Experimental Investigation on the Performances of Tractor-Powered Reforestation Machineries on the Artificial Forest Land of Japan

by

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Contents

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Symbols used for formulae

W_t Weight of tractor (kg)
W_r That of rotary cutter (kg)
W_d That of duster (kg)
F_t Tractive force of tractor (kg)
F_1 Propelling force of inner track (kg)
F_2 That of outer track (kg)
F_c Centrifugal force on tractor (kg)
F_s Cutting resistance force acting on the cutting teeth of stump cutter (kg)
F_r That acting on the cutter blade of rotary cutter (kg)
F_a Earth-drilling resistance force acting on the auger blade of mechanical drive type earth auger (kg)
F_a' That of hydraulic drive type earth auger (kg)
R_t Running resistance force of tractor (kg)
R_{rce} That with rotary cutter (kg)
R_{oc_1} Total resistance force of tractor climbing up a stump (kg)
R_{oc_2} That passing over a stump (kg)
R_1 Movement resistance of inner track (kg)
R_2 Movement resistance of outer track (kg)
Q_1 Vertical ground reaction on the stump-climbing or passing side track (kg)
Q_2 Vertical ground reaction on the ground running side track (kg)
M Moment of resistance to the rotation around the center of gravity on tractor (mkg)
Q Volumetric air flow of duster (m^3/min)
Q_d Volume of powder dusted per hour (l/hr)
Q_{sc} Volume of wood chipped by cutting teeth of stump cutter in unit time (cm^3/sec)
Q_{sc}' Total volume of stump cut by stump cutter (cm^3)
f Unit cutting resistance force acting on a cutting tooth (kg/mm^2)

f_t Coefficient of running resistance of tractor
f_r Coefficient of pulling resistance of rotary cutter
f_b Net fuel consumption rate of tractor with attached reforestation machineries (g/PS/hr)
ρ Specific gravity of fuel (g/cm^3)
ρ_o Density of atmosphere (kg/m^3)
g Acceleration due to gravity, 980 cm/sec^2
μ Coefficient of lateral friction of track on forest-land
μ_a Coefficient of real adhesion of tractor
μ_a' That of apparent adhesion of tractor
μ_i That of friction of impeller
d Effective diameter of sprocket of tractor (mm)
D Diameter of stump cut (cm)
D_p Depth of earth drilled (cm)
r Effective radius of rotary cutter blade (mm)
r_a That of earth auger blade (mm)
r_s Rotating radius of the edge of cutting tooth in stump cutter (mm)
l Contact length of tracks on forest-land (m)
l Length of wood chipped by cutting tooth of stump cutter (mm)
l_p Pitch length of track shoe (mm)
L Average intervals between stumps to be cut (m)
L Average intervals between planting holes to be planted (m)
δ Cutting depth of a cutting tooth in stump cutter (mm)
b Cutting width of the same (mm)
b Brush-cutting width of rotary cutter (m)
b Width of auger blade projected to the plane passing through the auger axis (mm)
V_t Theoretical running speed of tractor (m/sec)
V_a Actual running (pulling) speed of tractor (attached reforestation machinery), (m/sec)
V_0 Runinng speed of the center of tractor-chassis when turning (m/sec)
V_1 Controlled speed of inner track (m/sec)
V_2 That of outer track (m/sec)
V_f Feeding speed of cutting wheel or cutting drum in stump cutter (mm/sec)
V_c Peripheral speed of cutting tooth (auger blade) in stump cutter (earth auger), (m/sec)
V_r That of cutter blade of rotary cutter (m/sec)
N_e Revolutions per minute of tractor engine (rpm)
N_c That of cutting wheel in mechanical drive type stump cutter (rpm)
N_{sc} That of cutting drum in hydraulic drive type stump cutter (rpm)
N_r That of rotary cutter shaft (rpm)
N_a That of earth auger shaft (rpm)
N_b That of blower shaft in duster (rpm)
n Number of track shoes conveyed by one cycle of sprocket
n That of cutting teeth which chip wood at the same time, in stump cutter
n That of stumps
n_r That of planting trees per hectare
n_t That of tractors required for reforestation works in a given planting area
n_a That of attached machinery required for reforestation works in a given planting area
i Overall reduction gear ratio of tractor

i_1 Reduction gear ratio of tractor transmission
i_2 That of tractor differential
i_3 That of tractor final drive
i_5 That of PTO shaft
i_5' That of pump shaft
i_{sc} That of stump cutter transmission
i_r That of rotary cutter transmission
i_{cd} That of cutting drum in stump cutter
i_a That of earth auger transmission
i_6, i_7, i_8, i_9, i_{10} Those of duster transmission
η Overall mechanical efficiency of tractor
η_1 Mechanical efficiency of tractor transmission
η_2 That of tractor differential
η_3 That of tractor final drive
η_4 That of sprocket and track link
η_5 That of PTO shaft
η_5' That of pump shaft
η_{sc} That of stump cutter transmission
η_r That of rotary cutter transmission
η_{cd} That of cutting drum in stump cutter
η_a That of earth auger transmission
η_6, η_7, η_8, η_9, η_{10} Those of duster transmission
η_n Overall efficiency of blower
η_p That of oil pump
η_m That of oil motor
η_{pv} Volumetric efficiency of oil pump
η_{mv} That of oil motor
η_n Flowing efficiency of high pressure rubber hose
q_p Theoretical delivery volume of oil pump
q_m Theoretical inlet volume of oil motor
s Slip of tractor (%)
s_z Feeding length of a cutting tooth in stump cutter (mm)
T_t Torque of tractor engine required for tractor's running only straight on forest-land (mkg)
T_t' That with rotary cutter (mkg)
T_{oc1} That required for climbing up a stump by tracked layer from $0_1'$ to $0_1''$ (mkg)
T_{oc2} That required for passing over a stump by tracked layer (mkg)
T_{sce} That required for cutting stump, in mechanical drive type stump cutter (mkg)
T_{sce}' That required for cutting stump, in hydraulic drive type stump cutter (mkg)
T_{rcc} That required for cutting brush only in mechanical drive type rotary cutter (mkg)
T_{rcc}' That in hydraulic drive type rotary cutter (mkg)
T_{rce} That required for cutting brush when tractor is running, in mechanical rotary cutter (mkg)
T_{rce}' That required for cutting brush when tractor is running, in hydraulic rotary cutter (mkg)
T_{ae} That required for earth-drilling, in mechanical drive type earth auger (mkg)
T_{ae}' That required for earth-drilling, in hydraulic drive type earth auger (mkg)

T_{de} That required for dusting when tractor is stationary, in tractor-powered duster (mkg)
T_{dre} That required for dusting when tractor is running, in tractor-powered duster (mkg)
T_{scc} Torque of the cutting wheel shaft in mechanical drive type stump cutter (mkg)
T_{scc}' That of cutting drum in hydraulic drive type stump cutter (mkg)
T_{r1} That of PTO shaft (mkg)
T_{r2} That of rotary cutter shaft (mkg)
T_a That of auger shaft (mkg)
P Horsepower of tractor engine required for the whole running of tractor (PS)
P_c That required for the loss of running velocity (PS)
P_t That required for tractor's running only straight on forest-land (PS)
P_t' That with rotary cutter (PS)
P_{tc} That required for uniform curve turning when no acceleration of motion occurs (PS)
P_e That required for various kinds of reforestation works done with attached machinery (PS)
P_{oc1} That required for climbing up a stump by tracked layer (PS)
P_{oc2} That required for passing over a stump by tracked layer (PS)
P_{sce} That required for cutting stump, in mechanical drive type stump cutter (PS)
P_{sce}' That required for cutting stump, in hydraulic drive type stump cutter (PS)
P_{rcc} That required for cutting brush only, in mechanical drive type rotary cutter (PS)
P_{rcc}' That required for cutting brush only, in hydraulic drive type rotary cutter (PS)
P_{rce} That required for cutting brush when tractor is running, in mechanical drive type rotary cutter (PS)
P_{rce}' That required for cutting brush when tractor is running, in hydraulic drive type rotary cutter (PS)
P_{ae} That required for drilling earth, in mechanical drive type earth auger (PS)
P_{ae}' That required for drilling earth, in hydraulic drive type earth auger (PS)
P_{de} That required for dusting powder when tractor is stationary in duster (PS)
P_{dre} That required for dusting powder when tractor is running in duster (PS)
h Height of the center of gravity on tractor from the ground-surface (mm)
h Cutting depth of cutting drum (mm)
h_r Remaining height of bamboo grass after cutting by rotary cutter (mm)
a_c Volume of stump cut per unit fuel consumption of tractor-powered hydraulic stump cutter (cm^3/l)
a_r Running distance per unit fuel consumption when cutting brush by tractor-powered rotary cutter (km/l)
a_{do} Volume of powder dusted per unit fuel consumption of tractor-powered duster, when tractor is stationary (l_{powder}/l_{fuel})
a_d That when tractor is running (l_{powder}/l_{fuel})
A_r Brush-cutting area per unit fuel consumption of tractor-powered rotary cutter (ha/l)
A_i: A_1, A_2, A_3, A_4, A_5 Areas where a kind of mechanized operation using a tractor and attached machinery can be done in a year (ha)
A Area where the tractor combined operation for reforestation works can be done in a year (ha)
H_i: H_1, H_2, H_3, H_4, H_5 Operational efficiencies where a kind of mechanized operation using a tractor and attached machinery can be done in a year (ha)
H_r Land-clearing area per man-day in mechanized operation (ha/man-day)

t Total working hour per hectare per worker (hr)
t_n Net working hour per man-day (hr)
t_a Actual working hour per man-day (hr)
t_{sc} Net stump-cutting time in stump cutter (sec)
t_m Net moving time from stump to stump in stump cutter operation (sec)
t_p Preparation time before beginning to cut stump in stump cutter operation (sec)
t_q Preparation time before beginning to move from stump in stump cutter operation (sec)
t_r Walking time for driver from driver's seat to control-lever of cutter in stump cutter operation (sec)
t_w Walking time for driver from stump to stump in chain saw stump-cutting operation (sec)
t_0 Inspection time of chain saw (sec)
t_s Recess time per stump cut (sec)
t_b Net brush-cutting hour per hectare per worker in brush-cutting operation (hr)
t_i Inspection hour of machine per hectare per worker (hr)
t_t Turning hour of tractor per hectare per worker (hr)
t_t Turning time of tractor (sec)
t_f Filing hour for circular saw per hectare per worker in brush cutter team operation (hr)
t_c Working hour for clearing away branches per hectare per worker in brush cutter team operation (hr)
t_d Net earth-drilling time in earth auger (sec)
t_l Net moving time from planting point to planting point in tractor-powered earth auger operation (sec)
t_u Waiting time in tractor-powered earth auger operation (sec)
E Planned period for reforestation works (yrs)
X Given planting area (ha)
Y_i: Y_1, Y_2, Y_3, Y_4, Y_5 Net working days in the suitable time period for each tractor-powered reforestation machinery (day)
Y Working days on which the tractor operation in general can be done in a year (ha)
Z Net working rate
C_m Machine cost per net working hour (¥/hr)
C_c Depreciation cost per net working hour (¥/hr)
C_s Management cost per net working hour (¥/hr)
C_r Repairs cost per net working hour (¥/hr)
C_f Fuel cost per net working hour (¥/hr)
C_o Lubricating oil cost per net working hour (¥/hr)
C_i Interest, insurance premium, tax etc. per net working hour(¥/hr)
M_l Machine lifetime (hr)
r_r Repairs ratio to depreciation cost

1. Introduction

Development of heavy machineries used for reforestation works is now expected, not only in this country but also in other countries, to improve labour productivity concomitant with a great increase in the amount of forest seeding and planting works throughout the world.

Recently in this country, an increasing emphasis has been placed on planting good tree seedlings after complete land-clearing and careful preparation of planting-holes of sufficient depth and diameter, more than thirty centimeters respectively in general. Good planting practices need also weeding operation one or two times a year for several years after the plantation of tree seedlings. And when some diseases attack tree seedlings after their planting in forest-land, chemicals are often used for powder dusting to keep the forest-land in healthy condition.

The preliminary trial use of tractor-powered reforestation machineries for the reforestation works in this country was started at the so-called Pilot Forest, OHTA, KONSEN GENYA, situated at the eastern part of HOKKAIDO island, which had about 8,000 ha of non-stocked area to be planted within ten years from 1956 to 1965. In this area, there were almost no stumps and shrubs, as a result of forest fires many years ago. And there, after a trial use of various machines for several years, a mechanized method using both tractor-powered heavy machinery and one-man portable light machinery, now broadly used in this country i.e. principally a tractor-powered rotavator for land-clearing and weeding operations, one-man portable earth auger for planting-hole digging operations, one-man portable brush cutter for supplementary use and so on, was eventually applied for reforestation works.

On the other hand, in the general cutover forest-land of this country, there are a lot of stumps, shrubs and grasses having many big or fine roots under the ground. Therefore, the above-mentioned rotavator can not be used for plowing the surface of forest-land in land-clearing and weeding operations, because the rotating blades are easily broken by the heavy impact and load often encountered when hitting roots, gravel and other obstacles under the ground. This fact has been ascertained in the field experiments by the author. So, such a mechanized method as in the Pilot Forest can not be used in general for reforestation works on cutover forest-land of this country.

Accordingly, it can be said that the development of tractor-powered reforestation machineries must be pushed forward in this country in compliance with the silvicultural demand reached after long experience. That is to say, the mechanized method for planting from one- to three-year old seedlings on inclined forest-land and their attached works must be researched in the main, at the present stage of reforestation works in this country.

Thereupon, the author planned to investigate the mechanical or power performance of tractor-powered reforestation machineries as a fundamental study of forest machinery firstly, and the operational performance of them secondly, available for tree-plantation works in cutover forest-land with the help of the measuring methods and equipment originated by himself for the experiments in the test-field.

These field-experiments were done in some National Forests under the management of IWAMURATA, KUSATSU, NUMATA District Forest Offices situated in NAGANO and GUNMA Prefectures, in the summer and autumn seasons from 1963 to 1966. On all operations the author took charge of the control, measurement and analysis of these experiments himself, principally assisted by MIMURA, K. for driving the test tractor and attached machinery, by SHISHIUCHI, M. for surveying the test conditions of forest-land and others, and by HIRAMATSU, O. for the preparation of the measuring equipment in the test-fields. Thanks are due to them for their helpful cooperation.

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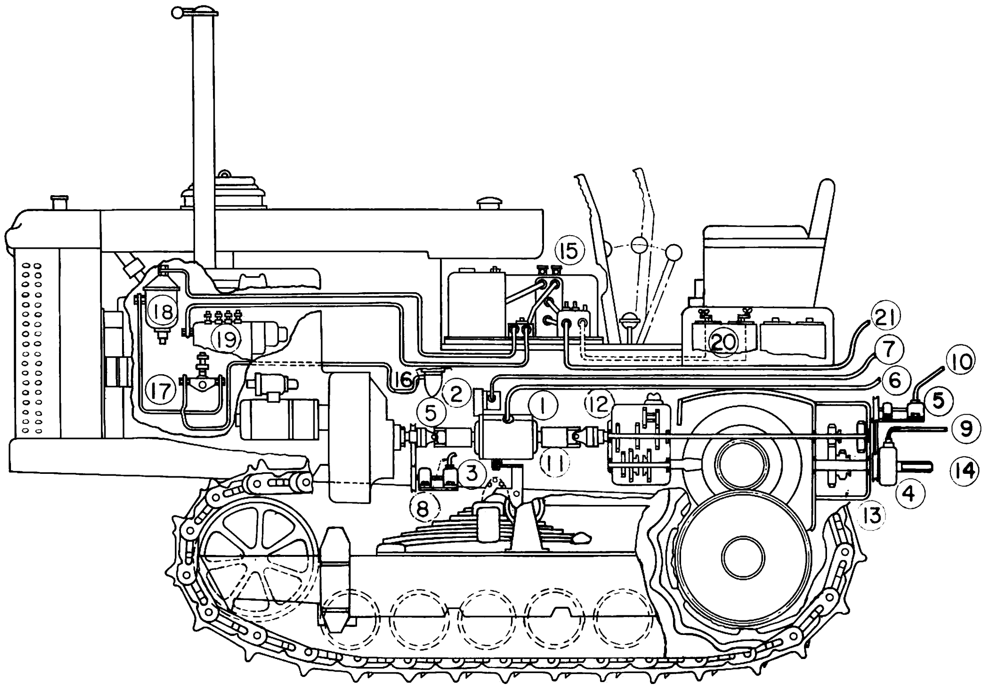
District Forest Offices for their cooperation in the field-experiments.

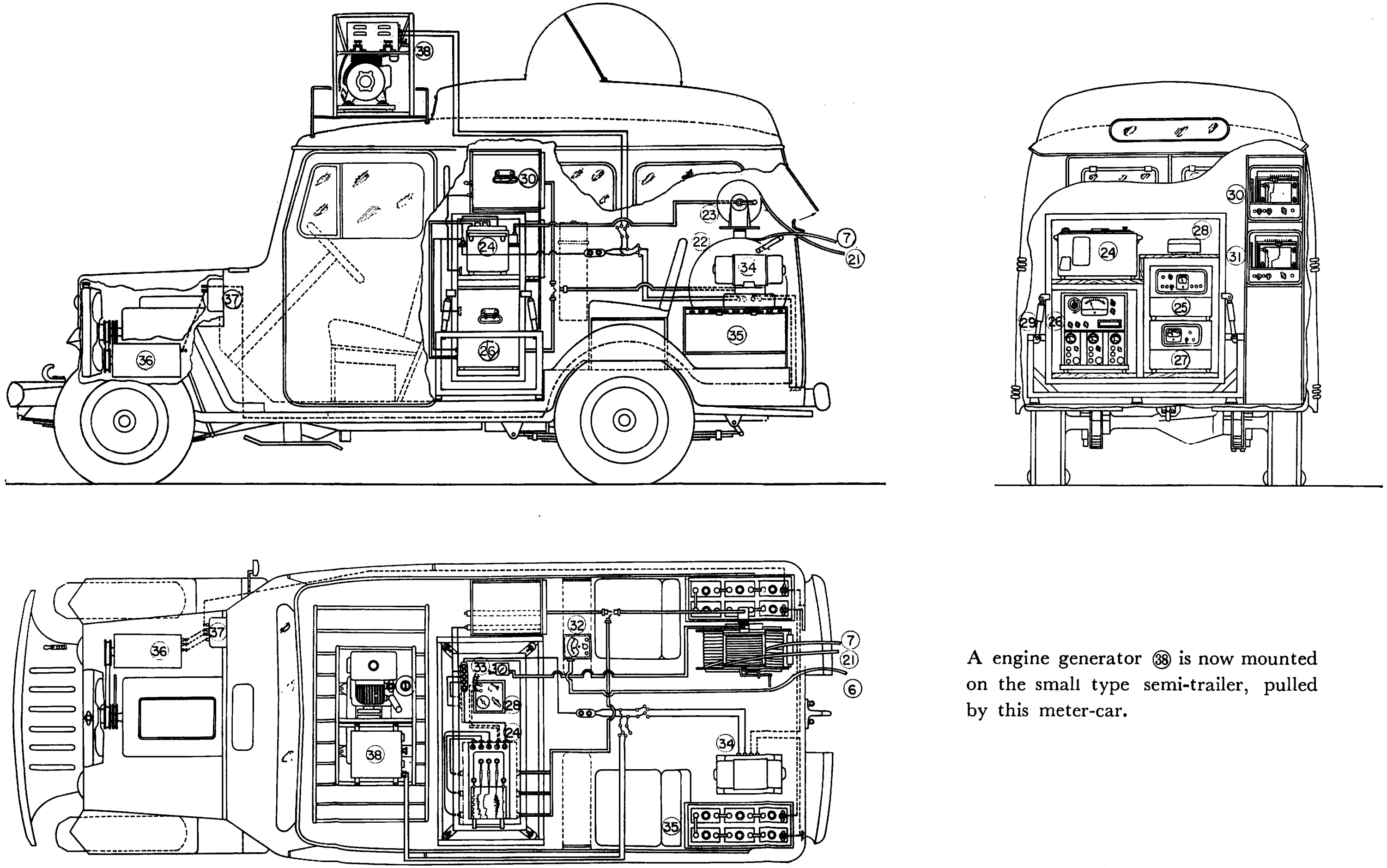
2. Test tractor and measuring equipment

To measure the mechanical performances of various kinds of tractor-powered reforestation machineries on forest-land, the author borrowed a CT 25 type crawler tractor from the Regional Forest Office as test tractor. This test tractor was rebuilt to make the chassis several hundred milimeters longer than the standard one, and then a 30 or 50 mkg torque pick-up was set to the drive shaft between the engine clutch and transmission by the use of a couple of universal joints to measure the engine-torque under load. A generating tachometer was also set to the same point of the drive shaft to pick up the engine speeds. The 100 mkg torque pick-up specially made was set to the PTO shaft to pick up the driven torque of the attached reforestation machinery through the PTO



① Torque pick-up for engine shaft (30 or 50 mkg), ② Generating tachometer for integrating horsepower, ③ Generating tachometer, ④ Torque pick-up for PTO shaft, ⑤ Generating tachometer for PTO shaft (100 mkg), ⑥ Cabtyre cord of torque pick-up for engine shaft, ⑦ Cabtyre cord of generating tachometer for integrating horsepower, ⑧ Cabtyre cord of generating tachometer for engine saft, ⑨ Cabtyre cord of torque pick-up for PTO shaft, ⑩ Cabtyre cord of generating tachometer for PTO shaft, ⑪ Universal joint, ⑫ Transmission, ⑬ Reduction gear box for PTO shaft, ⑭ PTO shaft, ⑮ Electro-magnetic fuel consumption meter, ⑯ Strainer, ⑰ Feed pump of fuel, ⑱ Fuel filter, ⑲ Fuel injection pump, ⑳ Battery, ㉑ Cord for fuel consumption meter, ㉒ Special reel for cord of torque pick-up, ㉓ Special reel for cord of fuel consumption meter, ㉔ Oscillograph, ㉕ Amplifier for oscillograph, ㉖ Dynamic strain meter, ㉗ Power supply, ㉘ Electric timer, ㉙ Meter case with shock absorber, ㉚ Torque indicator, ㉛ Horsepower indicator, ㉜ Generating tachometer, ㉝ Fuel consumption counter, ㉞ In verter, ㉟ Battery, ㊱ Electric generator to charge, ㊲ Rectifier, ㊳ Engine generator.

Fig. 1. Test crawler tractor



A engine generator ㊳ is now mounted on the small type semi-trailer, pulled by this meter-car.

Fig. 2. Meter car (Description is the same as Fig. 1)

Table 1. Specifications of test tractor

Overall length	3,435 mm with three-point implement hitch 2,765 mm without three-point implement hitch	Reduction gear ratio	Forward Ⅰst 59.7 Ⅱnd 40.2 Ⅲrd 18.2 Backward 44.1
Overall width	1,780 mm	Running speed	Forward Ⅰst 3.16 km/hr Ⅱnd 4.37 Ⅲrd 8.12 Backward 3.73
Overall height	1,515 mm		
Total weight	3,500 kg with three-point implement hitch		
Ground clearance	259 mm	Max. drawbar pull	Forward Ⅰst 3,250 kg Ⅱnd 2,200 Ⅲrd 1,270 Backward 2,770
Track shoe width	306 mm		
Ground contact length	1,520 mm		
Ground contact pressure	0.30 kg/cm^2		
Track gauge	1,220 mm	Steering gear	Double differential gear with spur and planetary gears
Engine, Type	ISUZU DA-220, four cylinder, four cycle, water cooling, diesel	Running part, Suspension	Half rigged, having leaf springs at right and left sides independently
Piston displacement	4,084 cc		
Rated horsepower	48 PS at 1,800 rpm	Upper roller	1 at each side
Max. torque	21 mkg at 1,500 rpm	Lower rollers	5 at each side
Fuel consumption rate	260 g/PS/hr	Track shoes	31 at each side

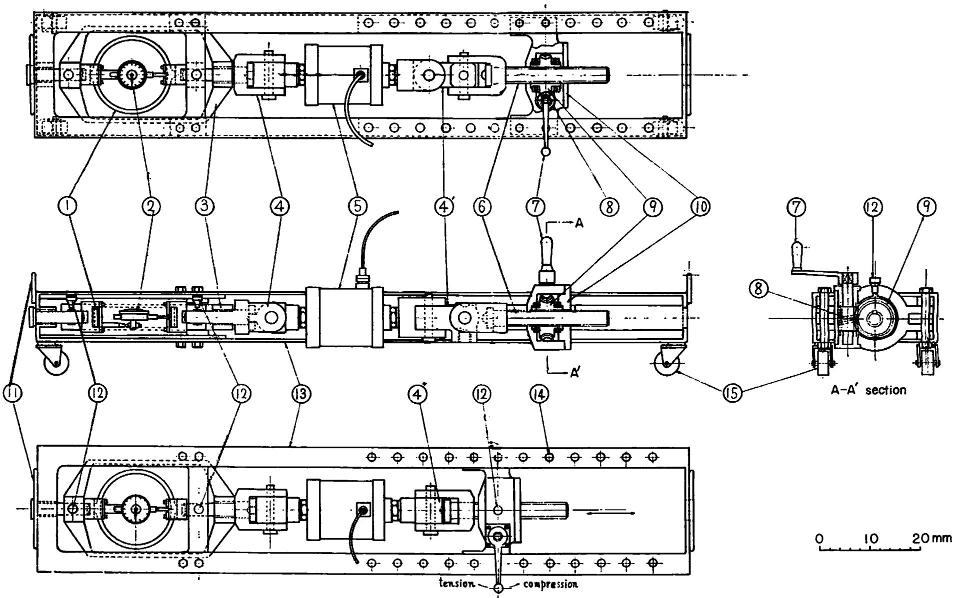
shaft, and also a generating tachometer was set to the same point through a couple of belt pullies. A magnetic fuel consumption meter was set to the fuel feeding pipe between the fuel tank and the fuel pump to measure the fuel consumption in the accuracy of 1 cc (Table 1, Fig. 1).

One 2-ton and one 5-ton load cells were sometimes used to measure the tractive force of tractor and the hauling force of attached machinery by tractor. A photoelectric tube tachometer was sometimes used to measure the revolutions per minute of the cutter driven by the oil motor set to the PTO shaft like a stump cutter, because the generating tachometer could not be directly set to the cutter shaft. An electric stop watch which can be connected to the oscillograph was always used to measure the running time with an electric time checker.

These pick-ups for torque, revolutions per minute, fuel consumption, running time and so on, were led to their recorders, meters, or counters mounted on the meter-car, by means of fifty meter long cabtyre cords and special reels.

The meter-car designed by the author is a rebuilt four-wheel drive type Jeep wagon, available for measuring the power performances of forest machineries on forest-land (Fig. 2). The kinds of measuring equipment on board were as follows: three-element dynamic strain meter, three-element ink-writing oscillograph (six-element electro-magnetic oscillograph), amplifiers, power sources, indicators for generating or photoelectric tachometers, counter of electro-magnetic fuel consumption meter, magnetic time checker, special reels for cabtyre cords, tranceiver and loud-speaker for communicating among the test controllers—the author and his several assistants. A one kw generator driven by a four-cycle 4.5 PS gasoline engine is mounted on the small type semi-trailer, pulled by the meter-car.

As it is always necessary to check instantly the accuracy of electric meters in the case of the measurement of mechanical performances of forest machineries on forest-land, the author originated a portable mechanical tester equipped with 750 kg and 5,000 kg strain rings of which the tolerance had preliminarily been inspected by the authority concerned, to check the linearity of load-cells for tension and compression (Fig. 3). Moreover, another portable mechanical torque tester for from two



① Strain ring, ② Dial gauge, ③ Guide ring, ④ Connector, ④′ Connector for tension, ④″ Connector for compression, ⑤ Load cell, ⑥ Screw, ⑦ Handle, ⑧ Worm, ⑨ Worm wheel, ⑩ Gear box, ⑪ Hand hook, ⑫ Grease cup, ⑬ Frame, ⑭ Adjusting bolt for span, ⑮ Rubber wheel.

Fig. 3. Portable mechanical tester for load cell

to fifty mkg torque pick-ups was ready*1. A pitot tube was used to measure the velocity of flow in duster. Flow meter and electric pressure pickup were also used to check the hydraulic drive.

3. Runnig performance of crawler tractor on forest-land

The working types of tractor-powered reforestation machineries can be broadly classified into the following three groups:

(1) The attached working machinery is transferred to an operational point on forest-land, either pulled by or mounted on the tractor, and then the reforestation job is done with the help of the attached machinery driven by the tractor-engine when the running part of tractor stops.

Example: stump cutter, earth auger, culti-auger etc.

(2) The reforestation job is done with the help of the attached machinery, pulled by or mounted on the tractor, driven by the PTO shaft when the tractor runs on forest-land.

Example: rotary cutter, chemicals blower or sprayer, rotavator etc.

(3) The reforestation job is done with the help of the attached machinery pulled or pushed by running tractor, while the PTO shaft is not driven.

Example: rake dozer, planter etc (for nursery use …… transplanter, root cutter, manure spreader, plow, disc-harrow, trailer etc.).

In common for each case mentioned above, it can be thought that the mechanical work of tractor-powered reforestation machinery is shown as the total work of the running on forest-land and the other works for simplicity. Strictly speaking, the work of running on forest-land in tractor-

*1 Yamawaki, S. *et al.* :Studies on silvicultural machines (I), Earth drill for tree-planting, Bulletin of the Government Forest Experiment Station, 139, p. 91, (1962).

powered reforestation machinery should be divided into the work of tractor's running and that of attached machinery's running. The latter work varies in accordance with the function of the attached machinery.

Therefore, it is very important first, to clearly distinguish the work required for the tractor's running on forest-land; and second, the work required for the attached machinery's running while working on forest-land, sometimes mounted on tractor.

3.1 Coefficient of adhesion of crawler tractor on forest-land

The adhesion of the crawler tractor on inclined forest-land under various conditions was measured by the author with the help of a load cell or dynamometer. Almost inmmediately after the tractor starts, the adhesion of it takes suddenly the maximum value and then goes down until a certain value that varies in accordance with the surface condition of forest-land. When the tractor begins to slip on the same ground, the more it slips, the smaller the adhesion of it becomes, because the ground surface turns into an unstable condition, either more soft in dry condition or more soggy in wet condition, under the action of track-shoes losing the bearing capacity of the soil.

The relations among the coefficient of the apparent maximum adhesion just before the tractor begins to slip on humus soil $\mu_a'{}_{max}$ and the slope-grade of forest-land $\alpha(°)$, the coefficient of the apparent average adhesion immediately after the tractor begins to slip on humus soil $\mu_a'{}_{mean}$ and the slope-grade of forest-land $\alpha(°)$ are given by the following empirical formulae, as shown in Fig. 4.

$$\left.\begin{aligned}\mu_a'{}_{,max} &= (0.968-1.617\times10^{-2}\alpha+7.322\times10^{-4}\alpha^2)\cos\alpha-\sin\alpha\\ \mu_a'{}_{,mean} &= 0.678\cos\alpha-\sin\alpha\end{aligned}\right\}\cdots\cdots(1)$$

where $\mu_a'=\frac{F_t}{W_t}$, F_t: tractive force of tractor (kg), W_t: weight of tractor (kg).

If μ_a is the coefficient of real adhesion, the tractive force of tractor F_t on inclined forest-land

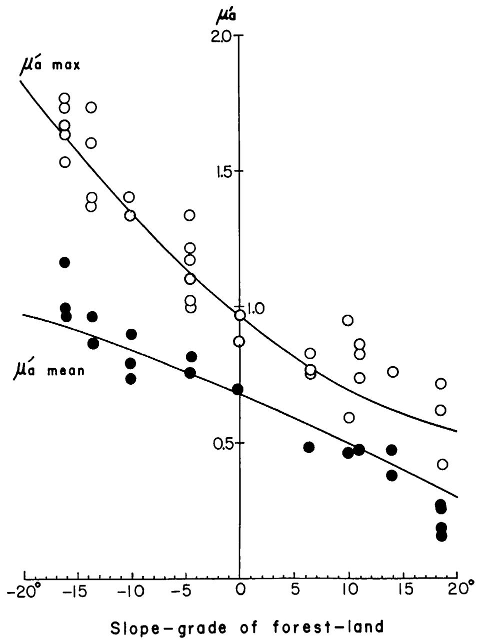


Fig. 4. Coefficient of apparent adhesion of crawler tractor, μ_a'

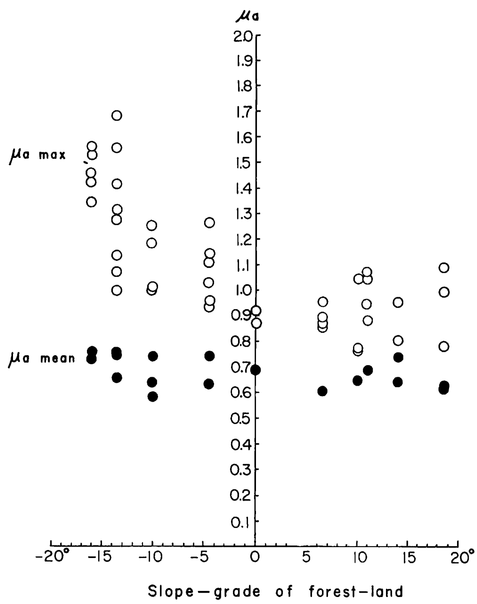


Fig. 5. Coefficient of real adhesion of crawler tractor, μ_a

with the slope-grade $\alpha(°)$ is expressed by

$$F_t=(\mu_a \cos\alpha-\sin\alpha)W_t \quad \cdots\cdots (2)$$

Therefore, μ_a is

$$\mu_a=\frac{F_t}{W_t \cos\alpha}+\tan\alpha \quad \cdots\cdots (3)$$

$\mu_{a,max}$ influenced and $\mu_{a,mean}$ not influenced by the slope-grade α are shown in Fig. 5.

It will be seen that the measurement of the coefficient of maximum real adhesion of tractor on forest-land with any slope-grade is difficult because the tractor is usually pulled by the accelerated force at the beginning. On the contrary of this, the coefficient of average real adhesion of it can be exactly obtained under no influence of slope-grade, from the ordinary measuring method.

3.2 Coefficient of running resistance of crawler tractor on forest-land

The running resistance force of crawler tractor in engine-clutch off, neutral or lst gear of transmission, was successfully measured on different surface conditions of forest-land, namely covered with black soil, slashed branches, bamboo grass and grass, because the test tractor was pulled by the other tractor (CT 35) through the load cell of which the tractive line was arranged to be horizontal with the help of the wooden sled under it, pulled by the other tractor at the same time.

The coefficient of running resistance of crawler tractor f_t increases in proportion to the increase of the actual pulling speed V_a (m/sec) and takes different values in accordance with the surface

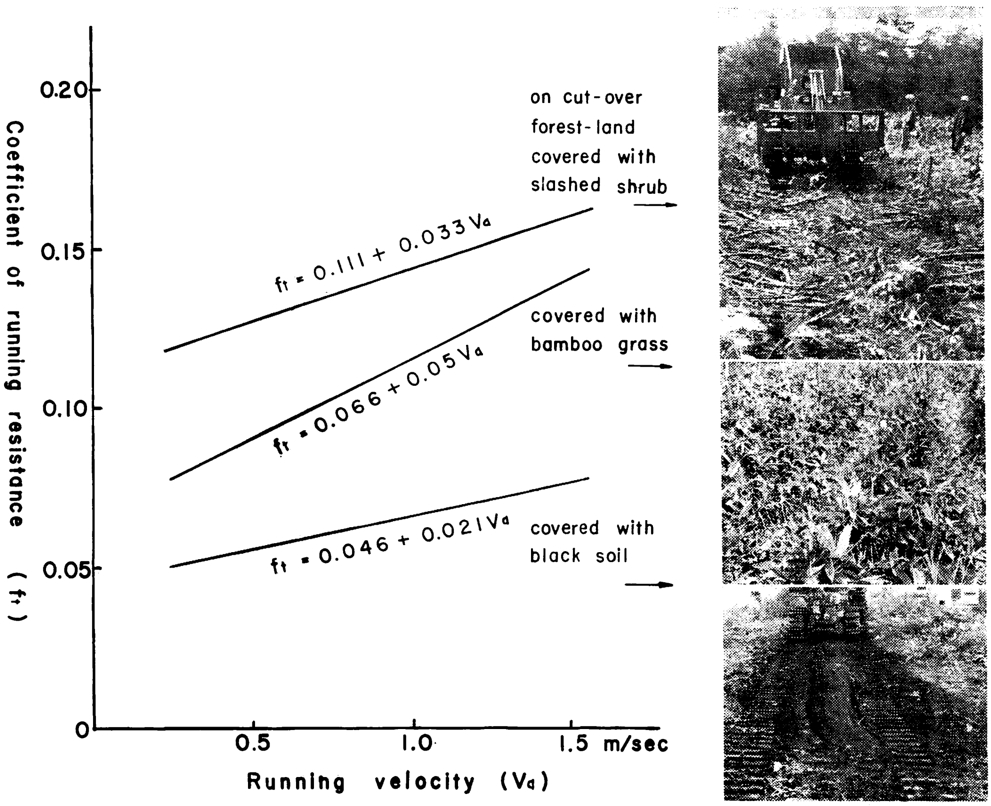


Fig. 6. Coefficient of running resistance of crawler tractor, f_t

condition of forest-land.

on cutover forest-land covered with slashed branches and grass

$$f_t = 0.111 + 0.033\,V_a \quad \cdots\cdots (4)$$

on forest-land covered with bamboo-grass

$$f_t = 0.066 + 0.05\,V_a \quad \cdots\cdots (5)$$

on forest-land of black soil

$$f_t = 0.046 + 0.021\,V_a \quad \cdots\cdots (6)$$

(see Fig. 6)

where they were in dry condition and the track shoes of tractor did not sink into the ground.

It can be said that the running resistance force of tractor is equivalent to the additional work of tractor which is subtracted from the actual tractive horsepower of tractor from the power of tractor engine. So, it will be seen that the tractor cannot work on forest-land covered with bamboo-grass or slashed branches more easily than on black soil, because the running resistance force of tractor on bamboo grass or slashed branches takes about 1.7 or 2.2 times of that on black soil as shown above.

3.3 Slip of crawler tractor running on inclined forest-land

In the crawler tractor, the theoretical running speed V_t (km/h) can be computed by

$$V_t = \frac{l_p \cdot n \cdot N_e}{60 \cdot i} \quad \cdots\cdots (7)$$

where n : number of track shoes conveyed by one cycle of the sprocket, $\frac{23}{2}$

l_p: a pitch length of the track shoe (m), 0.1524

N_e: revolutions per minute of the tractor engine (rpm)

i: overall reduction gear ratio of the tractor

It may be considered that the slip of crawler tractor s is equal to the ratio of the energy *i.e.* the horsepower consumed for the loss of running velocity P_c to the overall energy *i.e.* the horsepower consumed for the whole running P. So, the slip of crawler tractor s is given by

$$s = \frac{P_c}{P} = \frac{F_t \cdot V_t - F_t \cdot V_a}{F_t \cdot V_t} = 1 - \frac{V_a}{V_t} \quad \cdots\cdots (8)$$

where F_t: tractive force of tractor (kg).

V_a: actual running speed of tractor (km/h).

For instance, the slip of test tractor with lifted rotary cutter, nearly equal to that of tractor only when merely running on various inclined forest-lands covered with bamboo-grass, was measured by scaling*2 the actual running distance and the track-laying distance at the same place, and furthermore checking up the time required for running, From this experiment, we obtained an empirical formula for the slip s (%) in relation to the slope-grade of forest-land α (°).

$$s = -1.7 + 0.018\alpha + 0.007\alpha^2 + 0.0015\alpha^3 \quad \cdots\cdots (9)$$

(see Fig. 7)

It will be seen that the slip of crawler tractor is equal to or less than 0 % when the slope-grade is nearly 0°, because the gap between the grousers and the surface of forest-land covered with

*2 The scaling was done on the right and left running parts of tractor respectively, and then the slip of tractor s was taken as the average of the slip of left running part s_1 and that of right running part s_2.

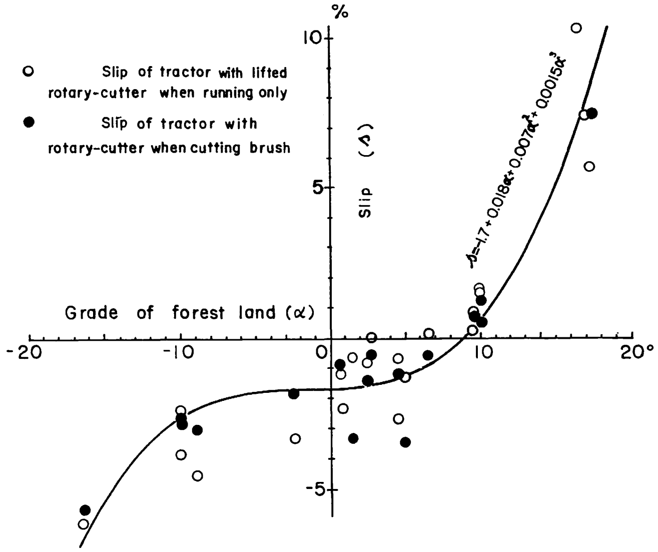


Fig. 7. Slip of crawler tractor (with rotary cutter) s on forest-land covered with bamboo grasses

bamboo-grass and others increases the effective diameter of sprocket a little more than that of the given one.

