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Analysis of plowing patterns and effect on the efficiency of land preparation following rice harvest

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ABSTRACT

This study aimed to examine the effect of different plowing patterns on land preparation efficiency. Three plowing patterns were tested: left-handed plowing, right-handed plowing, and headland plowing. A 90-horsepower tractor fitted with a 7-disc harrow was utilized for the experiments. The analysis of soil properties across all nine plots revealed no significant differences. The average soil moisture content ranged from 15% to 18% (dry basis), while the bulk density of the soil was measured between 1.18 and 1.23 g/cm³. Puncture resistance increased with greater depth. After plowing, the physical properties of the soil, including the average width of the plow furrow and soil depth, were approximately equal, with the width measuring around 127 cm. The depth varied slightly, but both the left-handed and right-handed plowing patterns achieved similar and greater depths compared to the headland plowing pattern. Due to the nature of skip-row plowing, it was necessary to lift and lower the plowshare when beginning a new row. The efficiency of the three methods of land preparation was assessed, with the left-handed plowing pattern demonstrating the highest efficiency, followed by the right-handed pattern, and then the skip-row pattern. The actual work capacities were measured at 2.57, 2.44, and 2.23 rai/hr respectively, while the spatial work efficiencies were 43.34%, 41.60%, and 38.20%. Furthermore, the fuel consumption rates for the three tillage methods did not show significant statistical differences ($p > 0.05$). The left-handed plowing method exhibited the lowest fuel consumption rate, while the skip-row plowing method provided the most consistent working pattern across the field.

Keywords: Tillage patterns, Tractor, Disk plow, Plough furrow, Fuel consumption

INTRODUCTION

Land preparation plays a critical role in crop production, serving as the foundation for optimal plant growth and productivity. Various methods of soil transformation are employed depending on the specific requirements of each cropping system. The selection of an appropriate land preparation method must consider factors such as soil and climatic conditions, the biological characteristics of the crops, the timing of operations, and the costs associated with inputs, machinery, and technology [1,2]. For proper soil preparation, farmers need to plow to an appropriate depth, ensuring that plant residues fall into zones with microbial activity where they can decompose quickly [2-4]. The soil should be plowed to a depth of approximately 150 to 300 millimeters. Therefore, soil plowing is a preliminary tillage operation conducted to break and invert the soil, affecting the structure of the upper soil layer and impacting the soil's ability to perform essential functions and services, such as root growth, gas and water transport, and organic matter turnover [5-7]. As a fundamental step in crop cultivation, plowing improves soil conditions, enhances crop yields, and contributes to the sustainability of agricultural systems and the livelihoods of farmers.

Tilling is the process of altering the condition of the soil to create an environment conducive to plant growth. The three factors related to soil tilling are the energy source (tractor), the soil, and the equipment (disk plow). Choosing the right tractor and equipment for each area requires data on their field performance of the tractor and equipment. Tractors and equipment must be tested in real-world conditions under different working scenarios to prevent severe damage, which will allow for the selection of tractors and equipment that are suitable for specific needs [8]. General field operations include primary tasks such as plowing the main part of the area where crops are to be planted, as well as additional tasks such as headland plowing and the interval for changing rows [9,10]. When the tractor turns into the work area, the downtime depends on the distance traveled during the turn and the average speed of movement [11-13]. Movement in the work area affects

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fuel consumption, exhaust gas pollution, and production efficiency. Longer and more complex movements require more fuel, produce more pollution, and reduce production efficiency [14, 15]. For those who are new to plowing, they often encounter difficulties in starting the task, such as not being sure where to begin on the plot and facing problems when having to reverse the plow to collect the remaining parts around the plot because they cannot turn the tractor to plow. Therefore, to ensure that plowing is done smoothly, the entire field must be plowed without gaps and without wasting much time turning around, so it is necessary to have a method of dividing the work. By dividing the area into sections to reduce redundant practices, past practices have shown that fuel use during tillage not only depends on soil conditions, technology and cultivation equipment, and plot size, but also on the shape of the plot [16].

