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REVIEW

Reduction Rates of Fuel Consumption by Gear Up and Throttle Down on an Agricultural Tractor

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Abstract

We investigated the effect of operating conditions such as travel gears, PTO gears and engine speed of a 24kW agricultural tractor on fuel consumption. In the indoor tests, we found that as the PTO power and the engine speed increased, the fuel consumption increased and the fuel consumption per power hour became minimum when loads corresponding to 70-90% of the maximum power were applied at each engine speed. In the field tests, the fuel consumption was reduced by shifting to a higher travel and PTO gear and by lowering engine speed. The reduction rates of the fuel consumption by gear up and throttle down compared with those at full throttle were about 15 to 30% with PTO power at 55% of maximum engine output, about 30 to 40% with PTO power at 30% of maximum engine output, about 30 to 45% with PTO power at 20% of maximum engine output, and about 40 to 50% with PTO power at 15% of maximum engine output. In the road tests, the reduction rates of the fuel consumption by gear up and throttle down compared with those at full throttle were about 30 to 50% for traveling at 10 km/h, and about 20 to 35% for traveling at 15 km/h.

Discipline: Agricultural machinery
Additional key words: engine speed, road traveling, rotary tillage

Introduction

In order to cope with the rise in oil prices and to reduce carbon dioxide emissions, the saving of fuel consumption in farm work is very significant. Especially, the fuel saving in tractor work is important because the tractor is one of the most fuel-consuming machines used in farm work[8]. The tractor is used for many kinds of farm work and its loads are varied with the kind of farm work.

In the high-load work, the main methods for fuel saving are improvements of the engine and the implements. However in the mid- or low-load work, the fuel consumption of tractor work can be saved by adjustments in working conditions such as engine speed and position of gears. In these load conditions, the fuel consumption can be decreased by lowering the engine speed and shifting up the gears. This adjustment method is called 'Gear Up and Throttle Down (GUTD)' and is widely utilized in Europe and America[6,9]. However, GUTD is not a common method in Japan[6] because the tractor has been mainly used for rotary tillage, the load of which is high.

Based on these backgrounds, we investigated the effect of operating conditions such as engine speed, travel gears and Power Take-Off (PTO) gears of an agricultural tractor on fuel consumption.

Materials and methods

1. Tested tractor

A four wheel drive agricultural tractor was used for the tests. A four-stroke cycle, three cylinder, 24 kW direct injection Diesel engine was installed in the tractor. Table 1 shows the main specifications of the tested tractor.

2. Measuring methods of the power and the fuel consumption

The PTO power was measured by a dynamometer in the indoor tests and by a PTO torque pickup and a PTO revolution speed detector in the rotary tillage tests. In other field tests, the working power of the tractor was

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measured by a prototype operating condition indicator[4] which can detect the engine power of a tractor. Fuel consumption was measured by a fuel flow detector and digital flow meter as shown in Fig. 1.

3. Methods of the indoor tests

The indoor tests[1] were conducted by fixing the tractor in the laboratory and applying loads to the PTO shaft of the tractor with a dynamometer. Engine speed was adjusted every 100 rpm of 1,000 to 2,600 rpm and 2,650 rpm. Applied load was every 2 kW and maximum load at each engine speed.

4. Methods of the field tests

The following field tests were conducted. (1) Rotary tillage tests with the various gear positions and various throttle positions of a rotary tiller[2] (The tilling pitch, the travel speed and the blade rotating speed were constant.), (2) Rotary tillage tests with the various gear positions and various throttle positions of a rotary tiller[2] (The tilling pitch was constant, the travel speed and the blade rotating speeds were changed.), (3) Rotary tillage tests with the various gear positions and keeping the full throttle position of a rotary tiller[2] (The tilling pitch was constant, the travel speed and the blade rotating speeds were changed.), (4) Mole drain installation tests with the various gear positions and various throttle positions of a vibrating subsoiler[10] (The travel speed and the vibrating frequency were constant.), (5) Fertilizer application tests with the various gear positions and various throttle positions of a broadcaster[3] (The travel speed was constant.), (6) Inter-row cultivation tests with the various gear positions and various throttle positions of a rotary cultivator[3] (The tilling pitch, the travel speed and the blade rotating speed was constant.). Table 2–4 shows field conditions of the field tests.