3.4 Running horsepower of crawler tractor straight on inclined forest-land

The torque required by the crawler tractor when running straight on forest-land T_t (mkg) which is transmitted to the crank shaft of tractor engine is given by the theory.

$$T_t=\frac{R_t \cdot d}{2 \cdot i \cdot \eta} \quad \cdots\cdots (10)$$

where R_t: running resistance force of tractor (kg)

d: effective dia. of sprocket of tractor (m)

η: overall mechanical efficiency of tractor

R_t is given by the theory.

$$R_t=W_t(f_t \cos\alpha+\sin\alpha) \quad \cdots\cdots (11)$$

i and η are

$$i=i_1 i_2 i_3 \quad \cdots\cdots (12)$$

where, i_1: reduction gear ratio of transmission, $\frac{33}{19}=1.735$

i_2: that of differential, $\frac{40}{6}=6.667$

i_3: that of final drive, $\frac{67}{13}=5.15$

$$\eta=\eta_1 \eta_2 \eta_3 \eta_4 \quad \cdots\cdots (13)$$

where, η_1: mechanical efficiency of transmission, supposed value for 1st gear, 0.95

η_2: that of differential, supposed value, 0.93

η_3: that of final drive, supposed value, 0.95

η_4: that of sprocket and track link, supposed value, 0.835

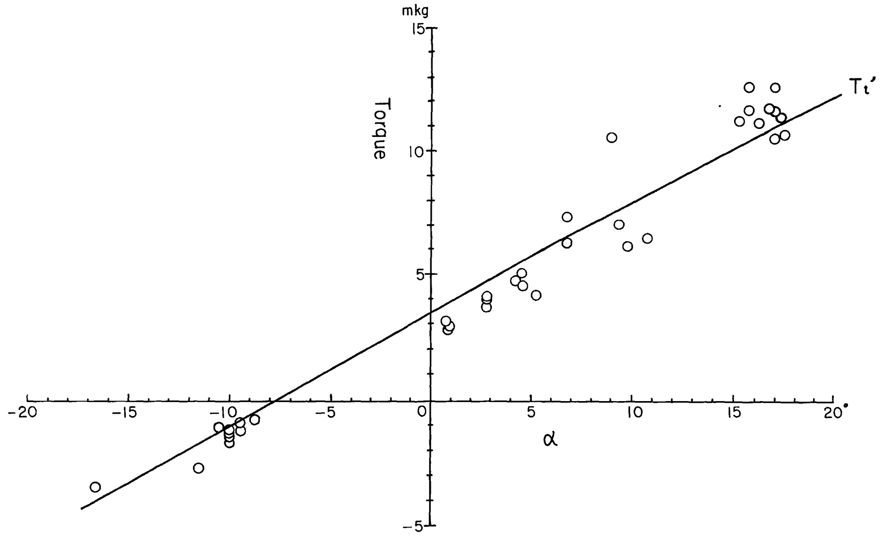


Fig. 8-a. The comparison between the theoretical and empirical values of the torque required for the crawler tractor when running straight on forest-land (T_t' will be described later)

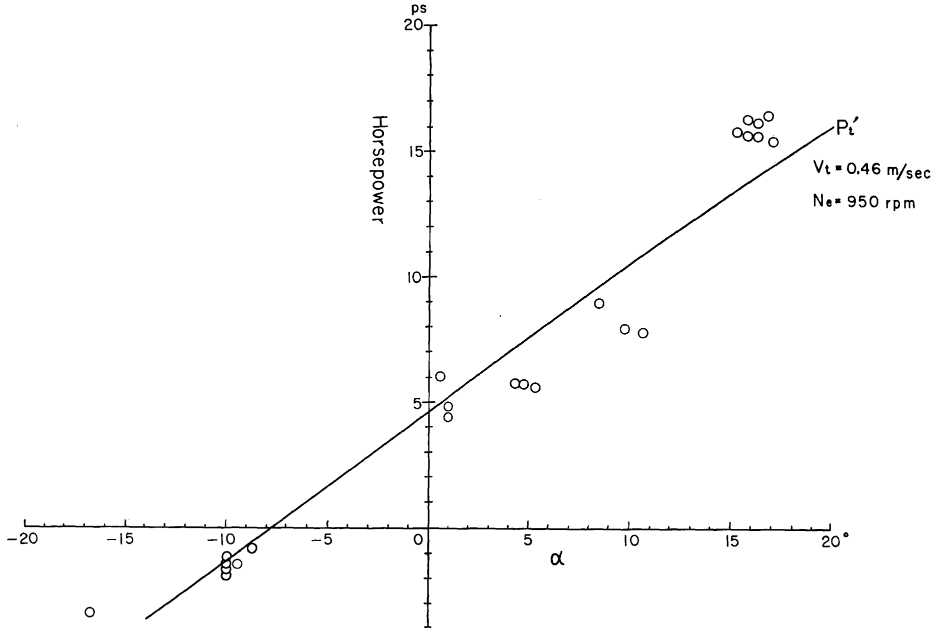


Fig. 8-b. The comparison between the theoretical and empirical values of the horsepower required for that (P_t' will be described later)

It can be said that the overall mechanical efficiency η of test tractor is near 0.7 in general, computed by these supposed values of each mechanical efficiency from the number and kind of gears on the basis of the data showing that the mechanical efficiency of PTO shaft is almost constant, approximately 0.95, from the results of experiment shown later.

From formulae (10), (11), (12), (13), T_t is written in the following form.

$$T_t=\frac{W_t(f_t\cos\alpha+\sin\alpha)\cdot d}{2\cdot i_1\cdot i_2\cdot i_3\cdot\eta_1\cdot\eta_2\cdot\eta_3\cdot\eta_4}\quad\cdots\cdots(14)$$

Then, the horsepower required by the tractor when running straight on forest-land P_t (PS) which is transmitted to the crank shaft of tractor engine is

$$P_t=\frac{R_t\cdot V_t}{75\cdot\eta}\quad\cdots\cdots(15)$$

From formulae (7), (8), V_t is written as

$$V_t=\frac{V_a}{1-s}=\frac{l_p\cdot n\cdot N_e}{60\cdot i}\quad\cdots\cdots(16)$$

From formulae (11), (12), (13), (15), (16), P_t is written as

$$P_t=\frac{W_t(f_t\cos\alpha+\sin\alpha)\cdot V_a}{75\cdot\eta_1\cdot\eta_2\cdot\eta_3\cdot\eta_4(1-s)}=\frac{W_t(f_t\cos\alpha+\sin\alpha)l_p\cdot n\cdot N_e}{75\cdot 60\cdot i_1\cdot i_2\cdot i_3\cdot\eta_1\cdot\eta_2\cdot\eta_3\cdot\eta_4}\quad\cdots\cdots(17)$$

For example, the torque and horsepower of test tractor with lifted rotary cutter, nearly equal to that of tractor only, when running only straight on various inclined forest-land covered with bamboo-grass, was successfully measured by the author, and are shown in Fig. 8-a, b, corresponding to the theoretical values T_t'', P_t'' computed from the formulae*3.

3.5 Turning horsepower of crawler tractor on forest-land

The turning horsepower of crawler tractor P_{tc} (PS) in the case of uniform turn when no acceleration of motion occurs, is given by

$$P_{tc}=\frac{F_2V_2+F_1V_1}{270\cdot\eta}\quad\cdots\cdots(18)$$

where, F_1: propelling force of inner track (kg)

F_2: that of outer track (kg)

V_1: controlled speed of inner track (km/h)

V_2: that of outer track (km/h)

When turning, the running speed of the center of tractor-chassis V_0 has a relation to V_1, V_2 and their turning radius.

$$V_2 : V_0 : V_1 = r : \left(r-\frac{b}{2}\right) : (r-b)\quad\cdots\cdots(19)$$

where, r: radius of curvature in outer track (m)

b: track gauge (m)

Thus we have

$$\left.\begin{aligned}V_2&=V_0\frac{2r}{2r-b}\\ V_1&=V_0\frac{2(r-b)}{2r-b}\end{aligned}\right\}\quad\cdots\cdots(20)$$

The well-known formulae first published by ZASLAVSKI are

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*3 $$T_t''=\frac{\{(W_t+W_r)(f_t\cos\alpha+\sin\alpha)\}\cdot d}{2\cdot i_1\cdot i_2\cdot i_3\cdot\eta_1\cdot\eta_2\cdot\eta_3\cdot\eta_4}$$

$$P_t''=\frac{\{W_t+W_r)(f_t\cos\alpha+\sin\alpha)\}\cdot V_a}{75\cdot\eta_1\cdot\eta_2\cdot\eta_3\cdot\eta_4(1-s)}=\frac{\{(W_t+W_r)(f_t\cos\alpha+\sin\alpha)\}l_p\cdot n\cdot N_e}{75\cdot 60\cdot i_1\cdot i_2\cdot i_3\cdot\eta_1\cdot\eta_2\cdot\eta_3\cdot\eta_4}$$

where, W_r: weight of rotary cutter, which will be described later.

$$\left.\begin{aligned} F_1 &= R_1 - \frac{M_0}{b} \\ F_4 &= R_2 + \frac{M_0}{b} \end{aligned}\right\} \cdots\cdots (21)$$

where, $R_1 = R_2$: movement resistance of inner and outer tracks

M_0: moment of resistance to the rotation around the center of gravity in tractor

Assuming that $R_1 = R_2 = ft\frac{W_t}{2}$, formulae (21) are

$$\left.\begin{aligned} F_1 &= ft\frac{W_t}{2} - \frac{M_0}{b} \\ F_2 &= ft\frac{W_t}{2} + \frac{M_0}{b} \end{aligned}\right\} \cdots\cdots (22)$$

The value of M_0 in this test tractor, is shown as $\frac{\mu W_t l}{4}$, where μ=coefficient of lateral friction of track on forest-land (0.1), l=contact length of tracks on forest-land, according to BEKKER, M.G.[*4] Accordingly, formulae (22) are

$$\left.\begin{aligned} F_1 &= ft\frac{W_t}{2} - \frac{\mu W_t l}{4b} \\ F_2 &= ft\frac{W_t}{2} - \frac{\mu W_t l}{4b} \end{aligned}\right\} \cdots\cdots (23)$$

From formulae (18), (20), (23), the turning horsepower of crawler tractor P_{tc} when no acceleration of motion occurs, may be written in the following form:

$$P_{tc} = \frac{W_t V_0}{270 \cdot \eta}\left\{ft + \frac{\mu l}{2(2r-b)}\right\} \cdots\cdots (24)$$

Considering the effect of the centrifugal force on tractor $F_c = \frac{W_t V_0^2}{g\left(r-\frac{b}{2}\right)}$ where g=acceleration due to gravity, when turning on level forest-land, M_0, R_1, R_2, F_1, F_2 are given by BEKKER, M.G.[*5]

$$M_0 = \frac{\mu W_t l}{4}\left\{1 - \frac{V_0^4}{\mu^2 g^2\left(r-\frac{b}{2}\right)^2}\right\} \cdots\cdots (25)$$

$$\left.\begin{aligned} R_1 &= ft\frac{W_t}{2} - \frac{h}{b}F_c\cos\beta \\ R_2 &= ft\frac{W_t}{2} + \frac{h}{b}F_c\cos\beta \end{aligned}\right\} \cdots\cdots (26)$$

where, h: height of center of gravity on tractor

β: angle of rotation corresponding to the displacement of the center of rotation.

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*4 BEKKER, M.G.: Theory of land locomotion, p. 346, (1956)

*5 BEKKER, M.G.: Theory of land locomotion, p. 356, (1956)

$$\left.\begin{aligned} F_1 &= f_t\frac{W_t}{2} - \frac{h}{b}\,\frac{W_tV_0^{\,2}}{g\left(r-\dfrac{b}{2}\right)} - \frac{\mu W_t l}{4b}\left\{1-\frac{V_0^{\,4}}{\mu^2 g^2\left(r-\dfrac{b}{2}\right)^2}\right\} \\ F_2 &= f_t\frac{W_t}{2} + \frac{h}{b}\,\frac{W_tV_0^{\,2}}{g\left(r-\dfrac{b}{2}\right)} + \frac{\mu W_t l}{4b}\left\{1-\frac{V_0^{\,4}}{\mu^2 g^2\left(r-\dfrac{b}{2}\right)^2}\right\} \end{aligned}\right\} \cdots\cdots(27)$$

From formulae (18), (20), (27), the horsepower of crawler tractor P_{tc} under the effect of the centrifugal force, may be written as:

$$P_{tc} = \frac{W_tV_0}{270\eta}\left[f_t + \frac{\mu l}{2(2r-b)} + \frac{2V_0^{\,2}\{2\mu hg(2r-b)-V_0^{\,2}l\}}{\mu g^2(2r-b)^3}\right] \cdots\cdots(28)$$

Comparison among the empirical values successfully measured and the theoretical values computed from formulae (24), (28) about the turning horsepower of crawler tractor on level forest-land is shown in Fig. 9. From this comparison, it will be seen that the value of P_{tc} is given by the theoretical formula (28) considering the effect of the centrifugal force for the case of more than about 1 km/h of turning speed, and also is given by the theoretical formula (24) when no acceleration of motion occurs for the case of less than about 1 km/h of turning speed.

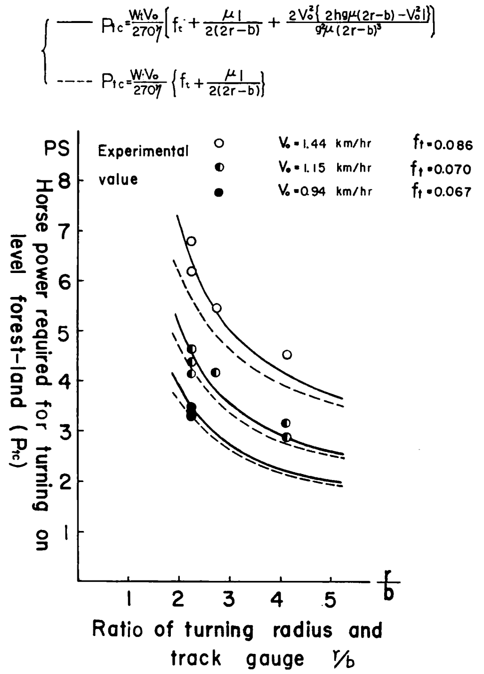

Fig. 9. Horsepower required for crawler tractor turning on level forest-land, P_{tc}

Then, considering an uphill and downhill turn which starts parallel to the contour line on a slope of forest-land with its grade α, the following formulae are given by BEKKER, M.G.[*6]

in uphill turn

$$\left.\begin{aligned} F_1 &= f_t\frac{W_t}{2}\left(1-\frac{2h}{b}\tan\alpha\right) - \frac{\mu W_t l}{4b_*}\left\{1-\left(\frac{\sin\alpha}{\mu}\right)^2\right\} \\ F_2 &= f_t\frac{W_t}{2}\left(1+\frac{2h}{b}\tan\alpha\right) + \frac{\mu W_t l}{4b_*}\left\{1-\left(\frac{\sin\alpha}{\mu}\right)^2\right\} \end{aligned}\right\} \cdots\cdots(29)$$

in downhill turn

$$\left.\begin{aligned} F_1 &= f_t\frac{W_t}{2}\left(1+\frac{2h}{b}\tan\alpha\right) - \frac{\mu W_t l}{4b_*}\left\{1+\left(\frac{\sin\alpha}{\mu}\right)^2\right\} \\ F_2 &= f_t\frac{W_t}{2}\left(1-\frac{2h}{b}\tan\alpha\right) + \frac{\mu W_t l}{4b_*}\left\{1+\left(\frac{\sin\alpha}{\mu}\right)^2\right\} \end{aligned}\right\} \cdots\cdots(30)$$

*6 BEKKER, M.G.: Theory of land locomotion, pp. 351～354, (1956)
The symbol b in the formulae (29), (30) is corrected by the author, for it seems to have been misprinted in the above book.

Accordingly, the uphill or downhill turning horsepower of crawler tractor on a slope of forest-land will be given by the following formulae, after substituting (29) or (30), (20) into (18).

in uphill turn

$$P_{tc}=\frac{W_t V_0}{270\eta}\left[f_t+\frac{1}{2r-b}\left\{2f_t h\tan\alpha+\frac{l}{2}\left(\mu-\frac{\sin^2\alpha}{\mu}\right)\right\}\right] \quad \cdots\cdots(31)$$

in downhill turn

$$P_{tc}=\frac{W_t V_0}{270\eta}\left[f_t-\frac{1}{2r-b}\left\{2f_t h\tan\alpha-\frac{l}{2}\left(\mu-\frac{\sin^2\alpha}{\mu}\right)\right\}\right] \quad \cdots\cdots(32)$$

Now, when the tractor turns uphill or downhill on a slope of forest-land with slope-grade γ, the lateral inclination angle α, the uphill or downhill angle β of tractor on a slope and the progressing angle ω of tractor to the contour line on a slope vary from each other as the tractor progresses in its turning (Fig. 10). Furthermore, there are some relations among α and γ, β and γ, that is

$$\alpha=90-\cos^{-1}\{\sin(90-\omega)\sin\gamma\}=\sin^{-1}\{\sin(90-\omega)\sin\gamma\}$$

and

$$\beta=90-\cos^{-1}\{\sin\omega\ \sin\gamma\}=\sin^{-1}\{\sin\omega\ \sin\gamma\}$$

(see Fig. 11)

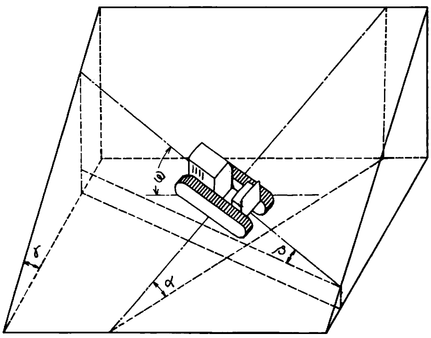

Fig. 10. Various angles α, β, γ, ω, when tractor turns uphill or downhill on a slope of forest-land

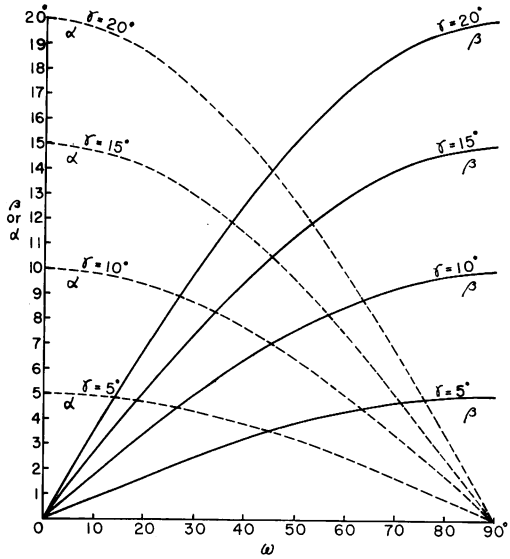

Fig. 11. Relations among α and γ, β and γ
$\alpha=\sin^{-1}\{\sin(90-\omega)\sin\gamma\}$
$\beta=\sin^{-1}\{\sin\omega\ \sin\gamma\}$

Finally, from formulae (28); (31), (32), the turning horsepower of tractor taking any course on a slope of forest-land P_{tc} is rewritten in the following form.

$$P_{tc}=\frac{W_t V_0}{270\eta}\left[f_t+\frac{\mu l}{2(2r-b)}+\frac{2V_0\{2hg\mu(2r-b)-lV_0^2\}}{g^2\mu(2r-b)^3}+\frac{1}{(2r-b)}\left\{2f_t h\tan\alpha+\frac{l}{2}\left(\mu-\frac{\sin^2\alpha}{\mu}\right)\right\}+\sin\beta\right] \quad \cdots\cdots(33)$$

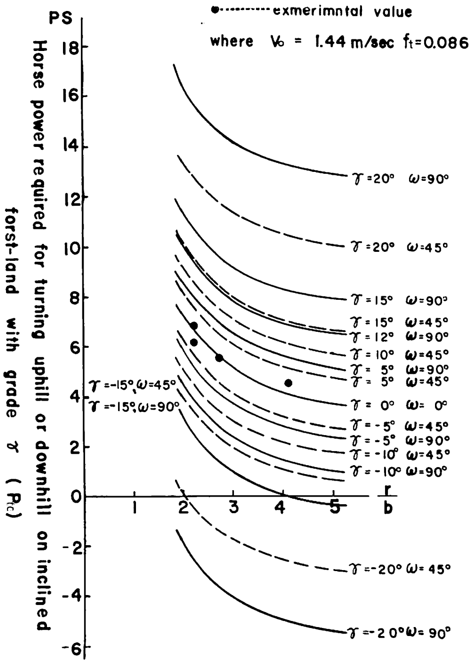

Fig. 12. Horsepower P_{tc} required for crawler tractor turning uphill or downhill on inclined forest-land with slope-grade γ

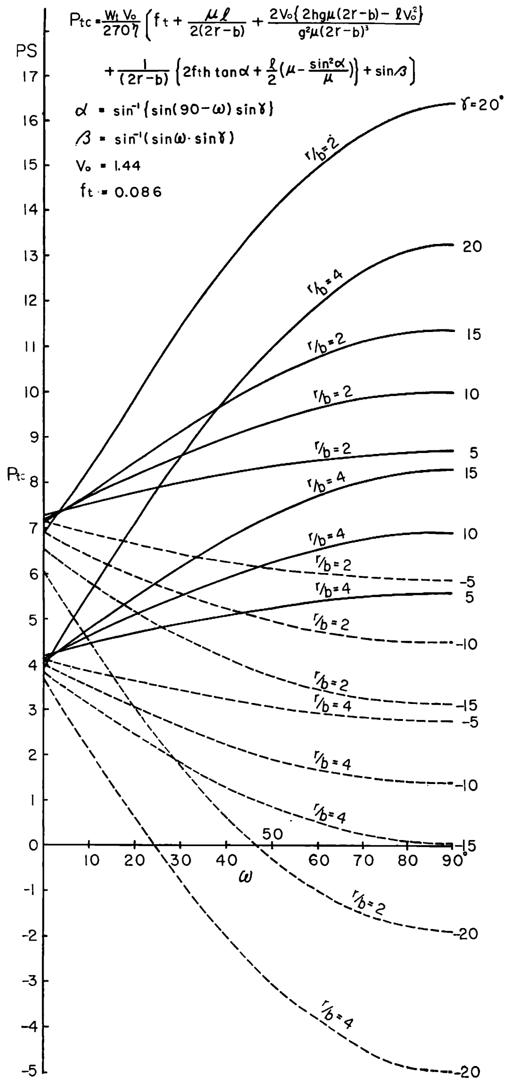

Fig. 13. Do.

The relations among P_{tc}, $\frac{r}{b}$, γ and ω when V_0 and f_t are constant, are shown in Fig. 12, 13.

3.6 Stump-crossing horsepower of crawler tractor on forest-land

Roughly speaking, there are two types of obstacles the tractor meets while running on inclined forest-land i.e. stumps and cavities. The cavity-crossing performance of crawler tractor is described in literature*7. In stump-crossing, the maximum height of stump crossed by crawler tractor is given by a graphical solution adopted by KRISTI*8.

It is needless to say that the tractor-engine must have enough torque in its performance to lift the full weight of the tractor up to the level of stump height with the help of the tractive effort of grousers around the front idler transmitted through the endless track layer driven by the rear sprocket.

When the center of the front idler O_1 moves from $O_1{}'$ to $O_1{}''$ i.e. climbs up a stump as shown in Fig. 15-a, b*9, the vertical ground reactions are

$$\left.\begin{aligned} Q_1&=\frac{W_t}{2}\left\{1-\frac{2h\tan(\alpha+\alpha_1)\cos\alpha_1}{B-\frac{b}{2}}\right\}\cos(\beta+\beta_2) \\ Q_2&=\frac{W_t}{2}\left\{1+\frac{2h\tan(\alpha+\alpha_1)\cos\alpha_1}{B-\frac{b}{2}}\right\}\cos(\beta+\beta_2) \end{aligned}\right\} \cdots\cdots(34)$$

where Q_1: vertical ground reaction on the stump-climbing track

Q_2: that on the ground-running track

The propelling forces as shown in Fig. 15-a on tractor F_1, F_2 are

$$\left.\begin{aligned} F_1&=Q_1\cos\alpha\left\{\frac{\frac{l}{2}}{L-l_x}\right\} \\ &=\frac{W_t}{2}\cos\alpha\cdot\cos(\beta+\beta_2)\left\{1-\frac{2h\tan(\alpha+\alpha_1)\cos\alpha_1}{B-\frac{b}{2}}\right\}\left\{\frac{\frac{l}{2}}{L-l_x}\right\} \\ F_2&=Q_1\cos\alpha\left\{\frac{\frac{l}{2}}{L-l_x}\right\} \\ &=\frac{W_t}{2}\cos\alpha\cdot\cos(\beta+\beta_2)\left\{1-\frac{2h\tan(\alpha+\alpha_1)\cos\alpha_1}{B-\frac{b}{2}}\right\}\left\{1-\frac{\frac{l}{2}}{L-l_x}\right\} \end{aligned}\right\} \cdots\cdots(35)$$

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*7 BEKKER, M.G.: Theory of Land Locomotion, p. 387, (1956)
If the center of gravity is located half way on the distance $l+0.7(r_f+r_r)$, the tractor can cross a cavity such as a ditch with $l_d=\frac{4}{9}\{l+0.7(r_f+r_r)\}$ of width.
where, l : the length of ground contact of track layer i.e. nearly equal to the length between the center of front idler and rear sprocket, r_f : radius of front idler, r_r : radius of rear sprocket, l_d : ditch width.

*8 The maximum height of stump h_{omax} crossed by test tractor and the maximum tilt α_{max} may be obtained from the intersection points 1′, 2′, 3′…… between any radiating line through the center of gravity in tractor C_G 1, C_G 2, C_G 3…… and their perpendicular and tangential line to the outer track circle around the rear driving sprocket, as shown in Fig. 14, from the literature——OHINOUE, H. *et al.*: Translation into Japanese of KRISTI's Avtotraktorny Spravotchnikh published in Moscow—1938, Tokyo, (1944).

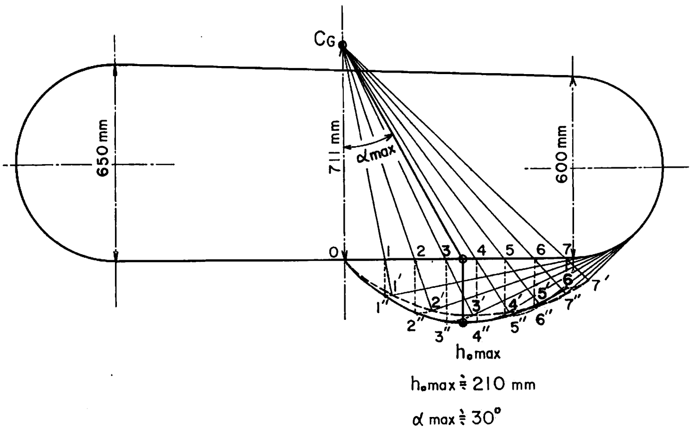

Fig. 14. Graph method to solve the maximum height of stump crossed by tracked tractor, h_{omax} (from KRISTI's Avtotraktorny Spravotchnikh)

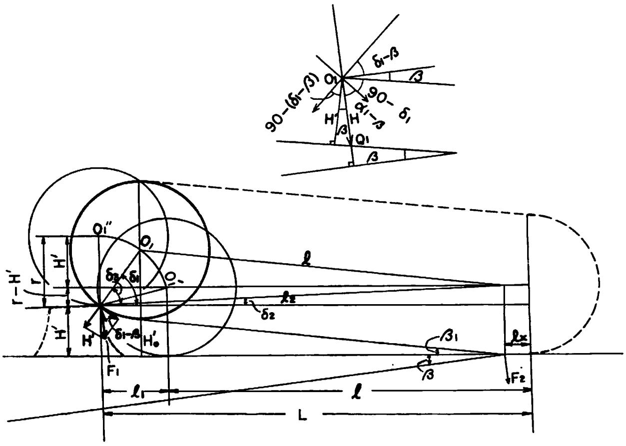

Fig. 15-a. Symbols when crawler tractor's climbing up a stump

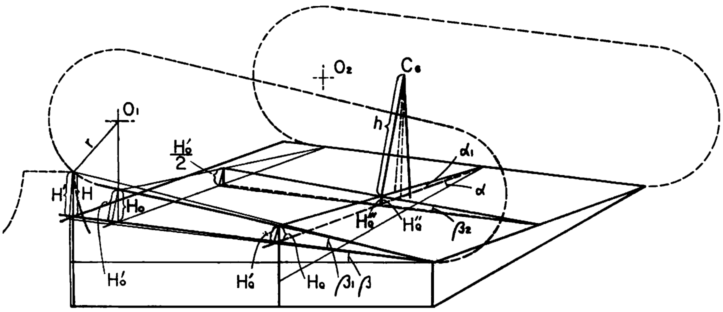

Fig. 15-b. Do.

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*9 $\alpha=90^\circ-\cos^{-1}(\cos\omega\sin\gamma)$

$\beta=90^\circ-\cos^{-1}(\sin\omega\sin\gamma)$

$$x_l=\frac{\sin(\beta+\beta_2)}{\sqrt{\cos^2(\beta+\beta_2)-\sin^2(\alpha+\alpha_1)}}h$$

$$y_B=\frac{\sin(\alpha+\alpha_1)}{\sqrt{\cos^2(\beta+\beta_2)-\sin^2(\alpha+\alpha_1)}}h$$

$$H_W=\sqrt{x_l{}^2+y_B{}^2+h^2}$$

$$1=\cos^2\delta+\cos^2\{90^\circ-(\beta+\beta_2)\}+\cos^2\{90-(\alpha+\alpha_1\}=\cos^2\delta+\sin^2(\beta+\beta_2)+\sin^2(\alpha+\alpha_1)$$

$$\cos\delta=\sqrt{\cos^2(\beta+\beta_2)-\sin^2(\alpha+\alpha_1)}$$

$$H'=H\sqrt{\cos^2\beta-\sin^2\alpha}$$

$$\beta_2=\tan^{-1}\left(\frac{H'}{2l_0}\right)=\tan^{-1}\left(\frac{H}{2l_0}\sqrt{\cos^2\beta-\sin^2\alpha}\right)$$

$$\beta_1=\tan^{-1}\left(\frac{H'}{2l_0}\right)=\tan^{-1}\left(\frac{H}{l_0}\sqrt{\cos^2\beta-\sin^2\alpha}\right)$$

$$H_Q{}'=\frac{l}{2}\cdot\sin\beta_1$$

$$H_Q=\frac{H_Q{}'}{\sqrt{\cos^2\beta-\sin^2\alpha}}=\frac{l}{2}\sin\beta_1\frac{1}{\sqrt{\cos^2\beta-\sin^2\alpha}}$$

$$\alpha_1=\tan^{-1}\left(\frac{H_Q{}'}{B-\frac{b}{2}}\right)=\tan^{-1}\left(\frac{\frac{l}{2}\sin\beta_1}{B-\frac{b}{2}}\right)$$

Then, the total resistance force R_{oc1} is

$$R_{oc1}=f_2 Q_2 \cos\alpha\cdot\cos\beta+f_1' F_2\cos(\beta+\beta_1)+F_2\sin(\beta+\beta_1)$$
$$+F_1\cos(\delta_1-\beta)+Q_2\cos\alpha\cdot\sin\beta+W_t\cos(\alpha+\alpha_1)\cdot\sin(\beta+\beta_2)$$
$$=\frac{W_t}{2}\cos\alpha\cdot\cos(\beta+\beta_2)\left[f_2\cos\beta\left\{1+\frac{2h\tan(\alpha+\alpha_1)\cos\alpha_1}{B-\frac{b}{2}}\right\}\right.$$
$$+f_1'\cos(\beta+\beta_1)\left\{1-\frac{2h\tan(\alpha+\alpha_1)\cdot\cos\alpha_1}{B-\frac{b}{2}}\right\}\left\{1-\frac{\frac{l}{2}}{L-l_x}\right\}$$
$$+\sin(\beta+\beta_1)\left\{1-\frac{2h\tan(\alpha+\alpha_1)\cdot\cos\alpha_1}{B-\frac{b}{2}}\right\}\left\{1-\frac{\frac{l}{2}}{L-l_x}\right\}.$$
$$+\cos(\delta_1-\beta)\left\{1-\frac{2h\tan(\alpha+\alpha_1)\cdot\cos\alpha_1}{B-\frac{b}{2}}\right\}\left\{\frac{\frac{l}{2}}{L-l_x}\right\}$$
$$\left.+\text{sih}\,\beta\left\{1+\frac{2h\tan(\alpha+\alpha_1)\cdot\cos\alpha_1}{B-\frac{b}{2}}\right\}\right]+W_t\cos(\alpha+\alpha_1)\sin(\beta+\beta_2)\cdots\cdots(36)$$

where, f_2: coefficient of running resistance of tracks on forest-land
f_1': that on stump

Finally, the torque T_{oc1} and the horsepower P_{oc1} required for climbing up a stump by the tracked tractor from O_1' to O_1'' as mentioned above, can be obtained by

$$T_{oc1}=\frac{d\cdot R_{oc1}}{2\cdot i\cdot\eta}\cdots\cdots(37)$$

$$P_{oc1}=\frac{\pi\cdot d\cdot N_e\cdot R_{oc1}}{75\cdot 60\cdot i\cdot\eta}\cdots\cdots(38)$$

When the tracked tractor crosses on a stump, before the front idler comes down to contact the ground after climbing up a stump as shown in Fig. 17*10, the vertical ground reactions are

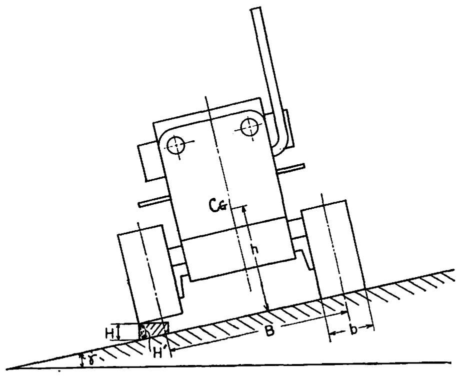


Fig. 16. Symbols when crawler tractor's passing over a stump

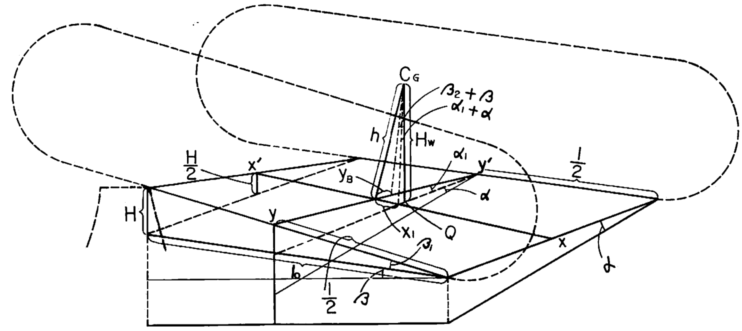


Fig. 17. Do.

$$\left.\begin{aligned} Q_1&=\frac{W_t}{2}\cos(\beta+\beta_2)\left\{1-\frac{2h\tan(\alpha+\alpha_1)\cos\alpha_1}{B-\frac{b}{2}}\right\} \\ Q_2&=\frac{W_t}{2}\cos(\beta+\beta_2)\left\{1+\frac{2h\tan(\alpha+\alpha_1)\cos\alpha_1}{B-\frac{b}{2}}\right\} \end{aligned}\right\}\cdots\cdots(38)$$

The propelling forces F_1 and F_2 are

$$\left.\begin{aligned} F_1&=Q_1\cos\alpha\cdot\frac{l}{2}\cdot\frac{\sin\beta_1}{H'} \\ &=\frac{W_t}{2}\cos\alpha\cdot\cos(\beta+\beta_2)\cdot\sin\beta_1\cdot\frac{l}{2H'}\left\{1-\frac{2h\tan(\alpha+\alpha_1)\cos\alpha_1}{B-\frac{b}{2}}\right\} \\ F_2&=Q_1\cos\alpha\left(1-\frac{l\sin\beta_1}{2H'}\right) \\ &=\frac{W_t}{2}\cos\alpha\cdot\cos(\beta+\beta_2)\left\{1-\frac{2h\tan(\alpha+\alpha_1)\cos\alpha_1}{B-\frac{b}{2}}\right\}\left\{1-\frac{l\sin\beta_1}{2H'}\right\} \end{aligned}\right\}\cdots\cdots(40)$$

The total resistance force R_{oc2} is

$$\begin{aligned} R_{oc2}=&f_2Q_2\cos\alpha\cos\beta+Q_2\cos\alpha\cdot\sin\beta+f_1F_1\cos(\beta+\beta_1)+f_1'F_2\cos(\beta+\beta_1) \\ &+Q_1\cos\alpha\sin(\beta+\beta_1)+W_t\cos(\alpha+\alpha_1)\sin(\beta+\beta_2) \\ &=\frac{W_t}{2}\cos\alpha\cdot\cos(\beta+\beta_2)\left[f_2\cos\beta\left\{1+\frac{2h\tan(\alpha+\alpha_1)\cos\alpha_1}{B-\frac{b}{2}}\right\}\right. \\ &+\sin\beta\left\{1+\frac{2h\tan(\alpha+\alpha_1)\cos\alpha_1}{B-\frac{b}{2}}\right\}+f_1'\cos(\beta+\beta_1)\left\{1-\frac{2h\tan(\alpha+\alpha_1)\cos\alpha_1}{B-\frac{b}{2}}\right\} \\ &\left.\cdot\left\{1-\frac{l\sin\beta_1}{H'}+\sin(\beta+\beta_1)\left\{1-\frac{2h\tan(\alpha+\alpha_1)\cos\alpha_1}{B-\frac{b}{2}}\right\}\right\}\right] \\ &+W_t\cos(\alpha+\alpha_1)\sin(\beta+\beta_2)\cdots\cdots(41) \end{aligned}$$

---

*10 $H'=H\sqrt{\cos^2\beta-\sin^2\alpha}$ $\quad l_1=\sqrt{r^2-(r-H')^2}=\sqrt{2rH'-H'^2}$

$L=l+l_1$ $\quad \delta_2=\tan^{-1}\frac{r-H'}{L-l_x}$ $\quad l_2=\frac{L-l_x}{\cos\delta_2}$ $\quad \delta_3=\cos^{-1}\frac{r^2+l_2^2-l^2}{2rl_2}$

$\delta_1=\delta_2+\delta_3$ $\quad H_0'=H'+r(\sin\delta_1-1)$ $\quad \beta_1=\sin^{-1}\frac{H_0'}{l}$ $\quad \beta_2=\sin^{-1}\frac{H_0'}{2l}$

$H_{Q}'=\sin\beta_1\cdot\frac{l}{2}$ $\quad \alpha'=\tan^{-1}\frac{H_Q'}{B-\frac{b}{2}}$

The torque T_{oc2} and the horsepower P_{oc2} required for passing over a stump by the tracked tractor are

$$T_{oc2}=\frac{d\cdot R_{oc2}}{2\cdot i\cdot \eta} \cdots\cdots (42)$$

$$P_{oc2}=\frac{\pi\cdot d\ N_e\cdot R_{oc2}}{70\cdot 60\cdot i\cdot \eta} \cdots\cdots (43)$$

Theoretical values of torque computed from formulae (36), (37); (41), (42) are shown in broken line and empirical values measured by the author are shown in full line, as seen in Fig. 18. From this comparison it follows that these theoretical formulae can be used for the estimation of main power required for stump-crossing by the tracked tractor.

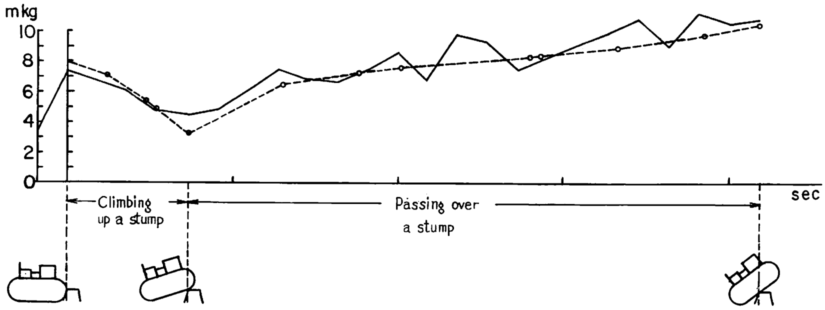


Fig. 18. Comparison between the theoretical values computed from formulae (36), (37); (41), (42)
where, $l=1.52$ m, $B=1.22$ m, $f_t=0.125$, $h=0.711$ m,
$d=0.56$ m, $W_t=3,810$ kg.
and empirical values of torques required for crawler tractor climbing up and passing over a stump

3.7 Mechanical efficiency of PTO shaft

The PTO shaft fitted on test tractor is led from the crank shaft of tractor-engine by a couple of spur gears having the reduction gear ratio $i_5=42/15=2.8$. The mechanical efficiency of the PTO shaft η_5 could be measured by the use of two electric torque pickups as mentioned above, instantly checkable by the mechanical torque tester manufactured for trial by the author.

