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Development and Testing of a New Tillage Apparatus

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Abstract

Disk plow combined with rotary blades, defined as Comboplow, is used for soil preparation for planting. A multiple tillage operation is reduced in a single pass resulting in a potential reduction of soil compaction, labor, fuel cost and saving in time. The Comboplow was tested at University Putra Malaysia Research Park, Serdang, Selangor, Malaysia, on three different plots of 675 m^2 in the year 2010/2011.The treatments were three types of blades [(straight (S), curved (c) and L-shaped)] and three rotary speeds (130,147 and 165 rpm). The parameters were Mean Weight Diameter Dry Basis (MWD_d), Mean weight Diameter Wet Basis (MWD_w), and Aggregate Instability Index (II). Result showed that an increase in the rotational speed from 130 to 165 rpm decreased the mean weight diameter (wet basis), mean weight diameter (dry basis) and instability index.

Keywords: tillage operation, combined implement, disk plow, rotary blade, mean weight diameter, stability index

1. Introduction

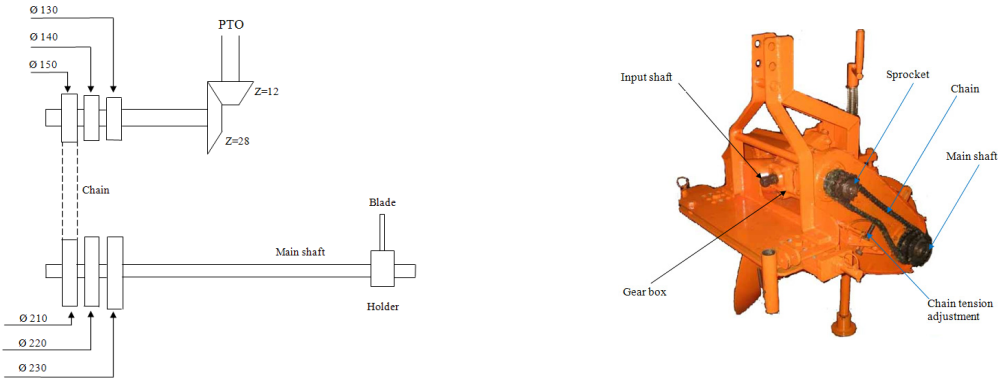
Plow is as old as agriculture which originated 10–13 million years ago in the Fertile Crescent of the Near East, mostly along the Tigris, Euphrates, Nile, Indus and Yangtze River valleys, and also were introduced into Greece and Southeastern Europe 8000 years ago (Lal et al., 2007). *Tillage* is one component in any system of soil management for crop production and is a process of applying energy to the soil to change its physical condition by disturbing it (Hill et al., 1985). Tillage or soil preparation has been an integral part of traditional agricultural crop production practice. It is the mechanical manipulation of the soil and plant residue to prepare a seedbed where seeds are planted to produce grain for our consumption. Also tillage breaks soil, enhances the release of soil nutrients for crop growth, destroys weeds and enhances the circulation of water and air within the soil (Reicosky et al., 2003). While farmers try to find out the best management to produce in lowlands in Brazil, researchers still have problems related to the correct physical characterization cropping systems of these soils in order to define the suitable operation methoths (Da Silva et al., 1997). *Tillage operation* is also defined as a procedure for breaking up soil; the soil failure depends largely upon the soil properties, tool parameters, and cutting speed. Also it is one of the highest power-required processes of the agricultural production. In addition, the high cost of energy, makes the farmers to find alternative economic tillage methods (Bayhan et al., 2006). The cost and the timeliness of operation assume critical importance while deciding the type of tillage tools. The large part of energy consumption in mechanized agriculture is related to tillage operation. Godwin (2007) reported that the cost of tillage operation is a vital component to determine farm profitability and recent years have seen a significant move to reduce tillage operation. Operations simultaneously utilizing two or more different types of tillage tools or implements to simplify, control or reduce the number of operations over a field are called *combined tillage* (Sahu et al., 2006), (Manian et al., 1999). Combined tillage is the act of using two or more different types of tillage implements or tools at the same time to manipulate control or reduce the number of operations in the field (Al-janobi et al., 1998) . Machines for tillage operation usually pass the farm four times or more which causes soil compaction, increases cost of labor and energy. The compression of soil causes reduction of the moisture penetration, soil oxygen capacity, penetration of root in the soil, organic materials capacity in soil and increasing energy consumption (Tebrügge et al., 1999). The past research work did not consider the combined effect of disk plow and rotary blades on farm. In this regard Ahmad and Amran (2004) studied the energy prediction model for disk plow combined with a rotary blade in wet clay soil. In order to produce cheaper agricultural products, it is necessary to reduce expenditure. The concept of Comboplow has the

