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Comparison of performance of moldboard plows and disk plows in upland soil conditions

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Abstract

Comparison of the performance of moldboard plows and disk plows in upland soil conditions. The objectives were to evaluate the performance of the moldboard plow and disk plow and to compare the costs associated with soil preparation using these implements. The experiment utilized two 90 hp tractors operating at an engine speed of 540 rpm with the L2 gear setting to measure draft force. Each test was repeated three times. The moldboard plow used had two bottoms with a working width of 45 cm, while the disk plow had three disks with a working width of 90 cm. The test soil was sandy loam with a moisture content of 1.10%. The study found that the soil penetration resistance in the test plot was 5.98 MPa for the moldboard plow. The operating speed was 2.45 km/h for the moldboard plow and 2.41 km/h for the disk plow. The slip ratio was 7.77% for the moldboard plow and 9.29% for the disk plow. The specific draft force was 71.56 kN/m² for the moldboard plow and 38.49 kN/m² for the disk plow. The draft power was 6.57 kW for the moldboard plow and 5.80 kW for the disk plow. The plowing depth was 0.30 m for the moldboard plow and 0.25 m for the disk plow. Regarding weed control efficiency, the moldboard plow achieved 82%, while the disk plow achieved 70%. The field efficiency was 82.59% for the moldboard plow and 66.05% for the disk plow. The fuel consumption rate was 7.59 l/h for the moldboard plow and 7.20 l/h for the disk plow. The annual operating cost was 11,318.80 Baht/Y for the disk plow and 7,106.81 Baht/y for the moldboard plow.

Keywords: Moldboard plows, Disk plows, Performance, Operating costs, Traction force

1. Introduction

In 2023, Thailand has a total land area of approximately 514,000 km^2, or around 320 million rai, with approximately 142.9 million rai, accounting for 44.5% of the total area used for agricultural activities [1]. Crop cultivation by farmers largely depends on the community's geographical context, including geographic characteristics, location, climate, water resources, and social conditions. Therefore, modern agricultural practices increasingly rely on mechanization to enhance and improve production efficiency in various stages, from land preparation and planting to crop maintenance and harvesting [2].

The moldboard plow is a primary tillage implement used for initial soil preparation. Its primary function is to invert the soil, creating large clods that are not yet suitable for planting [3]. The moldboard plow performs efficiently in areas that have been previously improved. Its operation begins with cutting and loosening the topsoil into sections, followed by inverting the soil along with weeds, which promotes decomposition into organic fertilizer.

The disk plow, also known as a disk harrow, is a type of primary tillage implement commonly used for land preparation in field crops and other agricultural applications. It consists of multiple concave disks mounted on a plow frame, designed to cut and invert the soil. However, its ability to invert soil and bury weeds is less effective than that of the moldboard plow, and it operates at a shallower depth. The disk plow is particularly suitable for new land clearing, where tree roots, stumps, and rocks are still present. The rotating disks cut through the soil while simultaneously inverting it, making the disk plow effective even in compacted soil conditions. Therefore, using agricultural machinery for soil preparation will allow farmers to work faster and gain more planting areas, save costs, increase the precision farming, and increase production efficiency and quality.

This study aims to compare the performance of moldboard plow and disk plow in upland soil conditions, along with the associated tillage costs, will provide valuable insights for farmers regarding the cost of land preparation before planting. This knowledge will support informed decision-making in selecting appropriate tillage equipment, ultimately helping to reduce costs and increase farmers' income.

