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Analysis of Fuel Consumption Rate of A Rotary Power Tiller on Various Tillage Patterns

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ABSTRACT

This study aimed to investigate the effect of five tillage patterns on fuel consumption rate. The five tillage patterns applied were 1) gathering pattern, 2) casting pattern, 3) one way pattern, 4) spiral pattern, and 5) alpha pattern. While, rotary power tiller operation was set for a) with-no implement and b) with implement. During the rotary power tiller operation, total time consumed (t) and fuel consumption rate (FCR) were measured. As the result, different tillage pattern gave different t and FCR values for the both conditions of rotary power tiller operation namely with-no implement and with implement conditions. The alpha pattern gave the highest values, for which t values were 11.77 and 13.67 minutes, respectively, and FCR values were 10.77 and 14.87 liters/ha, respectively. On the other hand, the one way pattern was found to be the most efficient after giving the lowest values, for which t values were 5.86 and 8.60 minutes, respectively, and FCR values were 4.27 and 5.04 liters/ha, respectively. The data further confirmed a positive correlation between t and FCR. This result suggested that tillage patterns affect t, by which FCR could be altered. In this case, the number of turning passage was thought as the property of tillage pattern that affects t. The higher values of t and FCR for the rotary power tiller operation with implement than those of the tractor operation with-no implement were probably due to the greater engine power required for dealing with the operated implement and tillage draft.

1. INTRODUCTION

Soil tillage plays an important role in agricultural processes by providing more proper soil properties through mechanical, biological, and chemical modifications for a better crop growth and yield (Qingjie *et al*., 2014; Ji *et al*., 2013; Mosaddeghi *et al*., 2009). The soil tillage may also give beneficial in weed, pest, and erosion controls (Sadiq *et al*., 2021; Lobb *et al*., 2007) as well as decomposition process of soil organic matter (Shang & Tiessen, 2003; Six *et al*., 2000).

Various tillage systems like conventional tillage, reduced tillage, zero tillage, conservation tillage, etc. have been widely developed and adopted by farmers into practices worldwide (Qamar *et al*., 2021; Gholami *et al*., 2014). In Indonesia, conservation tillage that commonly comprises of plowing (primary tillage) and harrowing (secondary tillage) downs into practices by farmers in two ways: a) traditionally using hoe and traditional plow/harrow, and b) modern-mechanically using tractor with the attached plow/harrow implement. For the latter, there are five types of tillage pattern have been introduced: gathering pattern, casting pattern, one way pattern, spiral pattern, and alpha pattern, of which some are familiar and practical already to farmers (Dahono, 1997; IRRI, 2007; Sinaga *et al*., 2015; Wirasantika *et al*., 2015).

On the other hand, fuel consumption is of a great importance in the selection, operation, and management of farm tractor and equipment (Taiwo, 2015; Mardinata and Zulkifli, 2014). Optimizing efforts of this fuel consumption is essential for improving the economic efficiency of agricultural enterprise, and may be environmental-friendly due to the very rapid dwindling in supply of the nonrenewable fossil fuel worldwide (Taiwo, 2015). In tillage practices, rate of fuel consumption may closely relates to some factors like tractor's speed and tillage depth (Nizatillah *et al*., 2019; Handayani, 2017; Mardinata and Zulkifli, 2014).

Some studies on these tillage patterns and fuel consumption rate have been conducted by others. For instance, Wirasantika *et al*. (2015) have tested the performance of 4 wheels tractors after adopting two types tillage patterns namely casting pattern and one way pattern on clay sandy soil. As the result, they found that the tillage pattern may affect the tillage result and energy consumption as well. Likewise, Sinaga *et al*. (2015) have conducted performance test on walking tractor for a wetland by employing two tillage patterns namely casting pattern and alpha pattern. Their results showed that the tillage patterns had significant effects on field capacity, fuel consumption, and tractor efficiency.

Nevertheless, data on these five tillage patterns namely gathering pattern, casting pattern, one way pattern, spiral pattern, and alpha pattern (Dahono, 1997; IRRI, 2007; Sinaga *et al*., 2015; Wirasantika *et al*., 2015) in term of fuel consumption remains scarce. Therefore, this study was conducted in order to investigate the effect of these five tillage patterns on fuel consumption rate of rotary power tiller operations.