following advantages; higher degree of soil crumbling; better mixing of soil and mineral fertilizer; improve parameters of work on heavy soils; the guarantee of complete preparation of the field; reduction of draft and wheel slip; reduces soil compaction, energy consumption, fuel consumption; decreases labor and machinery cost. The Comboplow is simultaneously utilized to prepare an adequate seedbed and bury crop residues. It is particularly adapted for use in hard-dry soils, shrubby or bushy land. It is utilized in clay soil for reduction of energy consumption in tillage operation, soil compaction and structural degradation due to vehicular traffic; because current two-pass or three-pass tillage treatments could be replaced with single-pass. The outstanding benefits with current single-pass tillage treatment are saving in fuel, labor and machinery cost.

2. Materials and Methods

A disk plow combined with rotary blades 'Figure 1' consists of the following components; a chassis, three point hitch, transmission system, disk, scraper, rear wheel, rotary blades and its cover and adjusting mechanism.

Figure 1. Comboplow



(a) (b)

Figure 2. Transmission system of Comboplow (a) schematic diagrams (b) photograph

The transmission system consists of PTO, universal joint shaft with safety clutch, gear box, input shaft, output shaft, chain, sprockets, main shaft, and holder of blades Figure 2. The sizes of the sprocket couples (13:23, 14:22 and 15:21) of the transmission system that give the speed of the rotary blades were selected based on the reported works from the literatures which reported that the speed of the rotary blades should be greater or equal to the travel speed of the tractor (Sahu et al., 2006) .The Comboplow is mounted on a tractor three point linkage system and driven by the tractor PTO.

The most widely used rotary tillers are those having straight, curved (C) and L-shaped blades 'Figure 3'. The C - type blades provide sliding cutting of the fibrous soil with the following advantages over the other type of blades; minimum resistance, have self-cleaning characteristics during working with damp soils, and also have sufficient resistance to breakage and abrasive wear.

The experiments were conducted at University Putra Malaysia Research Park, Serdang Selangor, Malaysia, on three different plots having 675 m^2 sizes each during the year 2010/2011. The site was located at longitude 101˚, 42.916´E, latitude 2˚, 58.812´N and an altitude of 46 to 48 m above sea level .The experimental site has an

average annual rainfall of 2548.5 mm with maximum and minimum temperatures of 33.1˚C and 23˚C respectively.

(a) (b) (c)

Figure 3. Photograph of blades of Comboplow (a) Straight blade, (b) L-shaped and (c) Curved (C-type)

Soil samples were collected from the topsoil layer of 0-30 cm depth at nine different locations in the experimental site before tillage operation in three replications. A comprehensive understanding of the physical characteristics (bulk density, moisture content, porosity, particle size, and aggregate size distribution) and mechanical soil properties (Cohesiveness, internal friction angle, shear stress and penetration resistance) are important in the designed and fabricated of disk plow combined with rotary blades. A penetrograph was used to determine the soil penetration resistance in the field. The penetrograph has the ability to show the penetration reading in the field at different depths from 0-80 cm. In the Cone Penetration test, a cone penetrograph is pushed into the ground at a constant rate and direct and automatic measurements are made of the resistance to penetration of the cone. A Wykeham Farrance International (WFI) SLI 4Hw shear box laboratory apparatus was used to obtain cohesion, angle of internal friction and shear stress of the soil . Experiments were conducted to determine the influence of various types of blade and rotational speeds on aggregate size distribution after tillage operation. In the experiment, soil physical characteristics investigated include mean weight diameter dry basis and mean weight diameter wet basis to find out the instability index of soil aggregate. The method of wet-sieving was adapted from Kemper, W. D. & R. C. Rosenau (1986).

The test was performed based on 2×3 factorial treatment experimental design in RCBD with three replications. The analysis of variance (ANOVA) and Duncan's multiple range tests were used to analyze the data using the statistical analysis systems (SAS) 1996 software.

