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DEVELOPMENT OF THE WHEEL DRIVING SYSTEM IN A TRAILING IMPLEMENT

Munehiro TAKAI
Agricultural Machinery Laboratory, Faculty of Agriculture, Hokkaido University, Sapporo 060, Japan

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Introduction

In potato or beet harvesting in Tokachi prefecture, which is a major production area of potatoes, processed potatoes and sugar beet in Japan, operations are conducted on soft, dirt farmland which is softened further by rain, frost thaw and early snow. The harvesting implement which digs, separates and collects tubers is a large trailing type harvester which weighs 2 to 3 tons and has an 1 ton size tuber tank. A pulling tractor of less than 52 kW is ordinary used and the engine is controlled at a nearly idle speed up to 1200 rpm. In the field test shown in Fig. 1, the total working energy is only 8 to 15 kW by the potato-harvester, and 3 to 8 kW by the beet-harvester. As the driving load is so little it would be expected that a tractor of very small size could be used instead. But a small tractor will not to be able to pull the large implement on the soft dirt land, so a large one must be used to get the require traction.

In the crop-production energy survey[5] taken in that area and shown in Fig. 2, energy input for the production of potato or beet is much larger than in any foreign country.[4] There is no special reason for such a high-input condition, except that the machine size is so big in proportion to the size of the farm area or the area covered is so small. These reason is increase energy cost. If a balance between tractor and harvester can be achieved, the tractor can be changed to a smaller one, and the fuel consumption will be reduced. Author developed and tested the idea of driving the wheels of the implement by the tractor hydraulic system to improve the trafficability in that field.

Fundamental Modeling Test

1.1 Test Device and Data Acquisition

A sketch of the test device which is modeled on the trailing harvester

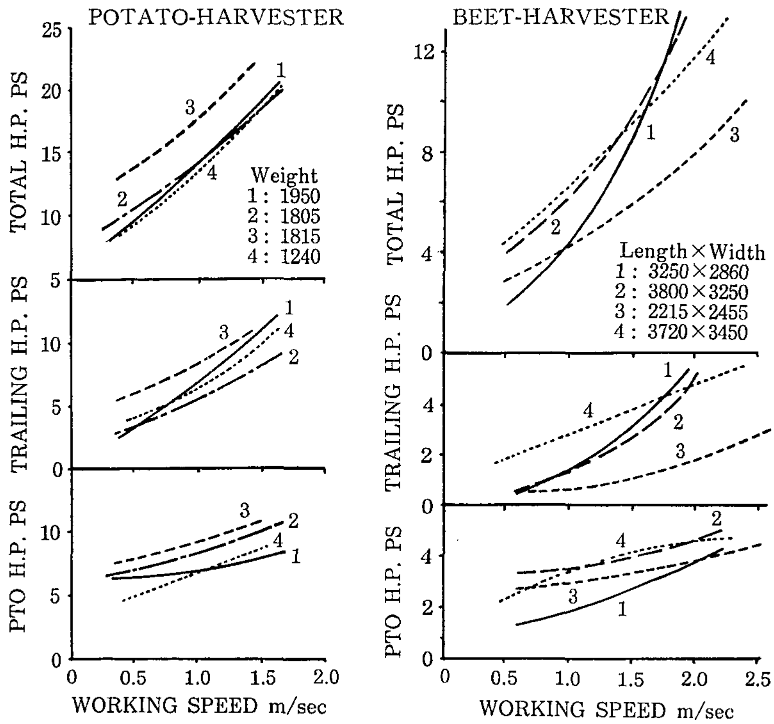


Fig. 1. Load Test Results of Potato, Beet-harvester
(Test field: Memuro-chyo, Tokachi-prefecture)

