

Effects of Agricultural Machine Fuel Consumption on Paddy Fields

Shinsuke Konno¹, Hayato Shindo², Mitsuhiro Katahira¹ and Motoyasu Natsuga¹

1. Yamagata University, 1-23, Wakabamachi, Tsuruoka, Yamagata, 998-8555, Japan

2. Akita Agricultural Experiment Station, Yuwa, Akita, 010-0864, Japan

Abstract: Recently, rice-growing farmers in Japan have confronted difficult conditions and decreasing market prices of rice. The Shonai area of Yamagata prefecture, which has many medium-scale cultivated fields, is among Japan's largest rice cultivation areas. However, few studies have described the fuel consumption of agricultural machines in medium-scale paddy fields. Farmers in this area use some working systems, and fuel consumption can be reduced by changing the machine settings. Nevertheless, few studies have compared working systems related to fuel consumption. Therefore, the influence of different working systems (two methods for each of tillage, puddling and harvesting operations) on fuel consumption was investigated in medium-scale paddy fields. Working information for each agricultural machine was obtained using GPS logger attached to them. Fuel consumption was measured using a top fill method for each work test. The total work rates were 4.4 h/ha and 4.7 h/ha for method 1 and method 2 at tillage, 4.5 h/ha and 4.7 h/ha for method 3 and method 4 at puddling, respectively. Work rate was 4.0 h/ha for both method 5 and method 6 at harvesting (cutting width: 1,440 mm; work speed: 1.25 m/s and 1.35m/s). Results showed that the fuel consumptions were 23 L/ha and 26 L/ha for method 1 and method 2 at tillage, 17.2 L/h and 18.4 L/ha for method 3 and method 4 at puddling, and 30 L/ha and 28 L/ha for method 5 and method 6 at harvesting, respectively. These results showed no significant difference in fuel consumption between any working methods of rice cultivation. Tillage operation showed increased fuel consumption with higher working hours (included turn, back and other movements), higher total work time and also higher total distance. Puddling showed increased fuel consumption with higher working time that included turn and other movements. Harvesting operation showed increased fuel consumption as the total working time increased.

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

1. Introduction

In recent years, climate change has become remarkable, with increasing amounts of greenhouse gas discharging. Among all industrial fields, agriculture accounts for a small amount of greenhouse gas emissions [1]. Nevertheless, one must consider greenhouse gas reduction methods as long as they account for even some emissions. Reportedly, CO₂ accounts for 95% of greenhouse gases [1]. Therefore, to decrease greenhouse gas emissions, one must reduce CO₂ emissions by automobiles and tractors. Crude oil prices have been unstable in recent years. Because Japan has few mineral resources and thus strongly affected by crude oil prices, high prices

engender increasing costs of fossil fuels used for agriculture, thereby increasing agricultural product costs. Furthermore, rice farmers in Japan face a difficult predicament of agriculture management because of the downward trend of rice prices. Japanese farmers must reduce fuel consumption to control production costs.

Sakai et al. [2] reported that fuel consumption per hour increased as running speeds increased. Gotoh and Teshima [3, 4] conducted experiments to alter running conditions in three or four stages with a fixed tillage pace during rotary tilling. They demonstrated that fuel consumption during rotary tilling was reduced by shifting to a higher traveling speed gear and power take-off (PTO) gear, and by lowering the engine speed. Park et al. [5] reported that fuel efficiency was higher

Corresponding author: Mitsuhiro Katahira, associate professor, research field: agricultural machinery.

with a higher gear set during plowing, because it reduced working hours, but excessively higher speeds caused difficulties in maintaining uniform tillage depth. In other words, fuel consumption tends to decrease with reduced working hours by shifting to higher traveling speed gear, considering the engine load state during rotary tilling and plowing.

Gotoh and Teshima [6] reported that fuel consumption during puddling was reduced by shifting to a higher forward speed and PTO speed, and by lowering the engine speed with a fixed tillage pace. Nevertheless, few reports have studied the tractor fuel consumption during puddling.