Many studies have proposed methods to optimize tillage paths in rice fields of various shapes. The direction of travel during the tillage is usually determined by the longest edge of the rice field and then continues in a rectangular pattern [17]. For the plowing methods, there are several ways to start depending on the condition of the area and the desired neatness of the work. They can be divided as follows: 1. Circuitous pattern, 2. Headland pattern [18]. The study by Sarkar et al. [19] examined appropriate tillage patterns by considering fuel savings and tillage costs. The patterns studied included circular, straight, and overlapping or traditional tillage. It was found that the circular tillage pattern had the highest fuel consumption rate at a tillage depth of 8 cm. No significant difference was found between the rotational and straight tilling methods. While the rotational tilling method requires the most tilling time, the traditional tilling method is found to be the most fuel-efficient for sandy loam soil. Bekele ZM and Ayanie CG [20] evaluated five tillage patterns based on time taken, plot efficiency, and plot capacity. The experiment was conducted using a completely randomized block design with three replications, considering physical, machine, and time parameters. The experimental results found that the plowing pattern from the rear furrow of the working head was recommended first, as it took less time, had higher efficiency and field capability, and reduced overall operating costs. Next is the mixed plowing method for using multiple machines at once. Kuncoro et al., [21] studied the impact of 5 different plowing patterns on fuel consumption rates. The results showed that different plowing patterns lead to varying times and energy consumption rates. The number of turns is a significant factor affecting these differences. Similar to the findings of Ranjbarian et al. [22], an increase in speed has been reported to enhance the capabilities of plowing equipment. It has been said that increasing the operational speed improves the performance of the equipment. Fuel consumption decreases when the speed increases from 1.5 km/h to 3 km/h but increases when the speed increases from 3 km/h to 4 km/h. Additionally, it was found that in order to save energy, the size of the tractor and the operating parameters must be matched appropriately with the equipment.

When considering research that studies tillage patterns, the important factors are the appropriate tillage method for the field conditions and the operator's expertise. Therefore, the main objective of this study is to test which tillage method is suitable for the horsepower of the tractor in the test field conditions. The variables considered include the type of tractor, horsepower, and number of plow discs, as well as measuring soil properties to improve the process and increase plowing efficiency, the performance indicators used include work capacity, performance, efficiency, and fuel consumption of the tractor.

MATERIALS AND METHODS

Study of tillage patterns affecting fuel consumption There is a concept of studying and testing work efficiency in three steps, which are: Step 1: Study the plowing patterns for soil preparation in rice fields and examine the soil properties. Step 2: Prepare the plot area for testing the plowing with a 7-disc plow attached to the tractor. Step 3: Record the test results and calculate efficiency. The study process has steps and concepts as shown in Figure 1.

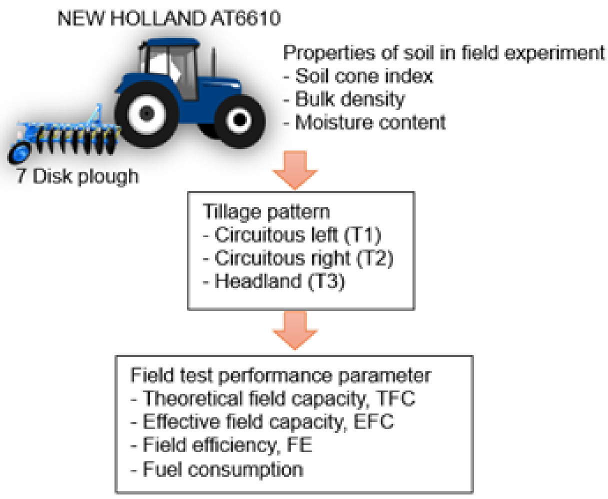

Figure 1 Schematic for study of tillage pattern.