2. Methodology

2.1 Soil properties in the test plots

2.1.1 Soil moisture content

The dry basis moisture content was determined by collecting soil samples before tillage preparation from five points within each plot. The samples were first weighed to record their initial weight before drying. The soil samples were then placed in an oven at a temperature of 95–105°C for 24 h. After the drying process, the samples were weighed again to obtain their post-drying weight. The soil moisture content was then calculated using Equation (1).

$$w = \frac{W_w}{W_s} \quad (1)$$

Where:

W = Soil moisture content on a dry basis (%db)
W_W = Soil weight before drying (g)
W_S = Soil weight after drying (g)

2.1.2 Determination of soil texture by sedimentation method

1) The soil sample was collected and crushed to break up aggregates before being placed into a 1000 ml graduated cylinder. A soil sample of 250 g was used, and clean water was added until the total volume reached 1000 ml.
2) The glass bottle was tightly sealed and shaken for approximately 5 minutes. It was then left undisturbed, with the timing recorded from the moment it was set aside.
3) After 45 s, the volume of soil sediment was measured. During this period, the sand particles would have settled.
4) The same procedure was repeated as in step 3. After 1 h, which is the settling time for silt particles, the sediment volume was measured.
5) The same procedure was repeated as in step 3. After 24 h, which is the settling time for clay particles, the sediment volume was measured using Equations (2) – (4).

Percentage of sandy soil = [Volume of sand (ml)/Total volume of soil (ml)] × 100 (2)

Percentage of loamy soil = [volume of loose soil (ml)/volume of total soil (ml)] × 100 (3)

Clay percentage = [Clay volume (ml)/Total clay volume (ml)] × 100 (4)

2.1.3 Find soil density

A cylindrical metal mold with a diameter of 101.6 mm and a height of 116.4 mm, having a volume of 944 cm³, was fixed to a base and equipped with a collar 50.8 mm high. A 2.5 kg metal rammer with a cross-sectional diameter of 50.8 mm was used.

The testing procedure involved using air-dried soil that passed through a 2 mm sieve, mixing it with a specific amount of water, and then compacting it in the mold using the rammer. The soil was divided into three approximately equal layers, with each layer being compacted with 25 blows. Afterward, the surface of the soil was levelled with the top edge of the mold. The sample was then weighed to determine its weight, and the wet density was calculated using Equation (5). A portion of the soil was taken to determine the moisture content (w), which was then used to calculate the dry density using Equation (6).

$$P = \frac{M}{V} \quad (5)$$

Where:

P = Soil density
M = Total soil mass
V = Total soil volume

Calculation of soil stress in the test plot according to Equation (6).

$$P = \frac{F}{A} \quad (6)$$

Where:

P = Soil stress (Pa)
M = Soil penetration resistance (N)
V = Test head area size (m^2)

2.2 Performance testing of moldboard plows and disk plows

Performance testing of the moldboard plow, the moldboard plow (Figure 1a) consists of 2 bottoms, with distance of 50 cm between the bottom of the side plates and the bottom of the furrow, and a 15 cm distance between the side of the side plates and the side of the furrow. The working width is 45 cm, and the weight is 250 kg, as shown in Figure 1b [4]. The disk plow consists of 3 disks with a diameter of 605 mm, a disk spacing of 700 mm, a disk angle of 41 degrees, and a disk tilt angle of 18 degrees. The working width is 90 cm, and the weight is 440 kg [5].

(a) (b)

Figure 1 Moldboard plow (a) and disk plow (b)

2.2.1 Slip

The slip ratio was determined by marking the tractor's wheels and counting the number of wheel rotations for 3 complete rotations. The number of rotations was then multiplied by the circumference of the wheel to calculate the theoretical distance the wheel would travel. The actual distance traveled by the wheel was measured using a measuring tape, and a marker was used to mark the starting and ending points for counting the wheel rotations. The experiment was repeated three times for each plot. The equipment used included a measuring tape and a pin marker, and the slip ratio was calculated using Equation (7).

$$D = \frac{D_1 - D_2}{D_1} \tag{7}$$

Where:

D = Slip

D_1 = Unloaded moving distance (m)

D_2 = Distance traveled when loaded (m)

2.2.2 Find traction

The cones were set 10 m apart. A tractor of equal or larger size was selected as the power unit, and a dynamometer was attached to the tractor's drawbar as shown in Figure 2a. A chain was then used to connect the tractor to another tractor equipped with the implement to be tested. The tractor was parked approximately 5-10 m away from the cones. Gear 3 was selected for the test, with the engine running at 540 rpm. The tractor pulling the implement should be in neutral gear, as shown in Figure 2b. The speed measured during the operation of the first tractor would be the speed of the second tractor. The tractor was driven through the cones with the implement lifted (no load). The time was recorded starting when the tractor passed the first cone until it passed the second cone. The time was then noted. For the loaded test, the procedure was repeated, except that the implement was engaged [6].

