FUEL CONSUMPTION OF AGRICULTURAL MACHINES ON PADDY FIELDS

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Abstract
Recently, Japanese rice-growing farmers have confronted difficult conditions and decreasing market prices of rice. The Shonai area of Yamagata prefecture, which has many medium scale cultivated fields, is one of Japan's largest rice cultivation areas. We discussed factors affecting fuel consumption through investigation of the working properties of tillage, puddling, and harvesting of paddy fields to decrease power farming system fuel consumption. Tillage increased fuel consumption as the working speed increased. Puddling increased fuel consumption as the turning time and distance increased. Harvest of paddy rice was related with fuel consumption and field conditions.

Key words: paddy field, tillage, puddling, harvest, fuel consumption.

INTRODUCTION

In recent years, weather modification has been remarkable because of increasing amounts of greenhouse gas discharge. Among all industrial fields, agriculture accounts for a small amount of greenhouse gas discharge. Nevertheless, one must consider greenhouse gas reduction methods as long as it accounts for even some amount of discharge. Actually, carbon dioxide causes 95% of greenhouse gas problems. To decrease greenhouse gas emissions, one must decrease carbon dioxide emitted by cars and tractors. Oil prices have been unstable in recent years. Because Japan holds miniscule mineral resources and is strongly affected by oil prices, high oil prices engender increasing costs of fossil fuels used for agriculture, thereby increasing agricultural product costs. Rice farmers in Japan are in a difficult predicament of agriculture management because of the downward trend of rice prices. Japanese farmers must decrease amounts of gas oil usage to control production costs. This study of the Shonai area of Yamagata prefecture, one of Japan's most productive rice cultivation areas, was conducted of medium scale cultivated fields in Yamagata prefecture, Japan. However, few reports have described studies of fuel consumption of agricultural machines in medium scale paddy fields. The objectives of this study are to decrease fuel consumption, to improve working efficiency, and to increase farmer income by reducing the variable costs of rice production to use power farming system. So, we discussed factors affecting fuel consumption to change shift gear and engine revolution of tractor, working system of tractor and combine harvester through an investigation of working properties of tillage, puddling, and harvesting of paddy fields.

MATERIALS AND METHODS

(1) Test location

We conducted tests in paddy fields of the Yamagata Field Science Center in Faculty of Agriculture, Yamagata University in Takasaka, Yamagata, Japan during April–November in 2015. Additionally, we used the rice cultivar "Haenuki."

(2) Machine components

We used any farm machines to investigate fuel consumption and work rate of power farming system on paddy field. We used a wheel type tractor (GL467, 33.8 kW; Kubota Corp.), a rotary tiller (ML197R: Kobashi Kogyo Co., Ltd.), a semi-crawler tractor (T1164C, 30.9 kW; Iseki Co. Ltd.), and rotary tiller (WXY205 L-S; Iseki Co. Ltd.) for tillage. Puddling was done by a wheel type tractor (GL467, 33.8 kW; Kubota Corp.) and a paddy harrow (PS248; Kobashi Kogyo Co., Ltd.). Then, we harvested rice by head-feeding combine (H064G, 44.9 kW; Iseki Co. Ltd.).

(3) Investigation contents

Working information for each was obtained using a GPS logger (Trip Recorder 747 Pro; TranSystems Corp.) attached to a tractor. That GPS logger can record the work speed and coordinates. Therefore, we analyzed the work speed, work distance, total work time and work rate using the data logger system. The tractor fuel consumption was measured using a top fill method for each work test (TEST METHODS OF FARM WORK, 1987).

(4) Test and investigation contents

1)Tractor setting

Tab. 1 shows the setting of tractors for tillage and puddling We set engine revolutions at 2000 rpm or 2500 rpm, and changed the main shift gear by two steps for every machine for tillage. PTO gear had one step. For puddling, we set the engine revolutions at 2000 rpm or 2500 rpm, and changed the main shift gear by three steps.

Tab. 1. – The setting of tractors for tillage and puddling

Test blocks	n	Engine revolution(rpm)	The main shift gear	PTO gear	PTO Rev.(rpm)	Operater	Type[1)]
T1	1	2000	High2	1	425	A	I
T2	1	2000	High3	1	425	A	I
T3	1	2500	High2	1	500	A	I
T4	3	2500	High2	1	500	B	I
T5	1	2500	medium-speed6	1	586	A	II
T6	1	2500	medium-speed7	1	586	A	II
S1	1	2500	High3	2	750	C	-
S2	2	2500	High3	2	750	A	-
S3	1	2000	High4	2	610	A	-
S4	1	2000	High3	3	940	A	-
S5	1	2000	High4	3	940	A	-
S6	1	2000	High3	2	610	A	-

1) No. I was wheel type tractor (GL467, Kubota Co. Ltd.) and rotary tiller (ML197R, Kobashi Kogyo Co.Ltd). No. II was semi-crawler tractor (T1164C, Iseki Co. Ltd.) and rotary tiller (WXY205 L-S, Iseki Co. Ltd.).