Preparing the testing area

The experimental field was situated at the Agricultural Engineering Department, Faculty of Agriculture and Technology, Rajamangala University of Technology Isan, Surin Campus, Thailand (14.90° N, 103.50° E). The soil at the experimental site was characterized as sandy loam, with a flat terrain predominantly covered by grass and rice stubble. Prior to the initiation of the main field experiment, initial soil samples were systematically collected for

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testing from nine points per plot, distributed across the front, middle, and rear sections of each plot, to determine baseline soil moisture content. Concurrently, soil penetration resistance was measured at three depths: 5 cm, 10 cm, and 15 cm, to assess other baseline soil conditions.

Experimental design

The study employed a Randomized Complete Block Design (RCBD). This design was selected to mitigate the impact of potential soil heterogeneity or other environmental gradients across the experimental field, thereby enhancing the precision of treatment comparisons. The experiment was structured into three blocks, with each of the three plowing methods (T1: left-handed plowing, T2: right-handed plowing, and T3: headland plowing) randomly assigned to one plot within each block. This arrangement yielded a total of 9 experimental plots (F1-F9), ensuring three replications for each plowing method. Each individual plot measured 1 rai (1,600 m^2) in area. The spatial layout of the experimental plots and the distribution of treatments are schematically represented in Figure 2. Data collected from these plots were subjected to statistical analysis to evaluate the effects of tillage patterns on fuel consumption.

Block 1	Block 2	Block 3
F1 T1	F4 T3	F7 T2
F2 T3	F5 T2	F8 T1
F3 T2	F6 T1	F9 T3

Figure 2 Field layout of the experimental area.

The initial weight of all samples was measured using a digital scale, and the samples were subsequently dried in a hot air oven at 105°C for 24 hours. After drying, the samples were removed from the oven and their final weights were recorded. The dry basis moisture content of soil (S_{db}) was calculated according to Eq. (1) [23, 24]. And the bulk density as Eq. (2), showing the average moisture content and bulk density as shown in Table 1 for the cone index indicating soil hardness, expressed as force per square centimeter for the conical penetrometer head penetrating the soil. The cone penetration resistance was measured with a dial static cone penetrometer [25, 18]. According to ASAE standards as shown in Figure 3. Then, record the values at different depths, measuring the cone index at 9 different points within the depth range of 0 - 15 cm. Table 2 shows the soil cone index results in the experimental area.

$$S_{db} = \frac{M_1 - M_2}{M_2} \times 100 \quad (1)$$

Where S_{db} is the dry basis moisture content of soil (%), M_1 is the weight of the soil before drying (g), and M_2 is the weight of the soil after drying (g) [23].

$$\rho_b = \frac{M_s}{V_b} \quad (2)$$

Where ρ_b is the bulk density of the soil (g/cm^3), M_s is mass or weight of the soil after drying (g), and V_b is total volume of soil (cm^3) [18, 24, 25].

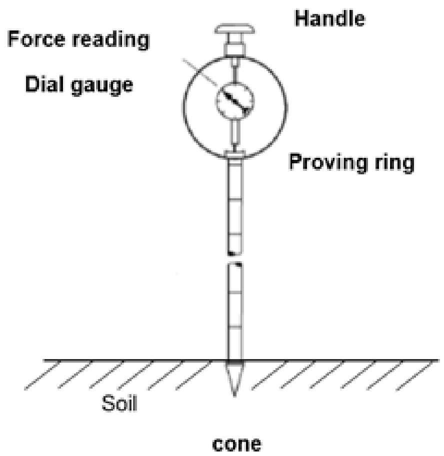

Figure 3 Cone penetrometer test.

Table 1 shows the average moisture content (%db) and bulk density determined for the field used in the experiment.

Field experiment	Moisture content (%db)	Bulk density (g/cm^3)
T1	15.13±0.96	1.23±0.09
T2	17.30±0.34	1.20±0.05
T3	18.07±0.83	1.18±0.06

Table 2 shows the average soil cone index over the 0–15 cm depth range, taken at 9 different spots.