(a) (b)

Figure 2 Traction force measurement: (a) Dynamometer (b) During traction force measurement

2.2.3 Measurement of furrow depth

A metal rod was placed along the edge of the furrow in a horizontal position, and a tape measure was used to measure the depth. During the test, the depth of each furrow was measured at three locations: the beginning, middle, and end of the test plot.

2.2.4 Effective field capacity

The width of the furrow at the beginning, middle, and end of the plot was measured. The furrow width data was recorded, and the actual working capacity in terms of area was calculated using Equation (8).

$$EFC = W_2 \times V \quad (8)$$

Where:
EFC = Effective field capacity (rai/h)
W_2 = Plow width (m)
V = Operating speed at specified rpm and gear position (m/s)

2.2.5 Field efficiency

The working efficiency of the moldboard plow and disk plow can be determined using Equation (9).

$$F_e = [EFC/TFC] \times 100 \quad (9)$$

Where:
F_e = Field efficiency (%)
TFC = Theoretical field capacity (rai/h)

2.2.6 Theoretical field capacity

The theoretical field capacity was determined by attaching either the moldboard plow or disk plow to a FORD 5640 tractor with 90 hp using a three-point hitch. The working width of the moldboard plow and disk plow was measured on a flat surface. The working speed during soil preparation was obtained by driving the tractor over a 10-m distance while maintaining an engine speed of 540 rpm and selecting gear position L2. The engine speed and gear position were kept consistent across all trials. The working speed was calculated using Equation (10), and the theoretical field capacity was determined using Equation (11).

$$V = S/t \quad (10)$$

Where:
V = Operating speed at specified rpm and gear position (m/s)
S = Working distance (10 m)
T = Working time over a distance of 10 m (s)

$$TFC = W_1 \times V \quad (11)$$

Where:
W_1 = Plow width (m)
V = Working time over a distance of 20 m (s)

2.2.7 Fuel consumption rate

Fueling the tank to full capacity before each plowing operation and measuring the fuel consumption after completing each test plot. The fuel volume is measured using a graduated cylindrical plastic beaker with precise readings, and the results are recorded according to Equation (12).

$$\text{Fuel consumption rate} = \text{Amount of fuel consumed} / \text{Actual working area} \quad (12)$$

2.3 Annual cost evaluation of moldboard plow and disk plow operation.

The annual cost evaluation for the operation of the moldboard plow and disk plow can be determined using Equation (13).

$$AC=\frac{FC\%P}{100}+\frac{cA}{Swe}[(RMP)+L+O+F+T] \quad (13)$$

Where:
AC = Annual cost of use (Baht /y)
FC% = Fixed costs (Baht /y)
P = Initial purchase Price (Baht)
c = A constant value of 1.6 when A is measured in rai and 10 when A is measured in ha
A = Operating area (rai)
S = Driving speed (km/h)

W = Working width of agricultural machinery (m)
e = Operational efficiency in the area
RMP = Repair and maintenance costs, represented as a decimal value of the initial purchase price/h
L = Labor wage rate (Baht/h)
O = Lubricant cost (Baht/h)
F = Fuel cost (Baht/h)
T = Tractor cost (Baht/h)

3. Results and discussion

3.1 Soil properties determination in test plots

The study results of the physical properties of the soil in the test plot prior to testing the performance of the moldboard plow and disk plow involved randomly collecting soil samples from the test plot to examine the physical properties of the soil. The average results were obtained by determining the soil texture, soil bulk density, soil moisture content, and soil penetration resistance, as shown in Table 1.