2)Working system of tractor and combine harvester

We set the headland in a paddy field. We performed tillage using return tilling at first. Then, we tilled using return and round tilling of about two rounds in the paddy field. Operator A started tillage near the paddy field entrance. Operator B started tillage from the distant entrance place on the paddy field. Puddling was done using return and round tilling at first. Then, we performed puddling using return tilling. We harvested using both return and round harvesting in about four rounds in the paddy field; then we used a method of return harvesting (method 1). Furthermore, we harvested using methods of both return and round harvesting with about seven rounds in the paddy field. Then we used return harvesting (method 2). Each method harvested from outside to inside on the paddy fields.

RESULTS AND DISCUSSION

(1) Tillage

Tab. 2 presents tillage results. Pulverizing rates were 29.6–49.2%, with standard deviations of 4.0–20.4%. The pulverizing rates differed greatly among test blocks. The dry basis moisture content was 0.47 for test block T-1, and 0.65–0.69 in other test blocks. The pulverizing rate of test block T-2, which was set on the transmission high-gear was higher than test block T-1. In addition, the pulverizing rate of test block T-6 was lower than that of test block T-5. Because of low dry basis moisture content, test blocks T-1 had a low pulverizing rate. The average working speed of advance work was 0.43–0.67 $m \cdot s^{-1}$. The working speeds of test blocks T-2 and T-6, which were set on transmission high gear, were higher than the other test blocks. Fuel consumption of test blocks T-1 to T-4 were 1.98–2.90 $L \cdot 10\ a^{-1}$, test blocks T-5 and T-6 were 1.84 and 2.13 $L \cdot 10\ a^{-1}$. The fuel consumption of test blocks T-2 and T-6, which were set on high gear, was lower than that of the other test blocks. These results correspond with the results from the past experiments (GOTO ET AL, 2009; C.M.KICHER. ET AL., 2010). The total work rates of test blocks T-1 to T-4 were 0.35–0.50 $h \cdot 10\ a^{-1}$, test blocks T-5 and T-6 were 0.32 and 0.36 $L \cdot 10\ a^{-1}$. The total work rates of test blocks T-2 and T-6 which were set on high-gear were lower than those of the other test blocks. Furthermore, these work rate were similar to standard data of Japan (FARM WORK SCIENCE, 1999). Fig. 1 shows the relation of fuel consumption and working speed. Although the correlation coefficient of those data was 0.31, the fuel consumption increased as the working speed increased.

Tab. 2 – The result of tillage

		T-1	T-2	T-3	T-4	T-5	T-6
Pulverizing rates(%)	Average	40.5	48.4	45.9	33.9	49.2	29.6
	S.D.	11.0	20.4	11.5	6.9	9.2	4.0
Dry basis moisture content(%)	Average	0.47	0.68	0.69	0.67	0.65	0.66
	S.D.	0.04	0.12	0.08	0.04	0.08	0.02
Tillage depth(cm)	Average	12.8	10.9	13.8	12.5	14.7	11.3
	S.D.	1.8	1.6	1.6	0.2	0.6	1.7
Working speeds($m \cdot s^{-1}$)	Average	0.43	0.63	0.50	0.51	0.54	0.67
	S.D.	0.01	0.03	0.02	0.01	0.01	0.01
Total work rates($h \cdot 10a^{-1}$)		0.50	0.35	0.44	0.35	0.36	0.32
Fuel consumption($L \cdot 10a^{-1}$)		2.22	1.57	2.90	1.98	2.13	1.84