From this result obtained, it seems that η_5 is generally constant$\fallingdotseq 0.95$ when the torque of

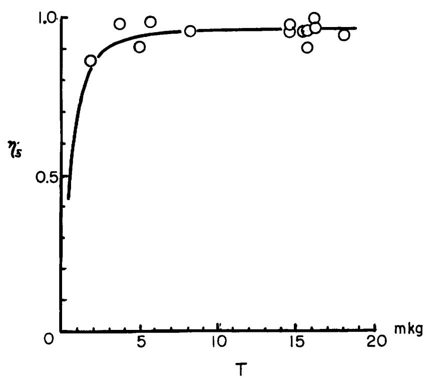


Fig. 19. Mechanical efficiency of PTO shaft

engine-crank shaft T (mkg) becomes more than 5 mkg, though it suddenly decreases with decreasing T at the range below 5 mkg (Fig. 19).

Then we may estimate other mechanical efficiencies of test tractor i.e. those of differential, final drive, sprocket and track link and so on, in accordance with the kind and number of gears as compared with this, as mentioned above.

4. Performance of tractor-powered stump cutter

4.1 Construction of tractor-powered stump cutter

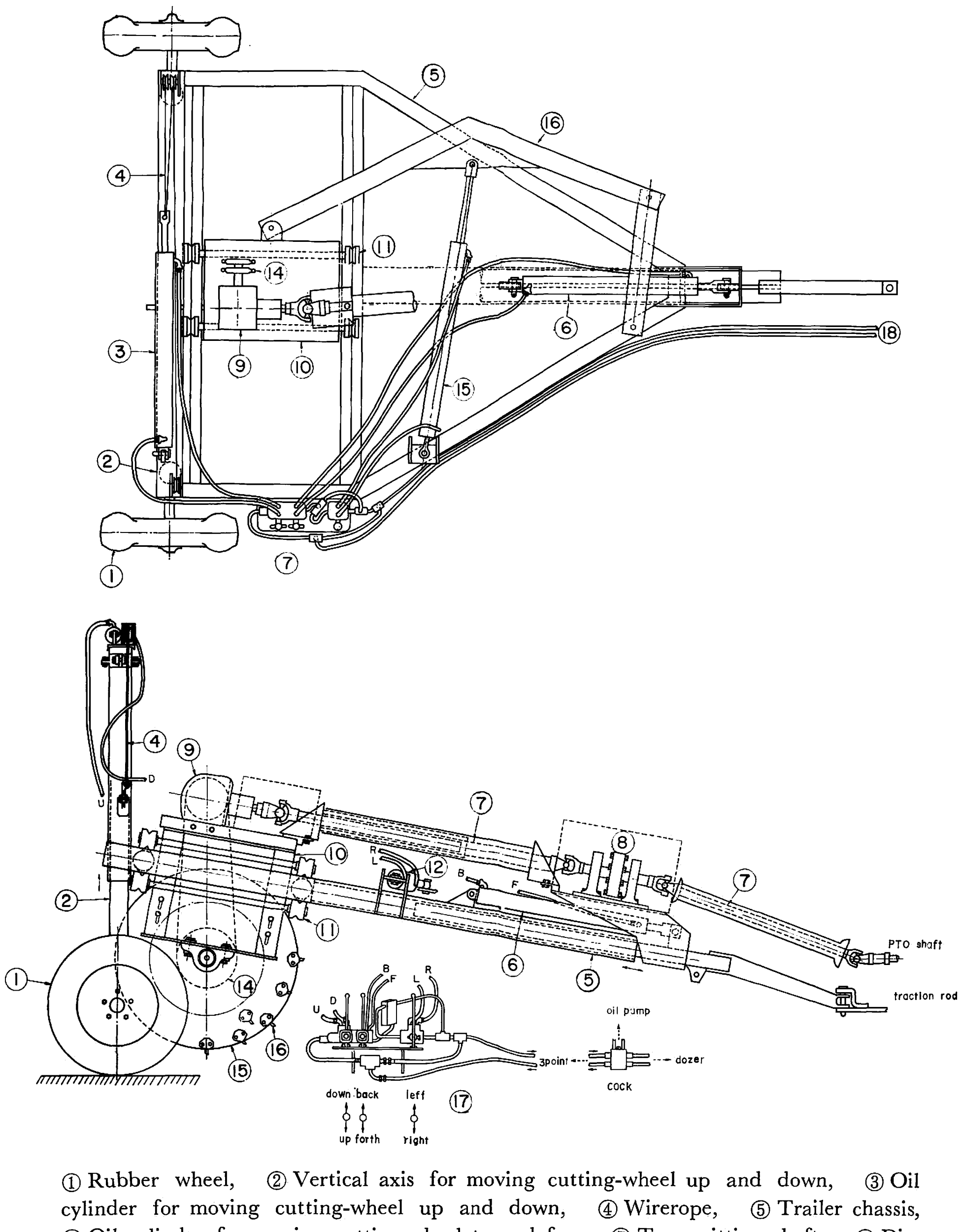
Tractor-powered stump cutters are classified into tow groups i.e. mechanical drive type and hydraulic drive type, or semi-trailer type and tractor mounted type.

The mechanical drive type stump cutter, that is the semi-trailer type, is called the VERMEER Pow-R-Stump Cutter, manufactured by the VERMEER Manufacturing Co. Pella, Iowa, U.S.A. The main parts of this machine are divided into several groups: two wheel type semi-trailer, power transmission from the PTO shaft to the cutting wheel, cutting wheel, hydraulic control system driven by the oil motor fitted on tractor to move the cutting wheel to and fro, up and down, right and left (Fig. 20, Table 2). The power from engine is transmitted through the PTO shaft, long shaft capable of being expanded and shortened like a drawtube, disc clutch, short shaft, gear box and chain and chain wheel, to the cutting wheel. Four universal joints are used for the connecting points between the PTO shaft and the drawtube-type long shaft, the long shaft and the disc clutch, the disc clutch and the short shaft, the short shaft and reduction gear shaft. So the

Table 2. Specifications of mechanical drive type stump cutter

Type		Mechanical drive type (Semi-trailer type)
Total weight	kg	1,375
Overall length	mm	3,800
Overall width	mm	3,070(2,280)
Overall height	mm	2,130
Outer diameter of cutting wheel	mm	920 turns clockwise while cutting
Cutting tooth		24 teeth at one side of cutting wheel
Maximum stump cutting height	mm	840
Maximum stump cutting depth under ground		380
Reduction gear ratio at test		
PTO shaft		2.67
Reduction gear of stump cutter		1.25
Overall		3.34

power can be easily transmitted from the PTO shaft to the cutting wheel even when the cutting wheel with the reduction gear box is removed on a side of trailer-chassis. The cutting wheel with gear box is mounted on a trolley-frame having four pulleys. The trolley can move right and left on a couple of L type steel rails at the back part of trailer-chassis. The movement of the cutting wheel in the direction to and fro, up and down, is done by the movement of the trailer-chassis in the same direction, because the trailer-chassis can move up and down by means of the vertical supporting tubes of two trailer wheels like the drawtubes, and can move to and fro by means of the oil pressure cylinder set between the drawbar hook and the front part of trailer-chassis.



① Rubber wheel, ② Vertical axis for moving cutting-wheel up and down, ③ Oil cylinder for moving cutting-wheel up and down, ④ Wirerope, ⑤ Trailer chassis, ⑥ Oil cylinder for moving cutting-wheel to and fro, ⑦ Transmitting shaft, ⑧ Disc clutch, ⑨ Gear box, ⑩ Trolley frame supporting cutting wheel, ⑪ Sheaves, ⑫ Oil cylinder for moving cutting-wheel right and left, ⑬ Lever mechanism, ⑭ Chain wheel, ⑮ Cutting wheel, ⑯ Chisel cutter, ⑰ Hydraulic control levers, ⑱ High pressure rubber hose.

Fig. 20. Mechanical drive type stump cutter powered by tractor

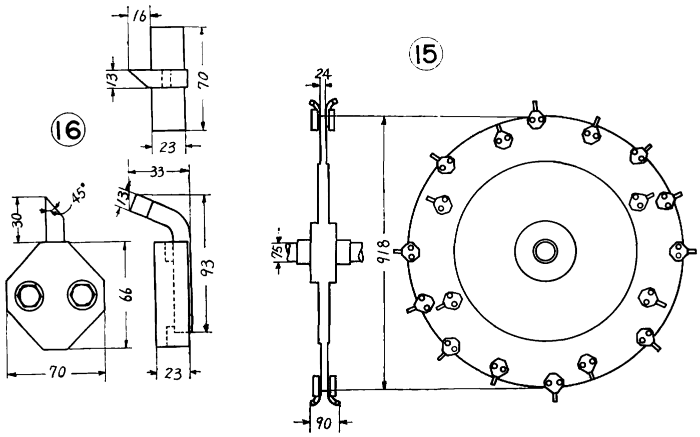


Fig. 21. Cutting wheel and cutter (Description is the same as Fig. 20)

The cutting wheel is equipped with square chisel-type 48 teeth which are held in place by retaining pockets (Fig. 21). The stump cutter backs up to the stump by the tractor, the canvas guard is lowered, and the cutting wheel is lowered to a point where it will cut approximately one inch from the edge of the stump. Then the cutting wheel is moved across the stump. When the stump cutter is placed on a stump, the tractor-driver gets off the cab with the tractor-engine

Table 3. Specifications of hydraulic drive type stump cutter

Type			Hydraulic drive type (Tractor-mounted type)
Total weight		kg	310 without oil tank
Overall length		mm	1,940
Overall widh		mm	560
Overall height		mm	1,100
Outer diameter of cutting drum		mm	{500 with cutting teeth 410 in drum only
Length of cutting drum		mm	416
Cutting tooth			3 teeth × 15 rows = 45 teeth chisel type
Oil pump	Type		Geared pump
	Max. delivery volume	l/min	77
	Max. pressure	kg/cm²	100
Oil motor	Type		Geared motor
	max. torque	mkg	11
Three-way hydraulic action control of cutting drum			
to and fro		mm	400
right and left		°	60
up and down		°	50
Reduction gear ratio			
PTO shaft			1
Oil pump			1
Oil motor			1.56
Reduction gear			1.37
Overall			2.14

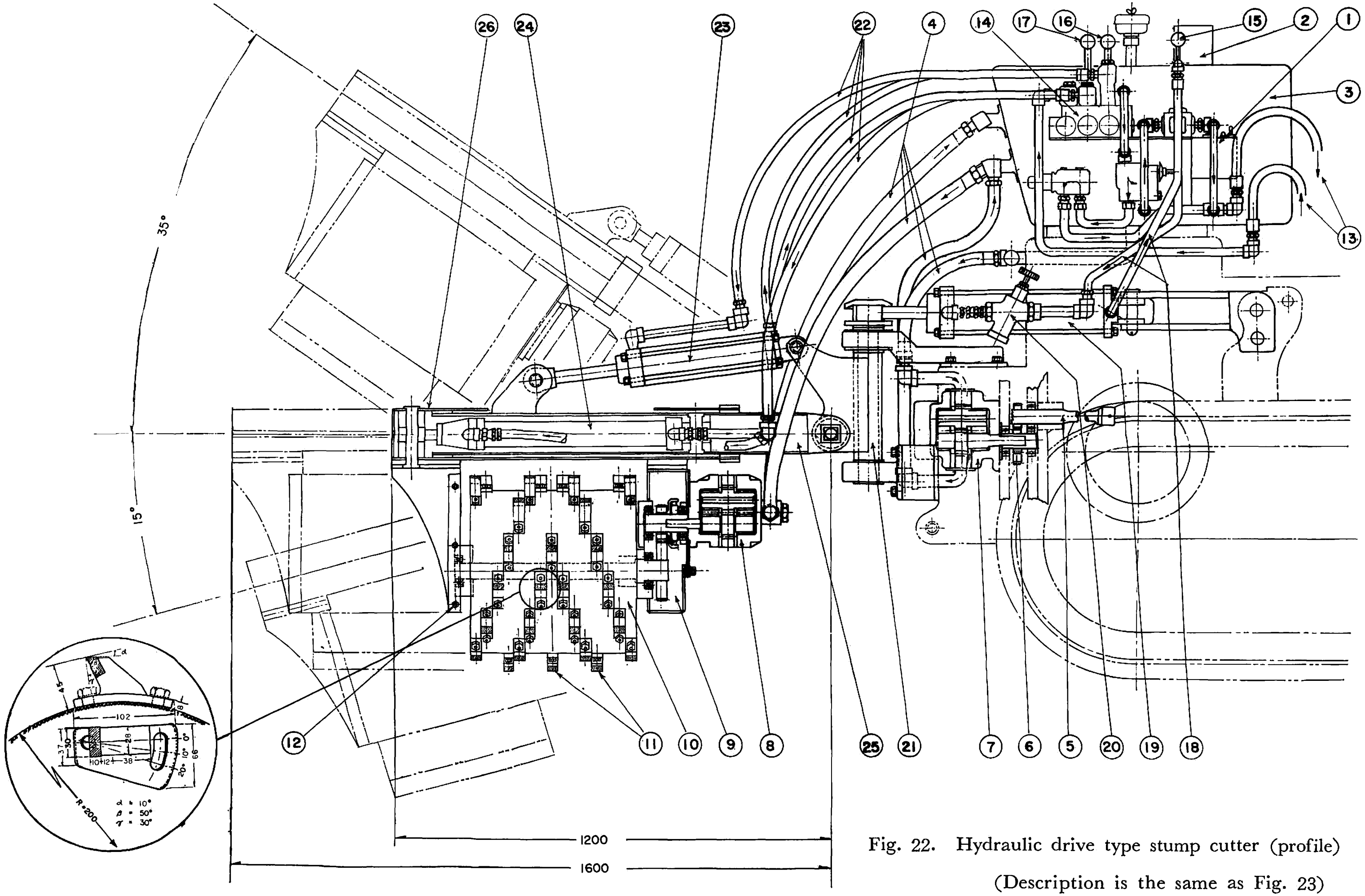
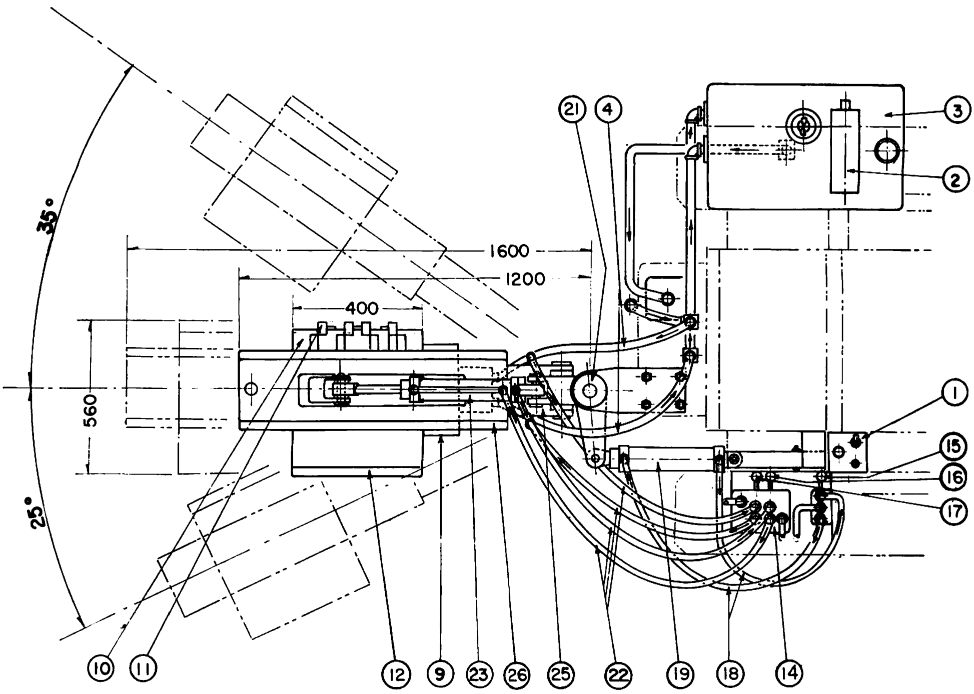


Fig. 22. Hydraulic drive type stump cutter (profile)
(Description is the same as Fig. 23)



① Switch box, ② Solenoid valve, ③ Oil tank for stump cutter, ④ High pressure rubber hose, ⑤ Engine shaft, ⑥ Intermediate gear, ⑦ Oil pump, ⑧ Oil motor, ⑨ Gear box, ⑩ Cutting drum, ⑪ Cutter, ⑫ Drum cover, ⑬ Oil tank for three point hitch, ⑭ Six-ways valve, ⑮ Control lever for right and left motion ot cutting drum, ⑯ Control lever for up and down motion of cutting drum, ⑰ Control lever for to and fro motion of cutting drum, ⑱ High pressure rubber hose, ⑲ Oil cylinder for right and left motion of cutting drum, ⑳ Flow control valve, ㉑ Axis for swinging, ㉒ High pressure rubber hose, ㉓ Oil cylinder for up and down, ㉔ Oil cylinder for to and fro, ㉕ Inner boom, ㉖ Outer boom.

Fig. 23. Hydraulic drive type stump cutter (plan)

rotating on full throttle, and operates the hydraulic control levers at the rear side of trailer-chassis to make chips from the stump in minutes.

The hydraulic drive type stump cutter which is also the tractor mounted type, is of Japanese make, manufactured for trial under the leadership of the author (Fig. 22, Table 3). It has three-way hydraulic action controls whereby all operations — raising, lowering, extending — can be controlled from the tractor seat. It can move laterally in either a left 35° arc or right 25° arc (see Fig. 23) and move vertically either up or down in 35° arc above or 15° arc below from horizontal level.

The oil pump driven by the tractor engine converts the mechanical power into the hydraulic power. The hydraulic power is transmitted through the high pressure rubber tube to the oil motor and then the oil motor is rotated by the hydraulic pressure. Therefore, the cutting drum directly connected to the oil motor can be smoothly driven. The solenoid and relief valves are also efficiently used for absorbing the shock load, in this hydraulic drive system. So, when the oil pressure increases to more than 100 kg/cm² at 1,500 rpm of engine revolution, the oil pressure is automatically controlled and the high revolutional force of more than 54 mkg will not be transmitted to the cutter shaft. It will be seen that the hydraulic drive and tractor-mounted type stump cutter has the characteristic of easy mobility on inclined forest-land, easy hydraulic action control and efficient absorption of shock load while removing stump, compared with the mechanical drive and semi-trailer type stump cutter.

4.2 Stump-cutting performance of mechanical drive type stump cutter

Total cutting resistance force of cutting teeth in a concentric circle which are actually chipping wood $\sum F_s$ is given by

$$\sum F_s = f \cdot \delta \cdot b \cdot n \quad \cdots\cdots (44)$$

where, f: unit cutting resistance force (kg/mm^2)

δ: cutting depth of a cutting tooth (mm)

b: average wood cutting width by a cutting tooth (mm)

n: effective number of cutting teeth which actually chip wood

Then, δ is given by

$$\delta = p\frac{V_f}{V_c} \quad \cdots\cdots (45)$$

where, p: pitch of cutting teeth in the same concentric circle of cutting wheel (mm)

V_f: feeding speed of cutting wheel (mm/sec)

V_c: peripheral speed of a cutting tooth (mm/sec), $=\frac{2\pi r N_c}{60}$ ……(46)

N_c: revolutions per minute of cutting wheel (rpm)

$2r$: outer diameter of rotating circle measured from the edge of cutting teeth fitted around the cutting wheel (mm)

And n is given by

$$n = \frac{l}{p} \quad \cdots\cdots (47)$$

Where the circular arc length of cutting wheel which actually chip wood (l) can be expressed as a function of the rotating radius of cutting tooth (r), the relative position between the cutting wheel and the wood chipped (h, h_0), as shown in Fig. 24.

$$l = r\left\{\cos^{-1}\frac{(r-h)}{r} - \cos^{-1}\frac{(r-h)}{r}\right\} \quad \cdots\cdots (48)$$

From formulae (44), (45), (46), (47) and (48), the following may be written:

$$\sum F_s = f \cdot b \cdot \frac{30}{\pi} \cdot \frac{V_f}{N_c}\left\{\cos^{-1}\frac{(r-h)}{r} - \cos^{-1}\frac{(r-h_0)}{r}\right\} \quad \cdots\cdots (49)$$

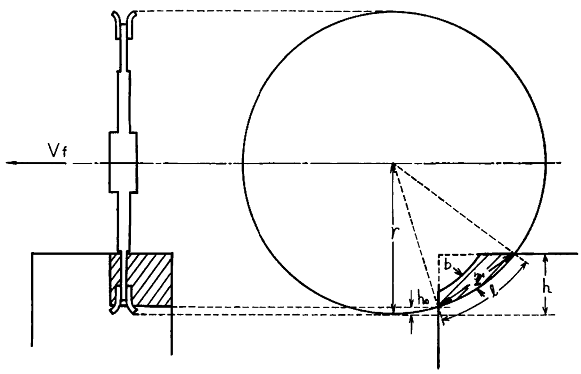


Fig. 24. Cutting wheel which chip stump

The torque of the cutting wheel shaft when cutting stump T_{scc} is

$$T_{scc}=r\sum F_r=\frac{30\cdot f\cdot b\cdot V_f\cdot r}{\pi\cdot N_c}\left\{\cos^{-1}\frac{(r-h)}{r}-\cos^{-1}\frac{(r-h_0)}{r}\right\} \quad\cdots\cdots(50)$$

So, the torque of tractor engine required for cutting stump T_{sce} arrives at

$$T_{sce}=\frac{T_{scc}}{i_5\, i_{sc}\, \eta_5\, \eta_{sc}}=\frac{30\cdot f\cdot b\cdot V_f\cdot r}{\eta_5\cdot\eta_{sc}\cdot\pi\cdot N_e}\left\{\cos^{-1}\frac{(r-h)}{r}-\cos^{-1}\frac{(r-h_0)}{r}\right\} \quad\cdots\cdots(51)$$

where, i_{sc}: reduction gear ratio of stump cutter

η_{sc}: mechanical efficiency of stump cutter

Finally, the horsepower of tractor engine required for cutting stump P_{sce} may be written as follows:

$$P_{sce}=\frac{2\pi\cdot T_{sce}\cdot N_e}{75\cdot 60}=\frac{f\cdot b\cdot V_f\cdot r}{76\cdot\eta_5\,\eta_{sc}}\left\{\cos^{-1}\frac{(r-h)}{r}-\cos^{-1}\frac{(r-h_0)}{r}\right\} \quad\cdots\cdots(52)$$

Further, l is written in the following form, because l is nearly equal to l' in actual operation (see Fig. 24).

$$l\fallingdotseq l'=\sqrt{2rh}=\sqrt{2}\,r^{\frac{1}{2}}\,h^{\frac{1}{2}} \quad\cdots\cdots(53)$$

Substituting formula (53) in formulae (51), (52), we obtain

$$T_{sce}=\frac{30\sqrt{2}\cdot f\cdot b\cdot V_f\cdot r^{\frac{1}{2}}\cdot h^{\frac{1}{2}}}{\eta_5\cdot\eta_{sc}\cdot\pi\cdot N_e} \quad\cdots\cdots(54)$$

$$P_{sce}=\frac{\sqrt{2}\cdot f\cdot b\cdot V_f\cdot r^{\frac{1}{2}}\cdot h^{\frac{1}{2}}}{75\cdot\eta_5\cdot\eta_{sc}} \quad\cdots\cdots(55)$$

Then, from the field experiment of cutting stumps of red pine with from 29 to 39 cm dia. and from 25 to 37 cm height, the relation between the unit cutting resistance force f and wood-chipping section area by a cutting tooth $b\cdot\delta$ is given in the empirical formula (see Fig. 25).

$$f=73.8(b\cdot\delta)^{-\frac{1}{1.62}} \quad\cdots\cdots(56)$$

The empirical values of P_{sce} when cutting stump of red pine with b=20 mm, l=from 330 to

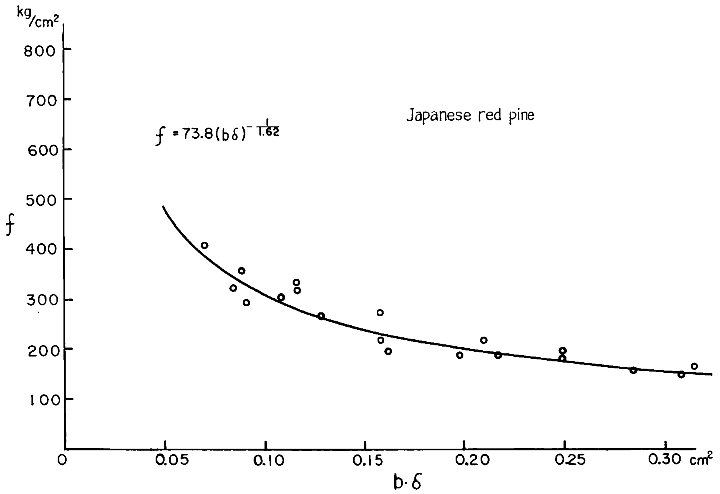


Fig. 25. Relation between the unit cutting resistance force and wood-chipping sectional area by a cutting tooth

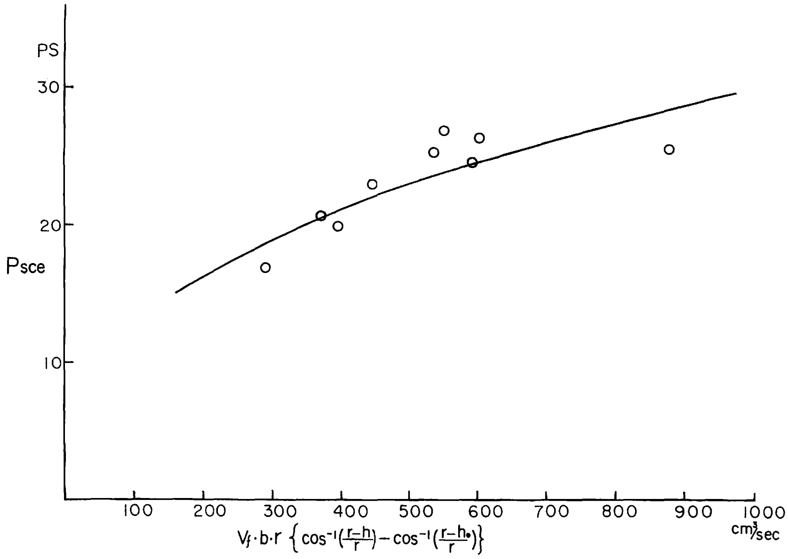


Fig. 26. Comparison between the theoretical and empirical values of the horsepower of tractor engine required for cutting stump by mechanical drive type stump cutter, P_{sce}

386 mm, $N_e \fallingdotseq 1,400 \pm 150$ rpm are dotted in round mark, and the parabolic curve of P_{sce} computed from the theoretical formula (52) in the case of $b=20$ mm, $l=358$ mm, $N_e=1,400$ rpm are drawn in Fig. 26. From the comparison between them, it will be noted that an approximate value of P_{sce} is given by the theoretical formula (52) or its approximate formula (55).

4.3 Stump-cutting performance of hydraulic drive type stump cutter

Supposing that l is the length of wood chipped by a cutting tooth and Q_{sc} is the volume of wood chipped by cutting teeth in unit time, in the case of cutting stump by the hydraulic drive type stump cutter (see Fig. 27), l and Q_{sc} are

$$l \fallingdotseq \sqrt{2}\, r^{\frac{1}{2}} h^{\frac{1}{2}} \qquad \cdots\cdots(57)$$

where, r: rotating radius of the edge of cutting tooth around the cutting drum
h: cutting depth of cutting drum

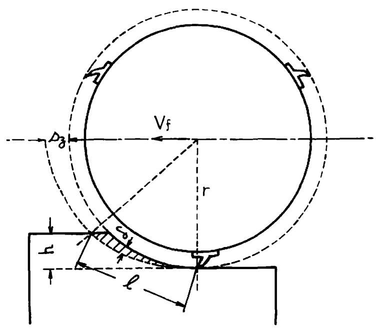


Fig. 27. Cutting drum which chip stump

$$Q_{sc}=b\cdot h\cdot V_f=\frac{b\cdot n\cdot N_{sc}\cdot\delta\cdot l}{60}=\frac{\sqrt{2}\,b\cdot n\cdot N_{sc}\cdot\delta\cdot r^{\frac{1}{2}}\,h^{\frac{1}{2}}}{60}\quad\cdots\cdots(58)$$

where, b: cutting width of a cutting tooth

V_f: feeding speed of cutting drum

N_{sc}: revolutions per minute of cutting drum

δ: average wood-chipping depth by a cutting tooth

n: number of cutting teeth which actually chip wood

From formula (58), we obtain

$$\delta=\frac{60\cdot V_f}{N_{sc}\cdot n}\sqrt{\frac{h}{2r}}=s_z\sqrt{\frac{h}{2r}}\quad\cdots\cdots(59)$$

where, s_z: feeding length of a cutting tooth

And s_z and n are written in the form:

$$s_z=\frac{60\cdot V_f}{N_{sc}\cdot n}=p\cdot\frac{V_f}{V_c}\quad\cdots\cdots(60)$$

where, p: pitch of cutting teeth in the same row around cutting drum

V_c: peripheral speed of a cutting tooth around cutting drum

$$n=\frac{l}{p}=\frac{\sqrt{2}\,r^{\frac{1}{2}}\,h^{\frac{1}{2}}}{\frac{2\pi r}{n}}=\frac{n\cdot h^{\frac{1}{2}}}{\sqrt{2}\pi\cdot r^{\frac{1}{2}}}\quad\cdots\cdots(61)$$

In this case also, the total cutting resistance force of cutting teeth around the cutting drum which actually chip wood $\sum F_s$ can be expressed by the same formula as (44).

And so, $\sum F_s$ is written as

$$\sum F_s=\frac{30\cdot f\cdot b\cdot h\cdot V_f}{\pi\cdot r\cdot N_{sc}}=60\cdot f\cdot b\cdot h\frac{V_f}{V_c}\quad\cdots\cdots(62)$$

Then, the stump-cutting torque of the cutting drum shaft T_{scc}' is given by

$$T_{scc}'=r\sum F_s=\frac{30\cdot f\cdot b\cdot h\cdot V_f}{\pi\cdot N_{sc}}\quad\cdots\cdots(63)$$

Finally, the stump-cutting torque T_{sce}' and the power P_{sce}' required for the tractor engine in the case of the hydraulic drive type stump cutter arrives at

$$T_{sce}'=\frac{q_p\cdot\eta_{pv}\cdot\eta_{mv}}{q_m\cdot i_5'\cdot i_{cd}\cdot\eta_5'\cdot\eta_{cd}\cdot\eta_p\cdot\eta_m\cdot\eta_h}T_{scc}'=\frac{30f\cdot b\cdot h\cdot V_f\cdot q_p\cdot\eta_{pv}\cdot\eta_{mv}}{\pi\cdot n_e\cdot i_5'\cdot i_{cd}\cdot\eta_5'\cdot\eta_{cd}\cdot q_m\cdot\eta_p\cdot\eta_m\cdot\eta_h}\cdots(64)$$

$$P_{sce}'=\frac{2\pi\cdot T_{sce}'\cdot N_e}{75\cdot 60}=\frac{f\cdot b\cdot h\cdot V_f}{75\,\eta'_5\cdot\eta_{cd}\cdot\eta_p\cdot\eta_m\cdot\eta_h}\quad\cdots\cdots(65)$$

where, i_5': reduction gear ratio of pump shaft, $\frac{32}{15}\cdot\frac{15}{32}=1$

i_{cd}: reduction gear ratio of cutting drum, $\frac{37}{27}=1.37$

η_5': mechanical efficiency of pump shaft, $0.95\times 0.95=0.90$

η_{cd}: mechanical efficiency of cutting drum, 0.95

η_p: overall efficiency of oil pump, 0.80 (fr. performance curve of the maker)

η_{pv}: volumetric efficiency of oil pump, 0.94 (do.)

η_h: flowing efficiency of high pressure rubber hose, 0.99 (do.)

η_m: overall efficiency of oil motor, 0.65 (do.)

η_{mv}: volumetric efficiency of oil motor, 0.95 (do.)

q_p: theoretical delivery volume (cc/rev), 57.8 (do.)

q_m: theoretical inlet volume (cc/rev), 82.0 (do.)

N_e: revolutions per minute of tractor engine (rpm),

$$=\frac{q_m \cdot i_5' \cdot i_{cd}}{q_p \cdot \eta_{pv} \cdot \eta_{mv}} N_{sc}$$

The empirical values of T_{sce}' and P_{sce}' in the case of b=from 210 to 300mm, h=from 7 to 24mm, V_f=from 7 to 39 mm/sec, $N_e=1,400\pm200$ rpm, in chipping stump of Japanese larch, are dotted in round mark and the parabolic curve of them computed from the formulae (64), (65) in the case of b=290 mm, h=20 mm, N_e=1,400 rpm, are drawn in Fig. 28, 29.

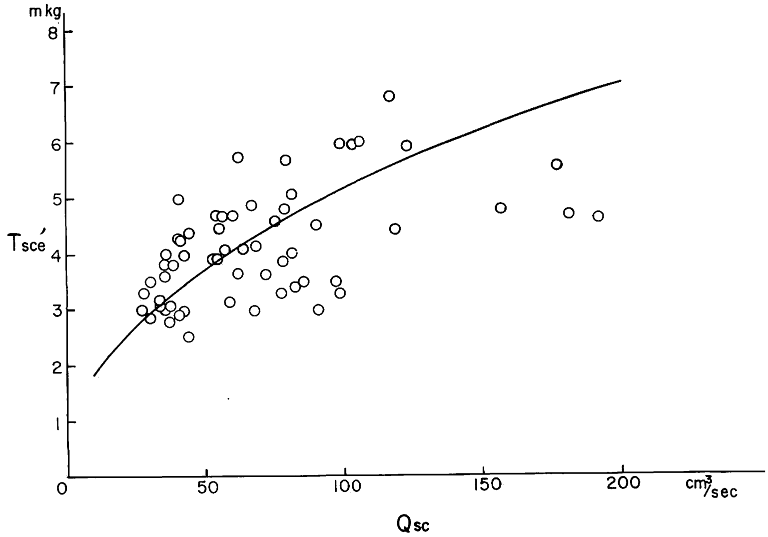


Fig. 28. Comparison between the theoretical and empirical values of the torque of tractor engine required for cutting stump by hydraulic drive type stump cutter, T_{sce}'

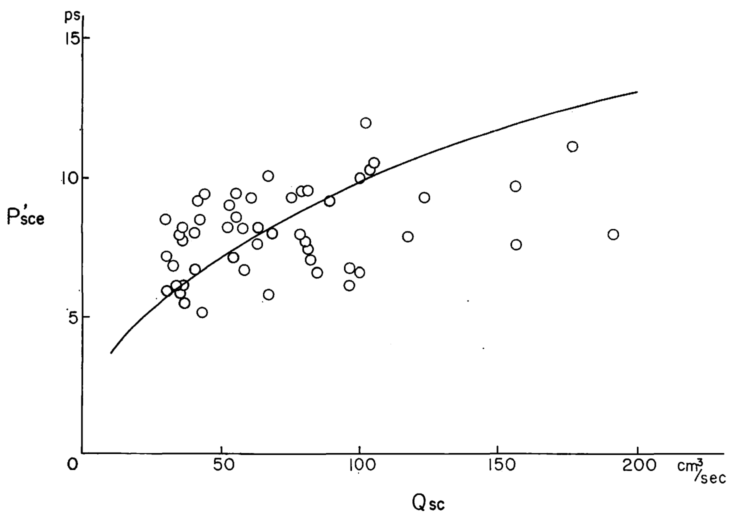


Fig. 29. Comparison between the theoretical and empirical values of the horsepower of tractor engine required for cutting stump by hydraulic drive type stump cutter, P_{sce}'

From these comparisons, it will be seen that these theoretical formulae may be used for the estimation of the torque and power of tractor engine required for cutting stump by the hydraulic drive type stump cutter.

The volume of stump cut per unit fuel consumption of tractor-powered hydraulic stump cutter a_c (cm³/l) is expressed as a function of Q_{sc}, f_b, ρ and P_{sce}'

$$a_c = 3.6\times10^6\frac{Q_{sc}\cdot\rho}{f_b\cdot P_{sce}'} \cdots\cdots (66)$$

where, ρ: specific gravity of fuel (gr/cm³) 0.825 in light oil used for test tractor by the measurement

Q_{sc}: from formula (58)

f_b: from formula (91), appearing later

P_{sce}': from formula (65)

Substituting formula (65) for P_{sce}' into formula (66), the following formula is derived.

$$a_c = \frac{3.6\times10^6\cdot Q_{sc}\cdot\rho}{f_b\left(\dfrac{f\cdot b\cdot h\cdot V_f}{75\cdot\eta_5\cdot\eta_{cd}\cdot\eta_p\cdot\eta_m\cdot\eta_h}\right)} \cdots\cdots (67)$$

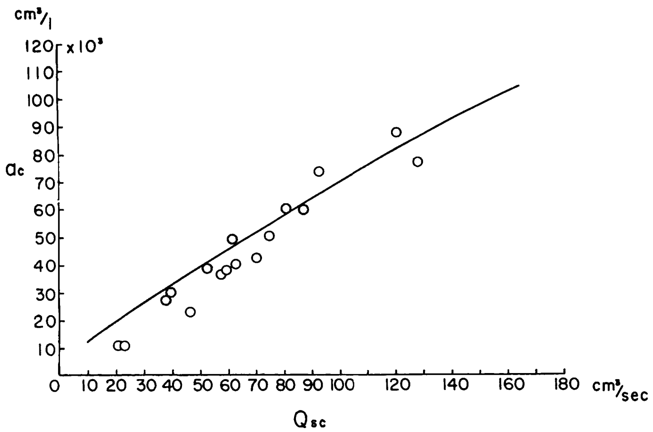


Fig. 30. Comparison between the theoretical and empirical values of the volume of stump cut per unit fuel consumption in hydraulic drive type stump cutter

The empirical values of a_c are dotted in round points and the theoretical values of them are drawn in solid line as shown in Fig. 30. From the comparative study, it will be seen that this theoretical formula can be generally used for the estimation of the fuel consumption of tractor-powered hydraulic stump cutter.

4.4 Operational efficiency of tractor-powered stump cutter

The operational efficiency of the mechanical drive type stump cutter when cutting stumps with their diameters = from 10 to 46cm, their heights = from 10 to 45cm, volumes of stump cut = from 10 to 90 cm³, their species = Japanese larch, Japanese pine half a year after felling, was surveyed with the help of time study for several working days in hilly NAGAKURAYAMA national forest with the slopegrade of less than 20°, situated near KARUIZAWA, NAGANO prefecture.

The stump-cutting operation of this machine powered by a CT-35 crawler tractor (IWATEFUJI, total weight = about 4,440 kg with dozer, rated horsepower of engine = 48 PS at 1,800 rpm) was maneuvered by one skilled driver. When this machine is carefully set on a stump to be cleared away in the backward motion, the driver gets off the tractor cab-seat, rotating the cutting wheel as driven by the tractor engine in full throttle and handles the three-way hydraulic control levers at the right side of the rear part of stump cutter, lowering the cutting wheel to a point where it will cut approximately one inch from the edge of the stump and one inch deep and moves the cutting wheel across the stump, then continue this procedure until the stump is removed as desired. Soon after a stump cut, the driver again gets on the cab-seat and backs the stump cutter up to a new stump and cuts the stump, handling the hydraulic control lever.

From the result of time study, it will be seen that the net stump-cutting time t_{sc} (sec) is given by a quadratic equation for D (cm) that is the diameter of stump cut, or a linear equation for Q_{sc}' (cm³) that is the volume of stump cut (see Fig. 31).

$$t_{sc}=aD^2+bD+c \quad \cdots\cdots(68)$$

$$=a'Q_{sc}'+b' \quad \cdots\cdots(69)$$

where, a, b, c; a', b' are constants which take the values as shown in Table 4.

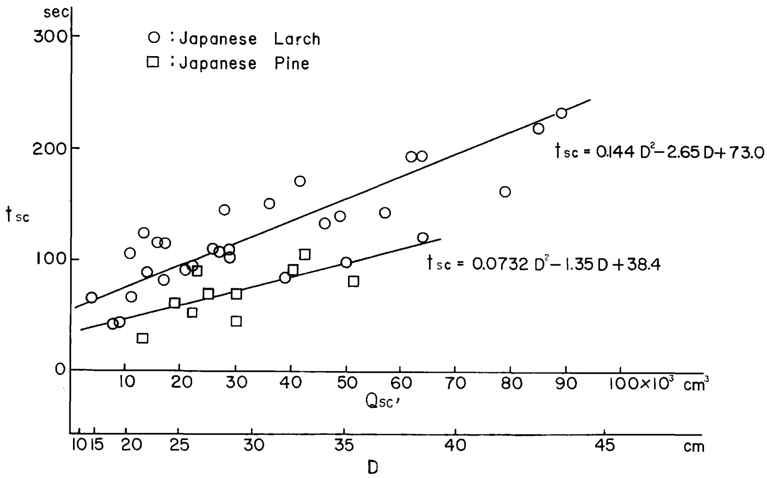


Fig. 31. Relation between net stump-cutting time by mechanical drive type stump cutter t_{sc} and diameter of stump D, volume of stump cut Q_{sc}'

Table 4. Empirical values of the constants of a, b, c; a', b'

Species of stump cut	a	b	c	a'	b'
Japanese larch	0.1440	−2.65	73.0	0.00201	57.3
Japanese red pine	0.0732	−1.35	38.4	0.00132	30.4

The net moving time of stump cutter t_m (sec) is given by a linear function for the distance L (m) to back up to a new stump from the stump removed (Fig. 32).

$$t_m=dL \quad \cdots\cdots(70)$$

where, d is constant which takes the values of 7.03 for the slope-grade from 4° to 5°, 7.80 for the slope-grade from 10° to 12°, 9.56 for the slope-grade from 14° to 18°.