2. MATERIALS AND METHODS

2.1. Tools, Machine, and Materials

Part of the experimental field that belongs to Paddy Seed and `Palawija` Center of Sub-district Purwanegara, Banjarnegara Region, Central Java Province of Indonesia, was taken as the research site. The altitude was about 153 m above sea level and located at 7°26`11.05" - 7°26`12.69" S and 109°33`35.2" - 109°33`36.10" E. The soil was loam (Table 1) and formerly cultivated with corn. The field was preliminarily cleared from weeds and crop debris, and then lightly harrowed to maintain the soil structure becomes uniform before the research treatments were latterly carried out. Upon this targeted field, five plots sized 195 m^2 (13.0 m x 15.0 m) of each that distanced 1.5 m each other were prepared as shown in Figure 1.

Table 1. Soil physical properties of the experimental field employed

Water content (%)	49.51
Dry bulk density (g/cm^3)	0.99
Partikel density (g/cm^3)	2.36
Texture:	
Sand (%)	38.22
Silt (%)	49.44
Clay (%)	12.34

Source: Laboratory of Soil, Faculty of Agriculture, Jenderal Soedirman University (2018)

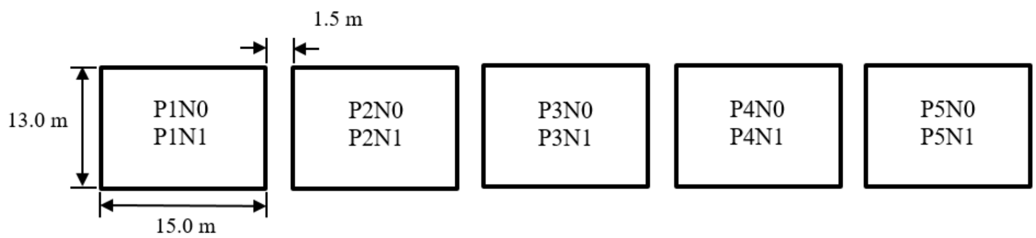

Figure 1. The targeted experimental field design (Note: P was tillage pattern, of which P1 = gathering pattern, P2 = casting pattern, P3 = one way pattern, P4 = spiral pattern, P5 = alpha pattern. N was power tiller's operation type, of which N0 = no-implement and N1 = with implement)

The tractor used in this study was a power tiller TR120 from Tong Yang Moolsan Co. Ltd. - TYM (Table 2) implemented with a rotary cultivator (Figure 2). The power tiller was operated at "low" rotary speed (PTO shift lever) and "1" tractor speed (main shift lever) by a professional operator within the forward speed 0.34 m/s for all combinations of the following research treatments employed.

Table 2. Specification of the rotary power tiller used during experiment

Specification	**Type/value**
Type	TYM-TR120
	Length (2465)
Dimension (mm)	Height (1180)
	Width (857)
Main clutch type	Disc clutch
Transmission type	Gear-gear
Number of shifts	F6, R2
Steering clutch type	Dogh clutch
Tire size	6-12
Weight (kg)	405 (422.5)
Rotary cultivator width (mm)	850
Rotary blade type	Opposite mounting of left or right bend blades

Figure 2. Rotary power tiller employed

2.2. Research Treatments

There were two research treatments applied: 1) soil tillage patterns, and 2) power tiller's implement usage. The soil tillage patterns consisted of P1: gathering pattern, P2: casting pattern, P3: one way pattern, P4: spiral pattern, and P5: alpha pattern (Figure 1, Figure 3). While, the power tiller's implement usage consisted of N0: no-implement, and N1: with implement (Figure 1). The implement used was a rotary cultivator (Tong Yang Moolsan Co. Ltd. - TYM), for which N0 treatment was the condition of rotary power tiller operation with no-implement attached (rotary blades were not operated into the soil), and N1 treatment was the condition of rotary power tiller operation with implement attached (rotary blades were operated into the soil).