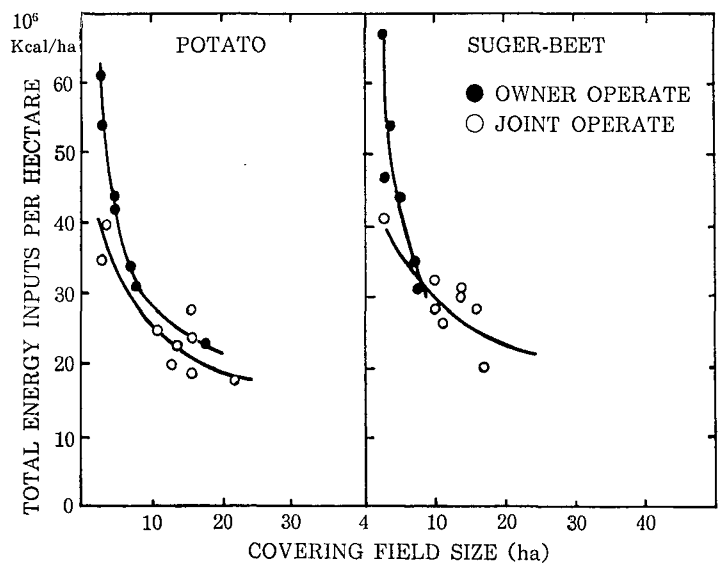


Fig. 2. Energy Inputs for Potato and Suger-beet Productions in Tokachi, Hokkaido.

is shown in Fig. 3. This type is similar in appearance to a conventional trailer for transport but different in nature therefrom in its wheel driving

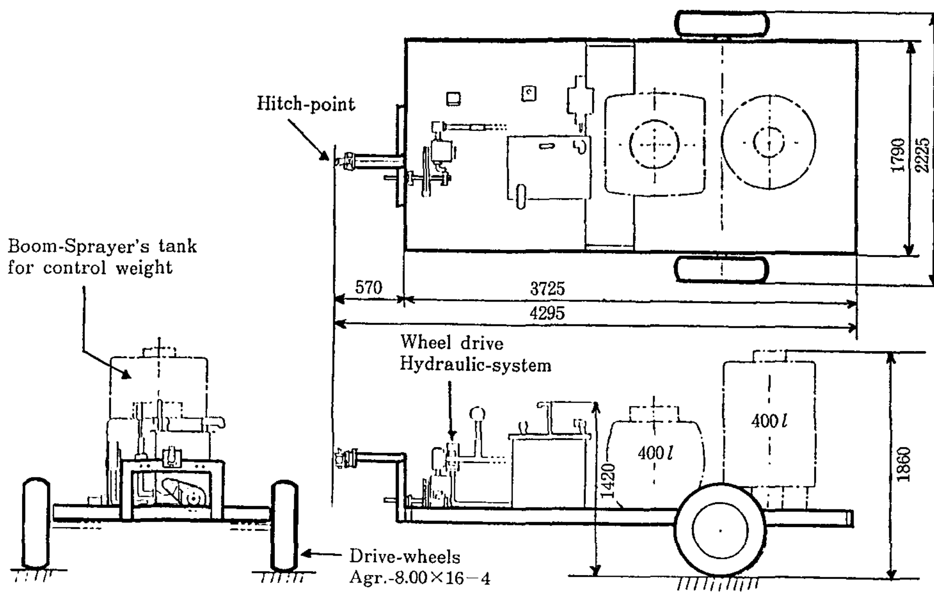
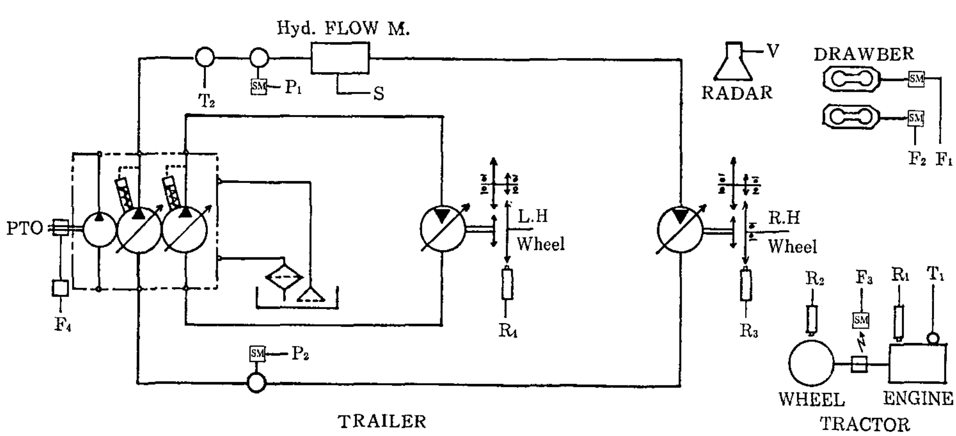


Fig. 3. Fundamental Test Device (Trailer) for Implement's Wheel Drive.