5. Methods of the road tests

The road tests[3] were conducted by driving the tractor on a concrete road. The travel gear was shifted into

Table 1. Main specifications of tractor

Type	4 wheel drive
Length×width×height	320 ×150×199.5cm
Wheelbase	180 cm
Tread	Front: 123 cm, Rear: 115 cm
Total mass, front weight	1,570 kg, 20 kg×5
Tire	Front: 8-18-4PR, Rear: 3.6-26-4PR
Type of engine	Four-stroke cycle, 3 cylinder Diesel
Engine power, capacity	24 kW/2,600 rpm, 1,642 mL
Type of injectors	Direct injection
Forward travel speed	0.21～26.7km/h (20 gears)
PTO speed	556, 787, 994, 1,300rpm

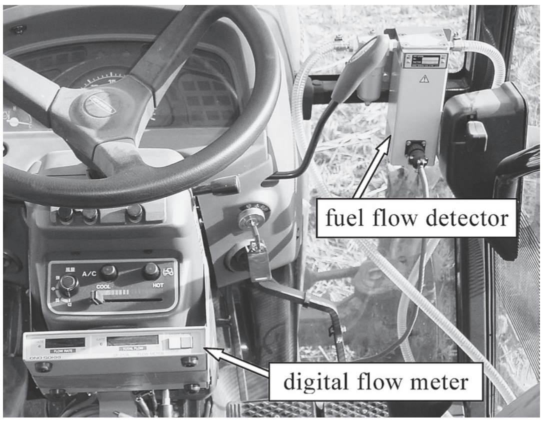

Fig. 1. Measuring device for fuel consumption

Table 2. Field conditions on rotary tillage tests

Field	Paddy field (after harvest of paddy rice)
Soil texture	Loam
Liquidity index	0.58 (Fig.4), 0.38 (Fig.5)
Wet bulk density (g/cm^3)	1.47 (Fig.4), 1.57 (Fig.5)
Dry bulk density (g/cm^3)	0.86 (Fig.4), 0.95 (Fig.5)
Cone index of 0–10cm (MPa)	0.43 (Fig.4), 0.48 (Fig.5)
Cohesion (kPa)	34 (Fig.4), 31 (Fig.5)
Internal friction (°)	35 (Fig.4), 35 (Fig.5)

Table 3. Field conditions on mole drain installation tests

Field	Dry field (after harvest of soybean)
Soil texture	Clay loam
Liquidity index	–0.12
Wet bulk density (g/cm^3)	1.28
Dry bulk density (g/cm^3)	0.95
Cone index of 0–40cm (MPa)	0.86
Cohesion (kPa)	24
Internal friction (°)	25

Table 4. Field conditions on fertilizer application and inter-row cultivation tests

Field	Dry field (after rotary tillage)
Soil texture	Loam
Liquidity index	0.58
Wet bulk density (g/cm^3)	1.03
Dry bulk density (g/cm^3)	0.57
Rectangle plate sinkage* (cm)	1.6
Cohesion (kPa)	16
Internal friction (°)	27

* Sinkage of 5×10cm plate (vertical load 500kN)

six levels and engine speed was adjusted to five levels of 1,100 to 2,650 rpm.

Results

1. Results of the indoor tests

The results of the indoor tests were as follows[1]. As the PTO power and engine speed increased, the fuel consumption increased (Fig. 2). The increasing rate of fuel consumption with increasing engine speed tended to rise as the PTO power was reduced. When no load was applied, the fuel consumption with the maximum engine speed was 3.7 times as large as that with the minimum engine speed. The fuel consumption per power hour ranged from 300 to 1,200 mL/kW·h and became minimum when loads corresponding to 70–90% of the maximum power were applied at each engine speed (Fig. 3).

2. Results of the field tests

In the rotary tillage tests with the various gear positions, various throttle positions and constant travel speed, the following results were obtained[2] (Fig. 4). The fuel consumption was reduced by shifting to a higher travel and PTO gear and by lowering engine speed. The reduction rates of specific fuel consumption (the fuel consumption per unit volume of the tilled soil) by gear up and throttle down compared with the specific fuel consumption at full throttle were 17 to 33% with PTO power at 55% of maximum engine output (traveling at 0.5 m/s) and 31 to 43% with PTO power at 30% of maximum engine output (traveling at 0.2 m/s).