Depth (cm)	Soil cone index (MPa)		
	T1	T2	T3
5	2.87	2.82	3.03
10	3.48	3.57	3.77
15	4.10	4.16	4.26

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From the soil moisture within the test plots for the three types of tillage, the moisture content is in the range of 15-18 %db, and the bulk density values are consistent with [20]. It is stated that the acceptable bulk density of soil should be less than 1.3 g/cm³, and the average bulk density of the soil in each plot falls within the recommended range as specified in Table 1. When considering the penetration resistance values in Table 2, it was found that in dry soil conditions and at greater depths, the penetration resistance values were higher [25].

Tractors and soil preparation tools

- *Tractors*

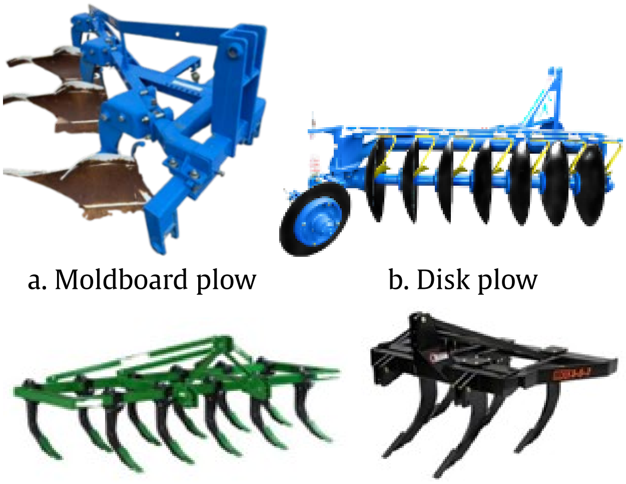
The tractor used as the power source was a NEW HOLLAND AT6610 with a capacity of 90 horsepower, a 4WD drive system, a 4-cylinder diesel engine with direct injection, a cylinder volume of 5,000 cc, an 8-speed forward and 2-speed reverse transmission, a PTO speed of 540 RPM, and a fuel tank capacity of 90 liters, as shown in Figure 4.

Figure 4 Tractor NEW HOLLAND AT6610.

- *Soil preparation tools*

Tilling is the management of soil using machinery to create conditions favorable for plant production. It involves breaking up the compacted surface soil to a specified depth and loosening the soil mass so that plant roots can penetrate and spread through the soil. Tillage can be divided into primary tillage to reduce soil compaction, cover plant residues, and rearrange soil mass. The tools used are called primary tillage implements, which are pulled by tractors and include moldboard plow, disk plow, subsoilers, and chisel plow. As shown in Figure 5, the second tillage is carried out to improve the soil suitable for sowing seeds and planting crops. It is a lighter and more detailed operation. The equipment used includes various types of rakes, tillers, soil levelers, and soil grinders [26-29].

Tillage is the mechanical manipulation of soil to improve conditions for crop growth, typically categorized into primary and secondary tillage. Disk plows, a type of primary tillage implement, are used to break up compacted soil, incorporate residues, and invert the soil layer. As shown in Figure 5b, the vertical disk plow features concave steel disks (60–80 cm in diameter, and 5–10 mm in thickness). An important characteristic of the vertical disk plow is that all disks are mounted on a single rotating shaft. This type of plow allows adjustment only to the disk angle, while the working depth is generally shallower compared to that of a standard disk plow. The working depth can reach up to 30 cm [30]. In the soil tillage test conducted in this study, the specific characteristics of the disk plow used are presented in Table 3.



a. Moldboard plow b. Disk plow
c. Chisel plow d. Subsoiler

Figure 5 The tillage implements.

Table 3 Specifications of selected tillage implements used for experiment.

Particulars	Disk plow
No. of bottom(s)/tines	7
Operating width	160 cm.
Depth of cut	15-20 cm.
Weight	660 kg.
Power requirement	>70 hp.