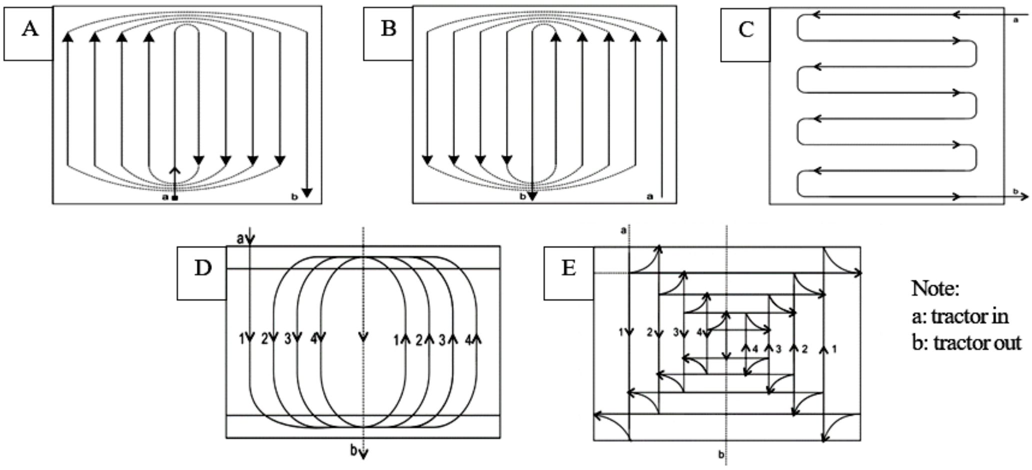

Figure 3. The soil tillage patterns employed: A) gathering pattern, B) casting pattern, C) one way pattern, D) spiral pattern, and E) alpha pattern (Dahono, 1997; IRRI, 2007; Sinaga *et al*., 2015; Wirasantika *et al*., 2015)

2.3. Variables and Measurements

Before a certain combination of research treatments was applied to a certain targeted research plot (Figure 1), undisturbed soil sample was preliminarily taken from the plot using standard soil core sampler (5 cm in diameter and 5 cm in height) for soil water content w (%) and dry bulk density ρ_d (g/cm^3) measurements. The sample was taken within 15 cm soil depth for 3 replications, assuming that the depth of tillage latterly conducted was 0 – 15 cm. Upon these samples, measurements of w and ρ_d were conducted using gravimetric method as also applied in Kuncoro *et al*. (2015; 2014a; 2014b) after the samples were being oven-dried within 105 °C for 24 hours.

Upon a certain targeted plot (Figure 1), the employed rotary power tiller was operated to cover the plot using a certain targeted tillage pattern without rotary blades operation into the soil (no-implement treatment). Still using the same tillage pattern, this work was then followed by tractor operation with the rotary blades operation into the soil (with implement treatment). Each of these works was conducted within 3 replications, and the time consumed for each work was recorded using stopwatch. All these works have been conducted and completed within the same day.

Along with this measurement of total time consumed, fuel consumption of the rotary power tiller employed was also measured using the following method. The fuel tank of rotary power tiller was preliminarily filled up with diesel fuel before it was operated on the targeted field. The fuel tank was filled up again with diesel fuel using beaker 500 ml after the rotary power tiller operation. This amount of diesel fuel added was then taken as the amount of fuel consumption (liters) of the rotary power tiller employed. Finally, the fuel consumption rate *FCR* may be calculated using the following formula (Butar *et al*., 2015):

$$FCR = \frac{V_{add}}{A} \tag{1}$$

where: *FCR* is the fuel consumption rate (liters/ha), V_{add} is the amount of fuel added (liters), and *A* is the area of land employed (ha).

2.4. Data Analysis

Collected data of the all variables measured were analyzed using structured (table) and graphical data. The statistical significance were examined using Student's *t*-test and analysis of variance (ANOVA) with post-hoc analysis of Tukey's HSD test ($P < 0.05$). These statistical analysis were performed using KaleidaGraph 4.1 software (Synergy Software 2012, USA) as used in Kuncoro *et al*. (2015; 2014a; 2014b).