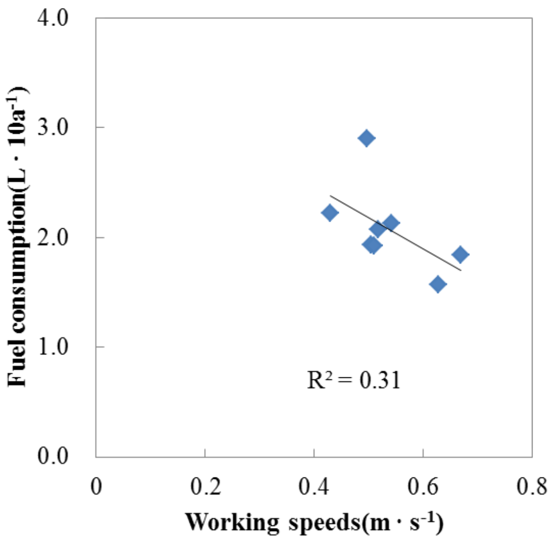

Fig. 1. – The relation of fuel consumption and working speed

(2) Puddling

Tab. 3 presents the puddling results. Working times were 2214–3603 s for advance work, and 498–783 s for turning. Working distances were 1655–1971 m for advance work, and 216–244 m for turning. Working speeds were 0.55–0.85 $m \cdot s^{-1}$, and 0.008-0.032 for standard deviations. When we set high engine revolutions and high gear, puddling tended to achieve short working times to have high working speed. The working distance showed much difference by test blocks. The fuel consumption was 0.85–1.51 $L \cdot 10\ a^{-1}$. Total work rates were 0.27–0.45 $h \cdot 10\ a^{-1}$. These work rate were similar to standard data of Japan (FARM WORK SCIENCE, 1999). And, these results correspond with the results from the past experiments (GOTO ET AL, 2009). Fig. 2 portrays the relation of PTO revolution and fuel consumption. Fig. 3 depicts the relation of turning time and fuel consumption. The relation of turn distance and fuel consumption is exhibited in Fig. 4. Actually, PTO revolution and fuel consumption showed a positive correlation for which the coefficient of determination was 0.58. The turn time and fuel consumption also showed a positive correlation for which the coefficient of determination was 0.77. Turn distance and fuel consumption showed a positive correlation for which the coefficient of determination was 0.47. Puddling had much fuel consumption as the turn time and distance increased.

Tab. 3 – The result of puddling

		S-1	S-2	S-3	S-4	S-5	S-6
Working times(s)	advance work	2568	2408	2214	3603	2610	3372
	turning	624	606	498	783	537	555
Working distances(m)	advance work	1709	1655	1764	1896	1882	1971
	turning	224	244	217	233	228	216
Working speeds($m \cdot s^{-1}$)	Average	0.68	0.73	0.83	0.55	0.85	0.56
	S.D.	0.024	0.026	0.019	0.008	0.019	0.032
Total work rates($h \cdot 10a^{-1}$)		0.34	0.30	0.27	0.42	0.31	0.45
Fuel consumption($L \cdot 10a^{-1}$)		1.33	1.30	0.85	1.51	1.19	0.99