A 63.4 kW John Deere 6405 tractor (PTO power 51 kW) was used for the tillage experiments. The tractor has static weight distribution of 40% front and 60% rear with total mass of 3891 kg and 180 kg balancer (6×30 kg). The front tires were radial 12.4-24 single operated at 220 kPa inflation pressure and the rear tires were radial 18.4-34 single operated at 160 kPa inflation pressure.

3. Results and Discussion

Soil texture was determined by standard pipette method analysis achieved by USDA textural classification system. The mean values of soil particle size with different texture content from clay, sand and silt as 23.91%, 53.54% and 22.55%, respectively. Indicating that under the classification of soil texture, the soil was found to be *sandy clay loam.*

The mean resistance values of nine cone penetration points randomly taken in the field using the penetrograph before tillage operation are presented in Figure 4. The penetrograph used has the ability to show penetration readings in the field at depths from 0-80 cm. The mean values of soil penetration resistance increased linearly at 5 cm depth with values of 280, 320 and 350 N/cm^2 for block B, C and A, respectively. However, the mean values of soil penetration resistance decreased linearly with depth to 200, 250 and 270 N/cm^2 at 25, 20 and 15 cm for blocks B, A and C, respectively. The soil penetration resistance remained uniform from the depth of 30 cm until 60 cm for all the three blocks. The maximum and minimum soil penetration resistance values of 380 N/cm^2 and 180 N/cm^2 were found in plots "A" at 75 cm and "C" at 65 cm depths, respectively.

Normal and shear stresses in all three blocks in all replicates are presented in Table 1. The normal stresses were 40.95, 69.2 and 97.45 kN/m^2. The typical graphs of maximum shearing strength versus normal stress load at the depth 0-30 cm are shown in Figure 5. The results of the direct shear tests showed that the mean values of soil friction angle (φ) were 18.77°, 15.96° and 10.7 ° and mean values of cohesion (C) were 11.98, 11 and 12.05 kN/m^2 for blocks A, B and C, respectively. This indicates linear relationships between shear stress and normal stress thus, produced linear equations of $Y_A = 0.34X+11.98$, $R2 = 1.00$, $Y_B = 0.286X+11$, $R^2 = 0.982$ and $Y_C = 0.189X +12.05$, $R^2 = 0.99$ for blocks A, B and C, respectively.

Table 1. Shear stress at different normal stress for blocks A, B and C

Block	Replication	Normal stress 40.96kN/m^2 Shear Stress(kN/m^2)	Normal stress 69.2kN/m^2 Shear Stress(kN/m^2)	Normal stress 97.45kN/m^2 Shear Stress(kN/m^2)
A	1	33.27	36.89	39.10
	2	20.68	32.60	50.06
	3	23.84	37.12	46.33
B	1	23.84	34.97	50.06
	2	23.84	31.19	37.18
	3	22.37	22.49	31.30
C	1	20.62	27.97	35.82
	2	24.18	24.97	31.64
	3	16.61	18.67	26.10