Špokas and Steponavicius [7] reported that fuel consumption can be lowered when a combine-harvester with single threshing-separation rotor is stopped. Technological drives are switched off and the rotation velocity of the engine is reduced from 2,100 rpm/min to 1,200 rpm/min when not working. They also reported that hourly fuel consumption decreased when the stubble height was increased from 0.2 m to 0.3 m, while fuel consumption increased when rotation of the threshing-separation rotor is increased from 500 rpm/min to 650 rpm/min during rape harvesting. Some reports have described fuel consumption of combine-harvesters during harvesting of cereals; nevertheless few reports have studied the fuel consumption of head-feeding combines, which Japanese farmers often use during paddy rice harvesting.

Shonai area of Yamagata prefecture, is one of Japan's most productive rice cultivation areas with medium-scale cultivated fields. However, few studies have described the fuel consumption of agricultural machines in medium-scale paddy fields. Farmers in this area use some working systems. Some studies have reported that fuel consumption can be reduced by changing the machine settings, nevertheless few studies have compared working systems related to fuel consumption. Therefore, the objectives of this study were to examine the influences of different working

systems on fuel consumption in medium-scale paddy fields, to decrease fuel consumption and improve working efficiency, by choosing a proper operation system.

2. Materials and Methods

2.1 Experiment Location

The experiment was conducted in medium-scale paddy fields of the Yamagata Field Science Center in Faculty of Agriculture, Yamagata University in Takasaka, Yamagata, Japan during September-October in 2015 and April-October in 2016.

2.2 Machine Components

Some farm machines were used to investigate fuel consumption and the work rate of power farming systems on paddy fields, as following:

(1) A semi-crawler tractor (T1164C, 30.9 kW; Iseki Co. Ltd.) and a rotary tiller (WXY205 L-S; Iseki Co. Ltd.) were used for tillage (Fig. 1), and the engine revolution was set at 2,000 rpm and maintained the main shift gear and PTO gear for tillage;

(2) Puddling was done using a wheel-type tractor (GL467, 33.8 kW; Kubota Corp.) and a paddy harrow (PS248; Kobashi Kogyo Co. Ltd.) (Fig. 2); the engine revolution was set at 2,000 rpm and maintained the main shift gear and PTO gear;



Fig. 1 Semi-crawler tractor and a rotary tiller.



Fig. 2 Wheel-type tractor and a paddy harrow.



Fig. 3 Head-feeding type combine harvester.

(3) The rice was harvested using ahead-feeding combine (H064G, 44.9 kW; Iseki Co. Ltd.) as shown in Fig. 3.

2.3 Investigation Contents

Working information for each agricultural machine was obtained using a GPS logger (Trip Recorder 747 Pro; TranSystems Corp.) attached to them. The GPS logger can record the work speed and coordinates. Using the data of logger system, the work speed, work distance, total work time and work rate were analyzed. Fuel consumption was measured using a top fill method for each work test [8, 9].

2.4 Rice Cultivation Working Systems

Fig. 4 showed these methods. First, the headland was set in a paddy field and tillage was performed

using return tilling. Subsequently, till was operated using return and round tilling of about two rounds in the paddy field (method 1). Used return tilling and tilled in the headland (method 2). Puddling was done using return and round tilling at first. Then puddling was performed using return tilling (method 3). Furthermore, puddling was performed using round tilling (method 4). Both return and round harvesting was used for harvest in about four rounds in the paddy field. Then a method of return harvesting (method 5) was used. Furthermore, methods of both return and round harvesting were used with about seven rounds in the paddy field. And then, return harvesting (method 6) was used. Each method harvested from outside to inside on the paddy fields.

3. Results and Discussion

3.1 Tillage

Tillage results were presented in Table 1. Dry basis moisture contents obtained using methods 1 and 2 were not significantly. The pulverization rate, tillage depth, slippage and the average working speed of advance work did not differ between them. The target of tillage depth was 15 cm. The total working rates were 4.4 h/ha and 4.7 h/ha for method 1 and method 2, respectively. No significant difference was found between them. There was also no significant difference of the fuel consumption (23 L/ha for method 1 and 26 L/ha for method 2, respectively).