Plowing operation procedures

- *Method of dividing the work*

To ensure that plowing is done smoothly, the entire area must be plowed without gaps and without wasting time turning around. Therefore, it is necessary to have a method of dividing the work by splitting the area into sections, each section should not exceed 40 m in width. As for the length, it can be as long as desired, and the longer it is, the better, as it saves time on turning around. After dividing the plot into sections according to the desired width, there should be markers or reference points for dividing the plot into sections and then estimate the area to be used as the headland for turning around [31]. The head cutting will be done after dividing the plot into sections, leaving a space at the head of the plot on both sides, approximately the length of two vehicles. Then, plow in a shallow line,

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ensuring that the rear plow touches the ground slightly along the entire length of the plot head on both sides. This serves as a reference point for setting the plow when starting work and lifting the plow when finishing work. If this is not done, it will cause the plow to be misaligned, resulting in uneven furrows and making it difficult to finish the work neatly.

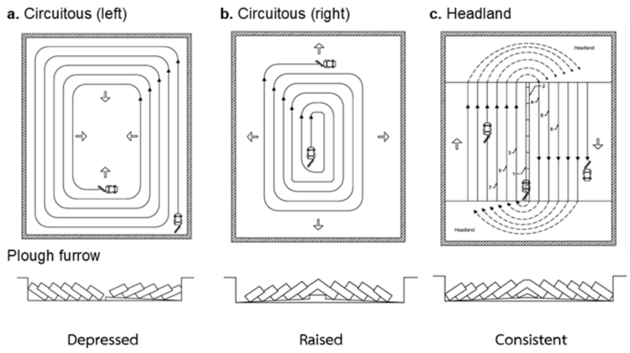

Figure 6 Tillage pattern and plough furrow.

- *Method for testing plowing patterns*

Agriculture in Thailand, especially rice cultivation, mostly involves small-sized rice fields. This leads to significant fuel loss during plowing. It is necessary to apply expertise and methods that can reduce such losses. There are several plowing methods that farmers commonly use. In this test, three methods were evaluated as follows: 1. The circular plowing method includes left-hand circular plowing (Figure 6a). This type of plowing, when repeated annually, will cause water to accumulate in the center of the plot., 2. Right-hand plowing (Figure 6b) is a method where farmers start plowing from the center of the plot and move outward to the edges. This method will cause the center of the plot to become a mound if plowed in the same way every year., 3. The headland plowing method (Figure 6c) begins by dividing the area in half along the length of the plot, leaving equal headland distances on both sides to allow for easy turning on both sides. Mark or aim the stakes to be clearly visible throughout the plowing process. Adjust the plow for the first time by rotating the middle arm so that the last plowshare digs a depth of about 10 cm, marking the first line. Drive the vehicle in low gear. When the vehicle reaches the designated end, lift the plow, turn around, and place the plow so that the left wheel of the vehicle is on the first line of the plowed soil. Adjust the arm to let the plow dig deeper into the soil. Drive the vehicle faster until the end of the field. Lift the plow and turn the vehicle around to plow the third line by placing the right wheel in the second line of the plowed soil. Adjust the middle arm of the plow and loosen the right arm to let the plow dig deeper into the soil. Plow at a slightly higher speed to ensure the plowed soil is smooth and not ridged. Follow the same steps for the fourth and fifth lines until the area is fully plowed, then finish the task neatly [32].

Field test performance parameter

The performance indicators in this study are the working efficiency of the 7-disc rotary tiller attached to the tractor and the fuel consumption rate, using the following equations.

- *Finding the working speed of a tractor*

The method for determining the appropriate speed for tractor operation involves placing markers at the midpoint of the field, spaced 20 m apart. The speed is calculated by dividing the time taken for the tractor to travel the 20 m distance by the time taken to pass the 20 m markers [33,34]. The starting position was set at least 2 - 5 m away from the first marker to maintain a constant speed before the measurement and data recording.