V: Radar-speed sensor, S: Hyd-flow meter, T1: Temp. of eng. exhaust gas, T2: Temp. of hyd-oil, R1: Tractor engine rpm, R2: Tractor-wheel rpm, R3: Impl.-wheel rpm RH, R4: Impl.-wheel rpm LH, P1: Hyd-pressure (high), P2: Hyd-pressure (Low), F1: Hitch horiz. force, F2: Hitch Vert. force, F3: Tractor mission torque, and F4: PTO-shaft torque

Fig. 4. Hyd-system for Test-device and Measuring Apparatus.

system, hitch-point to the tractor and weight control system. This system weighs 1200 kgf in machine unit and 2000 kgf when the tank mounted on it is filled with water. Figure 4 shows the wheel drive mechanisms and several measuring apparatuses. The wheel speed can be adjusted by changing the oil flow on the variable flow hydraulic-pumps. And wheel slippage can be calculated from data in relation to radar-real speed sensor and wheel rotating pulse pick-ups. The hitch-point resistance or push force between tractor and trailer is measured by two elongated octagonal force transducers with wire strain gages, and three dimensional forces can also be measured.

The measurement was carried out in such a way that the system traction speed was decreased from initial wheel slip to 100 percent slip by load "L" (shown in Fig. 5) at several initial setting speeds and implement wheel speeds (this initial speed varies tractor wheel speed). The digital and analog data from the measuring apparatus were recorded on a 14ch tape-recorder used with a one-board computer to convert several data to single digital data, and a data of recorded tape was processed by a digital personal computer (PC-9801) through an A/D converter, a counter and several such interfaces.

The tractor-harvester system as shown in Fig. 5 was loaded at the load-point "L" through the wire cable and load sensing unit by another tractor. (hereinafter referred to as the "load tractor" and system's tractor referred to as "pull tractor").

1.2 Mathematical Model

An understanding of the statics and dynamics between tractor and trailing implement is important in the analysis of stability, performance and handling. The two-dimensional analysis of this system is emphasized and,

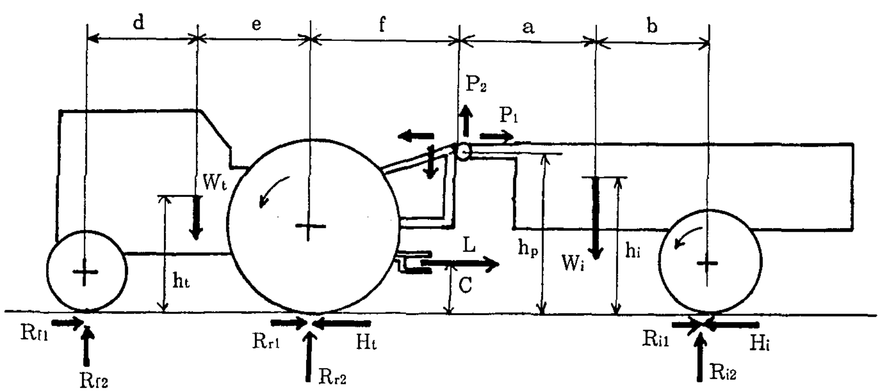


Fig. 5. Diagram of the Force Analysis of the System. (P_1, P_2 is System Inner Force)

referring to Fig. 5, the following six euqations express the constraint relation : —[2,3]

on tractor only ;

$$H_t-(R_{f1}+R_{r1})-L+P_1=0 \tag{1}$$

$$(R_{f2}+R_{r2})-W_t-P_2=0 \tag{2}$$

$$W_t\cdot a+P_2\cdot(a+b+c)+L\cdot c-R_{r2}\cdot(a+b)-P_1\cdot h_p=0 \tag{3}$$

on trailer only ;

$$H_i-R_{i1}-P_1=0 \tag{4}$$

$$R_{i2}+P_2-W_i=0 \tag{5}$$

$$P_2\cdot(d+e)+P_1\cdot h_p-W_i\cdot e=0 \tag{6}$$

Total driving force is calculated as follows ;