Fig. 5 showed the influence of total work time on fuel consumption in tillage. Total work times and fuel consumption pointed out a positive correlation with the coefficient of 0.68. Fig. 6 presented the influence of turn and back times (ineffective working time) on fuel consumption in tillage. These times and fuel consumption showed a positive correlation with coefficient 0.87. Fig. 7 presented the influence of total distance on fuel consumption in tillage. A positive correlation was also found for total distance and fuel consumption with the coefficient of 0.62. For tillage, method 2 had more turn and back distances than

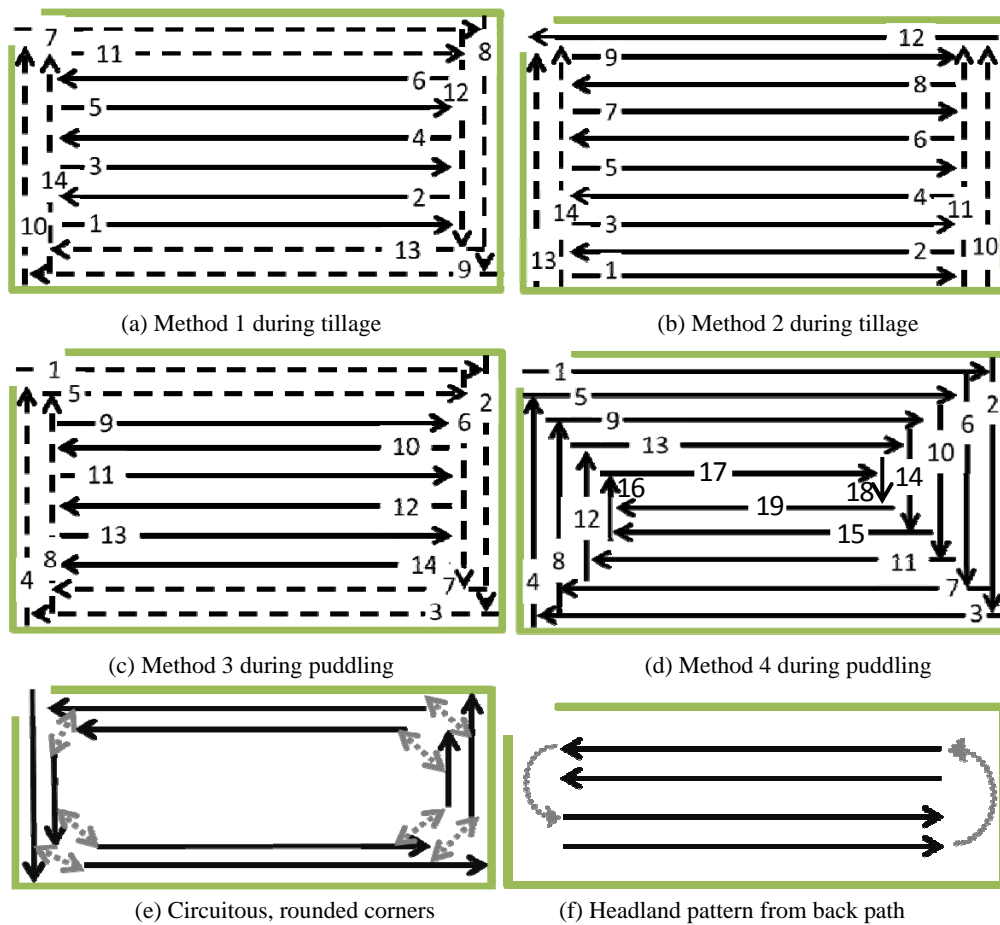


Fig. 4 Working methods.

Table 1 Tillage results.