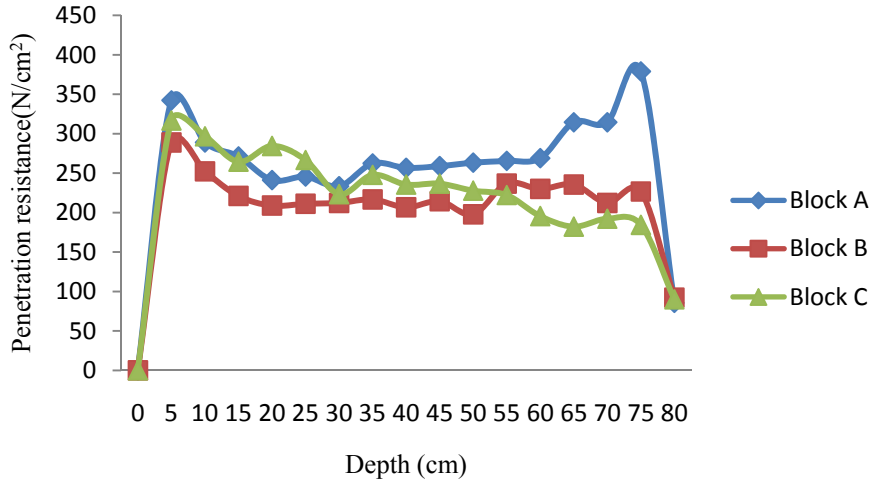


Figure 4. Soil penetration resistance in the experimental plots

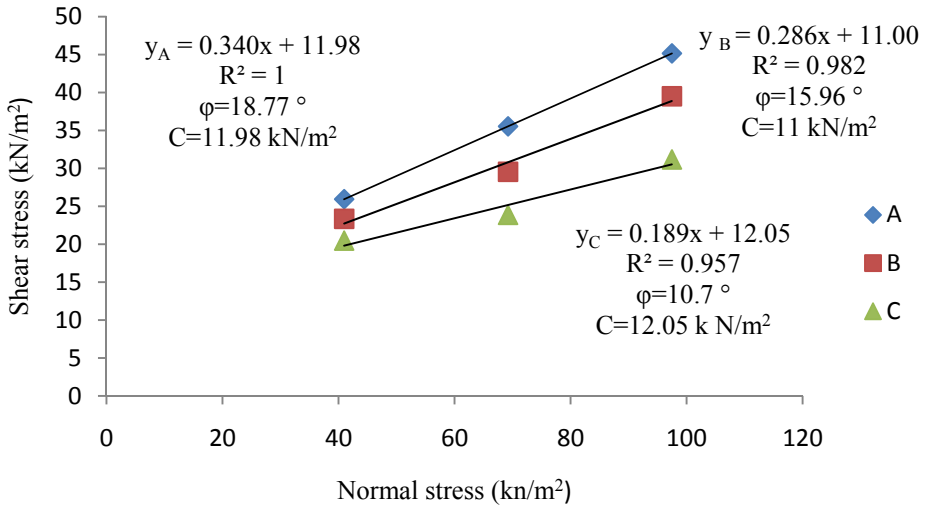


Figure 5. Maximum shear stress versus normal stress for blocks A, B and C

3.1 Effect of Type of Blade and Rotary Speed on MWD_w

There was a strong relationship between mean weight diameter (wet basis) with respect to type of rotary blade and rotational speed of blades. The rotational speed of blade was found to have significant effect on the mean weight diameter (wet basis) with the lowest value of 1.39 mm at the speed of 130 rpm (Tables 2-3 and Figure 6). Results showed significant differences ($p< 0.05\%$) with the highest value at 165 rpm rotational speed compared to the other speeds (Table 2). The values of the mean weight diameter (wet basis) were found to be 1.39, 1.66 and 1.73 mm at the rotational speeds of 130, 147 and 165 rpm, respectively. The significant ($p<0.001$) increase in the values of the mean weight diameter (wet basis) could be attributed to the rotary speed. The results for mean weight diameter (wet basis) proved that there were no significant differences between the types of blades. However, the highest value of the mean weight diameter (wet basis) was obtained with the curved type blade at 165 rpm (Figure 6). Furthermore, mean weight diameter (wet basis) of 1.63, 1.59 and 1.56 mm were obtained with the straight type blade, curved type blade and L-shaped blade, respectively. There was no significant interaction effect between rotary speed and type of blade (Table 3).

Table 2. Duncan's multiple range test on effect of blade type and rotary speed on mean weight diameter of soil aggregates (wet basis)

N	Type of blade	Mean (mm)
9	Straight type	1.63^{A}
9	Curved type	1.59^{A}
9	L-shaped	1.56^{A}

N	Speed (rpm)	Mean (mm)
9	165	1.73^{A}
9	147	1.66^{AB}
9	130	1.39^{B}

Means followed with the same superscript letter within the same column are not significantly different at $p<0.05$ according to Duncan's multiple range test (SAS1996)

Table 3. Analysis of variance table for effect of blade type and rotary speed on mean weight diameter of soil aggregates (wet basis)

S.O.V	d.f	M.S	F value	Pr>F
Block	2	5.36	72.98^{**}	0.0001<
Speed	2	0.28	3.87^{*}	0.0426
Blade	2	0.01	0.14^{ns}	0.8687
Blade×speed	4	0.02	0.29^{ns}	0.8775
Error	16	0.07		

** Significant at 1% level,* significant at 5% level and ns not significant;

C.V = 17.01% and R^2=90.65%;

S.O.V = Source of variance;

d.f = Degree of freedom;