$$H_t+H_i=L+R_{i1}+(R_{f1}+R_{ri}) \tag{7}$$

From the equations, the hitch point's horizontal force P_1 is the most significant one ; its values of plus (pushing the tractor by the trailer) or minus (pulling the trailer) are shown as follows ;

$$P_1=H_i-R_{i1} \tag{8}$$

$$P_2=-\left[h_p/(d+e)\right]\cdot P_1+\left[e/(d+e)\right]\cdot W_i \tag{9}$$

$$R_{r2}=-\left[h_p\cdot(a+b+c+d+e)/(a+b)/(d+e)\right]\cdot P_1 +\left[a\cdot(d+e)\cdot W_t+e\cdot(a+b+c)\cdot W_i\right]/(a+b)/(d+e) \tag{10}$$

$$R_{f2}=\left[h_p\cdot(c+d+e)/(a+b)/(d+e)\right]\cdot P_1+\left[b\cdot(d+e)\cdot W_t -e(a+b)\cdot W_i\right]/(a+b)/(d+e) \tag{11}$$

$$R=R_{f2}+R_{r2}=-\left[h_p/(d+e)\right]\cdot P_1+W_t+e\cdot W_i/(d+e) \tag{12}$$

As the equations from (8) to (12) are P_1's one-valued function, they show that the several effects to system performance and show lower the height "h_p" the better the traffic performance.

1.3 Results and Discussion

The trafficability or load test of the developed system was conducted at a dirt stable field in late fall, and also conducted in 30 cm deep wet snow in early winter. In the former test, the soil conditions slightly changed between each test, but in the latter test on the snow, ground conditions had better uniformity. So, in the former test the actual measurements were rather different and it was difficult to determine the relation of several parameters.

The effect of the implement wheel drive is shown in Figs. 6 and 7. In the extremely muddy field conditions, if the implement's wheel drive was off, the system cannot move on the trailing condition. However with addition of the wheel drive, the system could move steady. The effect of wheel drive was more effective.

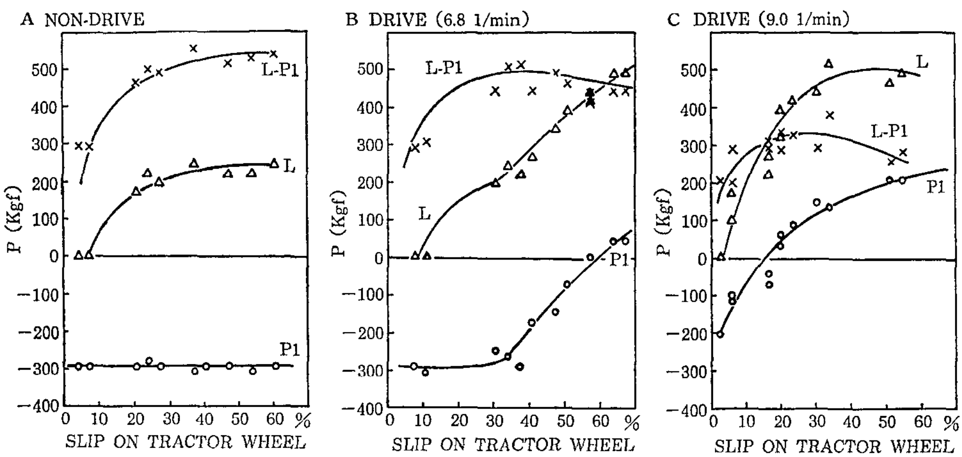


Fig. 6. Test Results on Sonw (Travel Speed is 0.5 m/sec).