- *Efficiency*

Theoretical field capacity (*TFC*) is defined as the maximum area that a machine can cover per unit of time under ideal conditions, without any operational losses. It is calculated using the following Eq. (3).

$$TFC = W \times V \tag{3}$$

Where *TFC* is the theoretical field capacity (m²/hr or rai/hr), *W* is the working width of the implement (m), *V* is the forward speed of operation (km/h), to convert *TFC* from square meters per hour to rai per hour, the result is divided by 1,600 (since 1 rai = 1,600 m²) [35].

Effective field capacity (*EFC*) is the actual working capacity of agricultural machinery or equipment in the field, accounting for various factors that reduce ideal performance. These include reduced operating speed due to field obstacles, environmental conditions, headland turns, or machine downtime. It can be calculated using Eq. (4).

$$EFC = \frac{A}{T_P - T_l} \tag{4}$$

Where *EFC* is the effective field capacity (m²/hr or rai/hr), *A* is total area worked (m²), T_p is time of equipment operation in the field (hr), T_l is the total lost time during field operation (hr).

Field efficiency (*FE*) is the ratio between actual working capacity and theoretical working capacity of the machine, expressed as a percentage, as shown in Eq. (5).

$$FE = \frac{EFC}{TFC} \times 100 \tag{5}$$

- *Fuel consumption rate*

The amount of fuel that a machine needs to operate over a certain period or to cover a specific area, which can be calculated in units such as liters per hour or liters per rai. The procedure for measuring fuel consumption involves using a measuring cylinder

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to refill the tractor's fuel tank when the work is completed. This can be determined as follows Eq. (6).

$$Fuel\ consumption\ (L.hr^{-1}) = \frac{V}{T} \quad (6)$$

Where V is the amount of fuel (L), T is time of working (hr) [36].

RESULTS AND DISCUSSION

Effects of soil width and depth from plowing

The width of the plow marks and the depth of the soil are shown in Table 4. The experimental results indicate that the width of the plow marks and the soil depth from the three plowing methods did not differ significantly, with an average plow mark width of approximately 127 cm and soil depth ranging from 13.07 to 14.26 cm , which is consistent with previous studies by Janulevicius et al. [14] and Damanauskas and Janulevicius [17], who concluded that tool dimensions and soil engagement depth are influenced more by implement design and soil conditions than by plowing direction; this consistency in plow width and depth suggests good tool calibration and performance, although differences in soil turning direction among the methods may affect post-tillage soil uniformity and potentially influence subsequent field operations such as planting or fertilization.

Table 4 Results of plowing width and soil depth.

Tillage pattern	Width (cm.)	Depth (cm.)
T1	127.43±2.39	14.24±1.58
T2	127.16±2.31	14.26±1.95
T3	127.18±2.55	13.07±1.51

- *Tillage efficiency*

From the testing of the three tillage preparation methods, the efficiency of the work was calculated. The test results are shown in Figure 7, which summarizes the average of TFC, EFC, and FE.

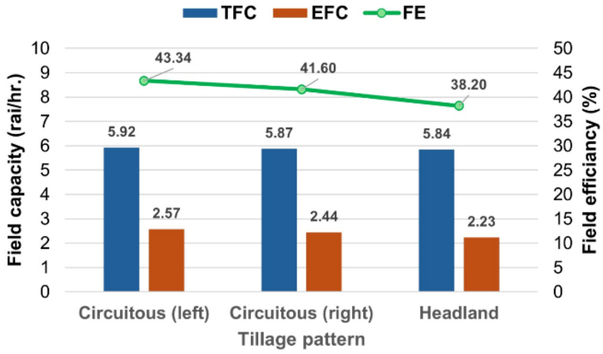

Figure 7 The work efficiency from the three types of land preparation.