3. RESULTS AND DISCUSSION

3.1. Soil Water Content and Dry Bulk Density

Results in Table 3 and Table 4 simply revealed that amongst the tillage patterns employed, soil water content *w* and dry bulk density ρ_d seemed to be not so different one another, and this was well confirmed by none statistical significant difference noticed for both no-implement and with implement treatments. If we take a look to each tillage pattern and comparing between no-tillage and with tillage condition, ρ_d values of the latter tended to slightly higher than those of the former, and likewise this was also confirmed statistically. This slightly higher ρ_d value was likely related to the possible occurrence of soil compaction by the previous passage of rotary power tiller employed within no-implement condition (Marinello *et al*., 2017; Chyba *et al*., 2014), because the rotary power tiller operation with implement condition was conducted using the same research plot afterward.

Table 3. Average value of soil water content before a certain tillage pattern was applied

Tillage pattern	Soil water content, *w* (%)	
	No-implement (N0)	**With implement (N1)**
Gathering	47.08 ± 0.64 Aa	36.17 ± 1.61 Ba
Casting	48.29 ± 2.39 Aa	35.21 ± 0.08 Ba
One way	47.29 ± 2.80 Aa	33.69 ± 2.26 Ba
Spiral	41.91 ± 2.56 Aa	38.60 ± 0.24 Aa
Alpha	43.71 ± 4.19 Aa	36.85 ± 3.67 Aa

Note: values of *w* followed by the same capital letter (row), and lowercase letter (column), are not significantly different ($P < 0.05$)

Table 4. Average value of soil dry bulk density before a certain tillage pattern was applied

Tillage pattern	Soil dry bulk density, ρ_d (g/cm^3)	
	No-implement (N0)	**With implement (N1)**
Gathering	0.99 ± 0.02 Aa	1.06 ± 0.09 Aa
Casting	0.83 ± 0.21 Aa	0.99 ± 0.14 Aa
One way	1.03 ± 0.03 Aa	1.06 ± 0.03 Aa
Spiral	1.01 ± 0.03 Aa	1.02 ± 0.05 Aa
Alpha	1.03 ± 0.03 Aa	1.03 ± 0.03 Aa

Note: values of ρ_d followed by the same capital letter (row), and lowercase letter (column), are not significantly different ($P < 0.05$)

In case of *w* values, however, the difference was a bit more noticeable, of which the latter resulted lower *w* values than the former, and this was statistically significant for the gathering pattern, casting pattern, and one way pattern. This lower *w* value was probably owed to the possible occurrence of evaporation (Piri *et al.*, 2021; Klocke *et al.*, 2009) since the rotary power tiller operation with implement attached was conducted at noon, while the rotary power tiller operation within no-implement condition was conducted in the morning. Overall, this narrow range of both *w* and *pd* values was probably owed to the preliminary condition of research plot that had been cleared from crop debris and harrowed, by which physical properties of the soil became relatively uniform. Besides, *w* and ρ_d were not designed as research treatment in this study.

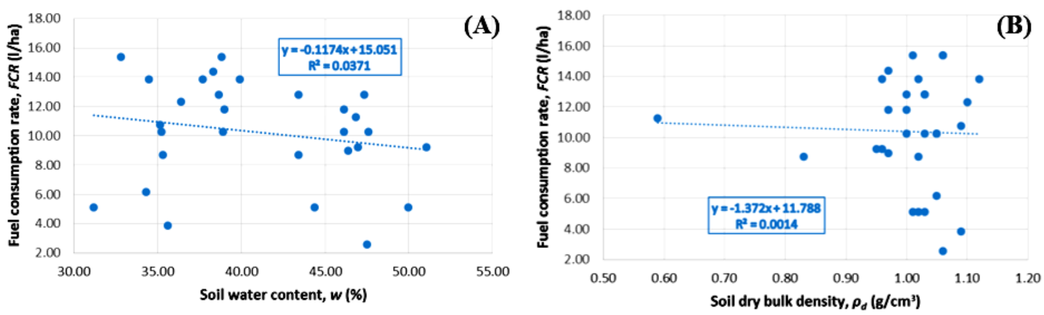

Figure 4. Relationship between: (A) soil water content and fuel consumption rate, and (B) soil dry bulk density and fuel consumption rate