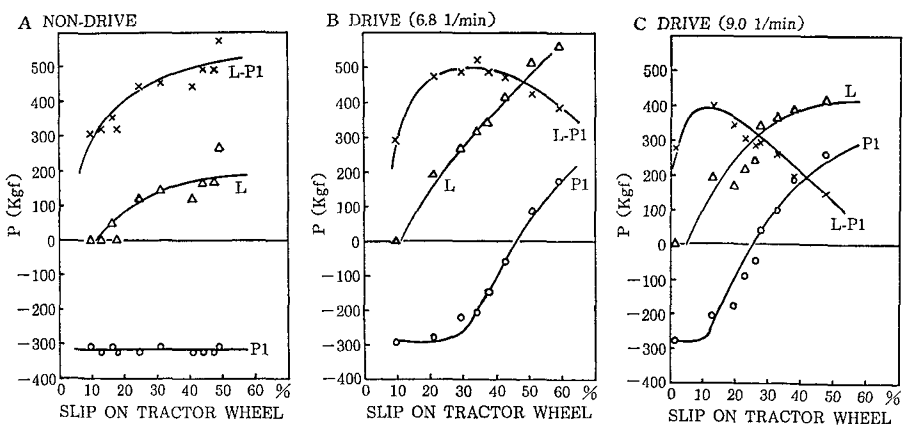


Fig. 7. Test Results on Snow (Travel Speed is 1.0 m/sec).

The test results shown in Figs. 6-B and 7-B were achieved under the conditions of the drive wheel speed of the implement was set slower than that of the pull tractor. When the pull tractor slippage is little, the system's draft "L" was gradually increased to nearly the same to the non-drive condition as shown in A. But when the pull tractor slippage grows up and slows down its speed, the system's draft "L" shows much greater than the non-drive. This change begins at the forward speed of the pull tractor is nearly the same to the implement wheel speed. Figures 6-C and 7-C show that the test conditions of the drive speed of implement's wheel was set higher than that of pull tractor. The result shows that the least movable slippage of the pull tractor wheel goes down from nearly 10% to about 3% (this means it speeds up). The draft of the system increases rapidly and shows much greater than that of non-drive as shown in Fig. 6-A.

The resistance of a digger part of potato or beet harvester is estimated to reach 150 kgf. Therefore if the draft of digger requires 200 kgf, the test results shows that the harvesting system cannot work in condition A and is slowly movable with 25 to 30% wheel slippage on B. In a moderate conditions, such as the implement wheel drives nearly the same speed to pull tractor wheel, it can work with only 10% slippage on 0.5 m/s speed (Fig. 6-C) and 15% slippage on 1.0 m/s. (Fig. 7-C)

It is clear that the pull tractor draft calculated ($L-P_1$) from system draft (L) and implement resistance (P_1) is decreased according to the increase in the implement's pushing force. These results agree approximately with the mathematical analysis shown in Eqs. (9) and (12), and are the limitations on this system. This is the reason why the implement push force creates upward force in hitch point shown in Fig. 8 and in Eq. (8), and decreases pull tractor drive wheel weight as shown in Eq. (10), and decreases weight transfer to the pull tractor rear wheels as shown below;

From Eqs. (10) and (11)

$$[dR_{t2}/dt]/[dR_{t1}/dt] = (c+d+e)/(a+b+c+d+e) < 1 \quad (13)$$

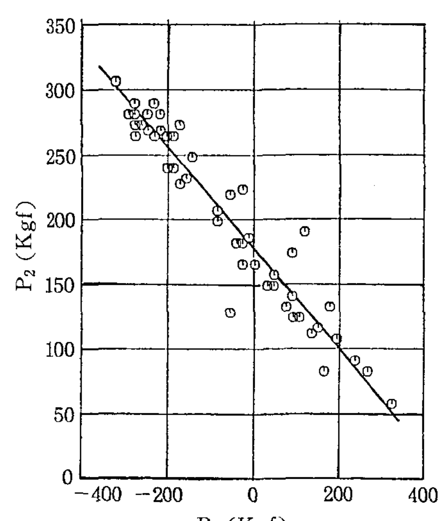


Fig. 8. Effect of P_1 and P_2.

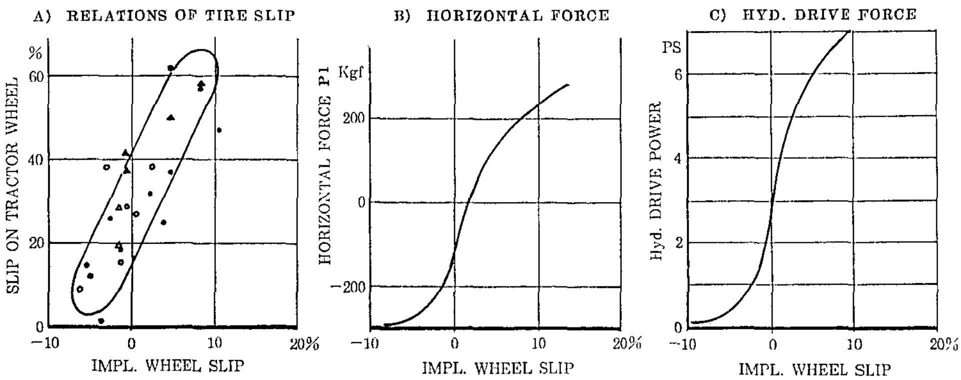


Fig. 9. Implement Drive Characteristics.