M.S= Mean square

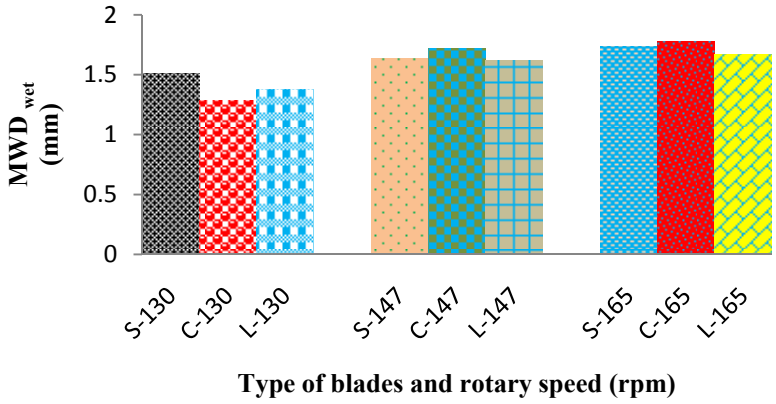


Figure 6. The effect of speed of rotary blades and type of blades on mean weight diameter of soil aggregates (wet basis)
(S= Straight type blade, C=curved type blade and L= L-shaped blade)

3.2 Effect of Type of Blade and Rotary Speed on Mean Weight Diameter of Soil Aggregates (Dry Basis)

Mean weight diameter (dry basis) was found to be significantly affected by the rotational speed of blade with the lowest value of 3.12 mm for the rotational speed of 165 rpm (Tables 4-5 and Figure 7). Results showed significantly ($p<0.001\%$) higher values at the 130 rpm rotational speed compared to the other speeds (Table 5). The mean weight diameters (dry basis) were 3.54, 3.28 and 3.12 mm at the speed of 130, 147 and 165 rpm, respectively. The increase in values (significant at 0.001<) of the mean weight diameter (dry basis) could be attributed to the rotary speed (Figure 7). The results on mean weight diameter showed that there was a significant difference between the types of blades. The highest mean weight diameter (dry basis) was obtained with the L-shaped blade (Table 5). The values of the mean weight diameter (dry basis) were 3.21, 3.36 and 3.38 mm with the straight type blade, curved type blade and L-shaped blade, respectively. There was a significant interaction effect between rotary speed and type of blades (Table 4). However, it was noted that the L-shaped blade at 130 rpm and straight type blade at 165 rpm recorded the maximum and minimum values of mean weight diameter (dry basis) respectively. These results were similar to the findings of Boyadas and Turgut (2007) who reported that operating speeds of mouldboard plough with rotary harrow significantly affected the mean weight diameter values. An increase in implement speed caused a decrease in mean weight diameter.

Table 4. Analysis of variance table for the effect of blade type and rotary speed on mean weight diameter of soil aggregates (dry basis)

S.O.V	d.f	M.S (mm)	F value	Pr>F
Blade	2	0.075	3.75*	0.0463
Speed	2	0.407	20.32**	<.0001
Block	2	0.408	20.41**	<.0001
Blade×speed	4	0.085	4.25*	0.016
Error	16	0.020		

** Significant at 1% level,* significant at 5% level and ns not significant;

C.V = 4.27 and R^2=86.87%;

S.O.V = Source of variance;

d.f = Degree of freedom;

M.S= Mean square

Table 5. Duncan's multiple range tests on effect of blade type and speed of rotary blades on mean weight diameter of soil aggregates (dry basis)

N	Type of Blade	Mean (mm)
9	L-shaped	3.38^{A}
9	Curved	3.36^{A}
9	Straight	3.21^{B}

N	Rotary Speed (rpm)	Mean (mm)
9	130	3.54 ^{A}
9	147	3.28^{B}
9	165	3.12 ^{C}

Means followed with the same superscript letter within the same column are not significantly different at $p<0.05$ according to Duncan's multiple range test (SAS1996)

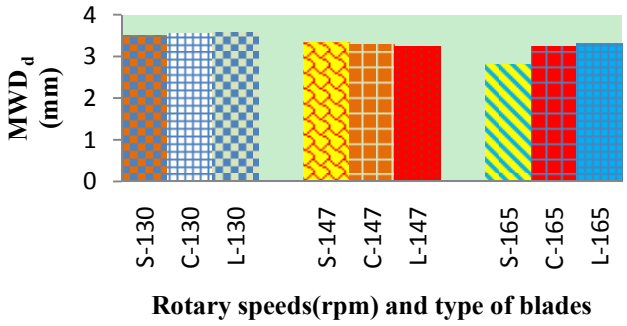


Figure 7. Effect of blade type and rotary speed on mean weight diameter of soil aggregates (dry basis)