Our data from this study as shown in Figure 4 simply revealed that there was clear relationship neither between *w* and *FCR* nor between ρ_d and *FCR*. This might be due to the very narrow range of *w* and ρ_d measured in this study. Indeed this must be reasonable to take the both *w* and ρ_d into account when dealing with *FCR* since they may have an influence on rotary power tiller's movability, by which total time consumed for the operation of rotary power tiller and thus the *FCR* may be influenced. Therefore, further study upon this issue is considerably needed.

3.2. Total Time Consumption

The results as shown in Table 5 revealed that the lowest average value of total time consumed for the field operation of rotary power tiller employed was resulted by one way pattern for both treatments of no-implement and with implement conditions as of 5.86 and 8.60 minutes, respectively. The highest value, on the other hand, was resulted by alpha pattern as of 11.77 and 13.67 minutes, respectively. The difference was only observed to be statistically significant between one way pattern and alpha pattern for both no-implement and with implement conditions. In case of the other tillage patterns, however, the difference was not statistically significant and remained varies each other. Nevertheless, the data might suggest that the type of tillage pattern applied may differ the total time consumed for a certain rotary power tiller operation.

Table 5. Average value of the total time consumed for each type of tillage patterns applied

Tillage pattern	Total time consumed, *t* (minutes)	
	No-implement (N0)	With implement (N1)
Gathering	8.74 ± 0.36 Ac	10.31 ± 1.51 Aabc
Casting	9.56 ± 0.46 Aecd	10.87 ± 0.81 Babc
One way	5.86 ± 0.96 Ab	8.60 ± 0.30 Ab
Spiral	9.10 ± 0.41 Adc	8.84 ± 1.68 Acb
Alpha	11.77 ± 1.23 Aa	13.67 ± 1.55 Ba

Note: values of *t* followed by the same capital letter (row), and lowercase letter (column), are not significantly different ($P < 0.05$)

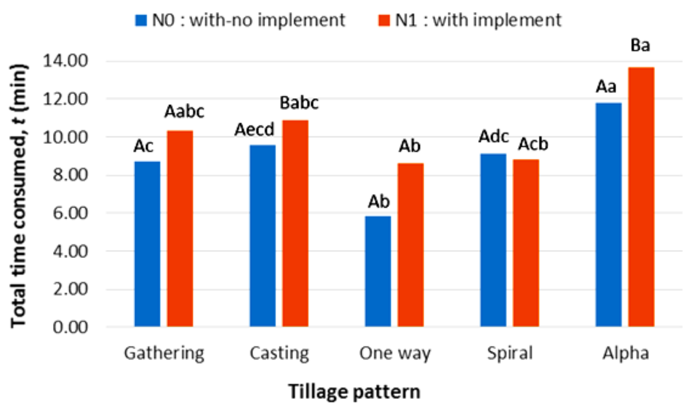

Figure 5. Average value of the total time consumed for each type of tillage patterns employed (Note: for each of tillage pattern, bars with the same capital letter are not significantly different; and for each of implement treatments, bars with the same lowercase letter are not significantly different ($P < 0.05$)

This observed lower value of total time consumed resulted by the one way pattern was likely due to the less number in turning passage as well as total length of the passage covered by the rotary power tiller operation (Figure 3). Conversely, the higher number in turning passage and total passage length performed by the rotary power tiller operation using alpha pattern was thought to contribute to the higher value of the total time consumed. Sinaga *et al*. (2015) has reported that alpha pattern has a higher number of tractor's turning passage after their study on the performance of walking tractor operation using casting pattern and alpha pattern. Further, Sulnawati *et al*. (2016) and Sinaga *et al*. (2015) also reported that tractor's time for turning has a contribution to the total time loss encountered.