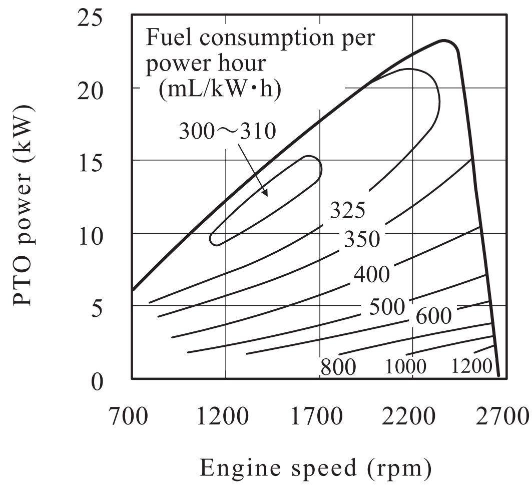

Fig. 3. Relation among engine speed, PTO power and fuel consumption per power hour

Symbol	PTO power (kW)
×	Maximum
■—■	22
◆—◆	20
▲—▲	18
●—●	16
□···□	14
◇···◇	12
△···△	10
○···○	8
□—□	6
◇—◇	4
△—△	2
○—○	0

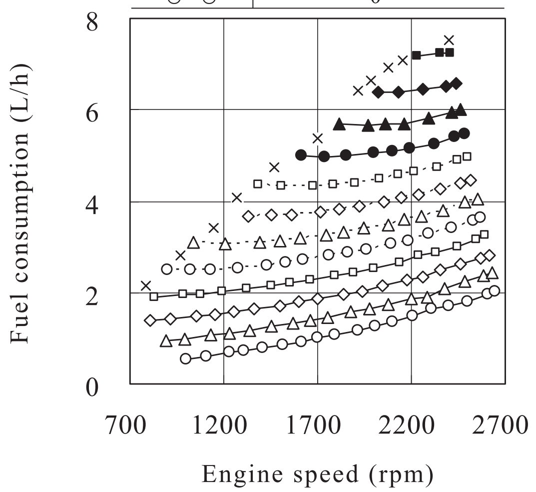

Fig. 2. Relation between engine speed and fuel consumption

Symbol	Travel gear	PTO gear	Travel speed (m/s)
○	5th	1st	0.50
△	6th	2nd	0.50
◇	7th	3rd	0.51
●	1st	1st	0.19
▲	2nd	2nd	0.19
◆	3rd	3rd	0.19
■	4th	4th	0.19

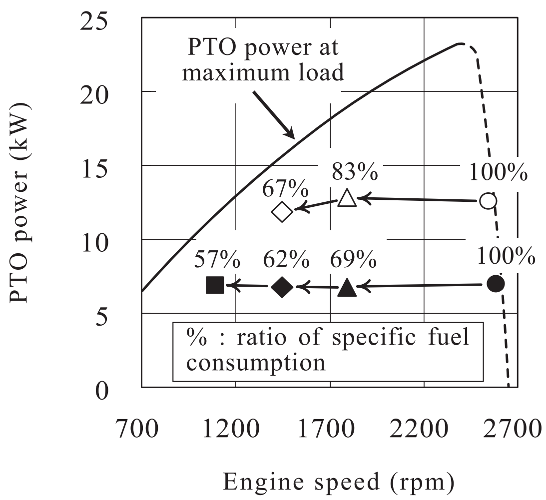

Fig. 4. Relation among engine speed, PTO power and specific fuel consumption for rotary tillage with constant travel speed

The results of the rotary tillage tests with the various gear positions, various throttle positions and various travel speeds were as follows[2] (○, ▲, ◆, ■ of Fig. 5). The fuel consumption was reduced by shifting to a higher travel and PTO gear. The reduction rates of specific fuel consumption by gear up and throttle down compared with the specific fuel consumption at full throttle were 22 to 29% (traveling at 0.19 to 0.32 m/s).

In the rotary tillage tests with the various gears position, keeping the full throttle position and various travel speeds, the fuel consumption was little reduced by shifting to a higher travel and PTO gear[2] (○, △, ◇, □ of Fig. 5). The reduction rates of specific fuel consumption by gear up compared with the specific fuel consumption at 1st travel gear and 1st PTO gear were 7 to 13% (traveling at 0.19 to 0.42 m/s).