Then, if t_p is the time required for the preparation before the cutting wheel moves across a stump after the operator's getting off the driver's seat, and t_q is the time required for the preparation

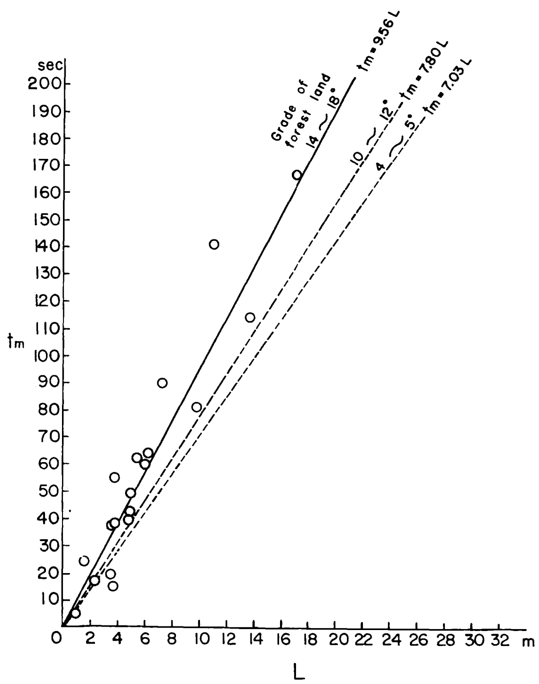


Fig. 32. Relation between net moving time of stump cutter from stump to stump t_m and its distance L

before tractor starts after a stump cut, and t_r is the time required for the driver's walking to the control-lever after getting off the driver's seat and the additional time for the inspection of the position of stump cutter to chip stump, and finally the total working hour per ha per worker t in stump-cutting operation of this machine will be given in the following form:

$$t = t_{sc} + t_m + t_p + t_q + t_r = \{aD^2 + bD + c + dL + (t_p + t_q + t_r)\}\, n \cdots\cdots\cdots\cdots\cdots(71)$$

where, n is the number of stumps to be cleared away in a hectoare, and the average of L is known by $L \fallingdotseq \frac{100}{\sqrt{n}}$ (m) when the shape of the clearing area is a square.

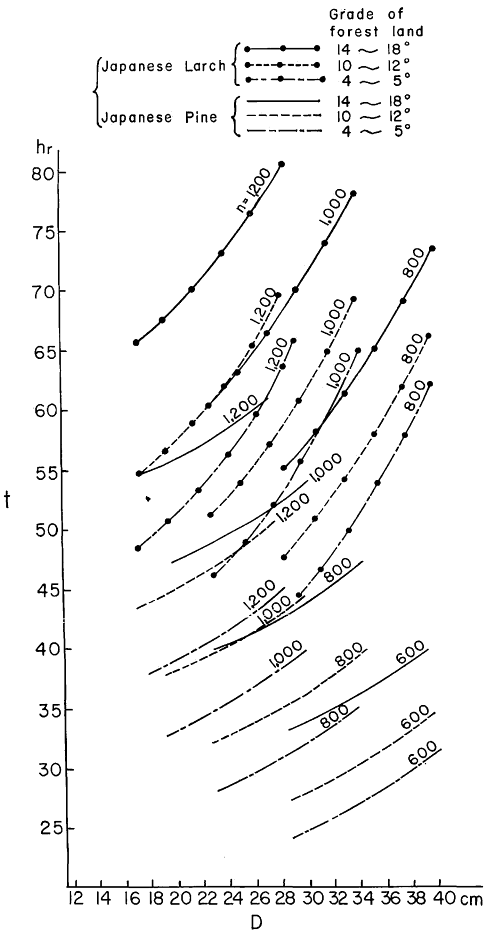
The empirical values of t_p, t_q and t_r obtained from the field test are shown in Table 5.

Table 5. Empirical values of t_p, t_q and t_r

Grade of forest-land	4～5°	10～12°	14～18°
t_p	32.4	35.0	43.2
t_q	8.3	11.7	13.7
t_r	24.6	36.7	60.6

Therefore, we will estimate the total working hours per ha per worker t as a function of D and n as shown in Fig. 33.

Next, the author planned to compare the operational efficiency of stump cutter operation with that of stump-cutting by a chain saw operation. One-man stump-cutting operation with a HOMELITE C-7 chain saw (piston displacement 90.6 cc) was studied with the help of time study for six working days to cut seven hundred and six stumps with from ten to fiftey cm diameter and thirteen cm in average height to be cut off, in a cutover area of fifty-year-old Japanese larch, in the AGATSUMAYAMA



$t = \{aD^2 + bD + c + dL + (p+q+r)\}n$

Grade of forest-land		14 ～ 18°	10 ～ 12°	4 ～ 5°
a	Japanese Larch	0.1440		
	Japanese Pine	0.0732		
b	Japanese Larch	− 2.65		
	Japanese Pine	− 1.35		
c	Japanese Larch	73.0		
	Japanese Pine	38.4		
d		9.56	7.80	7.03
t_p		43.2	35.0	32.4
t_q		13.7	11.7	8.3
t_r		60.6	36.7	24.6

Fig. 33. Relation between total working hour by mechanical drive type stump cutter per ha per worker t and the average diameter of stump cut D

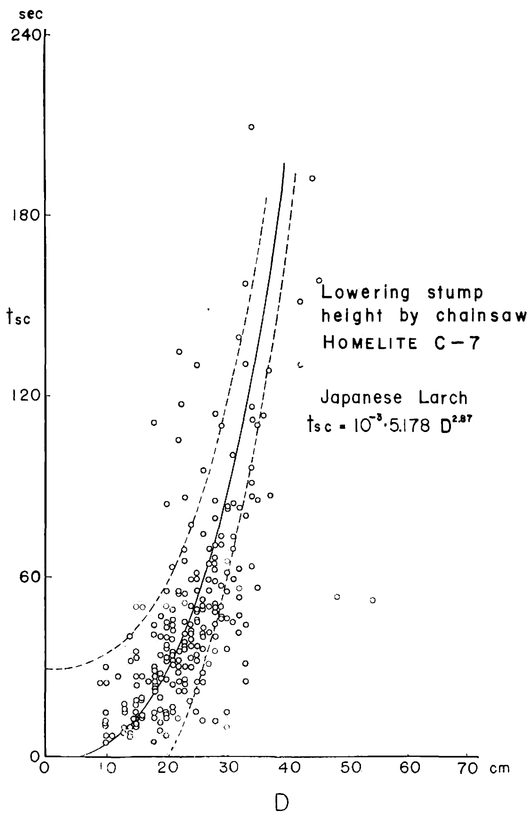


Fig. 34. Relation between net stump-cutting time by a chain saw t_{sc} and average diameter of stump D

national forest, situated near Mt. ASAMA, GUNMA prefecture.

The net stump-cutting time with a chain saw t_{sc} (sec) is expressed as a function of average dia. of stump D (cm) as shown in the empirical formula (see Fig. 34).

$$t_{sc}=5.178\cdot10^{-3}D^{2.87} \quad \cdots\cdots(72)$$

Average distance between stumps L (m) will be estimated by $L=\frac{100}{\sqrt{n}}$ where n is the number of stumps to be cut in a hectare.

Now if t_w (sec) is the time required for walking from a stump cut to a new stump, and t_o (sec) is the time required for the inspection of chain saw, oil feeding and others per stump cut, and t_s (sec) is the recess time per stump cut, the total time required for cutting stumps per ha per worker in a one-man chain saw operation t will be expressed in the following form.

$$t=n\,t_{sc}+(n-1)\frac{100}{\sqrt{n}}t_w+n\,t_o+t_s \quad \cdots\cdots(73)$$

From the time study, the average values of t_w, t_o, t_s are as follows: $t_w=7.62$ sec, $t_o=27.2$ sec, $t_s=15.3$ sec. Therefore, we may estimate the total time for cutting stumps per ha in a one-man chain saw operation t, substituting the empirical formula (72) and other average values mentioned above into the formula (73). Then the comparison between the operational efficiency of stump cutter operation and that of a one-man chain saw operation will be possible by the use of formulae (71), (73).

The remaining height of stump cut by a chain saw both when felling tree and when land-clearing in fifty-year-old Japanese larch forest was surveyed as shown in Fig. 35, 36. From this comparison between them, it will be seen that the average remaining height of stump cut when land-clearing is lowered to less than ten centimeters and that when felling carefully is also lowered to less than fifteen centimeters.

In both cases, the remaining height of stump cut is nearly low enough to allow the tractor run for reforestation works on cutover forest-land.

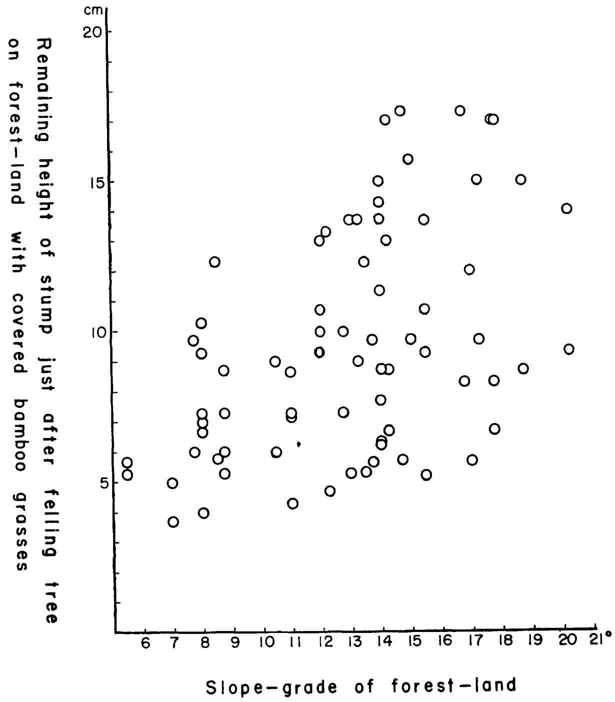


Fig. 35. Relation between remaining height of stump soon after felling and slope-grade of forest-land

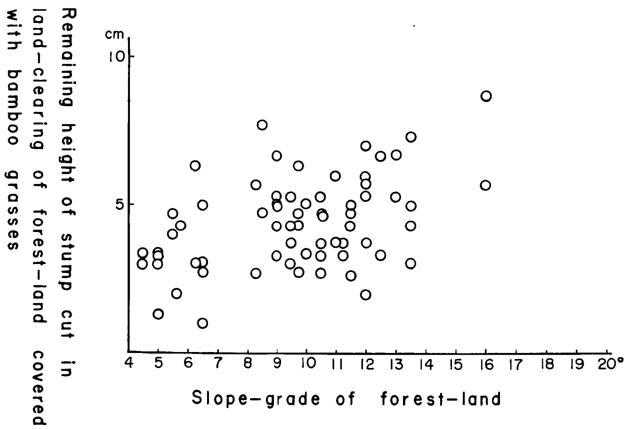


Fig. 36. Relation between remaining height of stump cut in land-clearing and slope-grade of forest-land

5. Performance of tractor-powered rotary cutter*11

5.1 Construction of tractor-powered rotary cutter

The mechanical drive type rotary cutters equipped with crawler tractor used in this country are now makes of either KONISHI or BUSH HOG. All their cutter blades are constituted by a couple of bill hook type cutter blades which are jointed in free at both ends of rotating arm (KONISHI) or at the opposite rim of disc (BUSH HOG), facing each other at the lower end of cutter shaft under the cutter cover (Fig. 37-a, b). The free-jointed cutter blades absorb the shock load caused when cutting big diameter hard woods or when striking stumps and other obstacles.

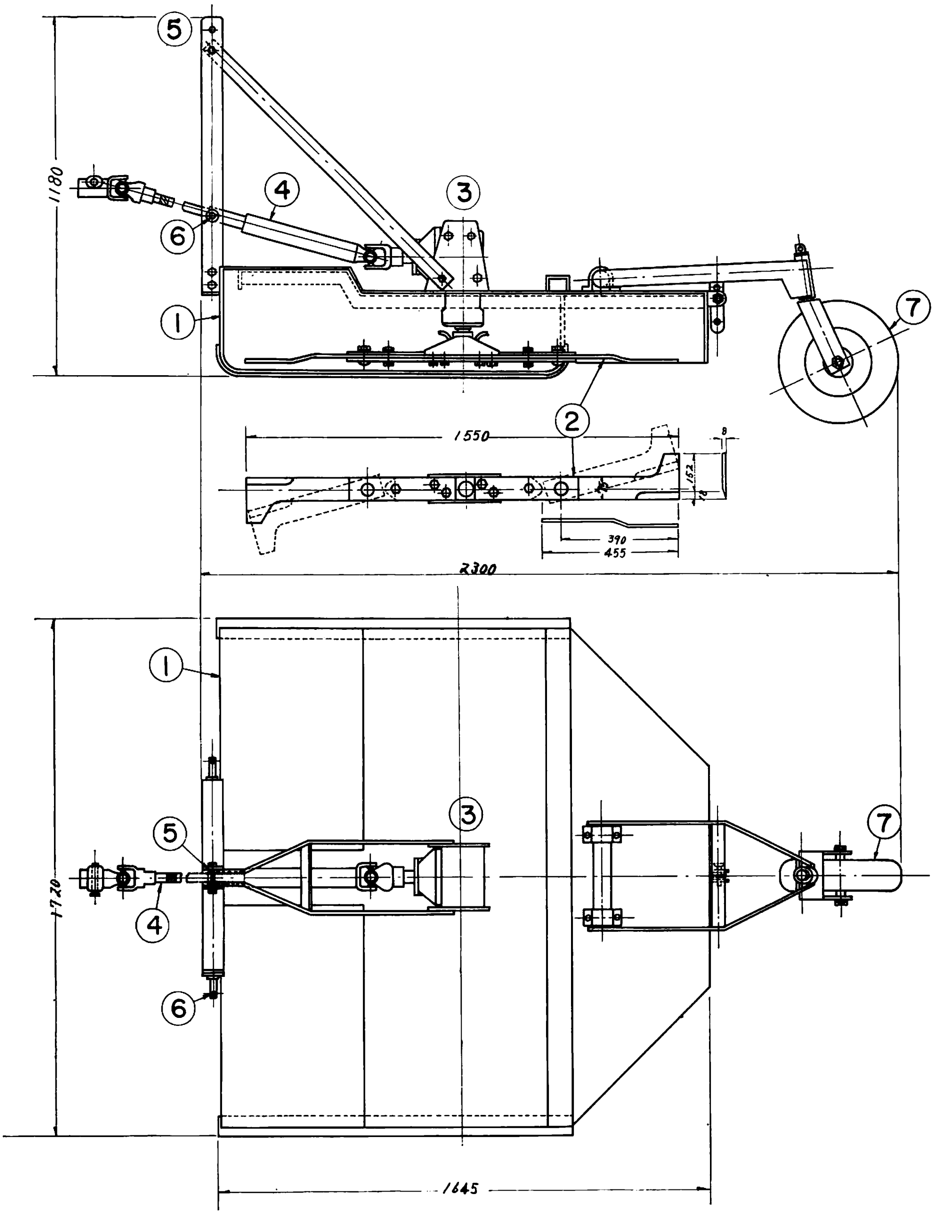
The cutter cover protects the tractor driver from possible injuries inflicted by slashed shrubs. The gap between the inside of cover and the upper side of cutter blades is not so wide that the cutting resistance force of cutter blade under the cover when slashing bamboo grass of high density and others seems to be more than that of cutter blade without the cover for the same slashing, notwithstanding the frequent clogging of the gap with bamboo grass or others.

The gear box with a couple of bevel gears is nearly at the center point of the upper face of cover in both makes and their gears are the over-drive gear of which the ratios are 0.504(KONISHI), 0.696 (BUSH HOG). The overall reduction gear ratio of them are 1.41 (KONISHI), 1.95 (BUSH HOG) when the reduction gear ratio of PTO shaft is 2.8 (see Table 6).

The three-point implement hitch can be set on the upper base of the cutter cover. An idler wheel with pneumatic tire set at the rear end of the cutter cover is used for adjusting the remaining height of slashed grass and shrub. In the author's opinion, the mechanical drive type rotary cutter for forestry use needs to be much stronger and more rigid in all parts of its construction than that for agricultural use, because the load in the former case is usually more severe than that in the latter case.

The hydraulic drive type rotary cutter used is manufactured for trial purposes under the supervision of the author and has also the same two cutter blades, one cutter cover, one idler wheel

*11 YAMAWAKI, S. *et al.*: Brush cutting performance of crawler tractor with rotary cutter on inclined forest-land, J. of the Jap. For. Soc., 48, 7, pp. 280～292, (1966)



① Cover or rotary cutter, ② Cutter blade, ③ Gear box, ④ Transmission shaft,
⑤ Pin for top link, ⑥ Pin for side link, ⑦ Guide wheel.

Fig. 37-a. Mechanical drive type rotary cutter powered by tractor (KONISHI)

and three-point linkage as the mechanical drive type rotary cutter. But the transmission of power from the shaft of tractor engine and the cutter shaft is done on the hydraulic power system which is very different from that of the mechanical type. Thereupon, the oil pump with flow rate 77 l/min, max. pressure 100 kg/cm^2 at 1,500 rpm is set to the shaft of tractor engine and the oil motor with max. torque 11 mkg at 750 rpm directly connected to the reduction gear box is set to the cutter

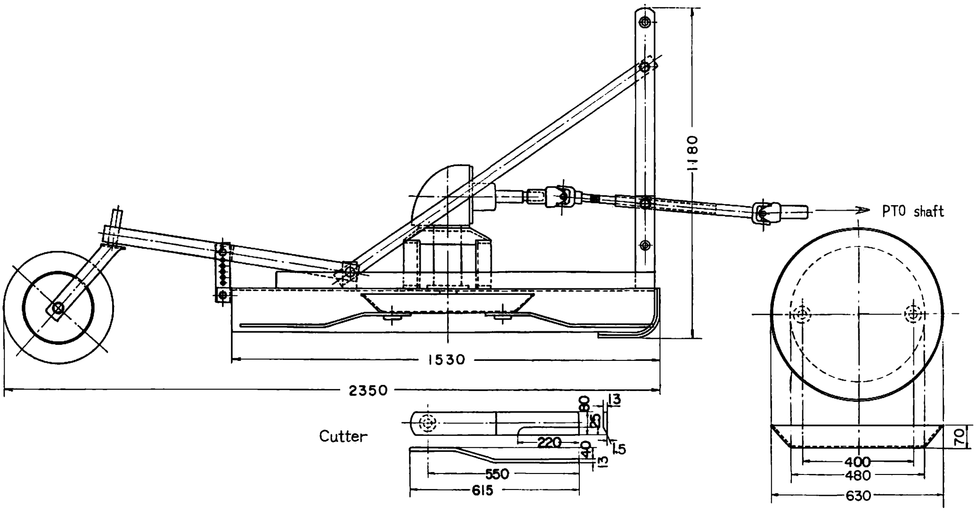


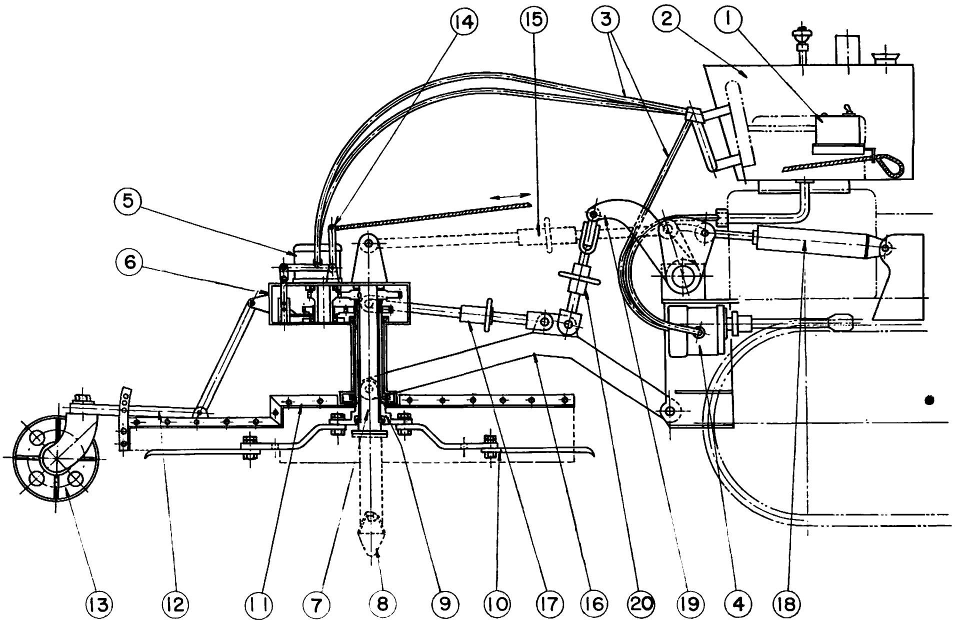
Fig. 37-b.　Do. (BUSH HOG)

Table 6.　Specifications of rotary cutter

Kind of rotary cutter		KONISHI	BUSH HOG	Hydraulic drive type rotary cutter
Type		Three-point mounting		
Weight	kg	310	370	without oil tank 360
Overall length	mm	2,300	2,350	2,450
width	mm	1,720	1,650	1,700
height	mm	1,450	1,550	900
Dia. of cutter blade	mm	1,550	1,500	1,500
Effective radius of cutter blade	mm	765	735	735
Ground clearance of cutter blade	mm	100～250	90～330	90～250
Reduction ratio: PTO shaft: crank shaft		2.67 (CT 25)	2.8(rebuilt to be equal to CT 35)	1 (crank shaft: oil pump shaft) 1.56 (oil pump: oil motor)
Reduction ratio: Cutter shaft: PTO shaft		0.504	0.696	1.12 (oil motor shaft: cutter shaft)
Reduction ratio: Cutter shaft: crank shaft		1.34	1.95	1.75
Calculated speed ratio (peripheral speed of rotary cutter: tractor speed at 1st)		123.2 : 1	82.3 : 1	71.6 : 1

shaft on the cover. The connection among them is done by means of high-pressure rubber hoses. The special oil tank of 70 *l* capacity is set on the left side of tractor seat (Table 6, Fig. 38).

In the author's opinion, it should be kept in mind that there are some time-lags in this hydraulic-type power transmission, though the system has the characteristic of protecting the tractor engine from the over-load given by the cutter blades slashing big dia. hard woods or striking stumps.



① Switch box, ② Oil tank, ③ High pressure rubber hose, ④ Oil pump, ⑤ Oil motor, ⑥ Gear box, ⑦ Auger shaft, ⑧ Auger blade, ⑨ Rotary cutter shaft, ⑩ Rotary cutter blade, ⑪ Cover for rotary cutter, ⑫ Bracket, ⑬ Guide wheel, ⑭ Change lever for rotary cutter, ⑮ Top link for earth auger, ⑯ Side link, ⑰ Fixed link, ⑱ Oil cylinder for three point linkage, ⑲ Lift arm, ⑳ Lift link.

Fig. 38. Hydraulic drive type rotary cutter powered by tractor

5.2 Brush-cutting performance of mechanical drive type rotary cutter

5.2.1 Coefficient of pulling resistance of rotary cutter

The pulling resistance of rotary cutter (KONISHI) on forest-land covered with slashed shrub, bamboo grass and grass was measured successfully by pulling the rear guide wheel backward through the wire resistance strain gauge type lood cell. From the result obtained, it can be said that the coefficient of pulling resistance of rotary cutter f_r increases in proportion to the increase in the pulling speed V_a (m/sec) as follows (see Fig. 39):

$$f_r = 0.186 + 0.129\, V_a \quad \cdots\cdots (74)$$

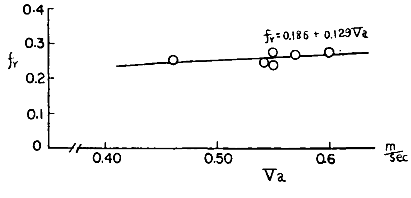


Fig. 39. Relation between coefficient of pulling resistance of rotary cutter on forest-land covered with slashed shrub and grass f_r and the pulling speed of it V_a

5.2.2 Cutting resistance force of rotary cutter blade

If the rotary cutter blade is rigidly attached to the boss of the cutter shaft, the cutting resistance force of the cutter blade F_r (kg) can be computed by the following formula.

$$F_r=\frac{T_{r2}}{r}=\frac{T_{r1}\cdot i_r\cdot \eta_r}{r} \quad \cdots\cdots (75)$$

where, T_{r2}: torque of cutter shaft (mkg)

T_{r1}: torque of PTO shaft (mkg)

r: effective radius of cutter blade (m), shown in Table 6

i_r: gear ratio of rotary cutter shown in Table 6

η_r: mechanical efficiency of rotary cutter, almost equal to 0.95

From the empirical data and this relation, F_r and T_{r2} can be computed, and the results are shown in Fig. 40, as a function of the revolutions per minute of the cutter shaft N_r (rpm) or the peripheral speed of the cutter blade V_r (m/sec). Namely, F_r and T_{r2} decrease in inverse proportion to the increase in N_r or V_r and the values of F_r and T_{r2} change according to the kind of the objects to be cleared, that is, shrub > bamboo grass in high density > bamboo grass in medium density > grass, as expressed in the empirical formulae.

$$F_r=a_1-b_1 N_r=a_1-b_1' V_r \quad \cdots\cdots (76)$$

$$T_{r2}=a_2-b_2 N_r=a_2-b_2' V_r \quad \cdots\cdots (77)$$

where, a_1, b_1, b_1'; a_2, b_2, b_2' are constants which take the approximate values given in Table 7.

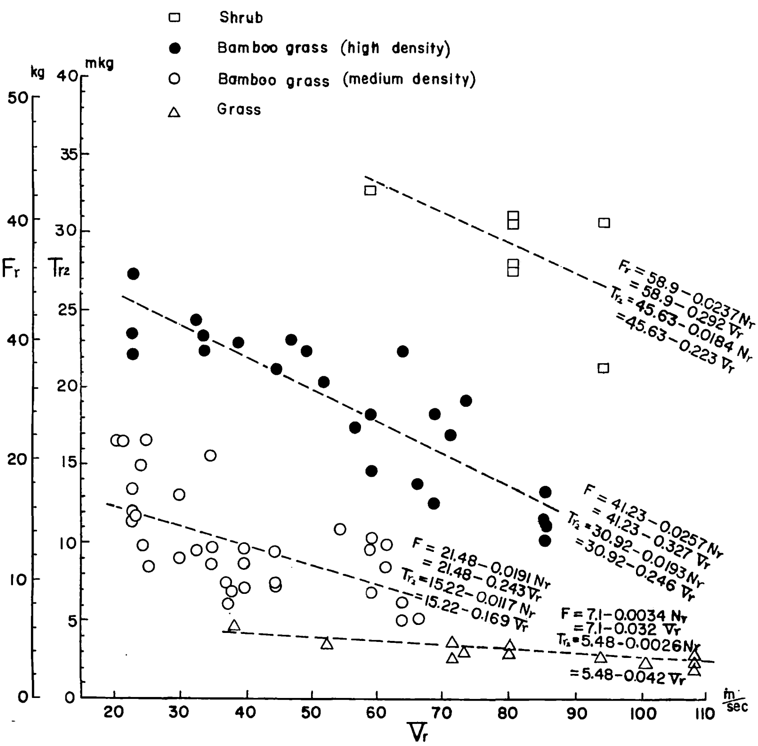


Fig. 40. Cutting resistance force of cutter blade F_r and torque of cutter shaft T_{r2} under various load in relation to peripheral speed of cutter blade V_r

Table 7. Values of a_1, b_1, b_1'; a_2, b_2, b_2'

	a_1	b_1	b_1'	a_2	b_2	b_2'
Shrub[1)]	58.9	0.0237	0.292	45.62	0.0184	0.223
Bamboo grass in high density[2)]	41.23	0.0257	0.327	30.42	0.0193	0.246
Bamboo grass in medium density[3)]	21.48	0.0191	0.243	16.08	0.0133	0.169
Grass[4)]	7.1	0.0034	0.042	5.48	0.0026	0.032

Note 1) Shrubs with 2~6.5 cm dia. were cut by KONISHI.
2) Bamboo grass with 2.7~7.0 mm base dia., 126~182 stems/m² were cut by BUSH HOG.
3) Bamboo grass with about the same base dia., 74~144 stems/m² were cut by BUSH HOG.
4) Grasses were cut by KONISHI.

5.2.3 Brush-cutting torque of crawler tractor with rotary cutter running on inclined forest-land

The total torque required for the crawler tractor with rotary cutter when cutting brush T_{rce} (mkg) is the sum of the torque required for the crawler tractor with rotary cutter running only T_t' (mkg) and the torque required for cutting brush T_{rcc} (mkg) which is transmitted to the crank shaft of the tractor engine.

$$T_{rce}=T_t'+T_{rcc} \quad \cdots\cdots (78)$$

The total running resistance force of the crawler tractor with rotary cutter R_{rce} (kg) equals the sum of the running resistance force of tractor mentioned in formula (11) and the pulling resistance force of rotary cutter on forest-land.

$$R_{rce}=W_t(f_t\cos\alpha+\sin\alpha)+W_r(f_r\cos\alpha+\sin\alpha) \quad \cdots\cdots (79)$$

From formulae (79), (10), (12), (13), T_t' is written in the following form.

$$T_t'=\frac{\{W_t(f_t\cos\alpha+\sin\alpha)+W_r(f_r\cos\alpha+\sin\alpha)\}d}{2\,i_1\cdot i_2\cdot i_3\cdot\eta_1\cdot\eta_2\cdot\eta_3} \quad \cdots\cdots (80)$$

T_{rcc} is given by

$$T_{rcc}=\frac{T_{r1}}{i_5\cdot\eta_5} \quad \cdots\cdots (81)$$

substituting (75) into (81), T_{rcc} is

$$T_{rcc}=\frac{F_r\cdot r}{i_5\cdot i_r\cdot\eta_5\cdot\eta_r} \quad \cdots\cdots (82)$$

From formulae (78), (80), (82), the final formula then takes the shape of

$$T_{rce}=\frac{\{W_t(f_t\cos\alpha+\sin\alpha)+W_r(f_r\cos\alpha+\sin\alpha)\}d}{2\cdot i_1\cdot i_2\cdot i_3\cdot\eta_1\cdot\eta_2\cdot\eta_3\cdot\eta_4}+\frac{F_r\cdot r}{i_5\cdot i_r\cdot\eta_5\cdot\eta_r} \quad \cdots\cdots (83)$$

Now, the empirical values of T_{rce}, T_t'', T_{r1}, T_{rcc} in relation to α when the engine speed is 950 ± 150 rpm are dotted in Fig. 41. It will be seen that T_{r1} and T_{rcc} are almost independent of α, namely $T_{r1}\doteqdot 11.44$ mkg, $T_{rcc}\doteqdot 4.3$ mkg in this case, and then T_{rce} and T_t'' increase almost in linear proportion to the increase of α. For the sake of comparison, the linear curve of T_{rce} and T_t' computed from the theoretical formulae (83), (80), using $T_{r1}=11.44$ mkg obtained in this experiment are drawn in Fig. 41, and then it can be said that the computation gives the values close to those obtained in the experiment.

Corresponding to the study about the torque described above, the total horsepower required for

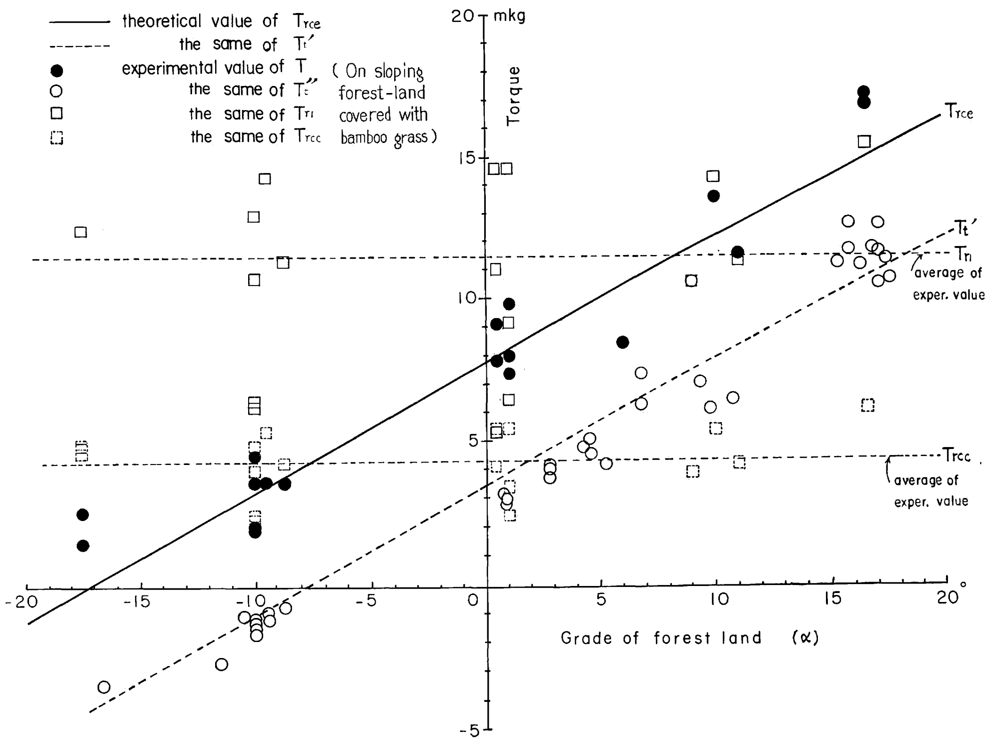


Fig. 41. Comparison between theoretical and empirical values of T_{rce}, T_t'

the crawler tractor with rotary cutter when cutting brush P_{rce} (PS) is the sum of the horsepower required for running on P_t' (PS) and the horsepower required for cutting brush P_{rcc} (PS) which are transmitted to the crank shaft of the tractor engine.

$$P_{rce}=P_t'+P_{rcc} \cdots\cdots (84)$$

From formulae (79), (15), (16), (12), (13), P_t' arrives at

$$P_t'=\frac{\{W_t(f_t\cos\alpha+\sin\alpha)+W_r(f_r\cos\alpha+\sin\alpha)\}V_a}{75\cdot\eta_1\cdot\eta_2\cdot\eta_3\cdot\eta_4(1-s)} \cdots\cdots (85)$$

$$=\frac{\{W_t(f_t\cos\alpha+\sin\alpha)+W_r(f_r\cos\alpha+\sin\alpha)\}l\cdot n\cdot N_e}{75\cdot 60\cdot i_1\cdot i_2\cdot i_3\cdot\eta_1\cdot\eta_2\cdot\eta_3\cdot\eta_4} \cdots\cdots (86)$$

P_{rcc} is derived from formulae (81), (82)

$$P_{rcc}=\frac{2\pi\cdot T_{r1}\cdot N_e}{75\cdot 60\cdot i_5\cdot\eta_5} \cdots\cdots (87)$$

$$=\frac{2\pi\cdot F_r\cdot r\cdot N_e}{75\cdot 60\cdot i_5\cdot i_r\cdot\eta_5\cdot\eta_r} \cdots\cdots (88)$$

Accordingly, from formulae (84), (85), (86), (87), (88), the final formula takes the form:

$$P_{rce}=\frac{\{W_t(f_t\cos\alpha+\sin\alpha)+W_r(f_r\cos a+\sin\alpha)\}V_a}{75\cdot\eta_1\cdot\eta_2\cdot\eta_3\cdot\eta_4(1-s)}+\frac{2\pi\cdot F_r\cdot r\cdot N_e}{75\cdot 60\cdot i_5\cdot i_r\cdot\eta_5\cdot\eta_r} \cdots\cdots (89)$$

$$=\frac{\{W_t(f_t\cos\alpha+\sin\alpha)+W_r(f_r\cos\alpha+\sin\alpha)\}l\cdot n\cdot N_e}{75\cdot 60\cdot i_1\cdot i_2\cdot i_3\cdot\eta_1\cdot\eta_2\cdot\eta_3\cdot\eta_4}+\frac{2\pi\cdot F_r\cdot r\cdot N_e}{75\cdot 60\cdot i_5\cdot i_r\cdot\eta_5\cdot\eta_r} \cdots (90)$$

Then, the empirical values P_{rce} and P_t'' under the same condition as mentioned above are dotted, and the linear curve of P_{rce} and P_t' computed from the theoretical formula (89), (90); (86) in the case of $N_e = 950$ rpm are drawn in Fig. 42. From this comparison between them, it can be said that an approximate value of P_{rce} is given by the theoretical formula (89) or (90).