Comparing between no-implement and with implement treatments, results shown in Table 5 and Figure 5 revealed that rotary power tiller operation with implement attached gave a higher value of the total time consumed, except for spiral pattern that resulted values as of 9.10 and 8.84 minutes, respectively. Unfortunately, reason for this discrepancy was not apparent in this study. Despite the statistical significant difference that only noticed for the casting pattern and alpha pattern, however, overall the result might suggest that the operated rotary blades into the soil may cause an increase in total time consumed in this study. In line with this, Manggala *et al*. (2014) also reported that tractor operation with implement would result a higher time consumption compared to the tractor operation without implement.

Within the condition of no-implements attached, the rotary power tiller may just simply move forward without any efforts required to dealing with tillage draft from the soil and the hauled and operated rotary blades as well. As the attached rotary blades work into the soil, the soil may react by providing a tillage draft (Imantho *et al*., 2022; Ismail *et al*., 2012), which may hinder the tractor movement forward. Adding to this, the operated rotary blades may act as the hauled load to the tractor, which in turn, may decrease the tractor's speed forward, and consequently the total time consumed would increase. In line with this, Desrial *et al*. (2010) has reported that an increase of hauled load to the tractor would decrease the tractor's forward speed, and consequently the tractor's drawbar power decreased but the tractor's drawbar pull increased.

3.3. Fuel Consumption Rate

From Table 6, it could be seen that tillage patterns applied gave different fuel consumption rates (*FCR*) each other. The one way pattern gave the lowest *FCR* value for the both no-implement and with implement conditions as of 4.27 and 5.04 liters/ ha, respectively. On the other hand, the alpha pattern followed by spiral pattern gave the highest *FCR* value as of 14.87 and 14.19 liters/ha, respectively for the condition with implement treatment. However, this was conversely for the condition of no-implement treatment as of 11.11 and 10.77 liters/ha, respectively. Despite the statistical significant difference that only observed for one way pattern and casting pattern, the data might suggest that tillage pattern affects fuel consumption rate *FCR*, of which the lowest and the highest *FCR* values were found for one way pattern and alpha pattern, respectively.

This lower *FCR* value resulted by one way pattern was likely due to the less number in turning passage as well as total length of the passage (Figure 3) with the entailed less value of the total time consumed for the rotary power tiller operation (Table 5). While, the higher *FCR* value resulted by alpha pattern was reasonably contributed by the higher number in turning passage as well as total length of the passage (Figure 3) with the entailed higher value of the total time consumed (Table 5). This result might suggest that the longer period of the rotary power tiller operation is the higher fuel consumption rate *FCR* becomes.

Table 6. Average value of fuel consumption rate of the rotary power tiller employed for each type of tillage patterns applied

Tillage pattern	Fuel consumption rate, *FCR* (liters/ha)	
	No-implement (N0)	With implement (N1)
Gathering	10.68 ± 1.96 Aa	13.34 ± 0.89 Aa
Casting	9.91 ± 1.18 Aa	9.92 ± 1.07 Ac
One way	4.27 ± 1.48 Ab	5.04 ± 1.15 Ab
Spiral	11.11 ± 2.13 Aa	14.19 ± 1.29 Ba
Alpha	10.77 ± 0.88 Aa	14.87 ± 0.88 Ba

Note: values of *FCR* followed by the same capital letter (row), and lowercase letter (column), are not significantly different ($P < 0.05$)

This result was in a good agreement with the finding of Sinaga *et al*. (2015) that fuel consumption rate of tractor is highly affected by the total time consumed for the tractor operation, of which a longer tractor operation results a higher fuel consumption rate. Similarly, Wirasantika *et al*. (2015) also reported that tillage patterns might affect fuel consumption rate due to several factors engaged including tractor's turning passage, of which a more turning passage would cause a longer period of the tractor operation, and thus, the entailing increase of fuel consumption rate.

Adding to this, the used small sized plot in this study (13 m x 15 m) (Figure 1) might give obstacle to the rotary power tiller employed when dealing with the turning passage (Sulnawati *et al*., 2016), which may increase the total time consumed, and thus the entailed fuel consumption rate. While, Sinaga *et al*. (2015) further mentioned that the number of turning passage would affect the tractor's thermal efficiency due to the increased both time and fuel consumed. Accordingly, this might become presumable that to some extents there is a correlation between soil tillage patterns and thermal efficiency of the rotary power tiller employed, and thus, correlation between the soil tillage pattern and the fuel consumption rate of the rotary power tiller employed, even though the thermal efficiency was not measured in this present study.