In the mole drain installation tests with the various gear positions, various throttle positions and constant travel speed the following results were found[10] (Fig. 6). The fuel consumption was reduced by a large amount by shifting to a higher travel and PTO gear and by lowering engine speed. The reduction rates of specific fuel consumption (the fuel consumption per unit working area and working depth) by gear up and throttle down compared with the specific fuel consumption at full throttle were 29 to 43% with PTO power at 15 to 20% of maximum engine output (traveling at 0.5 m/s).

The results of the fertilizer application tests with the various gear positions, various throttle positions and constant travel speed were as follows[3] (Fig. 7). The fuel consumption was reduced by a large amount by shifting to a higher travel and PTO gear and by lowering engine speed. The reduction rates of specific fuel consumption (the fuel consumption per unit working area) by gear up and throttle down compared with the specific fuel consumption at full throttle were 31 to 45% with PTO power at 20% of maximum engine output (traveling at 1.5 to 1.6 m/s).

In the inter-row cultivation tests with the various gear positions, various throttle positions and constant travel speed, the fuel consumption was reduced by a large amount by shifting to a higher travel and PTO gear and by lowering engine speed[3] (Fig. 8). The reduction rates of specific fuel consumption (the fuel consumption per unit working area) by gear up and throttle down compared with the specific fuel consumption at full throttle were 40 to 53% with PTO power at 15% of maximum engine output (traveling at 0.5 m/s).

3. Results of the road tests

The results of the road tests were as follows[3] (Fig. 9). The fuel consumption was reduced by a large amount by

Symbol	Travel gear	PTO gear	Travel speed (m/s)
○	1st	1st	0.19
△	2nd	2nd	0.27
◇	3rd	3rd	0.34
□	4th	4th	0.42
▲	2nd	2nd	0.24
◆	3rd	3rd	0.28
■	4th	4th	0.32

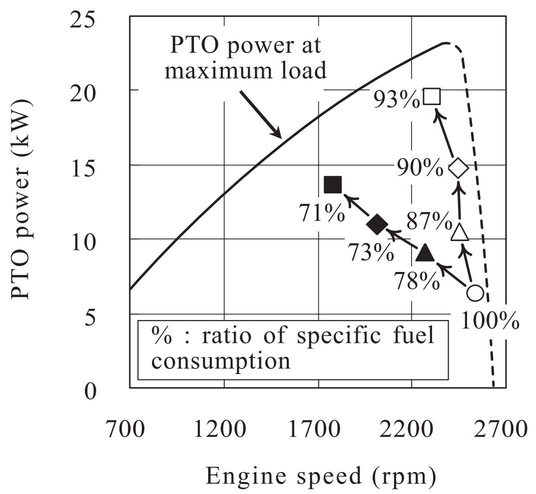

Fig. 5. Relation among engine speed, PTO power and specific fuel consumption for rotary tillage with various travel speeds

Symbol	Travel gear	PTO gear	Travel speed (m/s)
●	5th	1st	0.47
▲	6th	2nd	0.47
◆	7th	3rd	0.47
■	8th	4th	0.46

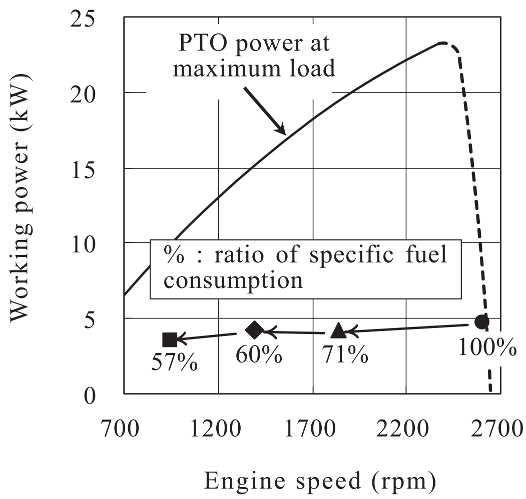

Fig. 6. Relation among engine speed, PTO power and specific fuel consumption for mole drain installation

Symbol	Travel gear	PTO gear	Travel speed (m/s)
●	9th	1st	1.5
▲	10th	2nd	1.6
◆	11th	3rd	1.6
■	12th	4th	1.6