Figure 7 shows the field capacity of the three tillage methods: the left-hand tilling method, the right-hand tilling method, and the skip-till method. The actual field capacities were 2.57, 2.44, and 2.23 rai/hr, respectively. When the test results were used to calculate the efficiency of spatial work, it was found that the left-turning plowing pattern had the highest efficiency, as it minimized turning time and maximized continuous tillage. This was followed by the right-turning plowing pattern and the skip-head plowing pattern, with values of 43.34%, 41.60%, and 38.20%, respectively. If a complete plow mark is desired, the entire plot must be plowed. In this case, the headland plowing method provides the most uniform working characteristics across the plot, as shown in the research by Janulevicius et al. [14], who reported that continuous plowing patterns reduce idle turning time at headlands, thus enhancing effective field capacity; the strength of this finding lies in the improved productivity and time savings offered by circuitous patterns, while the limitation remains in the potential for reduced plow uniformity in irregular fields.

Table 5 Results of average fuel consumption.

Treatment	Fuel consumption (L/hr)			Total	Mean
	P1	P2	P3		
Circuitous (left)	3.90	3.70	3.50	11.10	3.70
Circuitous (right)	3.50	3.90	4.00	11.40	3.80
Headland	4.50	3.95	3.80	12.25	4.08
Block total	11.90	11.55	11.30		
Block mean	3.97	3.85	3.77		
Total				34.75	
Grand mean					3.86

C.V. (%) = 8.59

The effect of fuel consumption rates

The analysis of variance of fuel consumption rates in Table 5 and Table 6 found that the fuel consumption rates of the three plowing methods were not statistically different ($p>0.05$). When comparing the experimental results, it was shown that the left-turn plowing method had the lowest fuel consumption rate, with an average of 3.70 L/rai. The right-turn plowing method followed, with an average of 3.80 L/rai, and

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the headland plowing method had the highest fuel consumption rate, with an average of 4.08 L/hr, respectively. This corresponds with the findings of Janulevicius et al. [14], who reported that headland turns requiring frequent lifting and repositioning of the implement significantly increase fuel consumption. A notable advantage of the left-hand turning method is its lower energy usage, as it reduces idle motion. In contrast, the headland turning method presents limitations due to increased operational complexity and fuel demand caused by frequent turning and tool repositioning at field boundaries.

Table 6 Results of the variance analysis of fuel consumption rates.

Source of Variation	df	SS	MS	F	p-value
Tillage pattern	2	0.24	0.12	1.10	0.42^{ns}
Fuel consumption	2	0.06	0.03	0.28	0.77^{ns}
Error	4	0.43	0.11		
Total	8	0.73			

Remark: ns- not significant

CONCLUSIONS

The study of soil properties in the test plots, including soil moisture, bulk density, and penetration resistance, found that the soil properties in each plot studied were not significantly different. The average soil moisture test results ranged from 15-18 %db. The bulk density of the soil is 1.18-1.23 g/cm³, and the average penetration resistance is consistent with the moisture content. Which indicates dry soil conditions and increased depth, resulting in higher penetration resistance values. If the penetration resistance values are very high, it may affect work efficiency and increase energy consumption. Physical characteristics of the soil in the test plot after plowing were measured for the average width of the plow marks and the soil depth. In all three plowing methods, the width of the plow marks did not differ, which corresponds to the size of the tool, specifically a 7-disc plow, with a measured width of approximately 127 cm. However, the measured soil depths varied slightly. The left and right circular plowing methods had similar depths, which were greater than the depth of the headland plowing method. This difference may be due to the lifting of the plow when starting to plow at the headland of a new row. The efficiency test of the three tillage preparation methods showed that when the test results were calculated for spatial work efficiency, the left-hand tilling method had the highest efficiency, followed by the right-hand tilling method and the tilling method with headland skipping, with values of 43.34%, 41.60%, and 38.20%, respectively. The fuel consumption rates for the three tillage methods do not differ statistically. However, the method of tilling with headlands has the highest fuel consumption rate but provides the most consistent working conditions across the field.

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