Parameters	Method 1	Method 2	<i>t</i> -test
Number of replications	4	4	
Dry basis moisture content (%)	64.0 ± 8.3	51.5 ± 12.0	NS
Pulverizing rates (%)	25.1 ± 10.42	22.6 ± 11.58	NS
Tillage depth (cm)	14.6 ± 1.28	14.5 ± 0.80	NS
Slippage (%)	0.32 ± 1.282	-0.52 ± 0.296	NS
Running speed (m/s)	0.41 ± 0.004	0.40 ± 0.027	NS
Total work rates (h/ha)	4.4 ± 0.09	4.7 ± 0.34	NS
Fuel consumption (L/ha)	23 ± 2.9	26 ± 1.7	NS

NS: not significant.

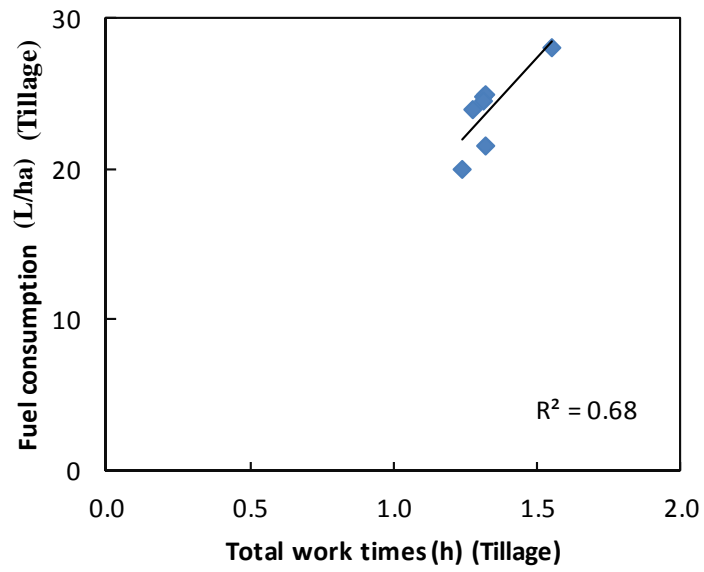


Fig. 5 Influence of total work time on fuel consumption during tillage.

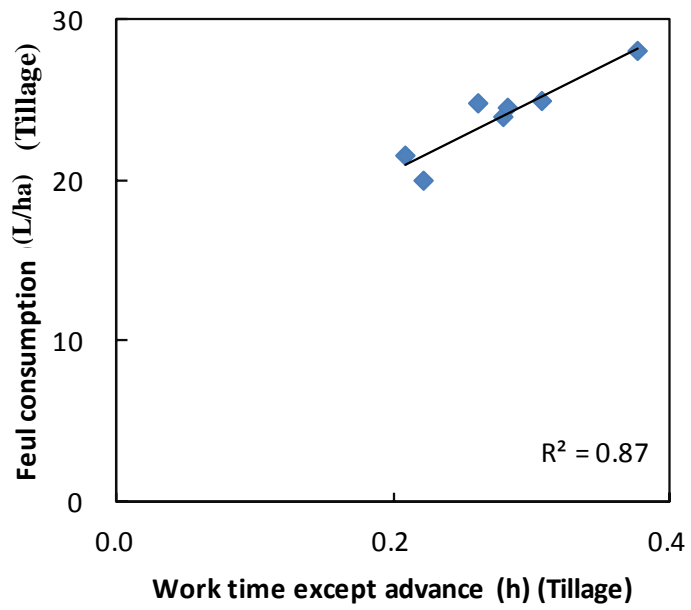


Fig. 6 Influence of ineffective working time on fuel consumption during tillage.