Our data in this present study as shown in Figure 6 further confirmed the aforementioned discussion that the higher fuel consumption rate was likely related to the higher total time consumed for the operation of rotary power tiller employed. Data scattering in this figure was considered to giving an insight for an existence of positive correlation between the total time consumed and fuel consumption rate, despite the small coefficient of determination R^2 0.4232. This small value of R^2 was probably owed to the limited range of the total time consumed observed. Other than this, the small value of R^2 might rather suggest the existence of other factors those affect the fuel consumption rate, like tillage depth and tractor's working speed (Nizatillah *et al*., 2019; Handayani, 2017; Mardinata and Zulkifli, 2014) those were not taken into account in this present study.

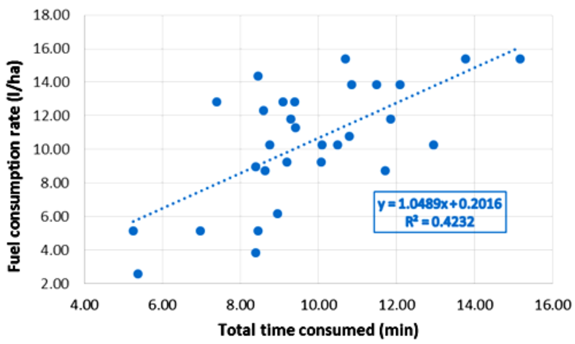

Figure 6. Relationship between total time consumed and fuel consumption rate of the rotary power tiller employed

Comparing between no-implement and with implement treatments, results shown in Table 6 suggested that rotary power tiller operation with implement operated gave a higher value of fuel consumption rate *FCR* regardless the tillage patterns employed, except for casting pattern. A statistical significant difference was only observed for both spiral and alpha patterns, and the highest difference between the two no-implement and with implement treatments was found for the alpha pattern. In case of casting pattern, the resulted *FCR* was very similar as of 9.91 and 9.92 liters/ha for these both no-implement and with implement treatments, respectively (Table 6) regardless the difference in total time consumed as of 9.56 and 10.87 minutes, respectively (Table 5). We supposed this might be related with the possible occurrence of wheel slip during the rotary power tiller operation. However, the more distinctive reason for this discrepancy was remained not apparent in this study since the wheel slip was not measured.

The result of higher *FCR* for the condition with implement than the condition of no-implement (Table 6) was considerably related to the higher value of total time consumed (Table 5). Adding to this, the rotary power tiller employed required more power to deal with tillage draft from the soil, the attached rotary tiller as the hauled load, and the required power to rotating the rotary blade. Thus, the rotary power tiller employed would use more engine power, by which the fuel consumption rate increased. This result was in a good agreement with Manggala *et al.* (2014) who reported that tractor operation with implement would result a higher fuel consumption compared to the tractor operation without implement.

4. CONCLUSION

Types of tillage patterns applied have an effect on fuel consumption rate (*FCR*), and this is considerably due to the number of turning passage they have, by which total time consumed (*t*) may be affected. Our data further confirmed a positive correlation between these *t* and *FCR*. Our data also revealed that rotary power tiller operation with implement attached (N1 treatment) results a greater *FCR* than the rotary power tiller operation with no-implement attached (N0 treatment), which probably due to the required greater engine power for dealing with the operated rotary blades and tillage draft as well. The highest *t* and *FCR* values were found for alpha pattern as of 11.77 minutes and 10.77 liters/ha for N0 treatment, and 13.67 minutes and 14.87 liters/ha for N1 treatment, respectively. On the other hand, the one way pattern was found to be the most efficient after giving the lowest *t* and *FCR* values as of 5.86 minutes and

4.27 liters/ha for N0 treatment, and 8.60 minutes and 5.04 liters/ha for N1 treatment, respectively.

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