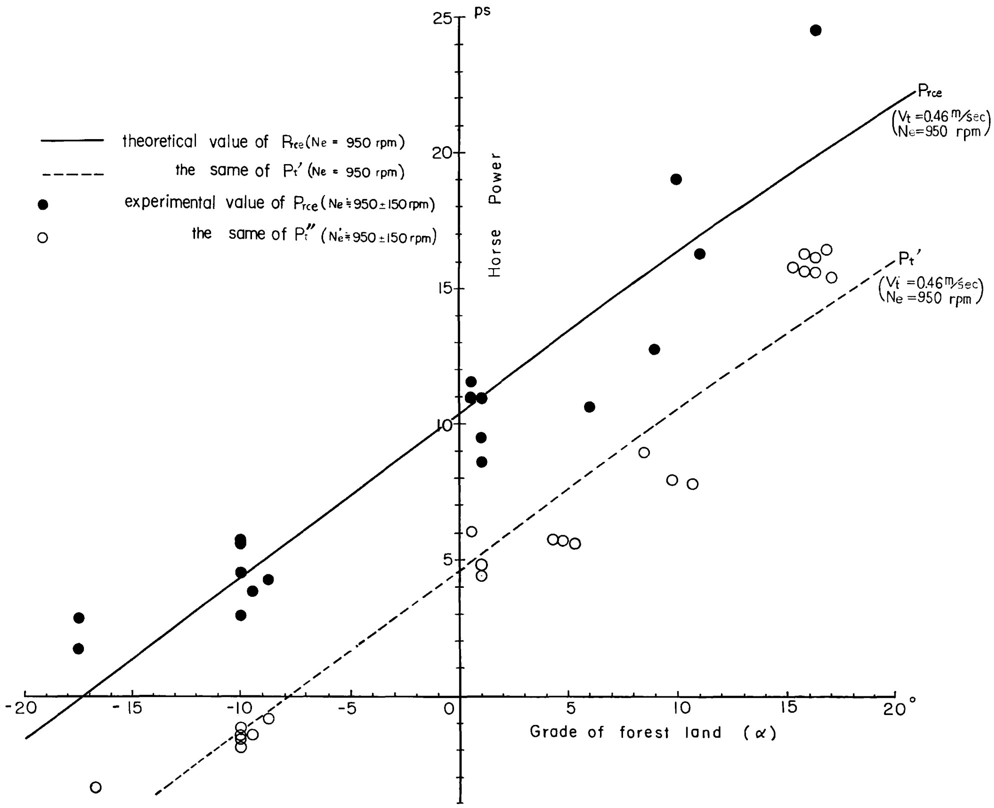


Fig. 42. Comparison between theoretical and empirical values of P_{rce}, P_t'

5.2.4 Fuel consumption rate of crawler tractor with rotary cutter when cutting brush

The relation among the net fuel consumption per unit horsepower per hour of the crawler tractor with attached machinery when doing reforestation works f_b (gr/PS·hr), the horsepower P_e (PS) and the speed N_e (rpm) of tractor engine at that time is given in the empirical formula from the results of experiments on various kinds of tractor-powered machineries.

$$f_b = \left(0.162 + \frac{1.39}{P_e}\right) N_e \qquad \cdots\cdots (91)$$

(see Fig. 43)

Now, supposing that a_r is the running distance per unit fuel consumption of the crawler tractor with rotary cutter when cutting brush (km/l) and A_r is the equivalent brush-cutting area per unit fuel consumption of the same (ha/l), a_r and A_r are given by

$$a_r = 10^3 \cdot \frac{V_a \cdot \rho}{f_b \, P_{rce}} \qquad \cdots\cdots (92)$$

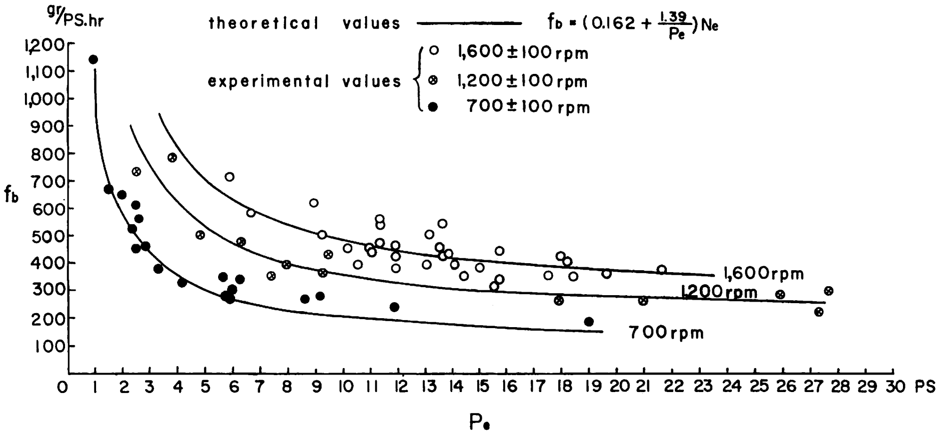


Fig. 43. Comparison between theoretical and empirical values of net fuel consumption per unit horsepower per hour of various tractor-powered attached reforestation machineries f_b in relation to horsepower of tractor engine required for reforestation works P_e

$$A_r=10^2\cdot\frac{V_a\cdot b\cdot\rho}{f_b\ P_{rce}}\cdots\cdots(93)$$

where, ρ: specific gravity of fuel (gr/cm^3), 0.825 in light oil used for test tractor by the measurement

b: brush-cutting width of rotary cutter, 1.5 m in BUSH HOG

V_a: as mentioned above

Substituting formula (16) for V_a and formulae (89), (90) for P_{rce} into formulae (92), (93), the following formulae are derived

$$a_r=10^3\cdot\frac{\rho}{f_b}\cdot\frac{75\cdot l\cdot n\cdot(1-s)\cdot i_5\cdot i_r\cdot\eta_1\cdot\eta_2\cdot\eta_3\cdot\eta_4\cdot\eta_5\cdot\eta_r}{l\cdot n\cdot i_5\cdot i_r\cdot\eta_5\cdot\eta_r\{W_t(f_t\cos\alpha+\sin\alpha)+W_r(f_r\cos\alpha+\sin\alpha)\}+2\pi\cdot F_r\cdot r\cdot i_1\cdot i_2\cdot i_3\cdot\eta_1\cdot\eta_2\cdot\eta_3\cdot\eta_4}\cdots\cdots(94)$$

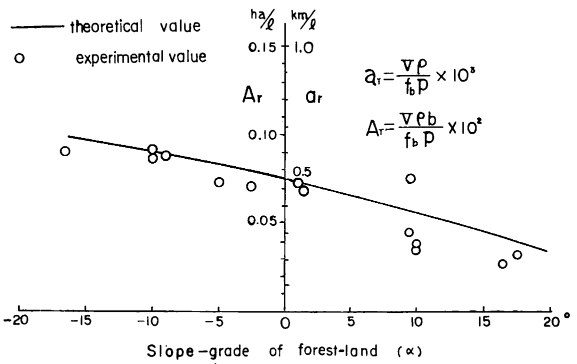


Fig. 44. Comparison between theoretical and empirical values of a_r, A_r

$$A_r=10^2\cdot\frac{\rho}{f_b}\cdot\frac{75\cdot l\cdot n\cdot(1-s)\cdot i_5\cdot i_r\cdot\eta_1\cdot\eta_2\cdot\eta_3\cdot\eta_4\cdot\eta_5\cdot\eta_r}{l\cdot n\cdot i_5\cdot i_r\cdot\eta_5\cdot\eta_r\{W_t(f_t\cos\alpha+\sin\alpha)+W_r(f_r\cos\alpha+\sin\alpha)\}+2\pi\cdot F_r\cdot r\cdot i_1\cdot i_2\cdot i_3\cdot\eta_1\cdot\eta_2\cdot\eta_3\cdot\eta_4}\quad(95)$$

The empirical values of a_r and A_r with regard to α are dotted in round points and the theoretical values of them computed from the above formulae are drawn in parabolic curves as shown in Fig. 44. From this comparison, it can be found that there is almost no difference between them, and these theoretical formulae may be generally used for the estimation of the fuel consumption in the crawler tractor with rotary cutter operation.

5.2.5 Brush-cutting quality of rotary cutter driven by running crawler tractor on forest-land covered with bamboo grass

Bamboo grass having from 2.7 to 7.0 mm in average 4.5 mm base dia., from 62 to 125 cm, in average 101 cm height and an average of 122 stems per m^2 in density, were cleared by the BUSH HOG rotary cutter. The relation between the remaining height of bamboo grass after being cut by the rotary cutter h_r (cm) and N_r, V_r is shown in Fig. 45. That is, h_r lowers in inverse proportion to the increase in N_r or V_r as shown in the empirical formula:

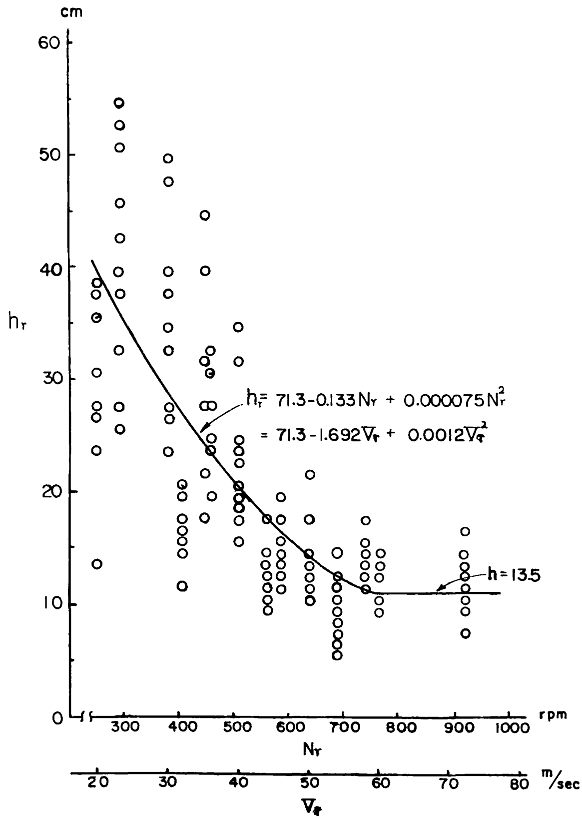


Fig. 45. Relation between remaining height of bamboo grass after being cleared h_r and peripheral speed V_r, revolution per minute N_r of rotary cutter blade

$$h_r = 71.3 - 0.133\,N_r + 0.000075\,N_r^2$$
$$= 71.3 - 1.692\,V_r + 0.012\,V_r^2 \cdots\cdots (96)$$

And when V_r becomes more than approx. 60 m/sec, that is, N_r becomes more than 750 rpm in this rotary cutter, h_r takes the lowest height, approx. 13.5 cm regardless of N_r or V_r.

Therefore, it can be said that the brush-cutting quality of the rotary cutter is good in general when the peripheral speed of cutter blade exceeds approx. 60 m/sec, especially in cutting bamboo grass, the most troublesome job in land-clearing operation in this country.

5.3 Brush-cutting performance of hydraulic drive type rotary cutter

In the case of the hydraulic drive type rotary cutter, the following formulae will be induced from formulae (82), (88) and the characteristic of hydraulic transmission.

$$T_{rcc}' = \frac{F_r \cdot r \cdot q_p \cdot \eta_{pv} \cdot \eta_{mv}}{i_5' \cdot i_r' \cdot q_m \cdot \eta_5' \cdot \eta_r' \cdot \eta_p \cdot \eta_m \cdot \eta_h} = \frac{F_r \cdot r \cdot q_p}{i_5' \cdot i_r' \cdot q_m \cdot \eta_5' \cdot \eta_r' \cdot \eta_{pm} \cdot \eta_{mm} \cdot \eta_h} \cdots\cdots (97)$$

$$P_{rcc}' = \frac{2\pi \cdot T_r \cdot N_e}{75 \cdot 60} = \frac{2\pi \cdot F \cdot r \cdot q_p}{75 \cdot 60 \cdot i_5' \cdot i_r' \cdot q_m \cdot \eta_5' \cdot \eta_r' \cdot \eta_{pm} \cdot \eta_{mm} \cdot \eta_h} \cdots\cdots (98)$$

where, i_r': reduction gear ratio of hydraulic type rotary cutter, 1.12

η_r': mechanical efficiency of that, supposed value 0.95

η_{pm}: mechanical efficiency of oil pump $= \frac{\eta_p}{\eta_{pv}}$, supposed value 0.85

η_{mm}: mechanical efficiency of oil motor $= \frac{\eta_m}{\eta_{mv}}$, supposed value 0.85

the others: as mentioned above

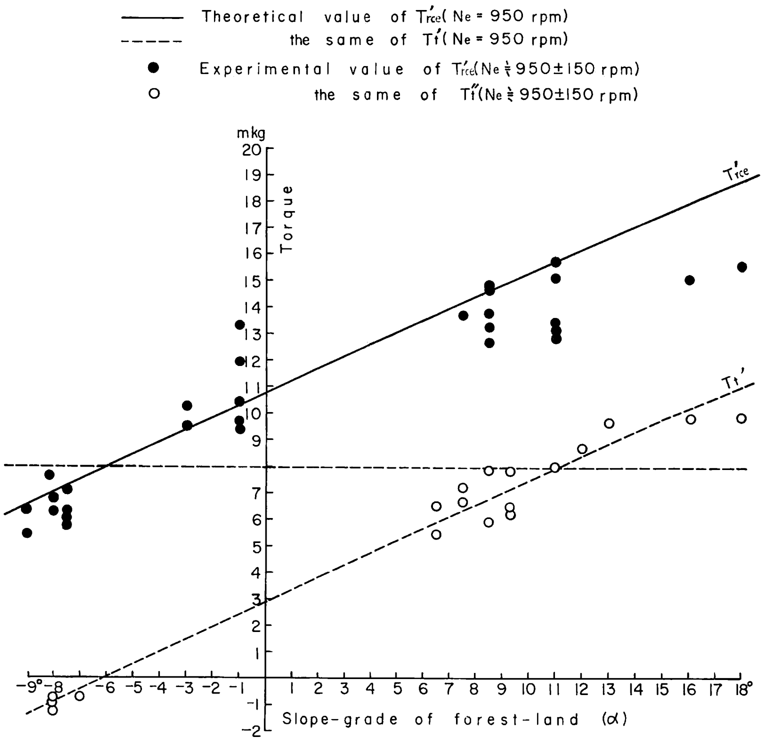


Fig. 46. Comparison between theoretical and empirical values of T_{rce}', T_t'

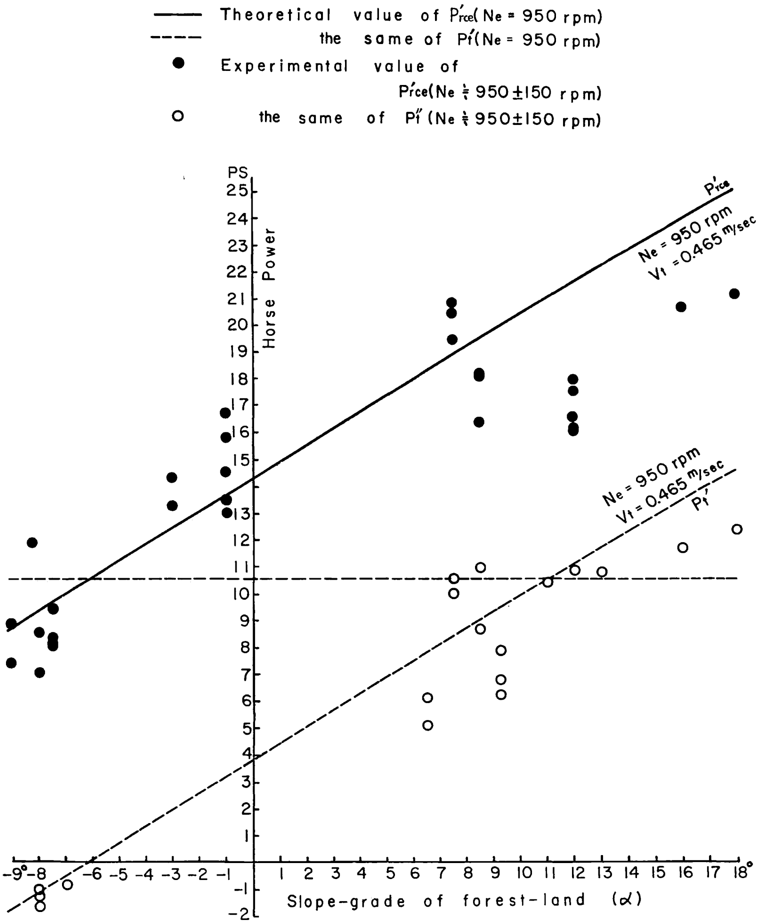


Fig. 47. Comparison between theoretical and empirical values of P_{rce}', P_t'

Accordingly, from formulae (83), (89), (90) and the same hydraulic feature, the total torque T_{rce}' (mkg) and horsepower P_{rce}' (PS) of the crawler tractor with hydraulic type rotary cutter when cutting brush arrive at

$$T_{rce}' = \frac{\{W_t(f_t\cos\alpha+\sin\alpha)+W_r(f_r\cos\alpha+\sin\alpha)\}\,d}{2\cdot i_1\cdot i_2\cdot i_3\cdot\eta_1\cdot\eta_2\cdot\eta_3\cdot\eta_4} + \frac{F_r\cdot r\cdot q_p}{i_5'\cdot i_r'\cdot q_m\cdot\eta_5'\cdot\eta_r'\cdot\eta_{pm}\cdot\eta_{mm}\cdot\eta_h} \qquad (99)$$

$$P_{rce}' = \frac{\{W_t(f_t\cos\alpha+\sin\alpha)+W_r(f_r\cos\alpha+\sin\alpha)\}\,V_a}{75\cdot\eta_1\cdot\eta_2\cdot\eta_3\cdot\eta_4\cdot(1-s)} + \frac{2\pi\cdot F_r\cdot r\cdot q_p}{75\cdot 60\cdot i_5'\cdot i_r'\cdot q_m\cdot\eta_5'\cdot\eta_r'\cdot\eta_{pm}\cdot\eta_{mm}\cdot\eta_h} \qquad (100)$$

$$= \frac{\{W_t(f_t\cos\alpha+\sin\alpha)+W_r(f_r\cos\alpha+\sin\alpha)\}\,l\cdot n\cdot N_e}{75\cdot 60\cdot i_1\cdot i_2\cdot i_3\cdot\eta_1\cdot\eta_2\cdot\eta_3\cdot\eta_4} + \frac{2\pi\cdot F_r\cdot r\cdot q_p}{75\cdot 60\cdot i_5'\cdot i_r'\cdot q_m\cdot\eta_5'\cdot\eta_r'\cdot\eta_{pm}\cdot\eta_{mm}\cdot\eta_h} \qquad (101)$$

The empirical values of T_{rce}' and P_{rce}' when cutting bamboo grass with from 3.3 to 6.2 mm in base dia, from 90 to 135 stems per m² in density and $N_e \fallingdotseq 950 \pm 150$ rpm by the help of hydraulic type rotary cutter driven by the running crawler tractor are dotted and the linear curve of T_{rce}' and P_{rce}' computed from the theoretical formulae (99); (100), (101), where $W_t = 3,500$ kg, $W_r =$ 500 kg, f_t is as in formula (5), f_r is as in formula (74), $N_e = 950$ rpm, V_a is as in formula (16), s is as in formula (9), $r = 0.66$ m, F_r is as in formula (76), Table 7, $N_r = \frac{N_e}{1.75}$, $V_r = 37.7$ m/sec, the others are as mentioned above, are drawn in Fig. 46, 47.

From comparison between them, it may be said that the computation by the help of the theoretical formulae (99); (100), (101) give the values close to those obtained in the experiments.

Furthermore, the brush-cutting quailty of the hydraulic drive type rotary cutter was almost equal to that of the mechanical drive type in both land-clearing and weeding operations in the field test.

5.4 Operational efficiency of tractor-powered rotary cutter

The operational efficiency of a crawler tractor with a mechanical drive type rotary cutter for land-clearing in a 4.03 ha forest-land (see Fig. 48) was compared with that of a team operation using seven knapsack type brush cutters, one filing machine and so on in a 4.35 ha forest-land(see Fig. 48) with the help of time study for several working days respectively, in hilly NAGAKURAYAMA national forest (Japanese larch 50-year-old artificial forest), situated near KARUIZAWA, NAGANO prefecture.

The land-clearing operation by a crawler tractor (IWATEFUJI CT-35, total weight=approx. 4,550 kg with dozer and three-point implement hitch, rated horsepower=48 PS at 1,800 rpm, diesel) with rotary cutter(KONISHI)was maneuvered by one skilled driver. Against this, the same operation by one-man knapsack type brush cutter (KYORITSU Power Scythe, total weight=approx. 15 kg, max.

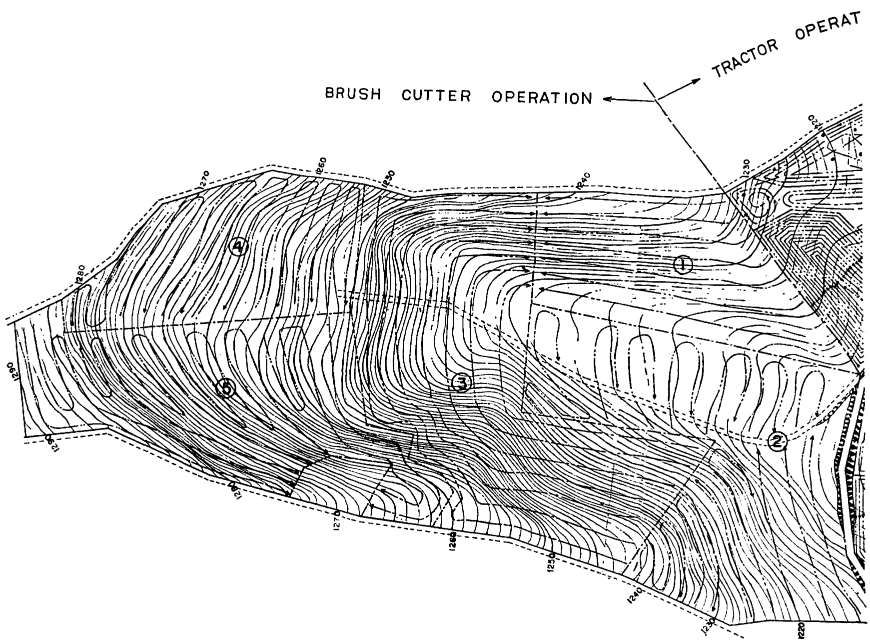


Fig. 48. Outline of test field for operational efficiency and comparison between tractor

horsepower = 1.7 PS at 5,000 rpm, gasoline) was carried out by the help of a team consisting of thirteen workers i.e. seven persons as brush cutter· operators, one person for filing circular saws used in brush cutters, four persons for clearing away branches in the rows to be planted after brush-cutting (including a team-leader) and one person for feeding fuel to all working brush cutters.

There was much difference in the operational style between the tractor operation and the brush cutter operation. That is, the tractor operation was conducted taking the running direction of tractor up and down the slope of forest-land from the point of view of stability of locomotion i.e. in the direction parallel to the slope and then clearing brush in a vortex motion of tractor-running on a slope of forest-land as shown in Fig. 48. But on the contrary, the brush cutter team operation was conducted taking the progressing direction of brush-cutting parallel to the contour line on the slope i.e. in the direction perpendicular to the slope and then clearing brush in several lines by seven brush cutter operators on a slope of forest-land as shown in Fig. 48.

Table 8-a, b show a sample of the working hour per day in the tractor operation and the brush cutter team operation obtained from the time study of their eight-hour work.

The total working hour per ha per worker t in the tractor operation and the brush cutter team operation can be separated into several terms in the following way:

$t = t_b + t_t + t_i$ (in tractor operation) ……………………………………(102)

where, t_b: working hour per ha per worker for net brush cutting operation

t_t: that for turning tractor at the edge of slope, obstacles and others

t_i: that for the inspection of machine

$t = t_b + t_i + t_f + t_c$ (in brush cutter team operation) ……………………(103)

where, t_b, t_i: the same as mentioned above, t_f: that for filing circular saws

t_c: that for clearing away branches

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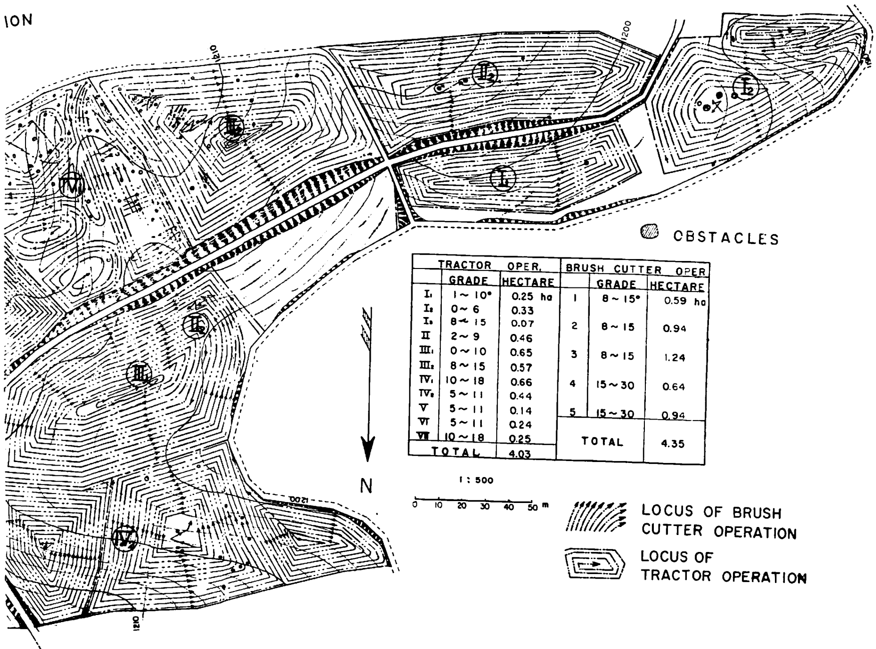


operation method and brush cutter team operation method for land-clearing

Table 8-a. Working hour per day in tractor opperation

Kind of work	Working hour		Percentage
Net work	4 hr	21 min	66.9%
Brush-cutting	3	52	59.4
Turning at the edge of forest-land, obstacles and others		09	2.4
Inspection of machine		20	5.1
Additional work	2	9	33.9
Fitting up the accessories		46	11.8
Feeding fuel, lubricating oil and others		29	7.4
Others		54	13.9
Total	6	30	100.0
Noon and other recess	1	30	
Grand total	8	00	

Table 8-b. Working hour per day in brush cutter team operation

Kind of work	Working hour				Percentage
	combined		per worker		
Net work by thirteen workers	73 hr	40 min	5 hr	40 min	87.2%
Brush-cutting by seven workers	39	25	3	02	46.7
Net brush-cutting	32	30	2	30	38.5
Inspection of machine	6	55	0	32	8.2
Filing of circular saw by one worker	3	20	0	15	3.8
Clearing away branches by four workers	30	55	2	23	36.7
Others	10	50	0	50	12.8
Total	84	30	6	30	100.0
Noon and other recess			1	30	
Grand total			8	00	

Then the average values of these terms obtained from the time study are shown in Table 9. From Table 9, it can be seen that the actual working hour per man-day t_a is six hours and thirty minutes in both operations, and the net working rate Z is 66.9 % in the tractor operation, 87.2 % in the brush cutter team operation and so the net working hour per man-day t_n is 4 hr 21 min in the tractor operation, 5 hr 40 min in the brush cutter team operation.

Table 9. Average values of

Kind of mechanized operation	Slope-grade of forest-land	t_b
Tractor operation	gentle (0～8°)	hr min ± hr min 2.39 ± 0.33
	moderate (8～15°)	4.05 ± 0.12
Brush cutter team operation	moderate (8～15°)	hr min ± hr min 29.05 ± 3.20
	steep (15～30°)	40.06 ± 3.25

Accordingly, the land-clearing area per man-day done with these mechanized operations H_r (ha/man-day) is given by

$$H_r=\frac{t_n}{t}=\frac{t_a Z}{t}$$

$$=\frac{t_a Z}{t_b+t_t+t_i} \text{ (in tractor operation)} \cdots\cdots (104)$$

$$=\frac{t_a Z}{t_b+t_i+t_f+t_c} \text{ (in brush cutter team operation)} \cdots\cdots (105)$$

The values of H_r in both operations obtained from this experiment are shown in Table 10.

Table 10. Comparison of efficiency in land-clearing

Kind of mechanized operation	Slope-grade of forest-land	Land-clearing area per man-day	Contrast for reference (Weeding area per man-day)
Tractor operation	Gentle (0～10°)	1.34 ha	1.32 ha
	Moderate (10～20°)	0.93	1.26
Brush cutter team operation	Moderate (10～20°)	0.09	
	Steep (20～30°)	0.07	

Finally, the crawler tractor with rotary cutter can easily cut brush on sloping cutover forest-land when the height of stumpage is less than ten centimeters and the slope-grade is less than twenty degrees. And if the condition of forest-land, especially the slope-grade is much the same, it will be found that the land-clearing efficiency of the tractor operation becomes nearly ten times that of the brush cutter team operation.

Moreover, it can be said that the weeding efficiency of the tractor operation is also about the same with land-clearing in the subsequent investigations in these test-fields (Fig. 49). And it seems that the operational efficiency of the hydraulic drive type rotary cutter is almost equal to that of the mechanical drive type in both land-clearing and weeding operations, gathered from the further investigation.

t, t_b, t_t, t_i, t_f, t_c

t_t	t_i	t_f	t_c	t
hr min hr min	hr min hr min	hr min hr min	hr min hr min	hr min hr min
0.10 ± 0.06	0.26 ± 0.23	0	0	3.15 ± 1.02
				4.41 ± 0.41
0	4.08 ± 1.04	2.25 ± 1.07	26.03 ± 4.06	61.40 ± 9.37
			38.22 ± 3.43	85.01 ± 8.79

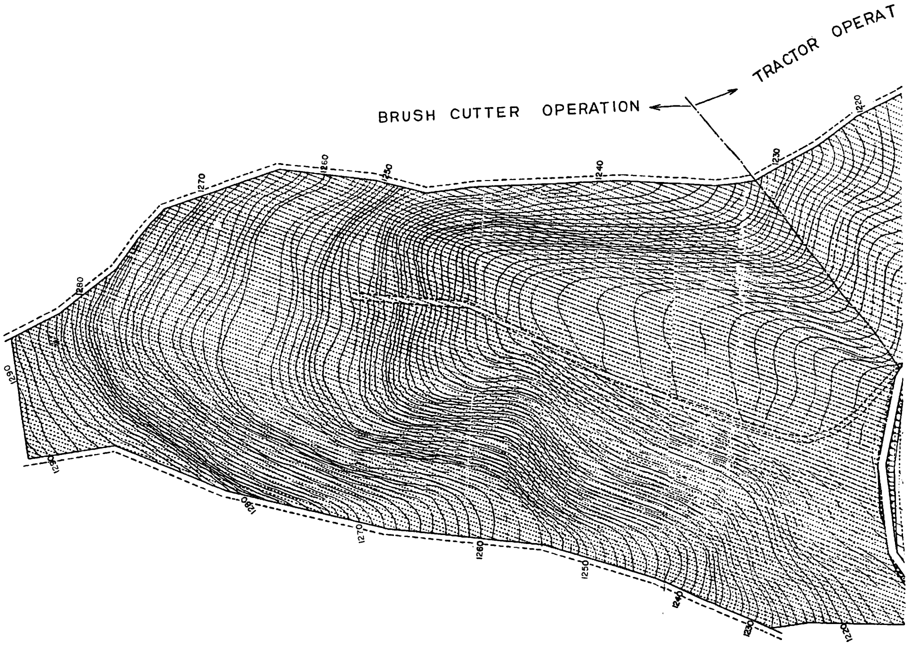


Fig. 49. Test field, where two kinds of weeding operations were done, after being planted being planted by one-man earth auger taking planting row space≒1.8 m in brush

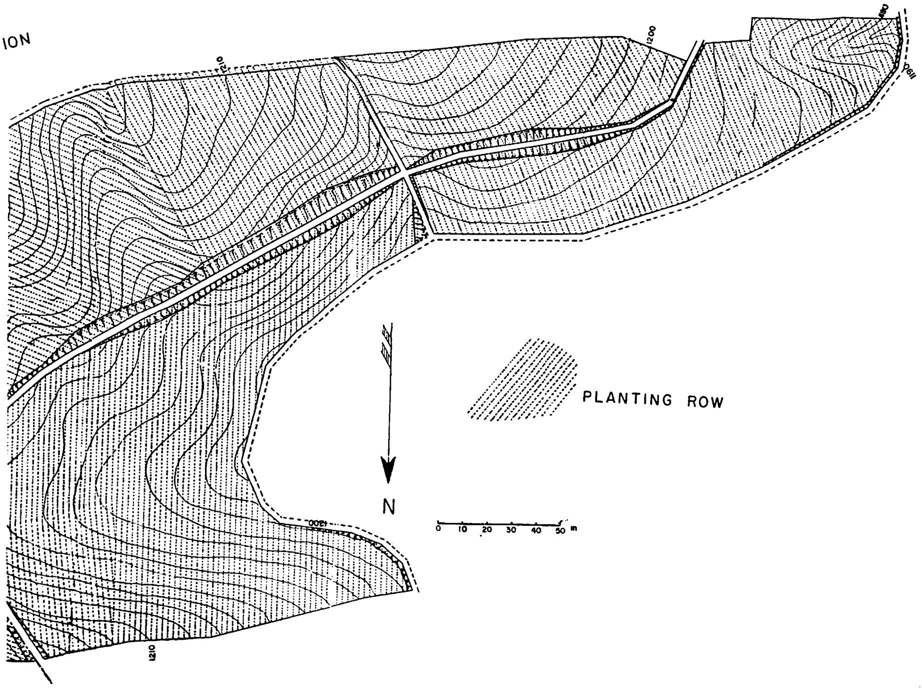
6. Performance of tractor-powered earth auger

6.1 Construction of tractor-powered earth auger

Two kinds of tractor-powered earth auger for tree-planting were investigated in the field experiment. One is the mechanical drive type earth auger manufactured on trial by Ito, S. and Ueda, Z., officer and operator of IWAMURATA District Forest Office, and the other is the hydraulic drive type earth auger manufactured on trial by a maker, under the supervision of the author.

The mechanical drive type earth auger is equipped with the long arm three-point hitch linkage to make the lifting height of auger head higher i.e. up to about 50 cm above the ground surface and to make the penetrating depth of auger head deeper i.e. down to about 60 cm into the ground. The overall reduction gear ratio is 20.19(19.23) where the reduction ratio of gear box with auger shaft is 7.21 and that of PTO shaft is 2.8(2.67). The diameter of propeller type auger equals about 600 mm to dig a full planting hole for the planting of tree seedling in a single operation (see Fig. 50, Table 11).

The hydraulic drive type earth auger is sometimes called the culti-auger in this country, because it has a couple of culti-blades at the upper point of auger shaft which can rotate at higher speed than that of the auger shaft, that is, at the same speed of the rotary cutter shaft, a feature originated by the author. The shaft of culti-auger is a double shaft of which the inner shaft motion is transmitted by a couple of reduction gears with 73/13 reduction ratio and the outer shaft motion is transmitted by a couple of reduction gears with 47/42 reduction ratio around the same axis of the



by tractor-powered earth auger taking planting row space≒2.5 m in tractor operation or after cutter operation

Table 11. Specifications of earth auger

Kind of earth auger			Mechanical drive type	Hydraulic drive type	
Type			Three-point mounting		
Weight		kg	150	195 (212) with culti-blades	
Overall length		mm	1,850	1,410(1,710)	
width		mm	810	650(1,200)	
height		mm	1,388	1,240	
Dia. of auger		mm	600	400	
Lifting height of auger on the ground		mm	500	400	
Penetrating depth of auger into the ground		mm	600	400	
					rebuilt
Reduction ratio of auger	PTO shaft		2.8(2.67)	1	1
	Oil pump			1	1
	Oil motor			1.15	2
	Reduction gear		7.21	1.96	4.56
	Overall		20.19(19.23)	2.45	9.12
Reduction ratio of culti-blade	PTO shaft			1	1
	Oil pump			1	1
	Oil motor			1.25	2
	Reduction gear			1.96	1.12
	Overall			2.45	2.24

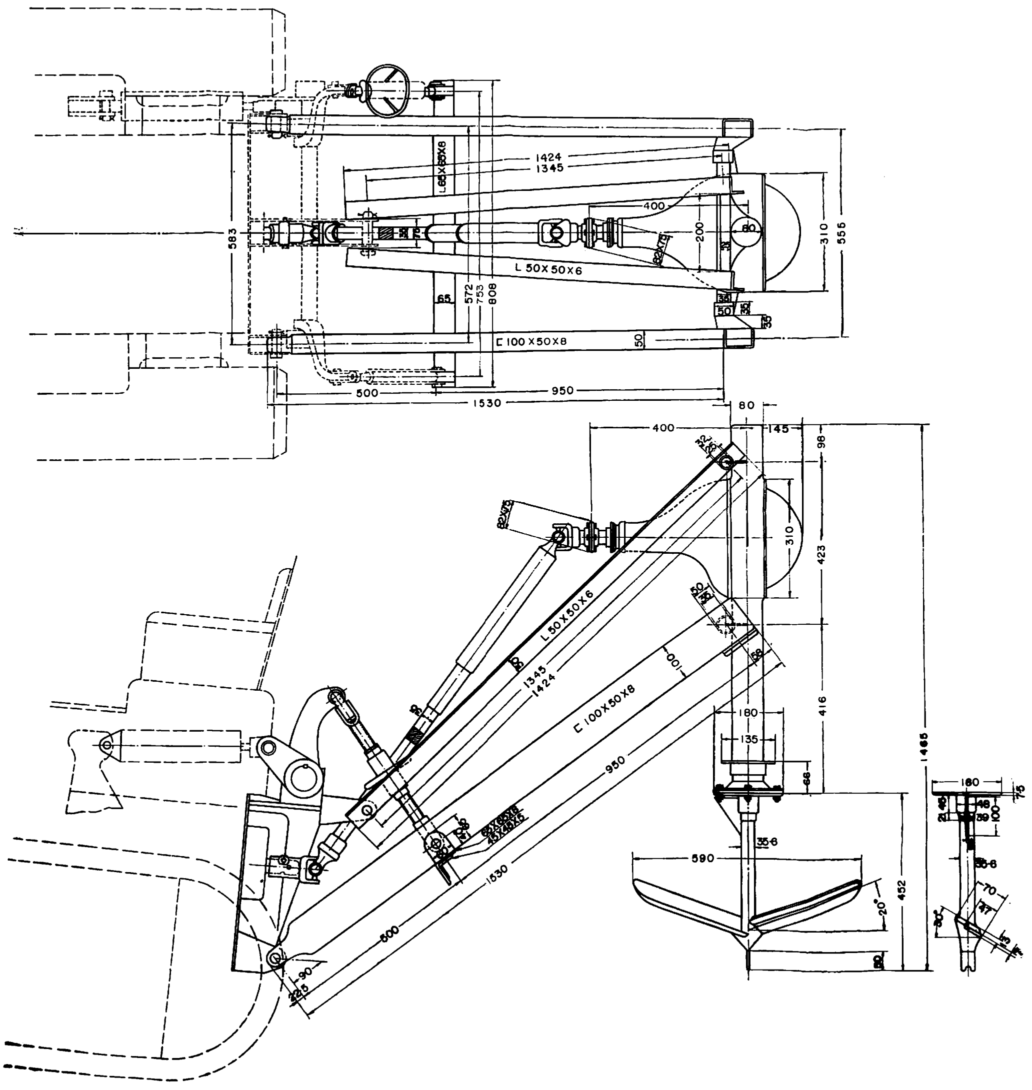


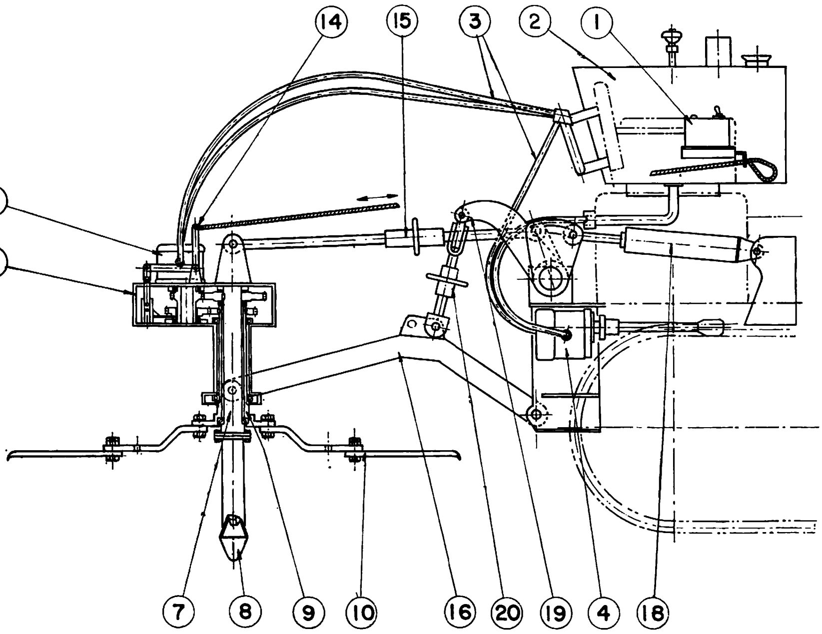
Fig. 50. Mechanical drive type earth auger powered by tractor

inner shaft (see Fig. 51, Table 11). By the use of this culti-auger, we can dig planting holes with from 400 to 500 mm dia. and from 300 to 400 mm depth by the auger action and cut brush and grass around the planting hole at the range of from 1,200 to 1,500 mm dia. by the action of culti-blades at the same time. It can be used, needless to say, for digging planting holes only, as an auger without culti-blades.

6.2 Earth-drilling performance of mechanical drive type earth auger

It is clear from the results obtained from the author's experiment about the earth-drilling performance of one-man portable earth auger*[12] that the torque required for earth-drilling is influ-

*[12] YAMAWAKI, S. *et al.*: Studies on silvicultural machines (I) Earth drill for tree-planting. Bull. of the Gov. For. Exp. Sta., 139, pp. 83～123, (1962)



Fhg. 51-a. Hydraulic drive type earth auger powered by tractor
(Description is the same as Fig. 38)

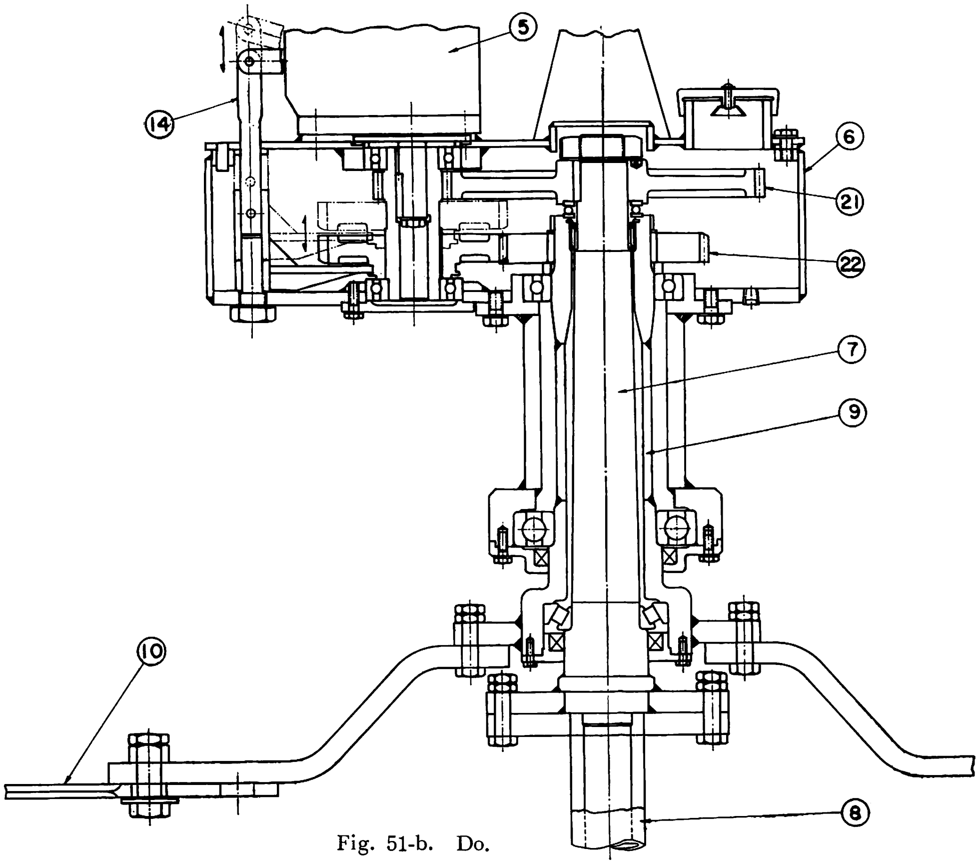


Fig. 51-b. Do.

enced by the penetrating speed of auger, the peripheral speed of auger, the hardness of soil, the moisture content of soil, the quantity of obstacles like roots and gravel under the earth surface and so on. Especially, the torque required for earth-drilling increases in almost linear proportion to the increase of the penetrating speed of auger into the earth*13, and it increases in a slightly convex parabolic curve or similarly linearly as the peripheral speed of auger speeds up*14.

