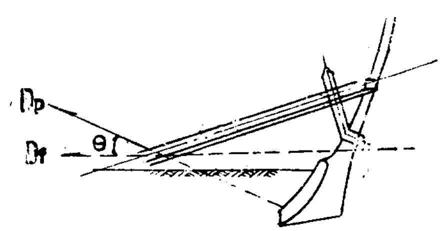


Fig(8) Projection arəa of the Korean plow bottom face

a) The value of the plowing velocity (Vo) was 0.425 m/sec, then the value of the shearing velocity (Vs) was determined through the relative velocity diagram as shown in Fig(7), being value was 0.25m/sec.

b) Fig(8) shows the projection area of the plow bottom face declined at 30 degrees to the horizontal plane, the value of the area(A2) is 926cm².

(c) Since the theoretical equation $(D_f)t$, is that of the draft force(D_f), and the experimental values were those of the draw bar pull(Dp), the relation between Df and Dpsho wn in Fig(9) is developed as follows:



Fig(9) Relation between the D_f and D_p

(2) Discussion of results

a) Comparison of the the oretical values with the experimental ones

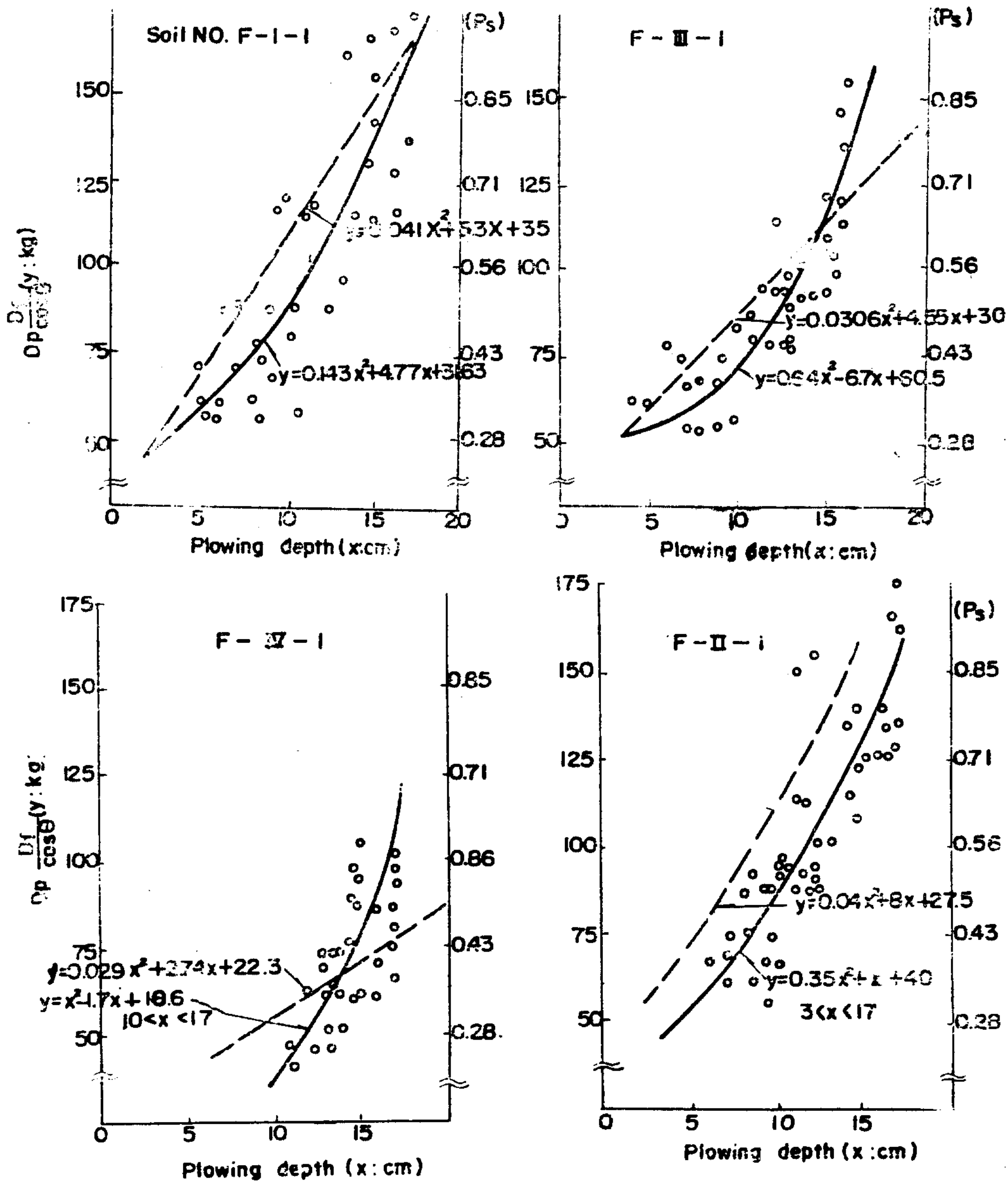
$Dp = \frac{D_f}{\cos Q}$ Wheie, Q; draft angle.