(S= Straight type blade, C=curved type blade and L= L-shaped blade)

3.3 Effect of Type of Blade and Rotary Speed on Instability Index

Instability index was found to be significantly affected by the rotational speed of blades with the lowest value of 1.40 for the speed of 165 rpm (Figure 8 and Tables 6-7). Results showed a significantly ($p< 0.001\%$) higher value at 130 rpm compared to other speeds (Table 7). The values of mean of instability index obtained were 2.15, 1.63 and 1.40 at the speeds of 130, 147 and 165 rpm, respectively. The decrease (significant at 0.001<) in instability index is associated with the rotary speed (Figure 8). This means that an increase in rotary speed from 130 to 165 rpm decreases the instability index 0.76. The results for instability index showed that there was no significant difference between the types of blades. However the highest instability index value was obtained with the L-shaped blade (Table 7). The values of instability index of 1.82, 1.76 and 1.58 were obtained with the L-shaped blade, curved blade and straight type blade, respectively. There was no significant interaction effect found between rotary speed and type of blades (Table 7). However the highest and lowest instability index values were recorded with the curved type blade at 130rpm and straight type blade at 165 rpm, respectively (Figure 7).

Table 6. Analysis of variance table for the effect of blade type and rotary speed on instability index of soil aggregates

S.O.V	d.f	M.S	F value	Pr>F
Blade	2	0.1359	2.03^{ns}	0.1635
Speed	2	1.3556	20.28^{**}	<.0001
Block	2	5.955	89.10^{**}	<.0001
Blade×Speed	4	0.1052	1.57^{ns}	0.2294

** Significant at 1% level,* significant at 5% level and ns not significant

C.V = 15.03 and R^2=93.47%

S.O.V = Source of variance,

d.f = Degree of freedom

MS= Mean square

Table 7. Duncan's multiple range tests for effect of type of rotary blades and speed of rotary on Instability Index of soil aggregates

N	Type of Blade	Mean	Speed (rpm)	Mean
9	Straight	1.58^{A}	130	2.15^{A}
9	Curved	1.76^{A}	147	1.63^{B}
9	L-shaped	1.82^{A}	165	1.40^{B}

Means followed with the same superscript letter within the same column are not significantly different at $p<0.05$ according to Duncan's multiple range test (SAS1996)

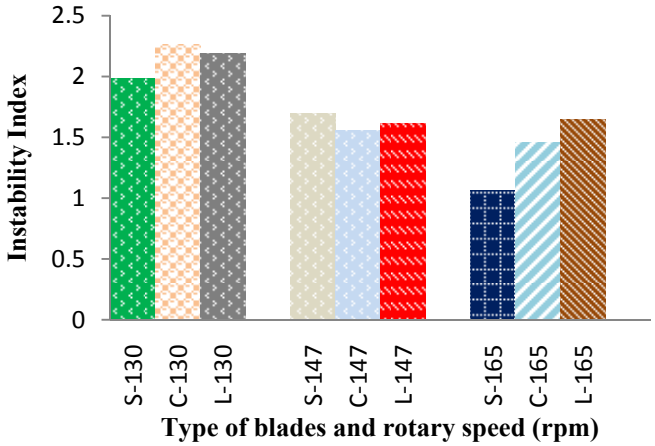


Figure 8. The effect of type of blades and speed of rotary blades on instability index of soil aggregates

(S= Straight type blade, C=curved type blade and L= L-shaped blade)

4. Conclusion

A Comboplow for land preparation has been successfully designed, fabricated and tested. The machine consists of a chassis, three point hitch, transmission system, disk, rear wheel, rotary blades and adjusting mechanism. The blades rotational velocity had high significant effect on selected parameters (MWD_d, MWD_w and II). The results for MWD_d showed that there was a significant difference among the types of blades. However, it was noted that the L-type blade at 130 rpm and S- type blade at 165 rpm had maximum and minimum values of MWD_d. The effect of types of blades was similar on MWD_w and II. The results of MWD_d and II suggest that the rotary blade speed of 130 rpm was highly effective than 147 and 165 rpm.

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