It seems reasonable to assume that these experimental facts mentioned above can be applied to the earth-drilling by the tractor-powered earth auger on forest-land. Then, it will be considered that the resistance force acting on the auger blade F_a (kg) is principally influenced by the peripheral speed V_c (m/sec) and the penetrating speed V_p (m/sec) of auger respectively, when drilling earth in any forest-land. The torque of auger shaft T_a (mkg) is given by

$$T_a=2\int_0^{r_a} r\cdot f\cdot b\cdot d_r=f\cdot r_a^2\cdot b=f\cdot 2r_a\cdot b\cdot \frac{r_a}{2}=F_a\cdot\frac{r_a}{2} \quad\cdots\cdots(106)$$

where, f: unit resistance force of auger blade

r_a: radius of auger blade (m), 0.30

b: width of auger blade projected to the plane passing through the auger axis (m), 0.035

F_a: $f\cdot 2r_a\cdot b$

And, the torque of PTO shaft T_1 (mkg) required for earth-drilling is

$$T_1=\frac{T_a}{i_a\ \eta_a}=F_a\cdot\frac{r_a}{2}\cdot\frac{1}{i_a\cdot\eta_a}$$

or

$$F_a=T_1\frac{2i_a\cdot\eta_a}{r_a} \quad\cdots\cdots(107)$$

where, i_a: reduction gear ratio of auger, 7.21

η_a: mechanical efficiency of auger, supposed value 0.93

Therefore, the resistance force of auger blade F_a can be computed from formula (107) and the relation between F_a and V_p when drilling earth at the revolution per minute of tractor engine $=1,200\pm100$ rpm, down to 30 cm in depth into the ground of various forest-land is given by the following empirical formula (see Fig. 52):

$$\left.\begin{aligned}F_a&=(a+bV_p)V_c^{\,d}\\&=(a_1+b_1V_p)N_e^{\,d}\end{aligned}\right\} \quad\cdots\cdots(108)$$

where a, b; a_1, b_1, d are constants as shown in Table 12.

Finally, the torque T_{ae} (mkg) and horsepower P_{ae} (PS) required for tractor engine when drilling earth by tractor-powered mechanical drive type earth auger can be written in the following form.

$$T_{ae}=F_a\frac{r_a}{2i_5\cdot i_a\cdot\eta_5\cdot\eta_a} \quad\cdots\cdots(109)$$

$$P_{ae}=\frac{\pi\cdot N_e\cdot F_a\cdot r_a}{75\cdot 60\cdot i_5\cdot i_a\cdot\eta_5\cdot\eta_a} \quad\cdots\cdots(110)$$

The aforementioned result of experiment as shown in Fig. 19 expresses that the mechanical efficiency of PTO shaft η_5 takes the following values when the torque of tractor engine is small i.e.

*13 Do. p. 95

*14 Do. p. 101

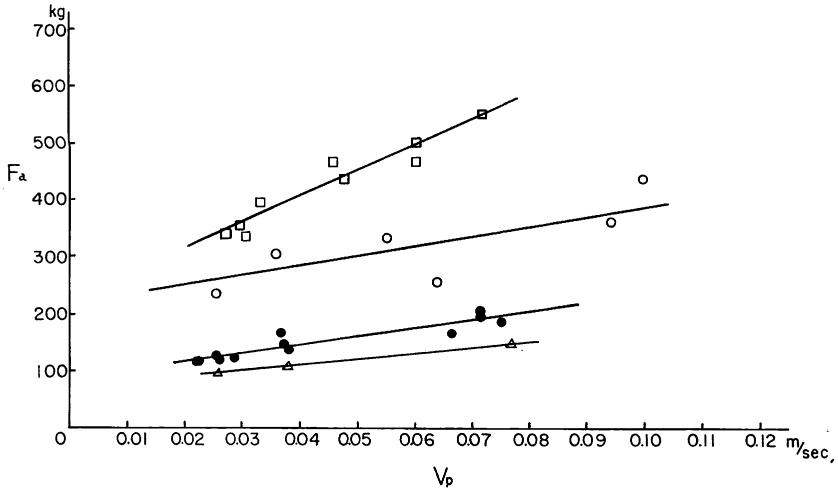


Fig. 52. Relation between resistance force acting on auger blade F_a and penetrating speed of auger V_p

Table 12. Average values of constants in formula (108)

Kind of earth in forest-land	a	b	a_1	b_1	d	Remark
In forest-land covered with bamboo grass	179.7	3,574	13.6	270	0.4	
In forest-land of hard black soil	170.5	1,289	12.7	91.1	0.4	hardness measured by penetro-meter=from 22 to 28 kg
In forest-land of soft black soil containing gravels	67.6	1,087	5.08	82.1	0.4	containing from twenty to seventy gravels with from 8 to 15 cm dia.
In forest-land of soft black soil only	55.4	735	4.17	55.3	0.4	hardness measured by penetro-meter=from 0.5 to 13 kg

$\eta_5=0.85$ in the case of earth-drilling on forest-land covered with bamboo-grass or hard black soil, $\eta_5=0.70$ in the case of earth-drilling in forest-land of soft black soil containing gravel or soft black soil only. And so, T_{ae} and P_{ae} can be computed from Formulae (109), (110) and their computed values are shown in solid lines as a function of V_p, as compared with dotted points of empirical values obtained under various conditions, in Fig. 53. From the comparison between them, it will be seen that the computation from formulae (109), (110) can give the approximate values for the torque and horsepower of tractor-powered earth auger when drilling earth.

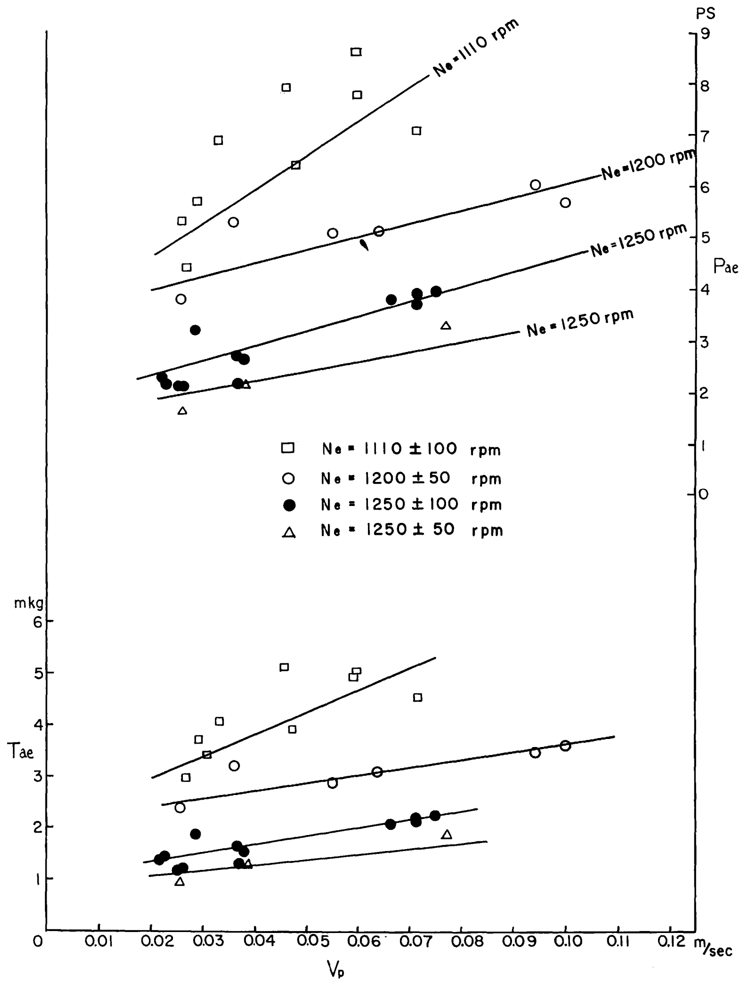
6.3 Earth-drilling performance of hydraulic drive type earth auger

Comparing the resistance force of auger blade of the mechanical drive type earth auger F_a with that of the hydraulic drive type F_a' when drilling earth in the same forest-land, it will be seen that there is a difference between them which is influenced by the projected area of auger blade to the plane running through the axis of auger shaft as expressed in the following form (see Fig. 54).

$$F_a'=0.37\cdot F_a(226.7V_p+80)V_c^{0.25} \quad \cdots\cdots(111)$$

where constant 0.37 is similarly equal to the ratio of the projected area of auger blade to the shaft axis in the hydraulic drive type earth auger and that in the mechanical drive type i.e. 78 cm^2 : 210 cm^2=0.37 : 1.

The torque T_{ae}' (mkg) and horsepower P_{ae}' (PS) required for tractor engine when drilling earth



Kind of forest-land (moisture content 29.2 ～32.7%)

□ covered with bamboo grasses: 0.7～1.7 stems, 0.06 ～0.25 cm² in section area of roots, 0.9～11.1 gr in weight of root cut per 1 cm of drilling depth,

○ covered with hard black soil: hardness of soil measured by penetrometer: 22, 24, 25, 24, 28, 28 Kg respectively at 5, 10, 15, 20, 25, 30 cm depth under the ground,

● covered with soft black soil after cultivated, and having from twenty to seventy gravels of from 8 to 15 cm in diameter,

△ covered with soft black soil after cultivated: hardness of soil measured by penetrometer: 0.5, 1, 2, 13, 28 Kg respectively at 5, 10, 15, 20, 30 cm depth under the ground

Fig. 53. Comparison between theoretical and empirical values of T_{ae}, P_{ae}

by tractor-powered hydraulic drive type earth auger will be expressed in the form.

$$T_{ae}' = \frac{F_a' \cdot r_a \cdot q_p}{2 \cdot i_5' \cdot i_a' \cdot \eta_5' \cdot \eta_a' \cdot q_m \cdot \eta_{pm} \cdot \eta_{mm}} \quad \cdots\cdots (112)$$

$$P_{ae}' = \frac{\pi \cdot N_e \cdot F_a' \cdot r_a \cdot q_p}{75 \cdot 60 \cdot i_5' \cdot i_a' \cdot \eta_5' \cdot \eta_a' \cdot q_m \cdot \eta_{pm} \cdot \eta_{mm}} \quad \cdots\cdots (113)$$

where, r_a: radius of auger in hydraulic drive type(m), 0.20

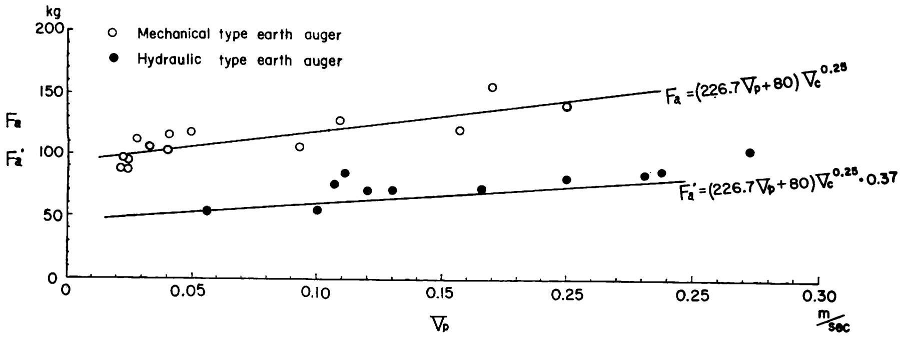


Fig. 54. Relation between F_a and $F_a{}'$

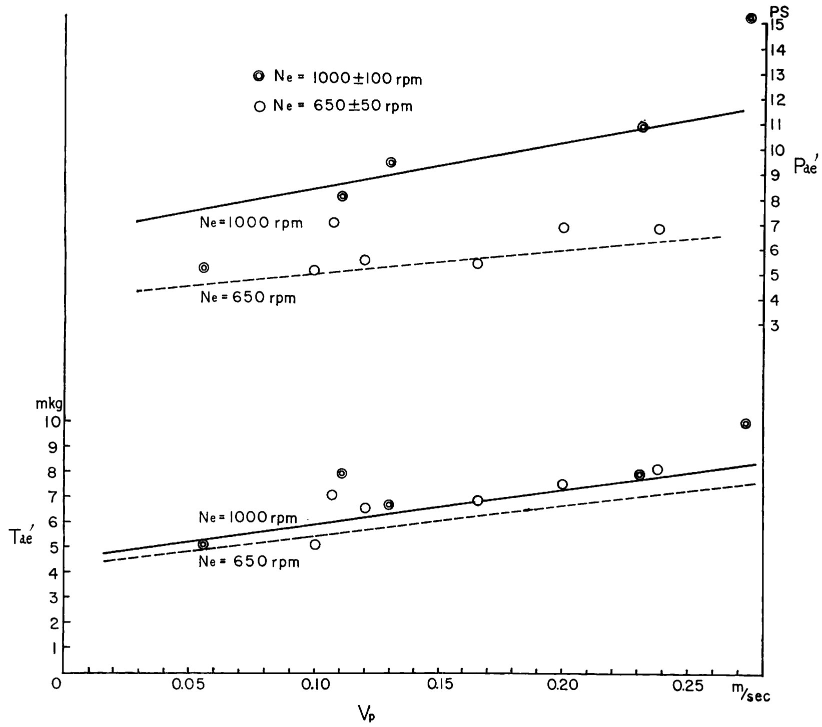


Fig. 55. Comparison between theoretical and empirical values of $T_{ae}{}'$, $P_{ae}{}'$

The empirical values of the torque $T_{ae}{}'$ and horsepower $P_{ae}{}'$ at $N_e=1,000\pm100$ rpm, 650 ±50 rpm are dotted in round point and the computed values of them at $N_e=1,000$ rpm, 650 rpm from formulae (112), (113) are drawn in solid and dotted lines, as shown in Fig. 55. It will be seen by comparing them that we can estimate the approximate values of the torque and horsepower required for earth-drilling by the use of hydraulic drive type tractor-powered earth auger from formulae (112), (113).

6.4 Operational efficiency of tractor-powered earth auger

The operational efficiency of the mechanical and hydraulic drive type tractor-powered earth auger was surveyed in the field. The mechanical type was operated in forest-land of hard soil mixed with volcanic ashes, in about 20% moisture content, soon after the land-clearing with the help of rotary cutter, in NAGAKURAYAMA national forest, under the management of IWAMURATA District Forest Office, NAGANO Prefecture. The hydraulic type was operated in forest-land of black soil and covered with bamboo grass, with about 20% moisture content, soon after the land-clearing by the use of rotary cutter, in AGATSUMAYAMA national forest, KUSATSU District Forest Office, GUNMA Prefecture.

The hydraulic type earth auger has the characteristic of absorbing the shock load given when drilling earth with the help of the hydraulic drive system. But it is seen that there is a time lag when starting and stopping in the hydraulic type as compared with the performance of the mechanical type. And also the driver was more skilled in operating the mechanical type auger than his counterpart operating a hydraulic type from several years' experience of forest tractor work. Therefore, in the field survey, the operational efficiency of the mechanical type seems to be a little better than that of the hydraulic type, as presented in the following results.

From the time study of their operations in the field, the net time for earth-drilling t_d (sec) is given by the empirical formula as a function of earth drilling depth D_p (cm) (see Fig. 56, 57).

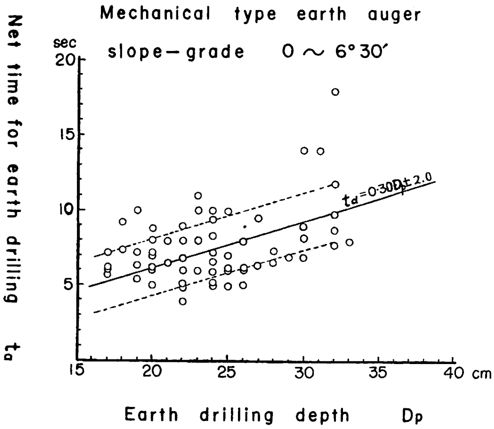


Fig. 56 Relation between net time for earth drilling t_d and depth of earth drilling D_p, in mechanical drive type earth auger

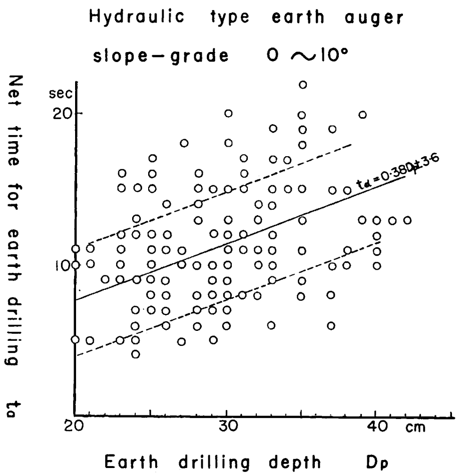


Fig. 57. Relation between net time for earth drilling t_d and depth of earth drilling D_p, in hydraulic drive type earth auger

$$\left.\begin{array}{l} t_d=0.30\,D_p\pm 2.0 \text{ (in mechanical drive type)} \\ t_d=0.38\,D_p\pm 3.6 \text{ (in hydraulic drive type)} \end{array}\right\} \cdots\cdots(114)$$

The running time t_l (sec) required for moving from a planting point to the next one L (m) is given by a linear formula (see Fig. 58, 59).

$$\left.\begin{array}{l} t_l=5.16\,L\pm 2.1 \text{ (in mechanical drive type)} \\ t_l=6.40\,L\pm 3.8 \text{ (in hydraulic drive type)} \end{array}\right\} \cdots\cdots(115)$$

The turning time t_t (sec) required for changing direction at the end of a planting row increases with the increase of the number n_r of planting rows in the planting area A (ha).

$$\left.\begin{array}{l} t_t=41.6\,n_r\pm 22.4 \text{ (in mechanical drive type)} \\ t_t=61.0\,n_r\pm 24.0 \text{ (in hydraulic drive type)} \end{array}\right\} \cdots\cdots(116)$$

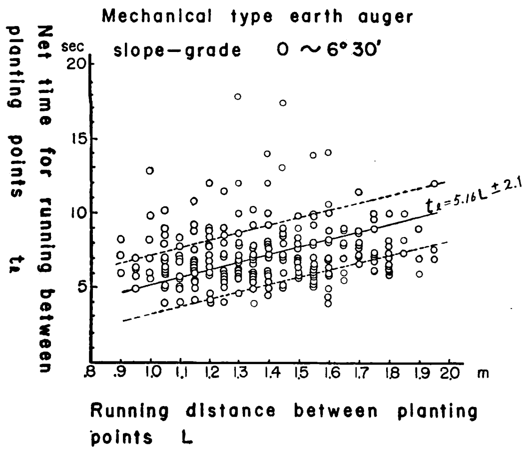


Fig. 58 Relation between net time for tractor's running from a planting point to the next one t_l and distance L, in mechanical drive type earth auger

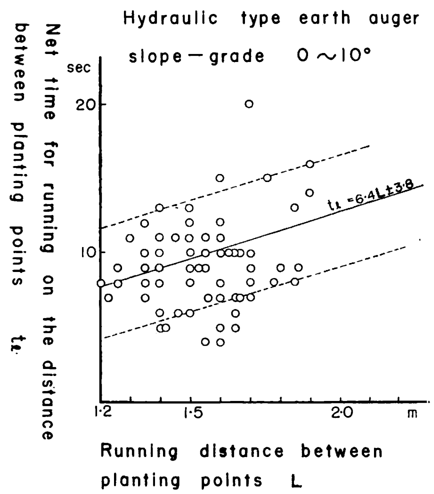


Fig. 59. Relation between net time for tractor's running from a planting point to the next one t_l and distance L, in hydraulic drive type earth auger

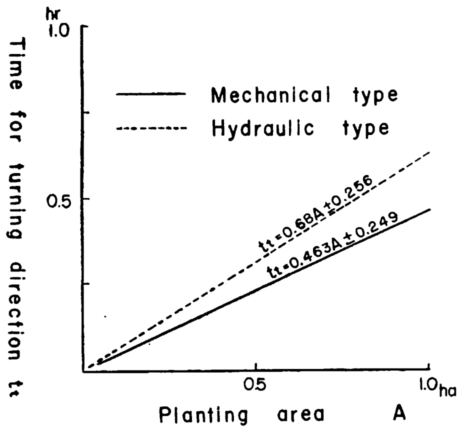


Fig. 60. Relation between turning time for tractor's changing direction at the end of planting row t_t and planting area A, in two type earth augers

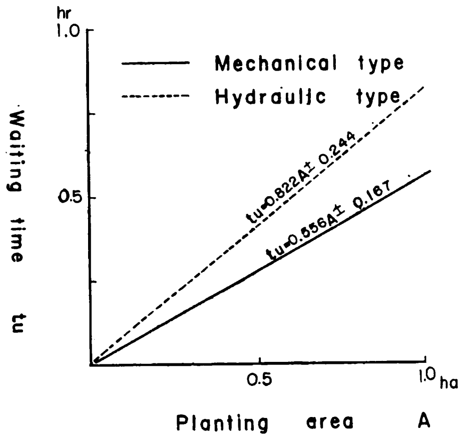


Fig. 61. Relation between waiting time in tractor with earth auger operation t_u and planting area A, in two type earth auger

So, formula (116) is similarly translated into a function of A as shown in Fig. 60, where the shape of planting area is a square and the interval between planting rows is 2.5 m.

The waiting time t_u (sec) increases with the increase of the running distance of tractor L (m) in relation to the planting area A (ha).

$$\left.\begin{array}{l} t_u=0.50\,L\pm0.15 \text{ (in mechanical drive type)} \\ t_u=0.74\,L\pm0.22 \text{ (in hydraulic drive type)} \end{array}\right\} \cdots\cdots(117)$$

So, formula (117) is similarly transformed into a function of A as shown in Fig. 61, where the planting area is a square.

Therefore, the total working hour per hectare t (hr/ha) required for drilling earth by the use of tractor-powered earth auger will be expressed in the following formula.

$$t=t_d\, n_d+t_t\, n_r+(t_l+t_u)L \quad \cdots\cdots (118)$$

where n_d is the number of planting trees per hectare and the running distance per hectare of tractor takes 4,000 m when the shape of planting area is a square, and the interval between planting rows is 2.5 m.

From formula (118), the total working hours required for earth-drilling t' (hr) in accordance with the hectare of planting area A when the number of planting trees per hectare n_d equals 2,500 or 3,000, will be expressed in the following form as shown in Fig. 62.

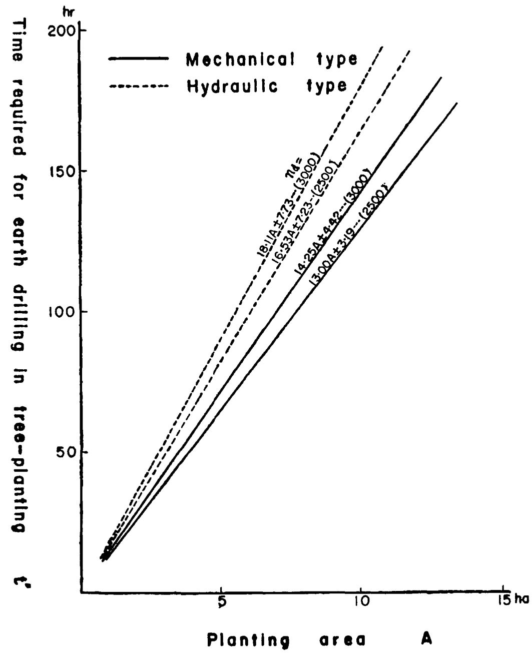


Fig. 62. Total working hour t' required for earth-drilling by tractor-powered earth auger in accordance with the hectare of planting area A

In mechanical drive type

$$t'=13.00\,A\pm 3.19\ (n_d=2{,}500)$$
$$=14.25\,A\pm 4.42\ (n_d=3{,}000)$$

In hydraulic drive type

$$t'=16.53\,A\pm 7.23\ (n_d=2{,}500)$$
$$=18.11\,A\pm 7.73\ (n_d=3{,}000)$$

7. Performance of tractor-powered duster

7.1 Construction of tractor-powered duster

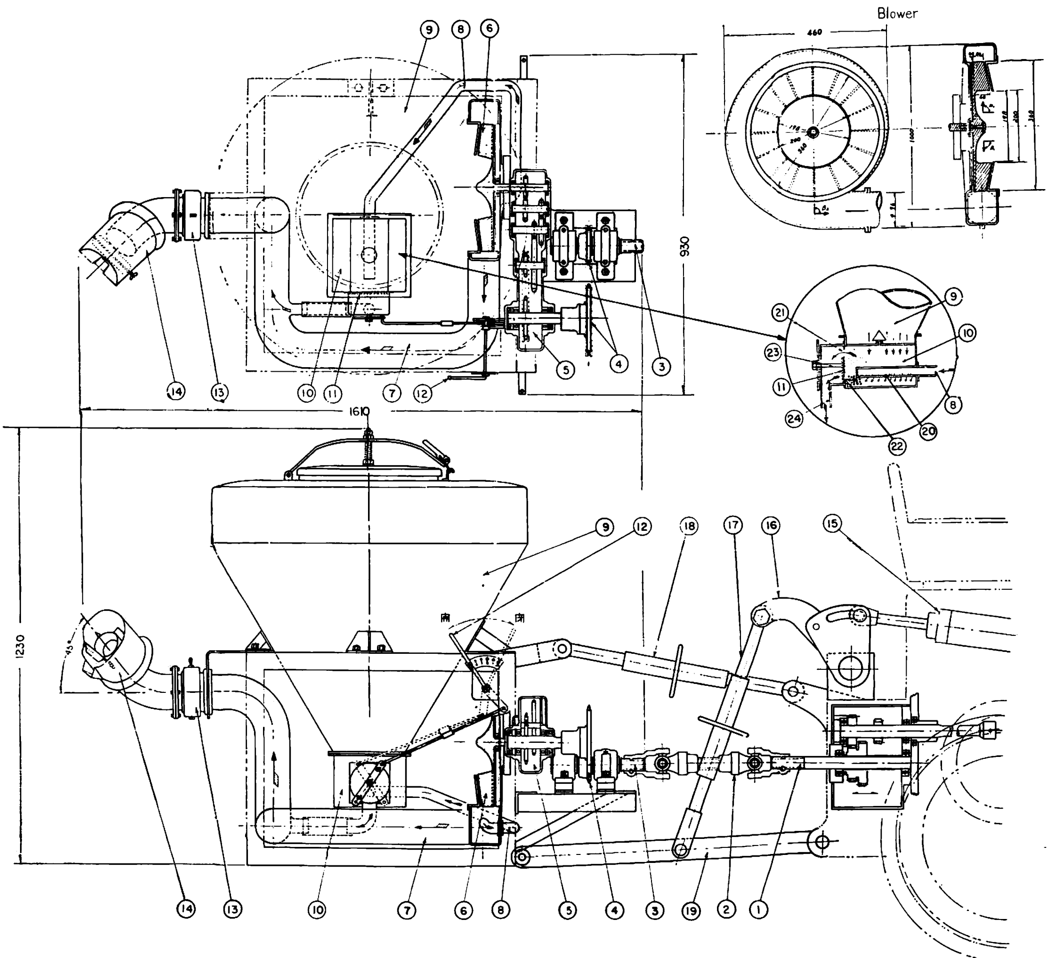
All will agree that there is need of controlling insect pests and diseases in forests by chemicals as an economical way of maintaining the forest in a healthy condition.

The tractor-powered duster was manufactured in trial under the supervision of the author to serve in the reforestation work with the help of tractor mounted machinery, and to serve the double duties of powder and grain type chemicals dusting i.e. the powder-dusting for pest and disease control and the grain-dusting for land-clearing or weeding work in forest-land.

The specifications of this duster are shown in Table 13, and its construction is shown in Fig. 63.

7.2 Dusting performance of tractor-powered duster

The total volumetric flow Q(m³/min) is obtained by integrating the local velocity measured with the pitot tube over the entire area of the flow cross-section in the outlet port (Fig. 64).

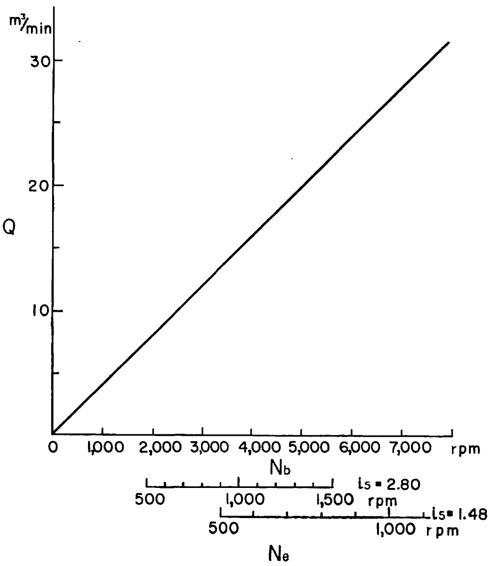


① PTO shaft, ② Universal joint, ③ Input shaft, ④ Sprocket, ⑤ Gear case, ⑥ Centrifugal blower, ⑦ Pipe, ⑧ Pipe, ⑨ Chemicals tank, ⑩ Mixing and feeding chamber of chemicals, ⑪ Slitter, ⑫ Outlet control lever, ⑬ Adjuster for dusting angle of nozzle, ⑭ Nozzle, ⑮ Oil cylinder, ⑯ Lift arm, ⑰ Lift link, ⑱ Top link, ⑲ Side link, ⑳ Feeding port of air, ㉑ Feeding port of powder, ㉒ Feeding port of grain, ㉓ Shaft for slitter, ㉔ Feeding pipe for chemicals.

Fig. 63. Tractor-powered duster

Table 13. Specifications of tractor-powered duster

Type		Three-point supporting type
Overall length	mm	1,610
Overall width	mm	930
Overall height	mm	1,230
Total weight	kg	210 with empty
Capacity of chemicals tank	*l*	200
Max. section area of outlet	cm^2	7.5 in powder-dusting 10.0 in grain-dusting (the outlet is opened or closed by the use of slitter)
Gear ratio of transmission		
PTO shaft: crank shaft		2.8
Blower shaft: PTO shaft		
roller chain		1.78 (32 : 18)
spur gear		0.526 (10 : 19) 0.241 (13 : 54) 0.454 (15 : 33) 1 (24 : 24) } 0.102
Blower, Type		Centrifugal blower
Number of impeller vane		16
Outer dia. of impeller	mm	360
Inner dia. of impeller	mm	200
Dia. of inlet port	mm	198
Dia. of outlet port	mm	98
Discharge pipe, Main inner dia.	mm	98
Sub inner dia.	mm	28



Eig. 64. Total volumetric flow of duster in the outlet port Q

Applying the theory*15 of the centrifugal compressor to the computation of the dusting performance of the tractor-powered duster, the torque of tractor engine T_{de} (mkg) required for dusting powders without tractor's running will be expressed in the following form.

$$T_{de}=\frac{2\pi\cdot Q\cdot\rho_o\cdot\mu_i\cdot r^2\cdot N_b\cdot 10^{-2}}{36\cdot g\cdot i_5\cdot i_6\cdot i_7\cdot i_8\cdot i_9\cdot i_{10}\cdot\eta_n\cdot\eta_5\cdot\eta_6\cdot\eta_7\cdot\eta_8\cdot\eta_9\cdot\eta_{10}}$$

$$=\frac{2\pi\cdot Q\cdot\rho_o\cdot\mu_i\cdot r^2\cdot N_e\cdot 10^{-2}}{36\cdot g(i_5\cdot i_6\cdot i_7\cdot i_8\cdot i_9\cdot i_{10})^2\cdot\eta_n\cdot\eta_5\cdot\eta_6\cdot\eta_7\cdot\eta_8\cdot\eta_9\cdot\eta_{10}} \quad\cdots\cdots(119)$$

where, ρ_o: density of atmosphere, 1.2 kg/m³ at 20°C, 760 mmkg, 75% humidity

μ_i: coefficient of friction of impeller that is expressed in the form:

$\mu_i=1-\frac{2}{Z}$ when Z is the number of the impeller blade, 16

r: outer dia. of impeller (m), 0.36

N_b: revolution per minute of blower (rpm)

g: acceleration due to gravity (m/sec²), 9.8

η_n: overall efficiency of blower which is the product of the frictional efficiency of impeller disc η_f (supposed value 0.99), the mechanical efficiency of blower η_m (supposed value 0.99), the volumetric efficiency of blower η_v (supposed value 0.98) and the total pressure efficiency of blower η_t (supposed value 0.84) i.e. 099×0.99×0.98×0.84=0.80

$i_6, i_7, i_8, i_9, i_{10}$: gear ratio of transmission gears of duster respectively i.e. 1.78, 0.526, 0.241, 0.454, 1 as shown in Table 13

$\eta_6, \eta_7, \eta_8, \eta_9, \eta_{10}$: mechanical efficiency of them i.e. supposed values 0.93, 0.94, 0.95, 0.95, 0.98 respectively

Then, the horsepower of tractor engine P_{de} (PS) required for dusting powder is

$$P_{de}=\frac{Q\cdot\rho_o\cdot\mu_i(2\pi\cdot r\cdot N_b)^2\cdot 10^{-3}}{216\cdot 75\cdot g\cdot\eta_n\cdot\eta_5\cdot\eta_6\cdot\eta_7\cdot\eta_8\cdot\eta_9\cdot\eta_{10}}$$

$$=\frac{Q\cdot\rho_o\cdot\mu_i(2\pi\cdot r\cdot N_e)^2\cdot 10^{-3}}{216\cdot 75\cdot g(i_5\cdot i_6\cdot i_7\cdot i_8\cdot i_9\cdot i_{10})^2\cdot\eta_n\cdot\eta_5\cdot\eta_7\cdot\eta_8\cdot\eta_9\cdot\eta_{10}} \quad\cdots\cdots(120)$$

The empirical values of T_{de} and P_{de} when dusting DESOLATE 50 weeding powder (manufactured by JAPAN CARLIT Co. LTD., chief ingredient $NaClO_3$, its content 50%, dia. 0.15~0.5 mm, specific gravity 1.36) without tractor's running are dotted in Fig. 65 and there the computed values approximated from formulae (119), (120) for them are drawn in full line. From the comparison between them it will be seen that the torque and horsepower for dusting by tractor-powered duster without tractor's running can be estimated from formulae (119), (120).

Furthermore, the same torque and horsepower of tractor engine as mentioned above, but when tractor is running on forest-land, can be expresssed in the form.

$$T_{dre}=\frac{\{(W_t+W_d)(f_t\cos\alpha+\sin\alpha)\}d}{2i_1\cdot i_2\cdot i_3\cdot\eta_1\cdot\eta_2\cdot\eta_4}$$

$$+\frac{2\pi\cdot Q\cdot\rho_o\cdot\mu_i\cdot r^2\cdot N_e\cdot 10^{-2}}{36\cdot g(i_5\cdot i_6\cdot i_7\cdot i_8\cdot i_9\cdot i_{10})^2\eta_n\cdot\eta_5\cdot\eta_6\cdot\eta_7\cdot\eta_8\cdot\eta_9\cdot\eta_{10}} \quad\cdots\cdots(121)$$

$$P_{dre}=\frac{\{(W_t+W_d)(f_t\cos\alpha+\sin\alpha)\}l\cdot n\cdot N_e}{75\cdot 60\cdot i_1\cdot i_2\cdot i_3\cdot\eta_1\cdot\eta_2\cdot\eta_3\cdot\eta_4}$$

*15 IGUCHI, I. *et al.*: Design of hydraulic machine, pp. 8~69, Tokyo, (1965).

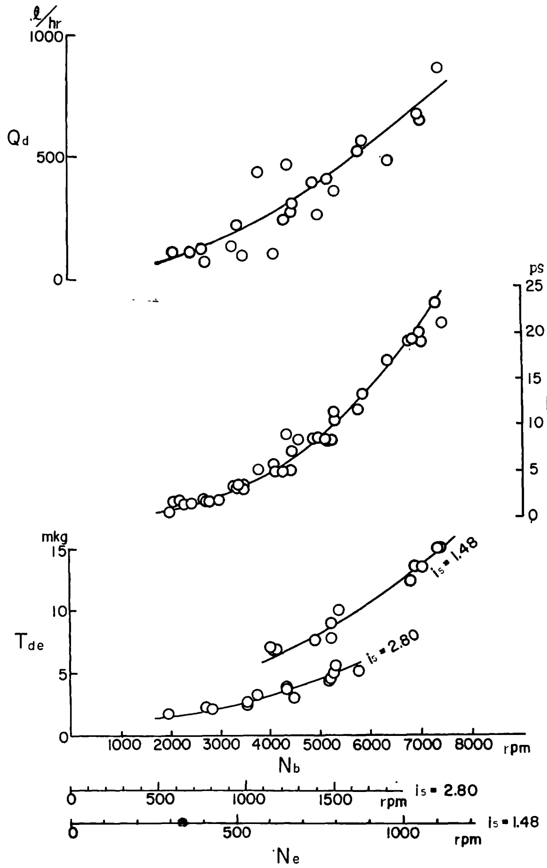


Fig. 65. Comparison between theoretical and empirical values of T_{de}, P_{de}

$$+\frac{Q\cdot\rho_o\cdot\mu_i(2\pi\cdot r\cdot N_e)^2\cdot 10^{-3}}{216\cdot 75\cdot g(i_5\cdot i_6\cdot i_7\cdot i_8\cdot i_9\cdot i_{10})^2\cdot\eta_n\cdot\eta_5\cdot\eta_6\cdot\eta_7\cdot\eta_8\cdot\eta_9\cdot\eta_{10}} \quad \cdots\cdots(122)$$

The empirical values of T_{dre} and P_{dre} are dotted in round mark and the computed values of them are drawn in full line as shown in Fig. 66. From the comparison between them, it will be seen that we can estimate the torque and horsepower for dusting by tractor-powered duster when tractor is running, by formulae (121), (122).

The powder-dusting volume per hour of this duster Q_d (l/hr) is given by the empirical formula based on the experiment (see Fig. 65, 66).

$$Q_d = 0.000225\, N_b^{1.688}$$
$$= 0.000225(N_e/i_5\cdot i_6\cdot i_7\cdot i_8\cdot i_9\cdot i_{10}\cdot)^{1.688} \quad \cdots\cdots(123)$$

It is needless to say that this formula can be applied for the powder-dusting of this duster both when the tractor runs and when it is stationary.

The range of the powder-dusting in windless condition will effectively reach from fifteen to twenty meters, and the grain-dusting (DESOLATE 50, dia. 0.84～2.38 mm, specific gravity 1.14) will be also similarly used for weeding operations with the help of this machine.

The volume of powder dusted per unit fuel consumption of the tractor-powered duster when

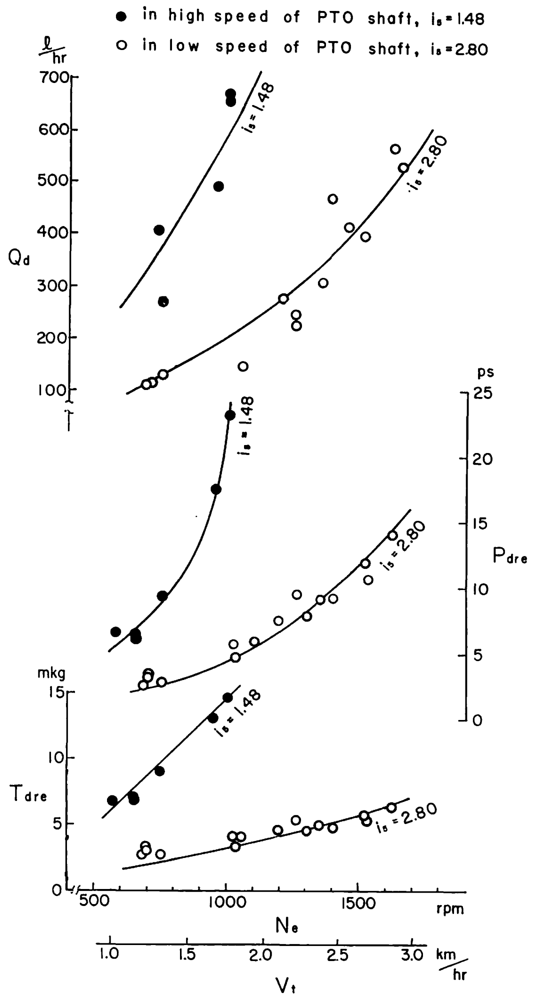


Fig. 66. Comparisn between theoretical and empirical values of T_{dre}, P_{dre}

tractor is stationary or when tractor is running a_{do} or a_d (l_{powder}/l_{fuel}) is given as a function of Q_d, f_b, ρ, P_{de} or P_{dre}

$$a_{do}=\frac{Q_d\cdot\rho}{f_b\cdot P_{de}}\cdot 10^3 \qquad \cdots\cdots(124)$$

$$a_d=\frac{Q_d\cdot\rho}{f_b\cdot P_{dre}}\cdot 10^3 \qquad \cdots\cdots(125)$$

where, Q_d from formula (123), f_b from formula (91), P_{de} from formula (120), P_{dre} from formula (122) are given.