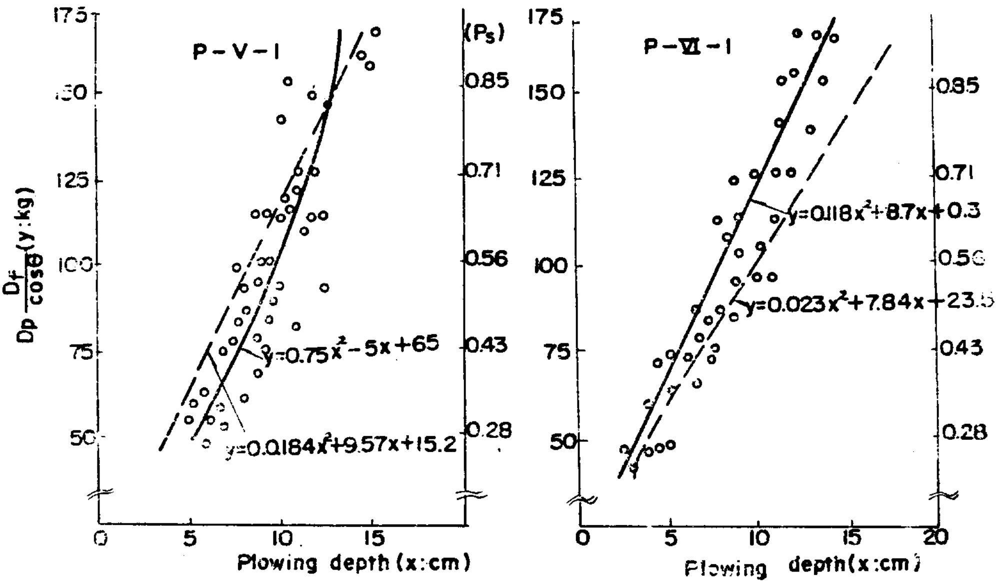
Fig (10) Comparison-curve of the theoretical values with the experimetal ones

Introductony remarks:

——————: experimental value

- - - - - - - -: Theoretical value





As shown in Fig(10), the increasing tendency of the experimental values, resulting from the ncrease of the plowing depth, showed a quad - ratic curve, and that of the theoretical ones howed the quadratic curve which looks like, recti-linear curve,but in many cases the differ- nce of the latter from the former was not large.

The more clay content in the soil, the less difference between them, and the greater the sand content, the larger the difference between hem.

Therefore the fact that the experimental va- lues approached the theoretical ones, could be interpreted as proof that the factors-d, t, Vs, Vo, A_1, A_2, ϕ, S, C, Ca, fs, fi-related to derive the theoretical equations, controled the experi- mental ones.

b) Effect of the soil moisture content on the draft resistance

As the Fig(11) shows, the draft resistance increased correspondingly to the decreasing of the moisture content.