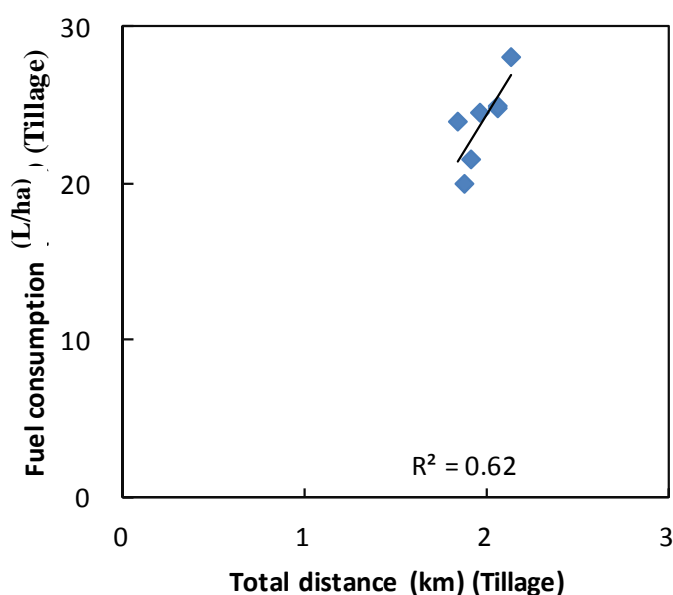


Fig. 7 Influence of total distance on fuel consumption during tillage.

Table 2 Puddling result.

Parameters	Method 3	Method 4	<i>t</i> -test
Number of replications	3	4	
Soil surface hardness (cm)*	2.1 ± 0.48	2.0 ± 1.64	NS
Depth from soil surface to plowsole layer (cm)	15.8 ± 2.56	15.8 ± 2.60	NS
Running speed (m/s)	0.50 ± 0.020	0.50 ± 0.012	NS
Total work rates (h/ha)	4.5 ± 0.24	4.7 ± 0.19	NS
Fuel consumption (L/ha)	17 ± 0.7	18 ± 1.8	NS

* Soil surface hardness (cm) indicates the depth from the soil surface to the bottom surface by dropping a golf ball from a height of 1 m; NS: not significant.

method 1 did, thus increasing its total distance. Therefore, method 2 showed greater waste of distances than method 1. In addition, method 2 had more turn and back times than method 1 did. Because results showed a close correlation between total distance and fuel consumption, there was also close correlation between turn and back times and fuel consumption in tillage. Fuel consumption showed no significant difference between tillage methods, but method 2 tended to use more fuel than method 1. Therefore, method 1 can work more effectively than method 2 for tilling on a medium-scale paddy field.

3.2 Puddling

Table 2 presented puddling results. Soil surface

hardness by golf ball, depth from surface to plow soil, the average working speed of advance work did not differ between methods 3 and 4. The total work rate was 4.5 h/ha and 4.7 h/ha for method 3 and method 4, respectively. There was no significant difference between them. There was also no significant difference of the fuel consumption (17 L/ha and 18 L/ha for these two methods, respectively). Fig. 8 showed the influence of working times except for advances in fuel consumption on puddling. Working times except for advance were positively related with fuel consumption with the coefficient of 0.70. Work times except for advance did not vary significantly between methods 3 and 4. Therefore, their fuel consumption was similar.

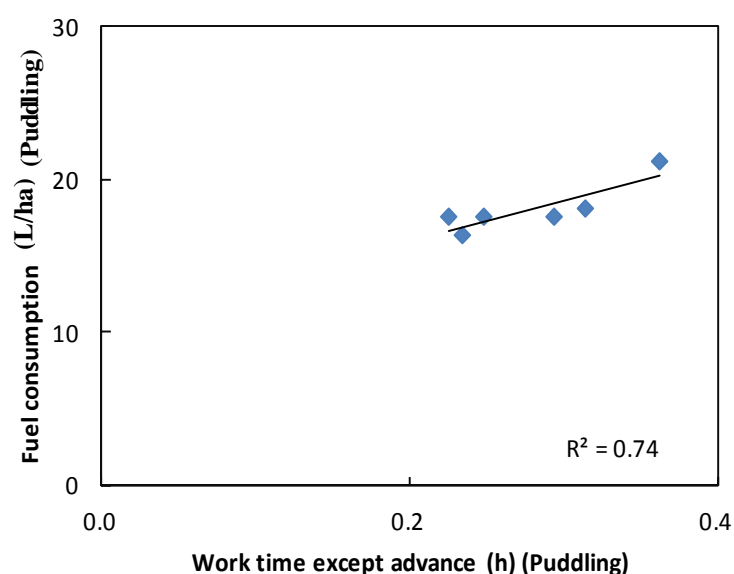


Fig. 8 Influence of ineffective operation time on fuel consumption during puddling.