Substituting formula (120) for P_{de} into formula (124), formula (122) for P_{dre} into formula (125), the following formulae are derived.

$$a_{do}=\frac{Q_d\cdot\rho\cdot 10^3}{f_b\left\{\frac{Q\cdot\rho_o\cdot\mu_i(2\pi\cdot r\cdot N_e)^2\cdot 10^{-3}}{216\ 75\cdot g(i_5\cdot i_6\ i_7\ i_8\ i_9\ i_{10})^2\cdot\eta_n\cdot\eta_5\cdot\eta_6\cdot\eta_7\cdot\eta_8\cdot\eta_9\cdot\eta_{10}}\right\}}\qquad\cdots\cdots(126)$$

$$a_d=\frac{Q_d\cdot\rho\ 10^3}{f_b\left\{\frac{(W_t+W_d)(f_t\cos\alpha+\sin\alpha)l\cdot n\cdot N_e}{75\cdot 60\ i_1\cdot i_2\cdot i_3\cdot\eta_1\cdot\eta_2\cdot\eta_3\cdot\eta_4}\right.*}$$

$$\frac{*}{\left.+\frac{Q\cdot\rho_o\ \mu_i(2\pi\cdot r\cdot N_e)^2\cdot 10^{-3}}{216\cdot 75\ g(i_5\ i_6\ i_7\ i_8\cdot i_9\cdot i_{10})^2\ \eta_n\cdot\eta_5\cdot\eta_6\cdot\eta_7\cdot\eta_8\cdot\eta_9\cdot\eta_{10}}\right\}}\qquad\cdots\cdots(127)$$

The empirical values of a_d with regard to the engine speed or the running speed of the tractor-powered duster are dotted in round points and the theoretical values of a_{do}, a_d computed from formulae (126), (127) respectively are drawn in broken and solid lines as shown in Fig. 67.

From these comparative studies, it may be said that these theoretical formulae are generally used for the estimation of fuel consumption of tractor-powered duster.

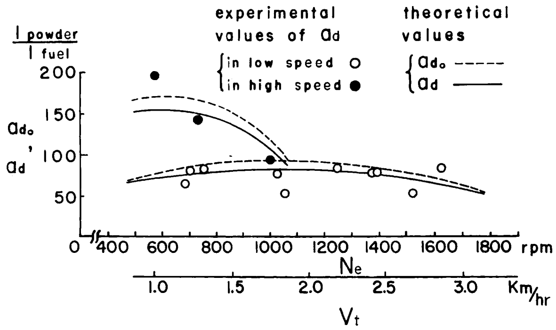


Fig. 67. Comparison between theoretical and empirical values of a_{do}, a_d

8. Overall operational efficiency of tractor reforestation operation

8.1 Overall operational efficiency of combined operations using a tractor and some attached reforestation machineries

On the assumption that the reforestation works are done on the forest-land with about ten degree slope-grade to plant 2,500 seedlings per hectare in 2.5 m planting row interval and 1.6 m seedling interval soon after land-preparation, and to weed once a year for five years after the tree plantation and that the operational efficiency of each operation by a tractor attached machinery is based on the result mentioned above in each chapter, the overall operational efficiency of combined operation using a tractor and some attached reforestation machineries will be estimated as follows.

Let us suppose that the tractor operation is done during the three seasons from April to December, that is 270 working days and $270\times 0.65=175$ net working days and $175\times 8\times 0.6=840$ net working hours a year, and that the unit cost of consumed materials for mechanized operation is as follows: sheet cover ¥ 10,000, light oil ¥ 32/l, gasoline ¥ 47/l, gear lubricating oil ¥ 100/l, turbine lubricating oil ¥ 72.3/l, grease ¥ 200/kg, chain lubricating oil ¥ 100/l, saw chain ¥ 7,000 (life 300 hrs), circular saw ¥ 1,000, and the price of machines is shown in Table 14.

On this supposition, the machine cost per net operating hour in each machinery C_m will be computed by the following formula.

$$C_{ml}=C_c+C_s+C_r+C_f+C_o+C_i$$
$$=\frac{C_p}{M_l}+C_s+C_c\cdot r_r+C_f+C_o+C_i \quad \cdots\cdots(128)$$

where, C_c: depreciation cost per hour (¥/hr) C_p: purchase price (¥)
M_l: machine lifetime (hr) C_s: management cost per hour (¥/hr)
C_r: repairs cost per hour (¥/hr) r_r: repairs ratio to depreciation cost
C_f: fuel oil cost per hour (¥/hr) C_o: lubricating oil cost per hour (¥/hr)
C_i: interest, insurance premium, tax etc. per hour (¥/hr), (neglected in this case)

Therefore, the estimation of total cost per hectare, total number of workers per hectare and so on in which each mechanized operation utilizes a tractor and some attached machineries can be compared with that of one-man portable machine operation as given in Table 14. Where, except the operation of putting the seedling in the planting hole dug by the mechanized method, all other operations are done by the mechanized method in every case mentioned above. And it is needless to say that the tractor operation is controlled by one operator, and the one-man portable machine team operation is controlled by a group of operators including a leader and assistant operators.

8.2 How many tractors and their attached machinery are required for reforestation works in a given planting area

When we have the question: How many tractors and their attached machinery are required for the reforestation works in a given planting area within a given period of time, it will be desirable for us to see the simple formulae answering the question.

The area in which a kind of mechanized operation using a tractor having attached reforestation machinery can be done in a year A_i (ha) will be given as a function of the net working days during the suitable time Y_i (day), the net working hour per day t_n (hr) and the operational efficiency H_i (hr/ha).

$$A_i=\frac{Y_i\cdot t_n}{H_i} \quad \cdots\cdots(129)$$

Where, in A_i, Y_i and H_i, $i=1$, 2, 3, 4 and 5 means a tractor's single operation using a stump cutter for chipping stumps ($i=1$), a rake dozer for collecting slashed brushes ($i=2$), a rotary cutter for land-clearing ($i=3$), an earth auger for digging planting-hole ($i=4$) and a rotary cutter for weeding ($i=5$). t_n is 8.0 hr × 0.6 = 4.8 hr in general.

Then, the area in which the tractor's combined operation is done for reforestation works with the help of a tractor and some attached machinery in a year A (ha), needs to be less than or equal to the area of which the tractor's single operation with machinery attachments, each of which can be done within the suitable period of time, A_1, A_2, A_3, A_4, A_5, ……; because each mechanized operation using the different kind of attached machinery must be done in the same place alternately within a year. Furthermore, the total net working days of each single operation of them in the same place for a year $\frac{A\sum_{i=\text{some}} H_i}{t_n}$ (day) needs to be less than or equal to the working days on which the tractor operation in general can be done in that place for a year Y (day).

$$\left.\begin{array}{l} A\leqq A_1,\ A_2,\ A_3,\ A_4 \text{ or } A_5\cdots\cdots \\ \dfrac{A\sum_{i=\text{some}} H_i}{t_n}\leqq Y \quad \therefore A\leqq\dfrac{Y\cdot t_n}{\sum_{i=\text{some}} H_i} \end{array}\right\} \quad \cdots\cdots(130)$$

Now, the number of tractors n_t required for the reforestation work in a given planting area

Table 14

Mechanized operation		Kind of machines	Machine cost per hour									
			Cost per hour	Distribution ratio						Remarks		
				Depre-ciation cost	Garag-ing cost	Repair cost	Fuel cost	Lubri-cants cost	Others	Lifetime of machine	Cost of repair per operating hour expressed as a fraction of the depreciation per operating hour	Purchase price
			Yen/hr							hr		Yen
Tractor operation	I	Stump cutter	1,479.5	0.472	0.015	0.398	0.085	0.030		4,500 (tractor 7,500)	0.7 (tractor 0.9)	1,500,000 (tractor 2,980,000)
	I	Rotary cutter (mechanical type)	1,090.2	0.443	0.022	0.384	0.115	0.036		3,000 (tractor 7,500)	0.7 (tractor 0.9)	260,000 (tractor 2,980,000)
	I	Earth auger (mechanical type)	1,093.8	0.438	0.029	0.380	0.114	0.038		3,000 (tractor 7,500)	0.7 (tractor 0.9)	250,000 (tractor 2,980,000)
	II	Rake dozer	929.5	0.427	0.013	0.384	0.135	0.041		7,500 (with tractor)	0.9	2,980,000 (with tractor)
	II	Rotary cutter	1,090.2	0.443	0.022	0.384	0.115	0.036		3,000 (tractor 7,500)	0.7 (tractor 0.9)	260,000 (tractor 2,980,000)
	II	Rebuilt culti-auger (hydraulic type)	1,320.0	0.469	0.015	0.388	0.095	0.033		4,500 (tractor 7,500)	0.7 (tractor 0.9)	1,000,000 (tractor 2,980,000)
	III	Rake dozer	929.5	0.427	0.013	0.384	0.135	0.041		7,500 (with tractor)	0.9	2,980,000 (with tractor)
	III	Rotary cutter (mechanical type)	1,090.2	0.443	0.022	0.384	0.115	0.036		3,000 (tractor 7,500)	0.7 (tractor 0.9)	260,000 (tractor 2,980,000)
	III	Earth auger (mechanical type)	1,093.8	0.438	0.029	0.380	0.114	0.038		3,000 (tractor 7,500)	0.7 (tractor 0.9)	250,000 (tractor 2,980,000)
One-man portable machine operation		One-man brush cutter	145.2	0.395		0.237	0.261	0.008	0.099	1,500	0.6	51,000
		One-man earth auger	91.1	0.395		0.237	0.209	0.005	0.154	1,500	0.6	54,000

Table 14 (continued)

Mechanized operation		Kind of machines	Operational efficiency	Machine cost per hectare	Wages paid per hectare		Total cost per hectare	Total cost per hectare of tractor operation expressed as a fraction of that of one-man portable machine operation	Total number of workers per hectare	Total number of workers per hectare of tractor operation as a fraction of that of one-man portable machine operation
					Number of workers per hectare	Wages paid per hectare				
			hr/ha	Yen/ha	Men/ha	Yen/ha	Yen/ha		Men/ha	
Tractor operation	I	Stump cutter	33.5	49,560	7.0	7,000	83,000	1.94	11.3	0.37
		Rotary cutter (mechanical type)	land clearing 3.75 weeding 3.23	4,090 3,520	0.8 0.7	800 700				
		Earth auger (mechanical type)	13.30	14,550	2.8	2,800				
	II	Rake dozer	5.25	4,880	1.1	1,100	40,600	0.95	6.1	0.20
		Rotary cutter	land clearing 3.75 weeding 3.23	4,090 3,520	0.8 0.7	800 700				
		Rebuilt culti-auger (hydraulic type)	16.70	22,040	3.5	3,500				
	III	Rake dozer	5.25	4,880	1.1	1,100	32,400	0.76	5.4	0.18
		Rotary cutter (mechanical type)	land clearing 3.75 weeding 3.23	4,090 3,520	0.8 0.7	800 700				
		Earth auger (mechanical type)	13.30	14,550	2.8	2,800				
One-man portable machine operation		One-man brush cutter	land clearing 43.5 weeding 22.4	6,320 3,250	16.9 6.7	16,900 6,700	42,700	1.00	30.7	1.00
		One-man earth auger	26.7	2,430	7.1	7,100				

X (ha) for the planned period of time E (year) is given in the following form.

$$n_t \geqq \frac{X}{E \cdot A} \left(= \frac{X \sum\limits_{i=\text{some}} H_i}{E \cdot Y \cdot t_n} \right) \cdots\cdots (131)$$

Secondly, the number of reforestation machinery attachments of the same kind required for the reforestation work in that case n_{ai} is given by

$$n_{ai} \geqq \frac{X}{E \cdot A_i} \left(= \frac{X H_i}{E \cdot Y \cdot t_n} \right) \cdots\cdots (132)$$

in the case of the tractor's single operation mentioned above.

When there are overlapping days Y_p (day) in the suitable period of time for two kinds of tractor mechanized operations Y_m, Y_n (day), the number of their attached machinery n_{am}, n_{an} are given by

in the case of $\frac{X H_m}{E \cdot t \cdot n_t} \leqq Y_m - Y_p$

$$\left. \begin{aligned} n_{am} &\geqq \frac{X}{E \cdot A_m} \\ n_{an} &\geqq \frac{X}{E \cdot A_n} \end{aligned} \right\} \cdots\cdots (133)$$

in the case of $\frac{X \cdot H_m}{E \cdot t \cdot n_t} > Y_m - Y_p$

$$\left. \begin{aligned} n_{am} &\geqq \frac{X}{E \cdot A_m} \\ n_{an} &\geqq \frac{X}{\frac{E \cdot t}{H_n} \left\{ \left(Y_m - \frac{X \cdot H_m}{E \cdot t \cdot n_t} \right) + (Y_m - Y_p) \right\}} \end{aligned} \right\} \cdots\cdots (134)$$

When there are no overlapping days Y_p (day) in the suitable period of time for two kinds of tractor mechanized operations Y_m, Y_n (day) using the same attached machinery, the number of that n_{am} or n_{an} is given by

$$\left. \begin{aligned} &\text{in the case of } A_m < A_n \\ &\quad n_{am} \text{ or } n_{an} \geqq \frac{X}{E \cdot A_m} \\ &\text{in the case of } A_m > A_n \\ &\quad n_{am} \text{ or } n_{an} \geqq \frac{X}{E \cdot A_n} \end{aligned} \right\} \cdots\cdots (135)$$

The nomogram for formulae (131), (132) is shown in Fig. 68.

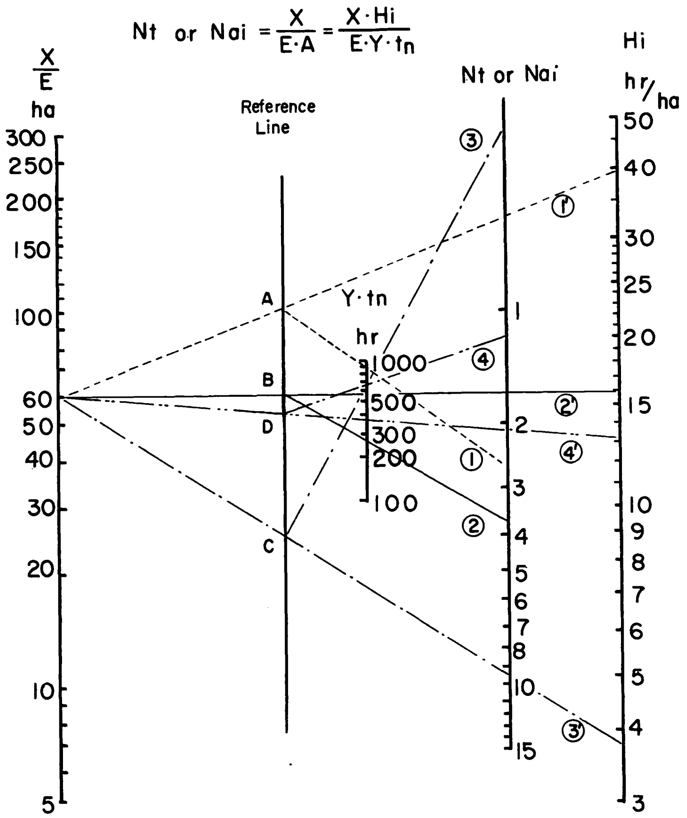


Fig. 68. Nomogram used for determining numbers of tractors and their attached machinery required for reforestation works in a given planting area

The use of nomogram

How many tractors and their attached reforestation machinery should you require to do the reforestation works in a given planting area of 600 ha within a given period of 10 yrs?

The supposition for this calculation are as follows: a) The mechanized reforestation works can be done with the use of some tractors, rake dozers for collecting slashed brush, rotary cutters for land-clearing and weeding operations and earth augers for drilling earth to make the planting holes. b) The new planting area in a year $\frac{X}{E}$ is 60 ha, and the weeding operations will be done for five years after the tree-plantation and more the weeding area from the time when five years passed after the biginning of tree-plantation will be 300 ha. c) The operational efficiency, suitable time, actual working day and hour in a year of the attached reforestation machineries for each reforestation work are shown in the following table, based on the results obtained from the above field experiments.

Kinds of mechanized operation	Land-clearing	Collecting slashed brush	Drilling earth to make the planting hole	Weeding
Kind of usable attached reforestation machineries	Rotary cutter	Rake dozer	Earth auger	Rotary cutter
Operational efficincy	3.75 hr/ha	5.25 hr/ha	13.3 hr/ha	3.23 hr/ha
Suitable time of operation	from Aug. to Dec. in the year just after the logging operation. from Apr. to May in the first year of tree-plantation.			from Jun. to Aug.
Net working days in a year	136 day			59 day
Net working hours in a year	653 hr			283 hr
Total practicable hours for tractor operation throughout the year	9 month × 30 day × 0.65 as a fraction of working days in a month × 4.8 hr ≒ 840 hr			

Solution 1 (the number of tractors)

a) Connect $\frac{X}{E}=60$ ha and $H_i=3.75+5.25+13.3+3.23\times5=38.45$ hr/ha as shown in the line ①′. Secondly, connect the intersection point A on the reference line and $Y\cdot t_n=840$ hr as shown in the line ①. So, we can see the number of tractors $N_t=2.7\doteqdot3$.

b) To check the number of tractors required for the weeding operations within the limit of suitable time, connect $\frac{X}{E}=60$ ha and $H_i=3.23\times5=16.15$ hr/ha as shown in the line ②′, the intersection point B on the reference line and $Y\cdot t_n=283$ hr as shown in the line ②. So, we can see the number of tractors $N_t=3.2\doteqdot4$. Therefore, it is better for us to take the number of tractor $N_t=4$ for these reforestation works.

Solution 2 (the number of rotary cutters)

a) To see the number of rotary cutters required for the land-clearing operations, connecting $\frac{X}{E}=60$ ha and $H_i=3.75$ hr/ha (the line ③′), the intersection point C on the reference line and $Y\cdot t_n=653$ hr (the line ③), we can see the number of rotary cutters for the land-clearing operations $N_{ai}=0.3\doteqdot1$.

b) To see the number of rotary cutters required for the weeding operations, connecting $\frac{X}{E}=60$ ha and $H_i=3.23\times5=16.15$ hr/ha (the line ②′), the intersection point B and $Y\cdot t_n=283$ hr (the line ②), just like in Solution 1-b, we can see the number of rotary cutters required for the weeding operations $N_{ai}=3.2\doteqdot4$.

Therefore it is better for us to take the number of rotary cutters $N_{ai}=4$ for the land-clearing and weeding operations.

Solution 3 (the number of earth augers)

Corresponding to Solution 1, 2, from $\frac{X}{E}=60$ ha, $H_i=13.3$ hr/ha, the intersection point D and $Y\cdot t_n=653$ hr (the line ④′, ④), we can see the number of earth augers $N_{ai}=1.3\doteqdot2$ required for these reforestation works.

Example 1

On the assumption that the suitable period of time for each operation is $Y_1=270\times0.65=175$ days in stump-cutting operation, $Y_2=210\times0.65=136$ days in slashed brush-collecting operation, $Y_3=210\times0.65=136$ days in land-clearing operation, $Y_4=210\times0.65=136$ days in planting-hole digging operation, $Y_5=90\times0.65=59$ days in weeding operation, the A_i of each mechanized operation will be obtained from formula (129), as shown in Table 15.

Table 15.

Kind of operation	Cutting stump	Collecting slashed brush	Land-clearing		Making planting-hole		Weeding	
Kind of attached reforestation machine	Stump cutter	Rake dozer	Rotary cutter		Earth auger		Rotary cutter	
			Mechanical type	Hydraulic type	Mechanical type	Hydraulic type	Mechanical type	Hydraulic type
H_i mentioned in above chapter hr/ha	33.5	5.25	3.75	3.75	13.3	16.7	3.23	3.23
A_i ha	25.1	125	175	175	49.3	38.2	86.9	86.9

Example 2

When the reforestation works with the help of the tractor's combined operations using rake dozers for collecting slashed shrubs, mechanical or hydraulic rotary cutters for land-clearing, mechanical or hydraulic earth augers for digging planting-hole and mechanical or hydraulic rotary cutters for weeding, would be done in a given planting area of 600 or 1,000 ha for the planned period of 5 or 10 years, the number of tractors and their required machinery attachments, the operational costs and the overall efficiency compared with those of one-man portable machine operation can be obtained from formulae (128), (131～135) and other results mentioned in the foregoing chapter, as shown in Table 16.

Table 16.

Kind of mechanized operation			Tractor combined operation using rake dozer, mechanical rotary cutter and mechanical earth auger				Tractor combined operation using rake dozer, hydraulic rotary cutter and hydraulic earth auger			
Planting area			600 ha		1,000 ha		600 ha		1,000 ha	
Period in years			10 yrs	5 yrs	10 yrs	5 yrs	10 yrs	5 yrs	10 yrs	5 yrs
Total operating days per year in each operation		Collecting slashed brushes	66 days	131 days	109 days	218 days	66 days	132 days	109 days	218 days
		Land-clearing	47	94	78	156	47	94	78	156
		Making planting-hole	166	334	277	554	209	418	348	696
		Weeding	202	404	336	672	202	404	336	672
Number of tractors and attached machineries		Tractor	4	7	6	12	4	7	6	12
		Rake dozer	1	2	1	2	1	2	1	2
		Rotary cutter	4	7	6	12	4	7	6	12
		Earth auger	2	3	3	5	2	4	3	6
Cost	Tractor operation	Total machine purchasing cost	Yen 13,960,000	Yen 23,430,001	Yen 20,190,000	Yen 40,130,000	Yen 16,228,000	Yen 28,476,000	Yen 24,342,000	Yen 48,684,000
		Annual interest (6%)*	419,000	703,000	606,000	1,404,000	487,000	854,000	730,000	1,461,000
		Annual cost**	3,378,000	6,621,000	5,537,000	10,868,000	4,148,000	8,177,000	6,833,000	13,663,000
	One-man portable machine operation	Total machine purchasing cost	Yen 1,332,000	Yen 2,664,000	Yen 2,307,000	Yen 4,509,000	Yen 1,332,000	Yen 2,664,000	Yen 2,307,000	Yen 4,509,000
		Annual interest (6%)*	40,000	80,000	69,000	136,000	40,000	80,000	69,000	130,000
		Annual cost**	4,989,000	9,834,000	8,379,000	16,635,000	4,909,000	9,834,000	8,319,000	16,635,000
	Ratio of tractor operation and one-man machine operation		0.68	0.67	0.68	0.68	0.83	0.83	0.82	0.82
Labour	Total number of operating workers per year	Tractor operation	Man-day 492	Man-day 984	Man-day 820	Man-day 1,640	Man-day 534	Man-day 1,068	Man-day 890	Man-day 1,780
		One-man machine operation	3,450	6,900	5,750	11,500	3,450	6,900	5,750	11,500
	Ratio of tractor operation and one-man machine operation		0.14	0.14	0.14	0.14	0.155	0.155	0.155	0.155

* $\frac{\text{Purchasing cost}}{2} \times 0.06$

** Including the depreciation cost, repair cost, fuel and lubricants cost, wages shown in Table 4 and annual interest.

Summary

The fundamental performances of tractor-powered reforestation machinery, newly or for the first time used for the reforestation works in artificial forest-land with slopes common to this country, which had not been consistently studied from the standpoint of the forestry machine research, were inclusively investigated with the help of original methods and equipment for field-experiments, are summarized as follows:

1. The adhesion of the crawler tractor on inclined forest-land can be considered as of two kinds: apparent, and real adhesion. The relations between the coefficients of apparent and real adhesion and the slope-grade of forest-land of humus soil were given by the form shown in the empirical formulae (1) (see Fig. 4) and Fig. 5. It is important to distinguish the maximun values from the average values of them as shown in the above-mentioned results, and the average real adhesion gives the most reasonable value among them.

2. The coefficients of running resistance of crawler tractor on forest-land of various surface conditions i.e. covered with slashed branches, bamboo-grass, and of black soil, were expressed in the empirical formulae (4), (5), (6) respectively being a function of the actual speed of tractor, as shown in Fig. 6. It can be seen that the running resistance force of crawler tractor on bamboo-grass or slashed branches takes about 1.7 or 2.2 times of that on black soil.

3. The slip of the crawler tractor running on inclined forest-land covered with bamboo-grass and others, from $-20°$ to $20°$ slope-grade, was obtained as a cubic expression relating to the slope-grade, as shown in the empirical formula (9) (see Fig. 7). The slip of that becomes smaller and less than 0% when the slope-grade is a little more than or less than $0°$, because it is found that the gap between the grousers and the surface of forest-land covered with bamboo-grass and others increases the effective diameter of the sprocket a little more than that of given.

4. The horsepower of the crawler tractor travelling straight on inclined forest-land could be written in the theoretical formula (17) and was verified by the results obtained from the field-experiments, as shown in Fig. 8-b.

5. The horsepower of the crawler tractor turning any course on inclined forest-land could be originally deduced in the theoretical formula (33), shown in Fig. 12, 13, as the result of the author's extensive investigation from the theory given by ZASLAVSKI and BEKKER, M.G. about the turning on level-land and his field-experiments.

6. The horsepower of the crawler tractor climbing up and passing over a stump on forest-land could be given by the theoretical formulae (38), (36); (43), (41) respectively. The torque of them could be similarly written in the theoretical formulae (37), (36); (42), (41) which were checked by the empirical values recorded on the oscillograph paper obtained from the field-experiments (see Fig. 18).

7. The mechanical efficiency of PTO shaft mounted on test crawler tractor under vairous loads was successfully measured, as shown in Fig. 19 and it provided the author an opportunity to estimate the other mechanical efficiencies of test tractor and attached machineries in accordance with the kind and number of gears as compared with this.

8. The mechanism of cutting stump by the tractor-powered mechanical drive type stump cutter was studied at first, and as a result of it, the horsepower of tractor-powered mechanical drive type stump cutter when cutting stump could be deduced in the theoretical formulae (52), (55), which was checked by the empirical values obtained from the field-experiment, as shown in Fig. 26.

9. The horsepower when cutting stump of tractor-powered hydraulic drive type stump cutter manufactured on trial for forestry use under the author's supervision, was similarly given by the theoretical formula (65), which was checked by the empirical values as the same of above (Fig.29). Then, the theoretical formula to estimate the fuel consumption rate of this reforestation machine when cutting stump was expressed in the formula (67) and it was also verified by the empirical values obtained from the field-experiments, as shown in Fig. 30.

10. The operational efficiency of the tractor-powered mechanical drive type stump cutter operation was studied on inclined forest-land and it was given by the empirical formulae (71) (see Fig. 33) —(68), (69), Table 4 (see Fig. 31); (70) (see Fig. 32); Table 5. In contrast to it, the operational efficiency of a one-man chain saw operation when cutting stump to be lowered to less than from ten to fifteen centimeters of the remaining height, was also studied and it was similarly given by the empirical formulae (73)—(72) (see Fig. 34). The remaining height of stump cut by a chain saw when land-clearing and that just after felling tree was comparatively surveyed, as shown in Fig. 36, 35. The results of the above-mentioned presents important information for us in solving the difficult problem that stumps as obstacles pose in the tractor's running on forest-land for reforestation works.

11. The coefficient of pulling resistance of rotary cutter was successfully measured, as shown in the empirical formula (74) (see Fig. 39).

The cutting resistance force of rotary cutter-blade under various loads was computed from the results of the field-experiments, which was written in the empirical formula (76), relating to the revolving or peripheral speed of rotary cutter-blade, as shown in Fig. 40, Table 7. It can be seen that the resistance force of rotary cutter-blade changes according to the kind of objects to be cleared i.e. shrub > bamboo-grass of high density > bamboo-grass of medium density > grass.

12. The horsepower of tractor-powered mechanical drive type rotary cutter when cutting brush could be written in the theoretical formulae (89), (90), which was substantiated by the empirical values obtained from the field-experiments, as shown in Fig. 42. The fuel consumption rate of this machine when cutting brush could be deduced in the theoretical formulae (94), (95), which was checked by the epmirical values obtained from the field-experiments, as shown in Fig. 44.

The brush-cutting quality of rotary cutter was examined and its index was given by the remaining height of objects to be cleared, which was expressed in the empirical formula (96), relating to the speed of rotary cutter-blade, as shown in Fig. 45.

13. The horsepower expended when cutting brush of the tractor-powered hydraulic drive type rotary cutter which was manufactured on trial for forestry use under the supervision of the author, could be similarly written in the theoretical formulae (100), (101), which gave the values close to those obtained from the measurement of the field-experiments, as shown in Fig. 47.

14. The operational efficiency of the tractor-powered mechanical drive type rotary cutter operation was studied in comparison with that of the one-man brush cutter team-operation. The results obtained from the studies were given by the empirical formulae (102), (103) respectively and Table 9.

The land-clearing area per man-day done with those mechanized operations were written in the empirical formulae (104), (105) respectively and Table 10. Then, the operational method of those mechanized operations was precisely surveyed in comparison as shown in Fig. 48, 49.

15. The resistance force of auger blade equipped with the tractor-powered earth auger when drilling earth, was given by the empirical formula (108) and Table 12, relating to the speed of the penetration and that of the revolution for auger-blade (see Fig. 52), on the basis of the results

obtained from the experimental study on one-man earth auger done by the author in 1962 (see reference 31).

16. The horsepower of the tractor-powered mechanical drive type earth auger when drilling earth, could be written in the theoretical formula (110), by which the computed values were compared with dotted points of empirical values obtained from the field-experiment under various conditions of forest-land, as shown in Fig. 53.

17. The horsepower of the tractor-powered hydraulic drive type earth auger manufactured on trial for forestry use under the author's supervision, when drilling earth, could be similarly written in the theoretical formula (113), which was checked by the empirical values obtained from the field-experiments, as shown in Fig. 55.

18. The operational efficiency of the tractor-powered earth auger operation was studied, and both types of earth auger compared. The results obtained were expressed in the empirical formulae (118)—(114) (see Fig. 56, 57); (115) (see Fig. 58, 59); (116) (see Fig. 60), (117) (see Fig. 61), and also were rewritten in the form relating to the hectare of planting area, as shown in Fig. 62.

19. The horsepower of the tractor-powered duster which was manufactured on trial for forestry use under the supervision of the author, when dusting powder or small grain chemicals, could be deduced in the theoretical formula (122), which was substantiated by the empirical values obtained from the field-experiments, as shown in Fig. 66.

20. The powder dusting volume per hour of this machine was given by the empirical formula (123) (see Fig. 65, 66). The fuel consumtion rate of this machine could be deduced in theoretical formula (126), (127), by which the computed values were testified by the empirical values obtained from the measurement in the field, as shown in Fig. 67.

21. The overall operational efficiency of the new combined mechanized operations using either a tractor and some attached reforestation machinery, or some tractors and some reforestation machinery attachments and their cost etc., were estimated as an application of the fundamental study on the forestry machines mentioned above to the actual forestry techniques, in contrast with those of one-man portable machine team operations using several brush cutters and earth augers, broadly used now in this country, as shown in Table 14, 16.

22. Furthermore, the formulae (128) to solve the machine cost per net operating hour, (129) to solve the area of which a kind of mechanized operation using a tractor with reforestation machinery attachments can be done in a year (ha) as shown in Table 15—the operational efficiency of that (hr/ha) is added—, (130) to solve the area of which the tractor combined mechanized operation using a tractor and some attached reforestation machinery in a year (ha), (131) to solve the number of tractors required for the reforestation work in a given planting area, (132) to solve the number of reforestation machinery attachments required for the same mentioned above,—nomogram for formulae (131), (132) shown in Fig. 68—, (133), (134) to solve the number of tractors and reforestation machinery attachments when there are overlapping days between the suitable times for two kinds of tractor mechanized operations, (135) to solve them when there are no overlapping days between the suitable times for the same mentioned above, and examples, are presented to give the approximate solution to how many tractors and their attached reforestation machinery required for reforestation works in a given planting area, as an application of this investigation.

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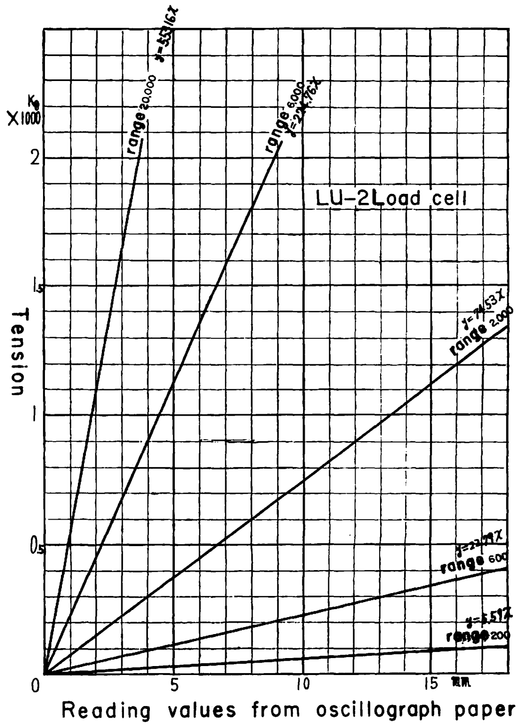
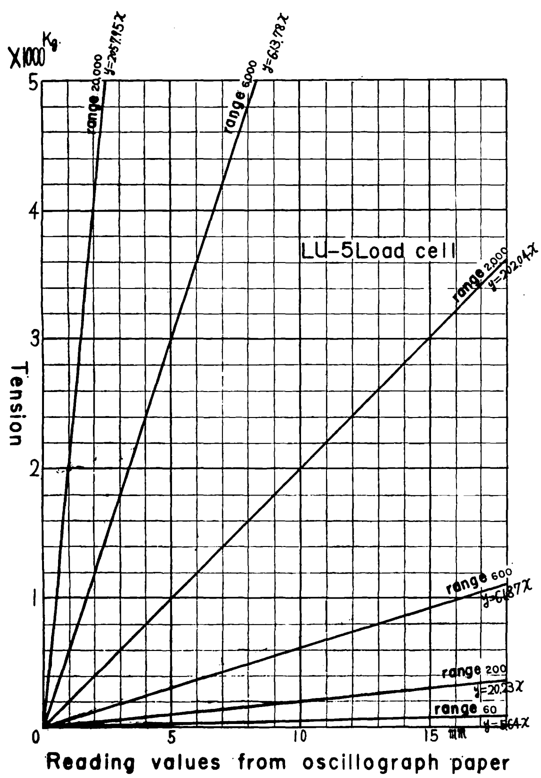


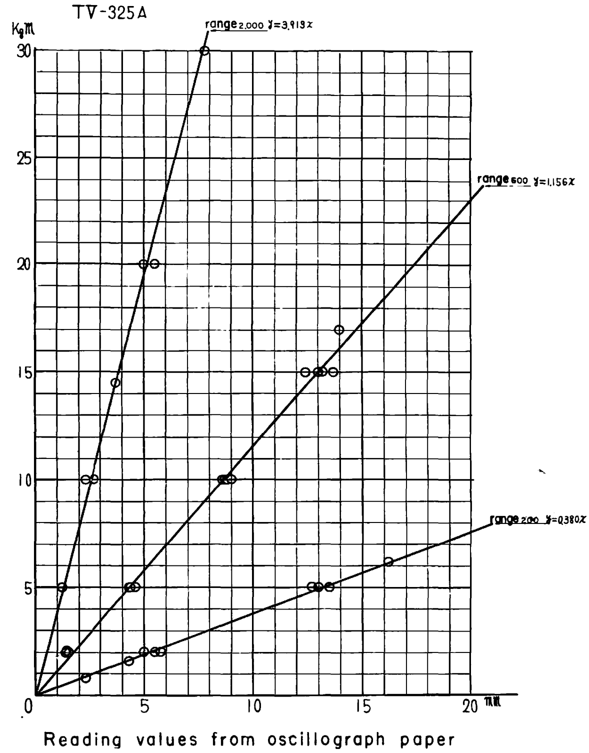
Appendix 1.

A check-result of 2 ton load cell connected to the dynamic strain meter and ink-writing oscillograph at the field-experiment checked by the portable mechanical tension and compression tester as shown in Fig. 3.

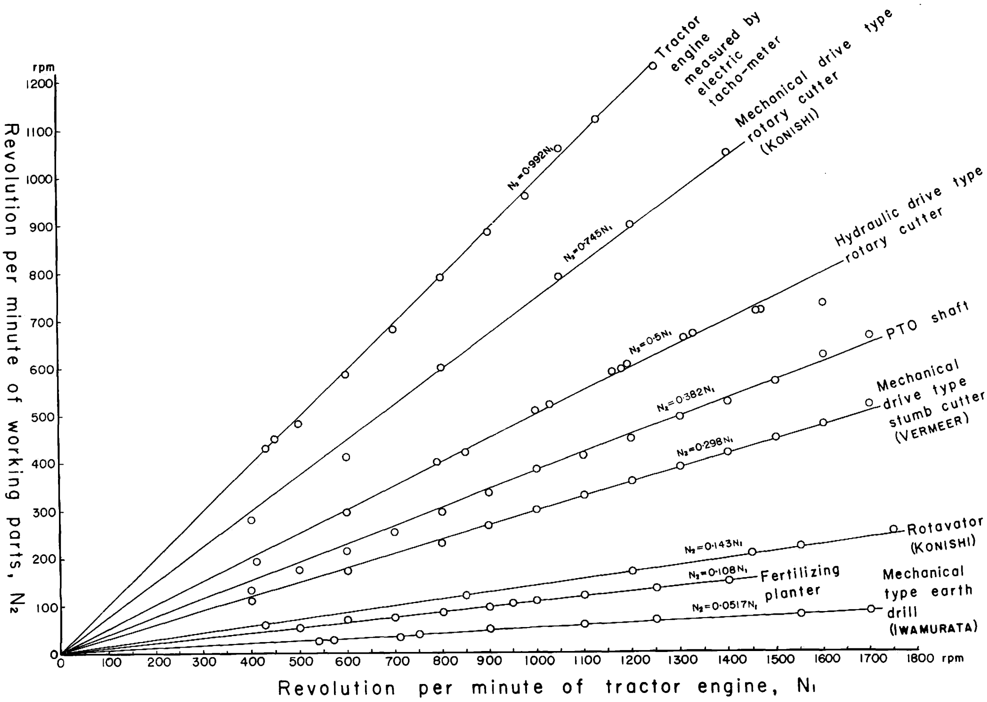


Appendix 2.

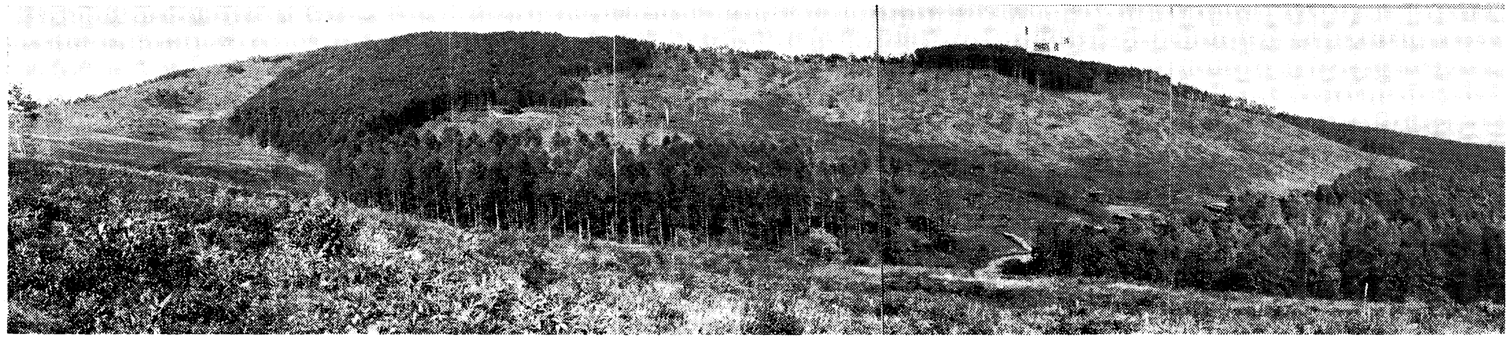
The same of 5 ton load cell.



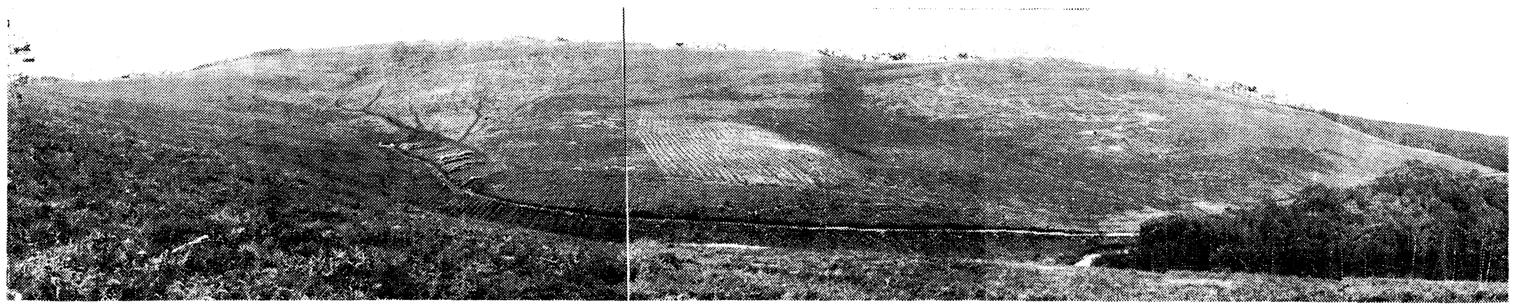
Appendix 3.
The same of 30 mkg torque pick-up, checked by the portable mechanical torque tester as shown in literature (31), p. 91.