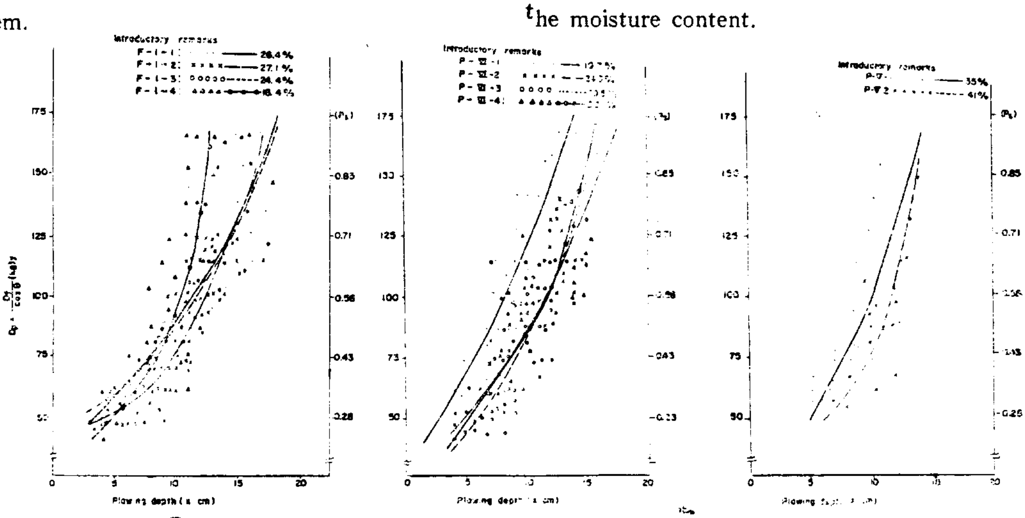


Fig (11) Relation curve between the soil moisture content and the draft resistance

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, therefore the shearing stresses of the soil block decrease naturally,

c) Effect of soil type on the draft resistance

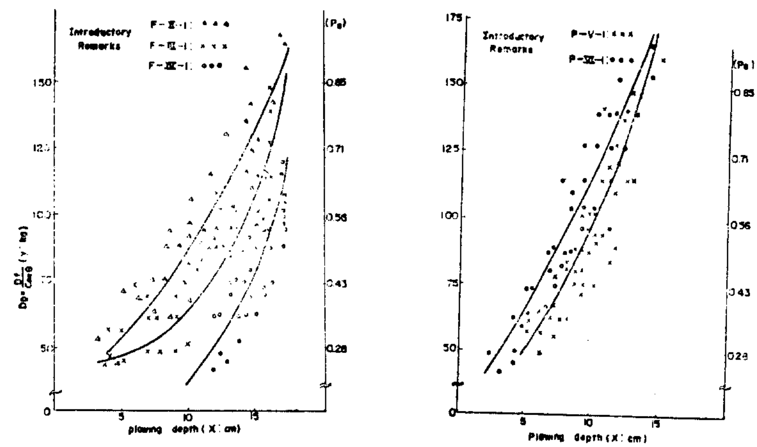
Besides the clay content, many other factors-soil air content, moisture content, soil hardness, organic content and plant roots etc. control the draft forces, but only two factors-the moisture and the clay content-were varied,and then the effect of the soil type to the draft forces was observed.

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

when the clay and moisture content simultaneously increased, as shown in Fig(12), 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 before, because we previously learned that the draft resistance decreased correspondingly to the increase of the moisture content.

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



Fig(12) Relation curve between the soil type and the draft resistance

Fig(12) Relation curvebetween the soil type and the draft resistance

V. SUMMARY AND CONCLUSIONS

This study was carried out to investigate the relationship between the draft resistance and some important related basic factors and to find out the most important factors on which the improvement of the Korean Janggi could be based.

In conducting the field experimant, the continuous plowing depths and the corresponding draft forces were measured by using a plowing depth-recorder and a draft force-measuring-gauge.

The results are as follows :

1) The draft resistance increased corespondingly to the increase of plowing depth. The functional relationnship between the depht and the draft was expressed by the equation :

$y = E \cdot x2 + F \cdot Bx + n$

where,

y is the draft resistance

x is the plowing depth

E, F and n are constants which depend upon soil and tool applied.

2) When the moisture content decreased, the draft resistance generally increased.

3) The more clay content in the soil, the larger the draft resistance, and the more clay content in the soil, the higher the increasing rate of the draft resistance.

The effect of the clay content on the draft resistance was more than that of the moisture content.

4) In many cases, the theoretical draft resistance was larger than the experimental one, but the difference between them was small. The more clay content, the less difference between them.

5) The important factors which controled the draft resistance were α, Vo, A_1, A_2, Vs for the Korean Janggi, and β, ϕ, C, fi, fs, Ca, for the soil.

Therefore, the most important factors that we must control in order to design an effective Korean Janggi are α, A_1, A_2, C_a, f_s

VI. REFERENCE BOOKS

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