Table1 Soil properties in test plots

Soil properties	Data
Types of soil particles	
sand (%)	86.85±1.93
Silt (%)	7.65±0.99
Clay (%)	5.48±1.12
Soil density (g/cm^3)	1.52±0.11
Soil moisture (%wb)	1.10±0.06
Penetration resistance at 5 cm (MPa)	5.98±8.98

Note: It is the maximum depth level when using a pressure head with a diameter size of 1 cm^2

Table 1 shows the soil properties in the test plot, where data was collected before testing at the Crop Science Field, Faculty of Agriculture and Natural Resources, Rajamangala University of Technology Tawan-Ok, Bang Phra Area, Chonburi Province. The results of soil sample collection in the test plot indicate that the percentage of sand is 86.85%, silt is 7.65%, and clay is 5.48%. The soil type is loamy sand, with a soil bulk density of 1.52 g/cm^3 and a moisture content of 1.10%. The soil penetration resistance at a depth of 5 cm is 5.98 kPa.

3.2 Comparison of the performance between moldboard plow and disk plow.

From the moldboard plow test, three repetitions were conducted using the L2 gear at an engine speed of 540 rpm. The test results are shown in Table 2.

Table2 Average values from the moldboard plow test

Details	Test results
Tractor speed (km/h)	2.45
Slip (%)	7.77
Traction force (kN)	9.66
Dragging (kN/m^2)	71.56
Specific traction force (kW)	6.57
Working time over a distance of 10 m (s)	14.71
Working time (s)	142.48
Plow width (m)	0.45

Table 2 shows the average values from the moldboard plow test in the actual field. The results of the moldboard plow test are as follows: speed of 2.45 km/h, slip of 7.77%, pulling force of 9.66 kN, specific pulling force of 71.56 kN/m^2, pulling power of 6.57 kN, tractor travel distance of 10 m in 14.71 s, actual working time of 142.48 s, and a working width of 0.45 m.

For the disk plow test, the engine speed was set to 540 rpm, and testing was conducted using the L2 gear with three repetitions. The test results are shown in Table 3.

Table 3 shows the average values from the disk plow test in the actual field. The results of the disk plow test are as follows: speed of 2.41 km/h, slip percentage of 9.29%, pulling force of 8.66 kN, specific pulling force of 38.49 kN/m^2, tractor travel distance of 10 m in 14.89 s, actual working time of 90.18 s, and a working width of 0.90 m.

Table 4 shows the performance of the moldboard plow. The calculation results for theoretical operational capacity in terms of area are 0.69 rai/h, while the actual operational capacity in terms of area is 0.57 rai/h. This shows that the actual operational capacity is lower than the theoretical capacity due to the small test area, which results in time loss during vehicle turning. The working efficiency is 82.59%, the weed control efficiency is 82%, the plowing depth is 0.30 m, and the fuel consumption rate is 7.59 l/h.

Table3 Average values from the disk plow test

Details	Test results
Tractor speed (km/h)	2.41
Slip (%)	9.29
Traction force (kN)	8.66
Dragging (kN/m^2)	38.49
Specific traction force (kW)	5.80
Working time over a distance of 10 m (s)	14.89
Working time (s)	90.18
Plow width (m)	0.90

Table4 The performance results of the moldboard plow

Details	Test results
Theoretical Field Capacity (rai/h)	0.69
Effective Field Capacity (rai/h)	0.57
Field Efficiency (%)	82.59
Plow width (m)	0.30
Efficiency of Weed Control (%)	82.00
Fuel Consumption Rate (l/h)	7.59

Table 5 shows the performance of the moldboard plow based on the calculation of theoretical operational capacity in terms of area, which is 1.36 rai/h. The actual operational capacity in terms of area is 0.90 rai/h. This shows that the actual operational capacity is lower than the theoretical capacity due to the small test area, which results in time loss during vehicle turning. The working efficiency is 66.05%, weed control efficiency is 70%, the plowing depth is 0.25 m, and the fuel consumption rate is 7.20 l/h.