Appendix 4. Comparison between revolution per minute of working parts in various reforestation machineries and that of tractor engine checked by the mechanical tachometer.



Appendix 5. AGATSUMAYAMA national forest, in August 1965, with from five to twenty-eight degree slope-grade, where fulltrees of fifty-year-old Japanese larch were skidded with the help of a crawler tractor with a sulky (31.17ha).



Appendix 6. AGATSUMAYAMA national forest in August 1966, where tree seedlings of Japanese larch has been planted with 2.5m interval of planting rows, after land-clearing, slashed brushes-collecting and plantation holedigging done by tractor-powered reforestation machineries.

人工林地帯におけるトラクタ育林機械の動力性能および作業性能に関する実験的研究

摘　　　　要

山　脇　三　平[1]

本州地方カラマツ人工林を主とする森林地帯において，トラクタ集材を実行した伐採跡地の再造林に，おなじくトラクタおよび同付属育林作業機を使用して育林作業を実行することにより，林業労働人口の減少に対処して労働生産性の画期的な向上をはかろうとするあたらしい機械化技術が台頭しつつある。この種の新機械化技術は，わが国の林業のみならず緩傾斜な森林地帯の多い海外の林業先進国とみなされる国々の林業においては，大いにその将来を期待されているものである。

この研究は，この新機械化技術に関して，造林学ほか林学生物系諸学および同技術の考え方をふまえつつ，林業機械の基本性能の面から科学的考察をくわえ，その可能性に厳密な検討をくわえるためとくに実施したものである。すなわち，このためとくにあたらしく考案試作したトラクタ育林作業機数種をふくめたトラクタ育林機械各機種の実機について，とくに筆者が考案せる計測装置，計測車および実験用として特殊改造せるトラクタ等をもちいて，実際森林地帯における各種条件下のトラクタ育林機械の動力性能および作業性能に関する実験計測をおこなうとともに，独自に解析せるトラクタ育林機械動力性能理論式の実験値との照合をおこない，それらの林業機械としての基本性能を明白ならしめた。さらにトラクタ育林機械作業性能実験式の作製をおこない，作業機各機の組み合わせ使用による総合作業性能の推定を容易ならしめた。またこの種の新機械化技術の可能性に関し，作業性能および費用の面からの比較推定を例示した。なおこれらの研究結果から現在すでに技術的に実行可能とみとめられるトラクタ育林機械化方式に対しては，与えられた造林予定地で与えられた期限内に再造林を実施する場合に適用できるトラクタおよび同付属育林作業機の選択使用計画に役だつ式・図表等を例示した。これらによりトラクタ育林機械の林業機械としての基本性能の理論的系統的はあくを明確ならしめるとともに，これらの実験的基礎研究結果の現在および将来の実際林業技術への応用も可能ならしめているものである。

この研究の範囲の概要は，つぎの目次にしめされるとおりである。

目　　　　次

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(1)　機械化部機械科長

このうち，独自に実験計測した実験値により照合検討されたおもな解析結果をしめせば，つぎのとおりである。

1.　クローラトラクタの林地傾斜面における粘着係数

$$\left.\begin{aligned}\mu_{a}'_{max} &= (0.968-1.617\times10^{-2}\alpha+7.322\times10^{-4}\alpha^{2})\cos\alpha+\sin\alpha \\ \mu_{a}'_{mean} &= 0.678\cos\alpha-\sin\alpha\end{aligned}\right\}\quad\cdots\cdots\cdots\cdots(1)$$

ここで，　μ_a': クローラトラクタの傾斜せる林地における見掛けの粘着係数，$=\frac{F_t}{W_t}$

F_t: クローラトラクタのけん引力，kg

W_t: クローラトラクタの装備重量，kg

α: 傾斜せる林地の勾配，°

$\mu_a'{}_{max}$: 同上見掛けの粘着係数最大値

$\mu_a'{}_{mean}$: 同上見掛けの粘着係数平均値

Fig. 4 参照。

$$\mu_a=\frac{F_t}{W_t\cos\alpha}+\tan\alpha \quad\cdots\cdots(2)$$

ここで，　μ_a: クローラトラクタの傾斜せる林地上における真の粘着係数

$\mu_{a\,max}$: 同上真の粘着係数最大値

$\mu_{a\,mean}$: 同上真の粒着係数平均値

Fig. 5 参照。

見掛けおよび真の粘着係数の最大および平均各値のうち真の粘着係数平均値が，粘着係数としては林地の勾配の影響もみられず，もっとも妥当な値をあたえるものということができる。

2. クローラトラクタの林地傾斜面における直線走行所要動力

$$P_t=\frac{W_t(f_t\cos\alpha+\sin\alpha)V_a}{75\cdot\eta_1\cdot\eta_2\cdot\eta_3\cdot\eta_4(1-s)}=\frac{W_t(f_t\cos\alpha+\sin\alpha)l_p\cdot n\cdot N_e}{75\cdot60\cdot i_1\cdot i_2\cdot i_3\cdot\eta_1\cdot\eta_2\cdot\eta_3\cdot\eta_4}\quad\cdots\cdots(17)$$

ここで，　P_t: トラクタの林地直線部走行出力 PS

W_t: トラクタ装備重量 kg

f_t: トラクタの林地走行抵抗係数
- $=0.111+0.033\,V_a$（枝条しきならべた林地）……（4）
- $=0.066+0.05\,V_a$（笹生地）……（5）
- $=0.046+0.021\,V_a$（黒土でおおわれた林地）……（6）

(Fig. 6 参照)

α: 林地斜面の勾配 °

V_a: トラクタの実際走行速度，m/sec

V_t: トラクタの理論走行速度，m/sec

s: トラクタのスリップ率，
- $=1-\frac{V_a}{V_t}$ ……（8）
- $=-1.7+0.018\,\alpha+0.007\,\alpha^2+0.0015\,\alpha^3$（笹生地）…（9）

l_p: トラックシューのピッチ長，m

n: スプロケットの1回転で送られるトラックシューの数

N_e: トラクタエンジンの回転数，rpm

i_1: トランスミッション（第1速）減速比

η_1: 同　機械効率

i_2: ディファレンシャル　減速比

η_2: 同　機械効率

i_3: ファイナルドライブ　減速比

η_3: 同　機械効率

η_4: スプロケットとトラックリンクの機械効率

Fig. 8-b 参照。

3.　**クローラトラクタの林地傾斜面における旋回走行所要動力**

$$P_{tc}=\frac{W_tV_0}{270\,\eta}\Big[f_t+\frac{\mu l}{2(2r-b)}+\frac{2V_0\{2hg\mu(2r-b)-lV_0^2\}}{g^2\mu(2r-b)^3}+\frac{1}{(2r-b)}\times\Big\{2f_t h\tan\alpha+\frac{l}{2}\Big(\mu-\frac{\sin^2\alpha}{\mu}\Big)\Big\}+\sin\beta\Big]\cdots\cdots(33)$$

ここで，　P_{tc}: トラクタが林地傾斜面で任意の方向に旋回する時に必要な出力，PS

V_0: トラクタ車体中心の走行速度，m/sec

η: トラクタの全機械効率，$=\eta_1\eta_2\eta_3\eta_4$

μ: 履帯の横方向の摩擦係数

l: 履帯の接地長，m

r: 外側履帯の旋回半径，m

b: 履帯幅，m

g: 重力加速度，m/sec², 9.8

h: トラクタ重心の地表面よりの高さ，m

α: トラクタの左右方向の傾き角度，$=\sin^{-1}\{\sin(90-\omega)\sin\gamma\}$
(Fig. 10, 11 参照)

β: トラクタの進行方向の上り下り角度，$=\sin^{-1}\{\sin\omega\sin\gamma\}$
(Fig. 10, 11 参照)

ω: トラクタの進行方向と斜面の等高線とのなす角度，°

γ: 林地斜面の勾配，°

Fig. 12, 13 参照。

4.　**クローラトラクタの林地における伐根のりこえ所要トルクおよび動力**

$$T_{oc_1}=\frac{d\cdot R_{oc_1}}{2\cdot i\cdot\eta}\cdots\cdots(37)$$

$$P_{oc_1}=\frac{\pi\cdot d\cdot N_e\cdot R_{oc_1}}{75\cdot 60\cdot i\cdot\eta}\cdots\cdots(38)$$

ただし，

$$R_{oc_1}=\frac{W_t}{2}\cos\alpha\cdot\cos(\beta+\beta_2)\Bigg(f_2\cos\beta\Bigg\{1+\frac{2h\tan(\alpha+\alpha_1)\cos\alpha_1}{B-\frac{b}{2}}\Bigg\}$$

$$+f_1'\cos(\beta+\beta_1)\Bigg\{1-\frac{2h\tan(\alpha+\alpha_1)\cos\alpha_1}{B-\frac{b}{2}}\Bigg\}\Bigg\{1-\frac{\frac{l}{2}}{L-l_x}\Bigg\}$$

$$+\sin(\beta+\beta_1)\Bigg\{1-\frac{2h\tan(\alpha+\alpha_1)\cos\alpha_1}{B-\frac{b}{2}}\Bigg\}\Bigg\{1-\frac{\frac{l}{2}}{L-l_x}\Bigg\}$$

$$+\cos(\delta_1-\beta)\Bigg\{1-\frac{2h\tan(\alpha+\alpha_1)\cos\alpha_1}{B-\frac{b}{2}}\Bigg\}\Bigg\{\frac{\frac{l}{2}}{L-l_x}\Bigg\}$$

$$+\sin\beta\left\{1+\frac{2h\tan(\alpha+\alpha_1)\cos\alpha_1}{B-\frac{b}{2}}\right\}\Bigg)+W_t\cos(\alpha+\alpha_1)\sin(\beta+\beta_2)\cdots\cdots\cdots\cdots(36)$$

ここで, T_{oc1}: 伐根はトラクタ片側の履帯がはい上がる (Fig. 18 参照) に要するトルク, mkg

P_{oc1}: 伐根にトラクタ片側の履帯がはい上がる (Fig. 18 参照) に要する出力, PS

d: スプロケット有効径, m

N_e: エンジン回転数, rpm

i: 全減速比, $=i_1i_2i_3$

R_{oc1}: 全抵抗力, kg

f_2: トラクタの履帯の林地面と接する部分の走行抵抗係数, 0.125

f_1': トラクタの履帯の伐根に接する部分の走行抵抗係数, 0.05

B: 軌間, m

$\alpha, \alpha_1, \beta, \beta_1, \delta_1, l, L$: Fig. 15-a 参照。

Fig. 18 参照。

$$T_{oc2}=\frac{d\cdot R_{oc2}}{2\cdot i\cdot\eta}\cdots\cdots\cdots\cdots(42)$$

$$P_{oc1}=\frac{\pi\cdot d\cdot N_e\cdot R_{oc2}}{75\cdot 60\cdot i\cdot\eta}\cdots\cdots\cdots\cdots(42)$$

ただし,

$$R_{oc2}=\frac{W_t}{2}\cos\alpha\cdot\cos(\beta+\beta_2)\Bigg(f_2\cos\beta\left\{1+\frac{2h\tan(\alpha+\alpha_1)\cos\alpha_1}{B-\frac{b}{2}}\right\}$$

$$+\sin\beta\left\{1+\frac{2h\tan(\alpha+\alpha_1)\cos\alpha_1}{B-\frac{b}{2}}\right\}+f_1'\cos(\beta+\beta_1)\left\{1-\frac{2h\tan(\alpha+\alpha_1)\cos\alpha_1}{B-\frac{b}{2}}\right\}$$

$$\times\left\{1-\frac{l\sin\beta_1}{2\mathrm{H}'}\right\}+\sin(\beta+\beta_1)\left\{1-\frac{2h\tan(\alpha+\alpha_1)\cos\alpha_1}{B-\frac{b}{2}}\right\}\Bigg)$$

$$+W_t\cos(\alpha+\alpha_1)\cdot\sin(\beta+\beta_2)\cdots\cdots\cdots\cdots(41)$$

ここで, T_{oc2}: 伐根にトラクタ片側の履帯がはい上がってから上がりきるまで (Fig. 18 参照) に要するトルク, mkg

P_{oc2}: 伐根にトラクタ片側の履帯がはい上がってから上がりきるまで (Fig. 18 参照) に要する出力, PS

$\alpha, \alpha_1, \beta, \beta_1, \beta_2, H'. B, b$: Fig. 15-b, 16, 17 参照。

Fig. 18 参照。

5. トラクタ・スタンプカッタ (機械駆動式) の伐根切削所要動力

$$P_{sce}=\frac{f\cdot b\cdot V_f\cdot r}{75\cdot\eta_5\cdot\eta_{sc}}\left\{\cos^{-1}\frac{(r-h)}{r}-\cos^{-1}\frac{(r-h_0)}{r}\right\}\cdots\cdots\cdots\cdots(52)$$

$$\fallingdotseq\frac{\sqrt{2}\ f\cdot b\cdot V_f\cdot r^{\frac{1}{2}}\cdot h^{\frac{1}{2}}}{75\cdot\eta_5\cdot\eta_{sc}}\cdots\cdots\cdots\cdots(55)$$

ここで, P_{sce}: トラクタ・スタンプカッタ (機械駆動式) の伐根切削所要動力, PS

f：カッタの単位切削抵抗力，kg/mm^2，$=73.8(b\cdot\delta)^{-\frac{1}{1.62}}$ ……………………(56)
(Fig. 25 参照)

b：カッタ1枚の平均切削幅，mm

δ：カッタ1枚の切削深さ，mm，$=p\cdot\frac{V_f}{V_c}$ ……………………(45)

p：同心円上にあるカッタのピッチ長，mm

V_f：カッタホイールの送り速度，mm/sec

V_c：カッタの周速，mm/sec，$=\frac{2\pi rN_c}{60}$ ……………………(46)

r：カッタ先端の回転切削円の半径，mm

h, h_0：カッタホイールと切削される木材の相対的位置，mm (Fig. 24参照)

η_{sc}：機械駆動式スタンプカッタの機械効率

η_5：PTO 軸の機械効率 (Fig. 19 参照)

N_c：カッタホイールの回転数，rpm

Fig. 26 参照。

6. トラクタ・スタンプカッタ（油圧駆動式）の伐根切削所要動力および燃料消費率

$$P_{sce}'=\frac{f\cdot b\cdot h\cdot V_f}{75\cdot\eta_5\cdot\eta_{cd}\cdot\eta_p\cdot\eta_m\cdot\eta_h} \quad \cdots\cdots(65)$$

ここで，　P_{sec}'：トラクタ・スタンプカッタ（油圧駆動式）の伐根切削所要動力，PS

b：カッタ1枚の切削幅，mm

h：カッタドラムの切削深さ，mm

V_f：カッタドラムの送り速度，mm

η_{cd}：スタンプカッタ（油圧駆動式）の機械効率

η_p：オイルポンプの全効率

η_m：オイルモータの全効率

η_h：高圧ゴムホースの効率

Fig. 29 参照。

$$a_c=\frac{3.6\times10^6\cdot Q_{sc}\cdot\rho}{f_b\left(\frac{f\cdot b\cdot h\cdot V_f}{75\cdot\eta_5\cdot\eta_{cd}\cdot\eta_p\cdot\eta_m\cdot\eta_h}\right)} \quad \cdots\cdots(67)$$

ここで，　a_c：トラクタ・スタンプカッタ（油圧駆動式）の単位燃料消費量あたり伐根切削量，cm^3/l

Q_{sc}：単位時間あたり伐根切削量，cm^3/sec，$=\frac{\sqrt{2}\cdot b\cdot n\cdot N_{sc}\cdot\delta\cdot r^{\frac{1}{2}}\cdot h^{\frac{1}{2}}}{60}$ ……(58)

N_{sc}：カッタドラムの回転数，rpm

n：同時に伐根を切削しているカッタの数

δ：カッタ1枚の実際に切削している深さ，mm

r：カッタ先端の切削回転半径，mm

ρ：燃料の比重，g/cm^3，軽油で 0.825

f_b：後述，(91)式よりもとめられる。

Fig. 30 参照。

7. トラクタ・ロータリカッタ(機械駆動式)の刈払い所要動力および燃料消費率

$$P_{rce}=\frac{\{W_t(f_t\cos\alpha+\sin\alpha)+W_r(f_r\cos\alpha+\sin\alpha)\}V_a}{75\cdot\eta_1\cdot\eta_2\cdot\eta_3\cdot\eta_4(1-s)}+\frac{2\pi F_r\cdot r\cdot N_e}{75\cdot 60\cdot i_5\cdot i_r\cdot\eta_5\cdot\eta_r}\cdots(89)$$

$$=\frac{\{W_t(f_t\cos\alpha+\sin\alpha)+W_r(f_r\cos\alpha+\sin\alpha)\}l_p\cdot n\cdot N_e}{75\cdot 60\cdot i_1\cdot i_2\cdot i_3\cdot\eta_1\cdot\eta_2\cdot\eta_3\cdot\eta_4}$$

$$+\frac{2\pi F_r\cdot r\cdot N_e}{75\cdot 60\cdot i_5\cdot i_r\cdot\eta_5\cdot\eta_r}\cdots\cdots(90)$$

ここで, P_{rce}: トラクタ・ロータリカッタ(機械駆動式)の刈払い所要動力, PS

W_r: 機械駆動式ロータリカッタの装備重量, kg

f_r: ロータリカッタの走行抵抗係数, $=0.186+0.129\ V_a$ ……(74)
(Fig. 39 参照)

F_r: ロータリカッタ刃の切削抵抗力, $\mathrm{kg}=a_1-b_1N_r=a_1-b_1{}'V_r$ ……(74)
(Fig. 40, Table 7 参照)

r: ロータリカッタ刃の有効半径, m
(Table 6 参照)

i_s: PTO 軸 減速比

η_5: 同 機械効率

i_r: ロータリカッタ 減速比

η_r: 同 機械効率

N_r: ロータリカッタ軸の回転数, rpm

V_r: ロータリカッタ刃の周速, m/sec

Fig. 42 参照。

$$a_r=10^3\cdot\frac{\rho}{f_b}\cdot\frac{75\cdot l_p\cdot n(1-s)\cdot i_5\cdot i_r\cdot\eta_1\cdot\eta_2\cdot\eta_3\cdot\eta_4\cdot\eta_5\cdot\eta_r}{l_p\cdot n\cdot i_5\cdot\eta_5\cdot\eta_r\ \{W_t(f_t\cos\alpha+\sin\alpha)+W_r(f_r\cos\alpha+\sin)\}+2\pi F_r\cdot r\cdot i_1\cdot i_2\cdot i_3\cdot\eta_1\cdot\eta_2\cdot\eta_3\cdot\eta_4}$$
$$\cdots\cdots(94)$$

$$A_r=10^2\cdot\frac{\rho}{f_b}\cdot\frac{75\cdot l_p\cdot n(1-s)\cdot i_s\cdot i_r\cdot\eta_1\cdot\eta_2\cdot\eta_3\cdot\eta_4\cdot\eta_5\cdot\eta_r}{l_p\cdot n\cdot i_s\cdot i_r\cdot\eta_5\cdot\eta_r\{W_t(f_t\cos\alpha+\sin\alpha)+W_r(f_r\cos\alpha+\sin\alpha)\}+2\pi F_r\cdot r\cdot i_1\cdot i_2\cdot i_3\cdot\eta_1\cdot\eta_2\cdot\eta_3\cdot\eta_4}$$
$$\cdots\cdots(95)$$

ここで, a_r: トラクタ・ロータリカッタ(機械駆動式)の単位燃料消費量当たり刈り払い走行距離, km/l

A_r: 同 単位燃料消費量当たり刈り払い面積, ha/l

ρ: 燃料の比重, g/cm^3, 軽油で 0.825

f_b: トラクタ育林機械の各種の育林作業をする場合の単位時間当たり正味燃料消費量,
g/PS・hr, $=\left(0.162+\frac{1.39}{P_e}\right)N_e$ ……(91)

P_e: トラクタエンジンの出力, PS

N_e: トラクタエンジンの回転数, rpm

Fig. 44 参照。

8.　**トラクタ・ロータリーカッタ（油圧駆動式）の刈り払い所要動力**

$$P_{rce}'=\frac{\{W_t(f_t\cos\alpha+\sin\alpha)+W_r'(f_r'\cos\alpha+\sin\alpha)V_a\}}{75\cdot\eta_1\cdot\eta_2\cdot\eta_3\cdot\eta_4\cdot(1-s)}+\frac{2\pi F_r\cdot r\cdot q_p}{75\cdot60\cdot i_5\cdot i_r\cdot q_m\cdot\eta_5'\cdot\eta_r'\cdot\eta_{pm}\cdot\eta_{nm}\cdot\eta_h}\cdots\cdots(100)$$

$$=\frac{\{W_t(f_t\cos\alpha+\sin\alpha)+W_r'(f_r'\cos\alpha+\sin a)l_p\cdot n\cdot N_e\}}{75\cdot60\cdot i_1\cdot i_2\cdot i_3\cdot\eta_1\cdot\eta_2\cdot\eta_3\cdot\eta_4}+\frac{2\pi\cdot F_r\cdot r\cdot q_p}{75\cdot60\cdot i_5'\cdot i_r'\cdot q_m\cdot\eta_5\cdot\eta_r'\cdot\eta_{pm}\cdot\eta_{nm}\cdot\eta_h}\cdots\cdots(101)$$

ここで，　P_{rce}'：トラクタ・ロータリーカッタ（油圧駆動式）の刈り払い所要動力，PS

W_r'：油圧駆動式ロータリーカッタの装備重量，kg

f_r'：同　走行抵抗係数

i_5'：油ポンプの軸の減速比

η_5'：同　機械効率

i_r'：油圧駆動式ロータリーカッタの減速比

η_r'：同　機械効率

q_p：油ポンプの理論吐出量，cc/rev

q_m：油モータの理論流入量，cc/rev

η_{pm}：油ポンプの機械効率

η_{mm}：油モータの機械効率

η_h：高圧ゴムホースの効率

Fig. 47 参照。

9.　**トラクタ・アースオーガ（機械駆動式）の植え穴掘り所要動力**

$$P_{ae}=\frac{\pi\cdot N_e\cdot F_a\cdot r_a}{75\cdot60\cdot i_5\cdot i_a\cdot\eta_5\cdot\eta_a}\cdots\cdots(110)$$

ここで，　P_{ae}：トラクタ・アースオーガ（機械駆動式）の植え穴掘り所要動力，PS

F_a：植え穴掘り刃の掘さく抵抗力，kg

$=(a+bV_p)V_c^{\,d}=(a_1+b_1V_p)N_e^{\,d}\cdots\cdots(108)$

a, b, a_1, b_1, d：常数（Table 12 参照）

N_e：トラクタエンジンの回転数，rpm

V_p：植え穴掘り刃の貫入速度，m/sec

V_c：植え穴掘り刃の周速，m/sec

r_a：植え穴掘り刃の有効半径，m

i_a：アースオーガ（機械駆動式）の減速比

η_a：同　機械効率

Fig. 53 参照。

10.　**トラクタ・アースオーガ（油圧駆動式）の植え穴掘り所要動力**

$$P_{ae}'=\frac{\pi\cdot N_e\cdot F_a'\cdot r_a\cdot q_p}{75\cdot60\cdot i_5'\cdot i_a'\cdot\eta_5'\cdot\eta_a'\cdot q_m\cdot\eta_{pm}\cdot\eta_{mm}}$$

ここで，　P_{ae}': トラクタ・アースオーガ（油圧駆動式）植え穴掘り所要動力，PS

F_a': 植え穴掘り刃の掘さく抵抗力，kg

$=0.37F_a=0.37(226.7V_p+80)V_c^{0.25}$

r_a': 植え穴掘り刃の有効半径，m

i_a': アースオーガ（油圧駆動式）の減速比

η_a': 同　機械効率

なお，0.37は油圧駆動式アースオーガの植え穴掘り刃のオーガ軸をとおる垂直面に対する投影面積の機械駆動式アースオーガの同様の投影面積に対する比である ($78\ cm^2$: $210\ cm^2=0.37:1$)。

Fig. 55 参照。

11. トラクタ・ダクタの薬剤散布所要動力および燃料消費率

$$P_{dre}=\frac{\{(W_t+W_a)(f_t\cos\alpha+\sin\alpha)\}l_p\cdot n\cdot Ne}{75\cdot 60\cdot i_1\cdot i_2\cdot i_3\cdot\eta_1\cdot\eta_2\cdot\eta_3\cdot\eta_4}+\frac{Q\cdot\rho_0\cdot\mu_i(2\pi\cdot r\cdot N_e)_2\cdot 10^{-3}}{216\cdot 75\cdot g(i_5\cdot i_6\cdot i_7\cdot i_8\cdot i_9\cdot i_{10})\cdot\eta_n\cdot\eta_5\cdot\eta_6\cdot\eta_7\cdot\eta_8\cdot\eta_9\cdot\eta_{10}}\quad\cdots\cdots(122)$$

ここで，　P_{dre}: トラクタ・ダスタ（薬剤散布機）の走行散布中に要する動力，PS

W_d: ダスタの装備重量，kg

Q: ダスタの風量，m^3/min

(Fig. 64 参照)

ρ_0: 空気密度，kg/m^3，気圧 760 mm，20°C，湿度 75% で 1.2 kg/m^3

μ_i: インペラの摩擦係数，

$=1-\frac{2}{Z}$，ただし Z はインペラの羽根の数

r: インペラの外径，m

g: 重力加速度，m/sec^2，9.8

$i_6, i_7, i_8, i_9, i_{10}$: ダスタの減速比

$\eta_6, \eta_7, \eta_8, \eta_9, \eta_{10}$: 同　機械効率

η_n: ブロワの全効率，$=\eta_f\cdot\eta_m\cdot\eta_v\cdot\eta_t$

η_f: インペラディスクの摩擦効率

η_m: ブロワの機械効率

η_v: ブロワの容積効率

η_t: ブロワの全圧効率

Fig. 66 参照。

$$a_d=\frac{Q_d\cdot\rho\cdot 10^3}{f_b\left\{\frac{(W_t+W_d)(f_t\cos\alpha+\sin\alpha)l_p\cdot n\cdot N_e}{75\cdot 60\cdot i_1\cdot i_2\cdot i_3\cdot\eta_1\cdot\eta_2\cdot\eta_3\cdot\eta_4}+\frac{Q\cdot\rho\cdot\mu(2\pi\cdot r\cdot N_e)^2\cdot 10^{-3}}{216\cdot 75\cdot g(i_5\cdot i_6\cdot i_7\cdot i_8\cdot i_9\cdot i_{10})^2\eta_n\cdot\eta_5\cdot\eta_6\cdot\eta_7\cdot\eta_8\cdot\eta_9\cdot\eta_{10}}\right.}\quad\cdots\cdots(127)$$

ここで，　a_d: トラクタ・ダスタの単位燃料消費量当たり粉剤の走行時散布量，l_{powder}/l_{fuel}

Q_d: トラクタ・ダスタの単位時間当たり粉剤散布量，l/hr

$=0.000225(i_5\cdot i_6\cdot i_7\cdot i_8\cdot i_9\cdot i_{10}\cdot N_e)^{1.688}\cdots\cdots(123)$

(Fig. 65, 66 参照)

Fig. 67 参照。

12.　トラクタ・スタンプカッタ（機械駆動式）の伐根処理作業性能

$$t=t_{sc}+t_m+t_p+t_p+t_r=\{aD^2+bD+c+dL+(t_p+t_q+t_r)\}n \quad \cdots\cdots(71)$$

ここで，　t: トラクタ・スタンプカッタによる伐根処理面積 1 ha 当たり総作業時間，sec

t_{sc}: 正味伐根処理時間，sec

$$\begin{cases} =aD^2+bD+c & \cdots\cdots(68) \\ =a'Q_{sc}'+b' & \cdots\cdots(69) \end{cases}$$

(Fig. 31 参照)

t_m: 伐根から伐根への移動距離，sec，$=dL$　(Fig. 32 参照)

D: 伐根直径，cm

L: 伐根から伐根への移動距離，m

$$\fallingdotseq \frac{100}{\sqrt{n}}$$

a, a', b, b', c, d: 常数 (Table 4 参照)

t_p: スタンプカッタを伐根の位置にすえつけてから，伐根処理をはじめるまでの間で準備に要する時間，sec (Table 5 参照)

t_q: 伐根処理をすませてから，スタンプカッタを移動しはじめるまでの間で，準備に要する時間，sec (Table 5 参照)

t_r: スタンプカッタを伐根の位置にすえつけてから，運転手がトラクタ運転席をおりて，スタンプカッタ油圧調整レバーの位置まであるいていくに要する時間，sec (Table 5 参照)

n: 1 ha 当たり伐根本数

Fig. 33 参照。

13.　チェンソーによる伐根処理作業性能

$$t=nt_{sc}+(n-1)\left(\frac{100}{\sqrt{n}}\right)t_w+nt_0+nt_s \quad \cdots\cdots(73)$$

ここで，　t: チェンソーによる伐根処理面積 1 ha 当たり総作業時間

t_{se}: 正味伐根切削時間，sec

$$=10^{-3}\cdot 5.178\,D^{2.87} \quad \cdots\cdots(72)$$

(Fig. 34 参照)

t_w: 伐根から伐根への歩行時間，sec

t_0: 伐根処理 1 本当たりチェンソー調整時間，sec

t_s: 伐根 1 本当たり休憩時間，sec,

なお，チェンソーによる伐根処理残存高さについては，伐倒時にひくく切る場合と地ごしらえ時にあらためて伐根処理する場合とを比較調査した結果，50 年生カラマツについて地ごしらえ時で 10 cm 以下，伐倒時で 15 cm 以下程度にひくめることができ，いずれも伐採跡地上トラクタ走行にほとんどさしつかえなくすることができることもたしかめられた(Fig. 35, 36)。

14. トラクタ・ロータリカッタ（機械駆動式）および刈払機（組作業）の地ごしらえ作業性能

$t=t_b+t_t+t_i$ ……(102)

ここで，
t: トラクタ・ロータリカッタによる地ごしらえ面積 1 ha 当たり総作業時間
t_b: トラクタ・ロータリカッタの 1 ha 当たり正味刈り払い作業時間
t_t: トラクタ・ロータリカッタの 1 ha 当たり旋回所要時間
t_i: トラクタ・ロータリカッタの 1 ha 当たり検査・調整に要する時間

Table 9 参照。

$t=t_b+t_i+t_f+t_c$ ……(103)

ここで，
t: 刈払機による地ごしらえ面積 1 ha 当たり総作業時間
t_b: 刈払機の地ごしらえ面積 1 ha 当たり正味刈り払い作業時間
t_i: 刈払機の地ごしらえ面積 1 ha 当たり検査・調整に要する時間
t_f: 刈払機の地ごしらえ面積 1 ha 当たり丸鋸目立に要する時間
t_c: 地ごしらえ面積 1 ha 当たり枝条整理に要する時間

Table 9 参照。

なお，ロータリカッタの刈り払い精度は，笹生地の地ごしらえ刈り払いにおいて，カッタ刃周速 60 m/sec，カッタ軸回転速度 750 rpm（ただしブッシュホグ）以上になるともっともよくなり，残存刈り払い高さが最低となることがたしかめられた。

15. トラクタ・アースオーガ（機械駆動式，油圧駆動式）の植え穴掘り作業性能

$t=t_a\cdot n_d+t_t\cdot n_r+(t_l+t_u)L$ ……(118)

ここで，
t: トラクタ・アースオーガによる植え穴掘り面積 1 ha 当たり総作業時間，sec
t_a: トラクタ・アースオーガの正味植え穴掘り時間，sec

$=0.30\,D_p\pm2.0$（機械駆動式）
$=0.38\,D_p\pm3.6$（油圧駆動式） ……(114)

(Fig. 56，57 参照)

n_d: 1 ha 当たり植穴掘り箇所数（1 ha 当たり植栽本数）
t_t: 植え列の終端でトラクタ・アースオーガ旋回に要する時間，sec

$=41.6\,n_r\pm22.4$（機械駆動式）
$=61.0\,n_r\pm24.0$（油圧駆動式） ……(116)

(Fig. 60 参照)

n_r: 1 ha 当たり植え列本数
t_l: 植え穴から植え穴への移動に要する時間，sec

$=5.16\,L\pm2.1$（機械駆動式）
$=6.40\,L\pm3.8$（油圧駆動式） ……(115)

(Fig. 58，59 参照)

L: 植え穴から植え穴への移動距離，m
t_u: 手待時間

$$\left.\begin{aligned}&=0.50\,L\pm2.1\ (\text{機械駆動式})\\&=0.74\,L\pm3.8\ (\text{油圧駆動式})\end{aligned}\right\}\cdots\cdots(117)$$

(Fig. 61 参照)

機械駆動式の場合

$$t'=13.00\,A\pm3.19\ (n_d=2,500)$$
$$=14.25\,A\pm4.42\ (n_d=3,000)$$

油圧駆動式の場合

$$t'=16.53\,A\pm7.23\ (u_d=2,500)$$
$$=18.11\,A\pm7.73\ (n_d=3,000)$$

ここで，　t': トラクタ・アースオーガの与えられた植え穴掘り面積 A を植え穴掘りするに要する総作業時間，hr

A: 植え穴掘り面積，ha

n_d: 1 ha 当たり植え穴掘り箇所数（植栽本数）

Fig. 62 参照。

16. トラクタ育林機械の作業経費の推定

$$C_m=C_c+C_s+C_r+C_f+C_0+C_i=\frac{C_p}{M_l}+C_s+C_r\cdot r_r+C_0+C_i\ \cdots\cdots(128)$$

ここで，　C_m: 各機械の正味作業1時間当たり機械経費，￥/hr

C_c: 機械の1時間当たり償却費，￥/hr

C_p: 機械の購入費，￥

M_l: 機械の寿命，hr

C_s: 機械の1時間当たり管理費，￥/hr

C_r: 機械の1時間当たり修理費，￥/hr

r_r: 機械の償却費に対する修理費率

C_f: 機械の1時間当たり燃料費，￥/hr

C_0: 機械の1時間当たり潤滑油費，￥/hr

C_i: 1時間当たりの利子，保険料，税金等に要する経費，￥/hr
Table 14 では無視。

Table 14 参照。

17. トラクタおよび同付属育林作業機各1台による年間作業実行可能面積の推定

$$A_i=\frac{Y_i\cdot t_n}{H_i}\cdots\cdots(129)$$

ここで，　A_i: トラクタおよび任意の育林作業機各1台で，1年間に，ある種類の機械化作業を実行できる面積，ha

Y_i: 同　機械の機械化作業適期の日数，day

t_n: 同　機械の1日当たり正味作業時間，hr

H_i: 同　機械の作業能率 hr/ha

例題 1，Table 15 参照。

18. **トラクタ1台および同付属育林作業機数台の組み合わせ作業による年間作業実行可能面積の推定**

$$\left.\begin{aligned} &A \leqq A_1, A_2, A_3, A_4 \text{ or } A_5 \\ &A \leqq \frac{Y \cdot t_n}{\sum_{i=some} H_i} \end{aligned}\right\} \cdots\cdots (130)$$

ここで，

A: 何種類かの育林作業機を組み合わせて，1年間に総合した機械化作業を実行できる面積，ha

A_1, A_2, A_3, A_4, A_5: 各種の育林作業機単独で1年間におのおの機械化作業を実行できる面積，ha

Y: トラクタ育林作業が1年間の中で実行できる作業日数，day

$\sum_{i=some} H_i$: 何種類かの育林作業機を組み合わせて実行する場合の，それら作業機の作業能率の合計，hr/ha

19. **与えられた面積と期限内で再造林の作業実行を可能ならしめるトラクタ および 同付属育林作業機の必要台数の推定**

$$n_t \geqq \frac{X}{E \cdot A}\left(=\frac{X \sum_{i=some} H_i}{E \cdot Y \cdot t_n}\right) \cdots\cdots (131)$$

(Fig. 68 参照)

$$n_{ai} \geqq \frac{A}{E \cdot A_i}\left(=\frac{X \cdot H_i}{E \cdot Y \cdot tn}\right) \cdots\cdots (132)$$

(Fig. 68 参照)

$$\left.\begin{aligned} &n_{am} \geqq \frac{X}{E \cdot A_m} \\ &n_{an} \geqq \frac{X}{E \cdot A_n} \end{aligned}\right\} \left(\frac{X \cdot H_m}{E \cdot t \cdot n_t} \leqq Y_m - Y_p\right) \text{のとき} \cdots\cdots (133)$$

$$\left.\begin{aligned} &n_{am} \geqq \frac{X}{E \cdot A_m} \\ &n_{an} \geqq \frac{X}{\frac{E \cdot t}{H_n}\left\{\left(Y_m - \frac{X \cdot H_m}{E \cdot t \cdot n_t}\right) + (Y_m - Y_p)\right.} \end{aligned}\right\} \left(\frac{X \cdot H_m}{E \cdot t \cdot n_t} > Y_m - Y_p\right) \text{のとき} \cdots\cdots (134)$$

$$\left.\begin{aligned} &n_{am} \text{ or } n_{an} \geqq \frac{X}{E \cdot A_m} \quad (A_m < A_n) \text{のとき} \\ &n_{am} \text{ or } n_{an} \geqq \frac{X}{E \cdot A_n} \quad (A_m > A_n) \text{のとき} \end{aligned}\right\} \cdots\cdots (135)$$

ここで，

n_t: 与えられた造林実行予定面積を与えられた期間に実行するのに必要なトラクタ台数

n_{ai}: 同上に必要な任意の育林作業機台数

X: 与えられた造林実行予定面積，ha

E: 与えられた造林予定実行期間，year

n_{am}: 同上に2種類の育林作業機をつかう場合の一方の作業機 (m) 必要台数

n_{an}: 同上他方の作業機 (n) 必要台数

Y_m: 作業機(m)の1年間の適期日数，day

Y_n: 作業機(n)の1年間の適期日数，day

Y_p: 同上作業機(m, n)の適期の重複する日数，day

A_m: 作業機(m)の1年間に機械化作業を実行できる面積, ha

A_n: 作業機(n)の1年間に機械化作業を実行できる面積, ha

H_m: 作業機(m)の作業能率, hr/ha

例題 2, Table 16 参照一次項。

20.　トラクタおよび同付属育林作業機による育林作業の推定所要台数, 所要経費および所要労力と刈払機および植穴掘機による1人用機械作業の推定所要経費および所要労力との比較例

Table 16 のとおり。

Table 16

種類			レーキドーザ付トラクタ，機械駆動式ロータリカッタ，機械駆動式アースオーガを使用するトラクタ育林作業				レーキドーザ付トラクタ，油圧駆動式ロータリカッタ，油圧駆動式アースオーガを使用するトラクタ育林作業			
造林予定面積			600 ha		1,000 ha		600 ha		1,000 ha	
実行予定期間			10年	5 年	10年	5 年	10年	5 年	10年	5 年
年間合計作業日数		枝条整理	66日	131日	109日	218日	66日	132日	109日	218日
		地ごしらえ	47	94	78	156	47	94	78	156
		植え穴掘り	106	334	277	554	209	418	348	696
		下刈り	202	404	336	672	202	404	336	672
トラクタおよび同付属育林作業機の台数		トラクタ	4	7	6	12	4	7	6	12
		レーキドーザ	1	2	1	2	1	2	1	2
		ロータリカッタ	4	7	6	12	4	7	6	12
		アースオーガ	2	3	3	5	2	4	3	6
経費	トラクタ作業	合計機械購入費	13,960,000円	23,430,000円	20,190,000円	40,130,000円	16,228,000円	28,476,000円	24,342,000円	48,684,000円
		年利子 (6%)*	419,000	703,000	606,000	1,404,000	487,000	854,000	730,000	1,461,000
		年間経費**	3,378,000	6,621,000	5,537,000	10,868,000	4,148,000	8,177,000	6,833,000	13,663,000
	1人用機械作業	合計機械購入費	1,332,000円	2,664,000円	2,307,000円	4,509,000円	1,332,000円	2,664,000円	2,307,000円	4,509,000円
		年利子 (6%)*	40,000	80,000	69,000	136,000	40,000	854,000	69,000	130,000
		年間経費**	4,989,000	9,934,000	8,379,000	16,635,000	4,909,000	9,834,000	8,319,000	16,635,000
	1人用機械作業に対するトラクタ作業の比率		0.68	0.67	0.68	0.68	0.83	0.83	0.82	0.82
労力	年間合計作業員数	トラクタ作業	492人-日	984人-日	830人-日	1,640人-日	534人-日	1,068人-日	890人-日	1,780人-日
		1人用機械作業	3,450	6,900	5,750	11,500	3,400	6,900	5,750	11,500
	1人用機械作業に対するトラクタ作業の比率		0.14	0.14	0.14	0.14	0.155	0.155	0.155	0.155

注 * $\frac{\text{購入費}}{2}\times 0.6$　　** 償却費，修理費，燃料・潤滑油費，賃金（Table 4 参照）および年利子を含む。