Table 3 Paddy rice harvesting results.

Parameters	Method 5	Method 6	<i>t</i> -test
Number of replications	7	7	
Dry basis moisture content (%)	66.0 ± 16.16	67.3 ± 29.11	NS
Soil hardness (MPa)	26 ± 35.2	32 ± 57.1	NS
Culm length (cm)	91 ± 5.6	89 ± 6.2	NS
Stand angle (°)	77 ± 3.8	80 ± 2.8	NS
Stubble height (cm)	17 ± 2.8	18 ± 2.5	NS
Plant density (number of hill/m ²)	23.7 ± 1.47	23.1 ± 1.50	NS
Moisture contents of rough rice (%)	23.4 ± 2.20	23.1 ± 2.37	
Moisture contents of foliage (%)	69.0 ± 3.08	66.5 ± 2.77	
Working speed (m/s)	1.25 ± 0.067	1.35 ± 0.042	*
Total work rates (h/ha)	4.0 ± 0.59	4.0 ± 1.49	NS
Fuel consumption (L/ha)	30.3 ± 3.6	28.3 ± 3.7	NS

NS: not significant; * $P < 0.05$.

3.3 Harvest

Table 3 presented paddy rice harvesting results. Dry basis moisture content, soil hardness, culm length, stand angle, moisture contents of rough rice, moisture contents of foliage, stubble height and planting density did not show great difference between methods 5 and 6. There was significant difference of average working speed of advance work between methods 5 and 6. The total work rate was 4.0 h/ha for both methods 5 and 6. Fuel consumption was 30.3 L/ha for method 5 and 28.3 L/h for method 6. No

significant difference was found between them.

3.4 Work Time and Work Distance for Tillage, Puddling and Harvesting

Table 4 presented results of work time and work distance for each working method. The work time and work distance for tillage, puddling and harvesting was in a 0.3 ha field. For tillage, advance times, advance distances and total work times did not differ significantly between methods 1 and 2, while work times except for advance, work distances except for advance, and total distances differ significantly

between them.

For puddling, advance times did not differ significantly between methods 3 and 4. The number of turns varied between them, but no significant difference between them was found for turn times. So the total turn times were either not significantly different between them.

For paddy rice harvesting, advance times and turn times differ significantly between methods 5 and 6. No significant difference was found between them for total work times, advance distances, working distances of turning or total distances. Because these times and distances are affected by field conditions; in

bad field conditions, the agricultural machine running performance worsened. In such cases, more fuel is needed because agricultural machines require more power.

Fig. 9 depicted the influence of total work times on fuel consumption when harvesting paddy rice. Positive correlation was found for total work times and fuel consumption with the coefficient of 0.70.

For tillage and paddy rice harvesting, total work times strongly affect fuel consumption. Therefore, if one tills paddy field and harvest paddy rice on a medium-scale field with shorter total work times, one can reduce fuel consumption. Consequently, one should

Table 4 Results of work time and work distance for tillage, puddling and harvesting.

Parameters		Tillage		Puddling		Harvesting paddy rice	
		Method 1	Method 2	Method 3	Method 4	Method 5	Method 6
Work time (h)	Advance	1.04	1.07	1.08	1.03	0.59*	0.55*
	Other ¹	0.24*	0.31*	0.20	0.22	0.24*	0.20*
	Total	1.28	1.38	1.33	1.34	1.18	1.20
Work distance (km)	Advance	1.57	1.57	-	-	2.35	2.39
	Other ¹	0.30*	0.48*	-	-	0.51	0.47
	Total	1.87*	2.05*	-	-	3.07	3.07

-.: not significant; * $P < 0.05$.

¹ Other time in tillage including turn, back and other movement; other time in puddling including turn and other movement; other time in harvesting including turn, working in corner.