then $dR_{t2} < dR_{t1}$ (14)

Equation (14) shows that a higher hitch point brings about a lower traction effect. Farmers, however, want to get a high hitch point to clear the potato leaves and to have clear visibility of the digging area. This is a design problem yet to be resolved.

The drive energy of the implement's wheel shown in Fig. 9 increases the pull tractor's engine load, but it is clear that the increasing tractive performance results in a positive rather than a negative effect on increasing drive energy.

Studies on The Commerical Models

2.1 Hardware of Commercial Model

A one-row digging, tanker type commerical potato-harvester was reassembled with wheel driving system. The harvester shown in Fig. 10 and described in Table 1 is large, weighs about 4500 kgf in working condition and costs about ¥4,650,000.

The driving system was constructed in such a way that it uses the ordinary variable flow hydraulic pumping system shown in Fig. 11, but the hyd-pump was selected with technical features. When the system turns at a headland or on a curve in a row, the implement's wheel speed goes higher than the pull tractor, so that it pushes the tractor and may result in an off-control. So the pump has a pressure compensating mechanism and limits the push force within a safety range.

2.2 Test Method

A harvesting and controlling test was carried out in a farmer's field in

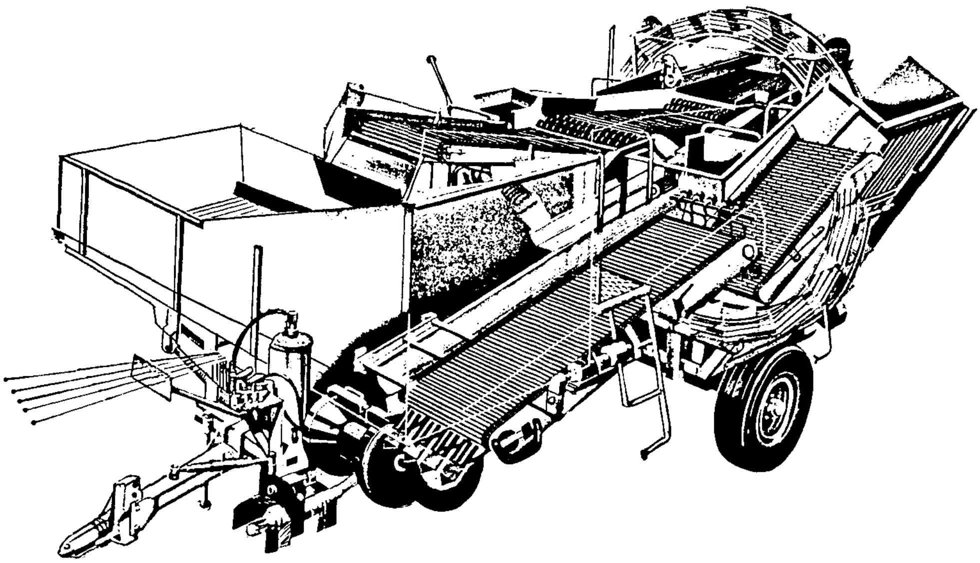


Fig. 10. Potato-harvester used for Actual Test (TOYO TPH7-U Type, One-row tanker).

TABLE 1. Specification of Potato Harvester

Nat., Test No.: 82036	Model: 1-row, Tanker, Trailing
Make: Toyo Noki Co. LTD.	Length: 6920 mm
Width (work): 3040 (4720) mm	Height (work): 2780 (2940) mm
Weight (dry): 2885 kg	Tire: 900×15
Main Tank: 2.6 m^3	Small Tuber Tank: 0.6 m^3
Rock Tank: 0.4 m^3	Hyd-oil Tank: 32 Liter
Tread: 1980–2160 mm	Tractor: Less than 60 PS
Work Speed: 0.4–0.6 (for Sweet), 0.7–1.0 (for process) m/s	

which the engine speed of the pull tractor was set on constant and the implement's wheel speed was set at 2 or 3 levels in each speed; the system was measured for field capacity, efficiency, wheel slip and fuel consumption.