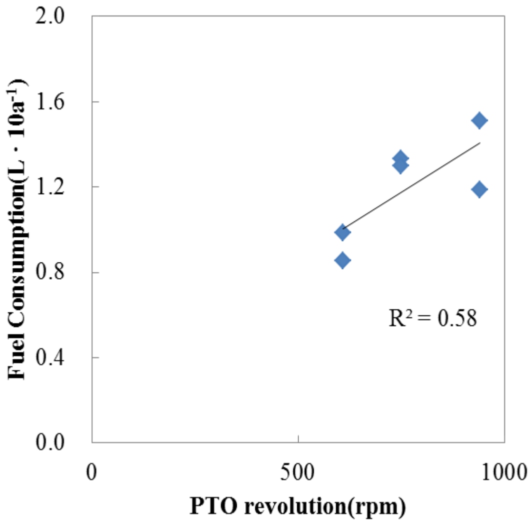

Fig. 2. – The relation of PTO revolution and fuel consumption

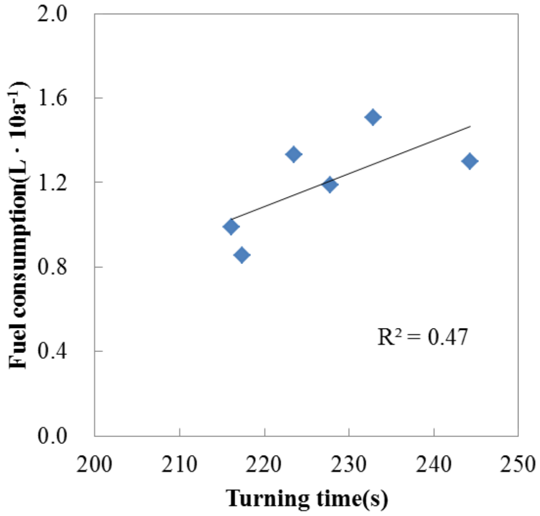

Fig. 3. – The relation of turning time and fuel consumption

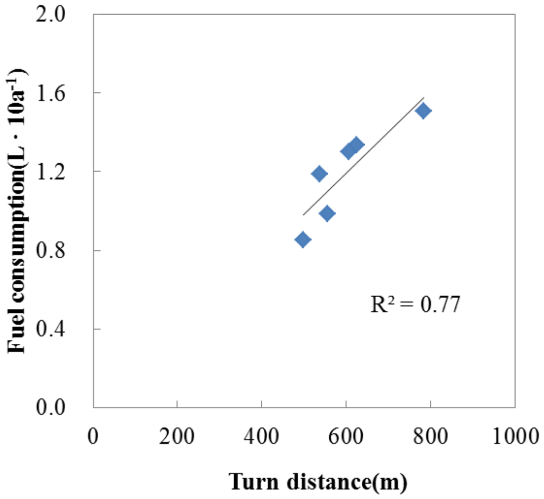

Fig. 4. – The relation of turn distance and fuel consumption

(3) Harvest

Tab. 4 shows data related to the paddy rice harvest. Dry basis moisture contents were 0.62 (S.D. 0.199) for test 1 and 0.55 (S.D. 0.108) for test 2. Soil hardness was 51.5 MPa (S.D. 25.58) for test 1 and 55.8 mm (S.D. 63.56) for test 2. Soil hardness increased as the dry basis moisture contents decreased. Working speeds were 1.26 $m \cdot s^{-1}$ (S.D. 0.085) for test 1, and 1.38 $m \cdot s^{-1}$ (S.D. 0.032) for test 2. Rice harvests were done with high working speed to improve traffic ability with high soil hardness. Advance times were 2198 s (S.D. 184) for test 1, and 1916 s (S.D. 117) for test 2. Turn times were 919 s (S.D. 93) for test 1, and 776 s (S.D. 143) for test 2. Advance distances were 2398 m (S.D. 54) for test 1 and 2343 m (S.D. 64) for test 2. Advance distances showed no difference among tests. Working distances of turning were 656 m (S.D. 39) for test 1, and 627 m (S.D. 69) for test 2. Test 2 showed a shorter turning distance than test 1 did. Total distances were 3111 m (S.D. 58) for test 1, and 3064 m (S.D. 96) for test 2. Fuel consumption was 3.05 $L \cdot 10\ a^{-1}$ (S.D. 0.369) for test 1, and 2.68 $L \cdot 10\ a^{-1}$ (S.D. 0.420) for test 2. Total work rates were 0.42 $h \cdot 10\ a^{-1}$ (S.D. 0.074) for test 1, and 0.48 $h \cdot 10\ a^{-1}$ (S.D. 0.222) for test 2. These work rate were similar to standard data of Japan (FARM WORK SCIENCE, 1999), too. Tab. 5 describes the coefficient of determination of fuel consumption and each investigation item. Dry basis moisture contents and fuel consumption showed a positive correlation, although soil hardness and fuel consumption showed a negative correlation. Coefficients of determination were, respectively, 0.57 and 0.67. Consequently, the fuel consumption of the combined rice harvest showed some relation to field conditions. Given high moisture contents in the field, decreased trafficability occurred because of softened soil. Therefore, the combine consumed fuel because of increased turn distance. Fuel consumption increased as the moisture contents of rough rice and foliage increased. Coefficients of determination were, respectively, 0.41 and 0.61. When it had high moisture contents of rough rice and foliage, the combine consumed much fuel to increase threshing power. Working speed and fuel consumption showed a negative correlation. The fuel consumption decreased as the working speed increased. Furthermore, the fuel consumption increased as the motion and turning time increased. Coefficients of determination between fuel consumption and advance and turn distances, and total distance were, respectively, 0.37, 0.40, and 0.42. These data showed only slight positive correlation. Fuel consumption increased as the distance increased.

Tab. 4. – The result of paddy rice harvest

	working method 1		working method2	
	Average	S.D.	Average	S.D.
Dry basis moisture contents	0.62	0.199	0.55	0.108
Soil hardness(MPa)	51.5	25.58	55.8	63.56
Moisture contents of rough rice(%)	23.6	2.31	23.6	2.77
Moisture contents of foliage(%)	67.4	3.35	66.0	2.56
Working speeds($m \cdot s^{-1}$)	1.26	0.085	1.38	0.032
Advance times(s)	2198	184	1916	118
Turn times(s)	919	94	776	143
Advance distances(m)	2398	54	2343	64
Working distances of turning(m)	656	39	627	69
Total distances(m)	3113	58	3064	96
Total work rates($h \cdot 10a^{-1}$)	0.42	0.074	0.48	0.222
Fuel consumption($L \cdot 10a^{-1}$)	3.05	0.369	2.68	0.420

Tab. 5. – The coefficient of determination of fuel consumption and each investigation item

	Coefficients of determination
Dry basis moisture contents	0.57
Soil hardness(mm)	0.77
Moisture contents of rough rice(%)	0.41
Moisture contents of foliage(%)	0.61
Working speeds($m \cdot s^{-1}$)	0.52
Advance times(s)	0.58
Turn times(s)	0.52
Advance distances(m)	0.37
Working distances of turn(m)	0.38
Total distances(m)	0.42

CONCLUSIONS

We examined factors that affect fuel consumption to change setting and work system through investigation of working properties of tillage, puddling, and harvesting of the paddy field to decrease fuel consumption using a power farming system. Tillage showed increased fuel consumption as the working speed increased. Puddling increased fuel consumption as the turning time and distance increased. Paddy rice harvesting showed a strong relation with fuel consumption and field conditions.

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