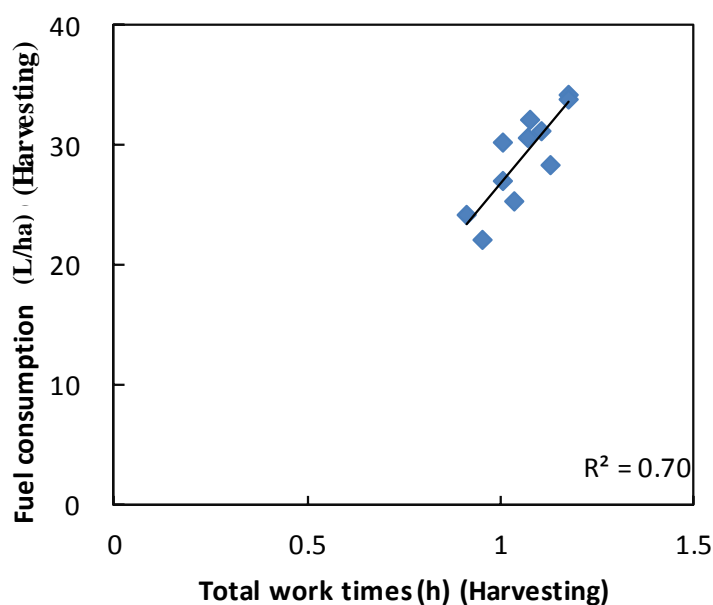


Fig. 9 Influence of total working time on fuel consumption during paddy rice harvesting.

reduce the progress of work, turn and back to reduce the total work time while using agricultural machines that have suitable horsepower matched with the field scale. One must remember to work at appropriate times, and to work with adequate field conditions and working speeds without exacerbating running performance or work accuracy.

4. Conclusions

The influence of working systems on fuel consumption during tillage, puddling and harvesting of paddy rice was examined in this study. No significant difference in fuel consumption was found between methods 1 and 2 for tillage, methods 3 and 4 for puddling, and methods 5 and 6 for harvesting. Fuel consumption during tillage increased as work time except for advance, total work time and the total distance increased. Fuel consumption during puddling increased within effective operation time. Fuel consumption at paddy rice harvesting increased as the total operation time increased.

References

- [1] National Institute for Agro-environmental Sciences. 2011. "Global Research Alliance on Greenhouse Gases in Agriculture." Accessed August 14, 2017. <http://www.naro.affrc.go.jp/archive/niaes/magazine/133/mgzn13310.html>. (in Japanese)
- [2] Sakai, N., Sunohara, W., Takatsuka, S., Eto, K., and Tsunoda, K. 1984. "Effects of Soil Texture and Travelling Speed on Fuel Consumption in Plowing." *Farm Work Research* 50: 14-9.
- [3] Gotoh, T., and Teshima, T. 2009. "Effect of Operating Conditions of an Agricultural Tractor on Fuel Consumption (Part 1)." *Journal of the Japanese Society of Agricultural Machinery* 71 (5): 67-72.
- [4] Gotoh, T., and Teshima, T. 2009. "Effect of Operating Conditions of an Agricultural Tractor on Fuel Consumption (Part 2)." *Journal of the Japanese Society of Agricultural Machinery* 71 (5): 73-90.
- [5] Park, S. J., Kim, Y. J., and Lee, D. H. 2013. "Analysis of Load and Fuel Efficiency of Agriculture Tractor by Gear Selection during Plow Tillage." *International Journal of Food, Agriculture and Environment* 11 (3-4): 631-5.
- [6] Gotoh, T., and Teshima, T. 2010. "Effect of Operating Conditions of an Agricultural Tractor on Fuel Consumption (Part 3)." *Journal of the Japanese Society of Agricultural Machinery* 72 (1): 63-71.
- [7] Spokas, L., and Steponavicius, D. 2011. "Fuel Consumption during Cereal and Rape Harvesting and Methods of Its Reduction." *Journal of Food, Agriculture & Environment* 9 (3-4): 257-63.
- [8] Editorial Committee of Test Methods of Farm Work. 1987. *Test Methods of Farm Work*. Japan: Japan Forest Technology Association.
- [9] Japanese Society of Farm Work Research. 1999. *Farm Work Science*. Japan: Association of Agriculture and Forestry Statistics.