As the climate in autumn of 1986 was clear, contrary to expectations, the test field was in a dry condition. The row length of the potato field was 250 meter, and row width was 75 cm.

2. 3 Results and Discussion

Table 2 shows that a comparison of the trafficability between the implement wheels on drive and non-drive. The hyd-pressure of the wheel drive

TABLE 2. Traficability Test Results

Hyd-Presure of Wheel Drive	WORKING SPEED	Speed Ratio on-drive/ non-drive	TRACTOR WHEEL Distance of Wheel Travel	TRACTOR WHEEL Slip of Wheel
kg/cm²	m/sec		cm	%
0	0.424		427	1.8
150	0.439	1.035	444	−3.2
0	0.618		428	1.7
145	0.642	1.039	445	−2.3
0	0.855		425	2.3
60	0.884	1.034	433	0.5

IMPLEMENT RIGHT-, LEFT-WHEEL			
Distance of L. H. Wheel travel	Slip of L. H. Wheel	Distance of R. H. Wheel travel	Slip of R. H. Wheel
cm	%	cm	%
269±4	−2.8	267±7	−2.0
254±1	2.7	249±2	5.0
268±3	−2.5	267±12	−2.2
256±2	2.3	249±2	4.7
268±3	−2.3	264±7	−0.9
262±1	0.2	262±3	0.0

in the table shows whether it is in the on drive condition (data of pressure is not zero) or the non-drive condition (data is zero). In the non-drive condition the implement wheels became resistant wheels and generated large rolling resistance; the slip then shows minus. Hence, in the drive condition, the wheels generated a thrust force to the system and minimized their own rolling resistance and the implement resistance of a digger unit. And at slow working speed, as the thrust force is greater than that in high working speed condition, the implement pushed the tractor. Then, the slip data of the pull tractor's wheels showed a violent fluctuation, changed its data from plus to minus and its fluctuation was greater at slow speed than at high speed. As the pull tractor is pushed by the trailing implement, it is clear that a smaller tractor size should be available. And this means energy saving.

The field capacity and fuel consumption test results shown in Table 3 are summarized in the two right hand columns. The ratio between drive and non-drive in capacity are shown to be greater than 100, and this result

TABLE 3. Field Capacity and Fuel Consumption Results

DATE TRACTOR	WORKING PRE-SET CONDITIONS AND RESULT	WORKING TIME MEASURED				CAPA-CITY	FUEL CONSUM-TION	RATIO OF	
		WORK	TURN	STOP	TOTAL			CAPA-CITY	FUEL CONS.
		min	min	min	min	m²/h	cc/10 a	%	%
10/25	P.SET V=1.67 m/s E=1050 rpm/load	— (non-drive)	—	—	19.37 330 m²	1022	3267		
JD- 2030 72PS	Gear change L2 V0=0.368 m/s V1=0.378 m/s	— (on-drive)	—	—	19.02 330 m²	1041	4533	101.9	138.8
10/25	P.SET V=1.67 m/s E=1050 rpm/load	— (non-drive)	—	—	10.12 330 m²	1778	2879		
	Gear change L4 V0=0.815 m/s V1=0.852 m/s	— (on-drive)	—	—	9.60 278 m²	1734	2364	97.5	82.1
11/07	P.SET V=1.20 m/s E=1200 rpm/set	14.80 (non-drive)	2.27	(1.20)	17.07 306 m²	1075	3572		
JD- 2140D 87PS	Gear change L2 V0=0.424 m/s V1=0.439 m/s	14.18 (on-drive)	1.97	(0.95)	16.15 306 m²	1136	3127	105.7	87.5
11/07	P.SET V=1.20 m/s E=1200 rpm/set	9.92 (non-drive)	1.58	(1.45)	11.50 306 m²	1596	2680		
	Gear change L3 V0=0.618 m/s V1=0.642 m/s	9.73 (on-drive)	1.43	(2.07)	11.17 306 m²	1644	2680	103.0	100.0
11/07	P.SET V=1.20 m/s E=1200 rpm/set	7.25 (non-drive)	2.30	(0.95)	10.50 306 m²	1922	892		
	Gear change L4 V0=0.855 m/s V1=0.884 m/s	7.13 (on-drive)	1.48	(0.72)	8.12 306 m²	2131	892	110.9	100.0

P.SET V=Pre-Set Impl. Wheel Speed, V0=Working Speed on non-drive, V1=Working Speed on drive.