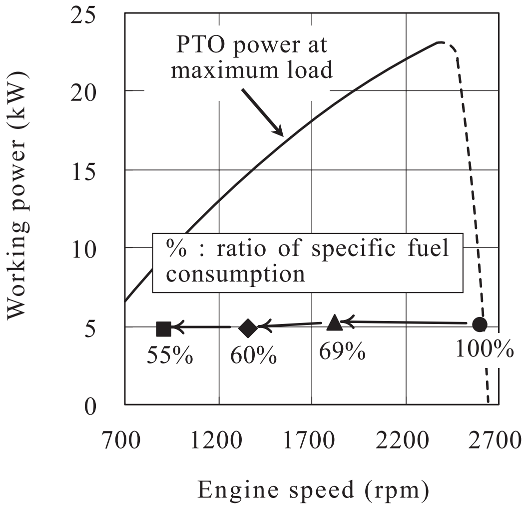

Fig. 7. Relation among engine speed, PTO power and specific fuel consumption for fertilizer application

Symbol	Travel gear	PTO gear	Travel speed (m/s)
●	5th	1st	0.47
▲	6th	2nd	0.47
◆	7th	3rd	0.47
■	8th	4th	0.46

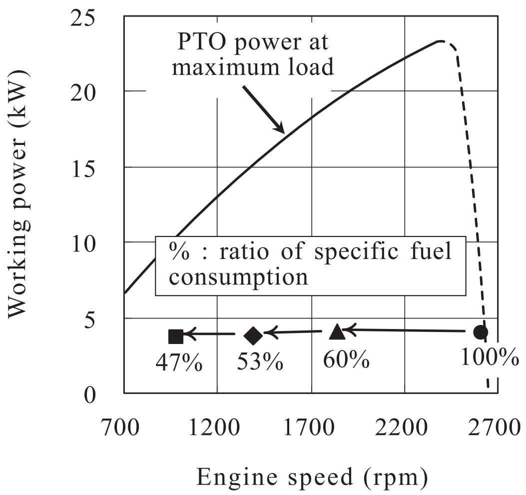

Fig. 8. Relation among engine speed, PTO power and specific fuel consumption for inter-row cultivation

shifting to a higher travel gear and by throttle down. The reduction rates of specific fuel consumption (the fuel consumption per unit travel distance) in a higher gear position compared with the specific fuel consumption at full

Symbol	Engine speed (rpm)
□	1,100
▲	1,500
△	1,900
●	2,300
○	2,650

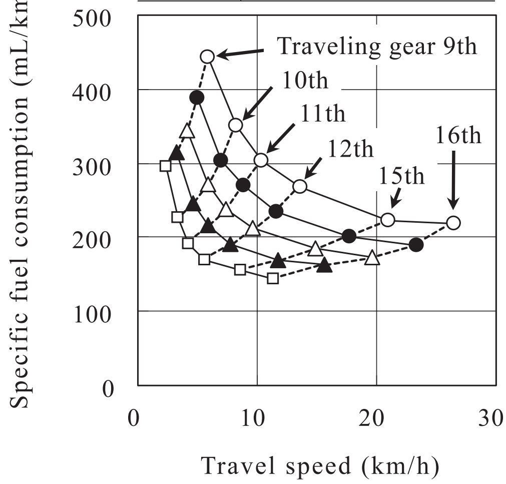

Fig. 9. Relation among engine speed, traveling gear and fuel consumption for road traveling

throttle were about 30 to 50% for traveling at 10 km/h and about 20 to 35% for traveling at 15 km/h.

Conclusion

We investigated the effect of operating conditions such as the position of travel gears and PTO gears and engine speed of an agricultural tractor on fuel consumption. As a result, 'Gear Up and Throttle Down' was effective to reduce the fuel consumption especially in the mid- or low-load works. The results of this research were reported in 'Manual for energy-saving utilization of agricultural machinery[7]' edited by Japanese Ministry of Agriculture, Forestry and Fisheries and were utilized widely by Japanese farmers.

In the tractor work, the accurate adjustment of operating conditions for the fuel saving is difficult because although we can find the engine speed by the tachometer, it is hard to know what the load is. A device[4] that indicates the operating condition consuming less fuel is useful to save fuel consumption of the farm work.

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