Table5 The performance results of the disk plow

Details	Test results
Theoretical Field Capacity (rai/h)	1.36
Effective Field Capacity (rai/h)	0.90
Field Efficiency (%)	66.05
Plow width (m)	0.25
Efficiency of Weed Control (%)	70.00
Fuel Consumption Rate (l/h)	7.20

Therefore, from Table 4 and 5, when comparing the weed control efficiency before and after plowing to soil preparation, it was found that the efficiency of weed control of the moldboard plow was more effective than the disk plow because the moldboard plow could turn the soil better than the disk plow.

3.3 Comparison of costs for land preparation plowing.

Calculation of annual costs for an area of 100 rai: The annual operating cost for the disk plow is 11,318.80 Baht, and for the moldboard plow is 7,106.81 Baht.

Table 6 shows the results of the comparison between the disk plow and the moldboard plow. It was found that the pulling force of the moldboard plow is greater than that of the disk plow due to its deeper penetration into the soil, which causes the plow furrow to be more compacted. The weed control efficiency of the disk plow averages 70%, while the moldboard plow averages 82%. The plowing depth for the disk plow averages 0.25 m and 0.30 m for the moldboard plow. The fuel consumption rates for the disk plow and moldboard plow are 7.20 and 7.59 l/h, respectively. These results are consistent with the research of Panjamathum [7], who compared the performance of a 3-bottom disk plow and a 2-bottom moldboard plow in rice field areas, finding that the weed control efficiency of the moldboard plow was higher than that of the disk plow, and the fuel consumption rate of the moldboard plow was greater than that of the disk plow. The theoretical operational capacity for the disk plow was 1.36 rai/h, while for the moldboard plow it was 0.69 rai/h. The actual operational capacity for the disk plow was 0.90 rai/h and 0.57 rai/h for the moldboard plow. The working efficiency of the disk plow and moldboard plow was 66.05% and 82.59%, respectively. These results are in line with the research of Junyusen [8], who tested land preparation using the disk plow and moldboard plow, finding that the actual operational capacity was lower than the theoretical capacity, and the working efficiency of the moldboard plow was higher than that of the disk plow.

Table6 The Comparison between disk plow and moldboard plow

Details	Test results	
	Disk plow	Moldboard plow
Traction force (kN)	8.66	9.66
Theoretical Field Capacity (rai/h)	1.36	0.69
Effective Field Capacity (rai/h)	0.90	0.57
Field Efficiency (%)	66.05	82.59
Efficiency of Weed Control (%)	70.00	82.00
Plow width (m)	0.25	0.30
Fuel Consumption Rate (l/h)	7.20	7.59

4. Conclusions

The testing of the moldboard plow and disk plow was conducted using a 90 hp tractor as the prime mover, coupled with a three-point hitch system. The tests were carried out at gear level L2 with an engine speed of 540 rpm. The test area consisted of loamy sand soil, with a pre-plowing soil moisture content of 1.10%, and a soil penetration resistance of 5.98 kPa at an average depth of 5 cm. The actual operational capacity in terms of area for the moldboard plow was 0.57 rai/h, while for the disk plow it was 0.90 rai/h. The average plowing depth for the moldboard plow was 0.25 m, and for the disk plow, it was 0.30 m. The weed control efficiency was 82% for the moldboard plow and 70% for the disk plow. The operational efficiency in terms of area was 82.59% for the moldboard plow and 66.05% for the disk plow. The results showed that the moldboard plow had better field operational efficiency than the disk plow, as its actual field performance was closer to the theoretical performance capacity. The fuel consumption rates for the moldboard plow and disk plow were 7.59 and 7.20 l/h, respectively. The annual operating costs for the moldboard plow and disk plow for an area of 100 rai were 7,106.81 and 11,318.80 Baht/y, respectively. Based on the results of this test, it is recommended to also test the shear force and soil fragmentation in the test plots. Suggestions: The moldboard plow is suitable for areas that have been used for farming for a long time, where stumps and rocks have been removed from the area. The disk plow is suitable for areas that are pioneers in the early years, where there are many rocks or stumps.

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