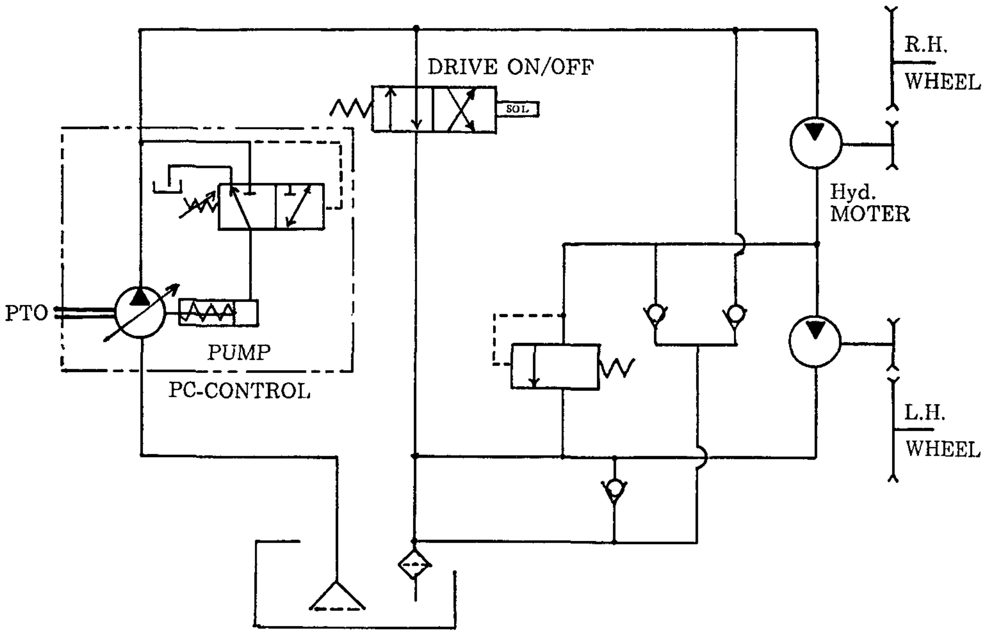


Fig. 11. Harvester Wheel Drive System Diagram.

shows that the field capacity is increased by adding wheel drive. The ratio in fuel consumption must be less than 100 for improving energy utilization, and in Table 3, good results are shown in the first one and others are equal. As the above experiment results show, the effect of the implement wheel drive system is useful on dirt ground, and if a condition is dry or hard, it shows little synergic effect. This effect is taken to be the same as that of the front wheel drive found in a four-wheel drive vehicle or farm tractor.[1,8)]

Synthesizing the results of this paper, the developed system is useful in dirt or soft ground and can improve energy utilization.

Summary

A new driving system was developed in order to improve the energy utilization in conventional trailing potato or beet-harvesters. Their wheels are driven by power of a pull tractor hydraulic system, and the tractor-harvester system gets better trafficability on heavy land in wet condition and it would be expected that a tractor of rather small size could be used instead.

A significant disadvantage in energy utilization in dry-field farming was first pointed out in author's previous energy studies.[5,6)] The results of the

studies showed that it was necessary for reducing the energy utilization to decrease the load of rotary tiller and to improve the harvester trafficability. And new energy saving system was developed in rotary tiller in that study.[6] If a improved system is developed for tractor-harvester system in this study, it can be expected that the maximum load for a tractor was less than 35 kW in all farm works. Then, it can decrease energy utilization so that a large tractor will be unnecessary for dry-land farming.

The test was conducted in two categories. A two-wheel trailer with a wheel driving system was developed, and a fundamental test was conducted on a soft dirt field and on snow. After this test, the commercial potato-harvester was adopted in the same way, and better results and improved energy utilization were shown.

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