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Comparison of Vibrations, Tillage Depths and Soil Properties for Moldboard and Disk Plows at Three Tillage Speeds

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ABSTRACT

Vibration is a very important parameter in tillage operations because it influences the soil properties and draft force. Hence, this research used a mathematical model (Rayleigh method) to compare the two plows under vibration conditions. For greater accuracy, we considered the soil resistance force to cut and consistency as vertical forces and calculated them from actual loads. Further, we have also compared the depths of the moldboard and disk plows (20-25 and 15-20 cm, respectively) and certain important soil physics properties such as the bulk density and total porosity at three different speeds (1.5, 3 and 4 km h^{-1}). The moldboard plow exhibited higher vibrations and bulk density than the disk plow but the latter showed higher total porosity and soil resistance force to cut and consistency. Moreover, when the speed was increased from 1.5 to 4 km h^{-1}, the vibration soil resistance force to cut and consistency and bulk density increased while the total porosity decreased. Finally, the bulk density and soil resistance force to cut and consistency were higher at lower tillage depths, whereas the vibrations and total porosity were higher at higher tillage depths.

Key words: Vibration, moldboard plow, disk plow, tillage depth, bulk density

INTRODUCTION

Energy conservation in agriculture operations is becoming increasingly important for the viability of the modern agriculture industry. Moreover, the endless desire for increased productivity from agricultural operations is motivating intensive researches for realizing more efficient methods of soil and earth moving processes. For example, the vibratory tillage operations in the conventional tractive method have been investigated for the potential realization of more effective soil cutting, the potential of the forced vibration as a promising mean for soil pulverization and reducing the draft force and machine weight (Awad-Allah *et al.,* 2009).

An appropriate amount of vibrations in tillage tools is important for reducing soil compaction. Moreover, the draft forces and energy consumption required to loosen compact soils are high. It is well known that tillage-tool vibrations reduce the draft force during tillage operations if the maximum velocity of the oscillation is higher than the velocity of the implement. Moreover, the clod sizes decrease while the numbers of cracks in the soil increases which promote the penetration of plant roots, nutrients, water and air circulation in all the soils that are necessary for plant growth (Soeharsono and Setiawan, 2010).

Blade vibrations during the tillage process have considerable influence on the tillage resistance; for example, the resistance decreases under operating conditions wherein blade vibrations are required when driving mechanisms without vibrations are not suitable to meet the tillage requirements. Furthermore, researchers have shown that the tillage depth, tillage velocity and blade angle are directly proportional to the tillage resistance force, whereas the vibration frequency and amplitude have desirable inverse proportional effects. The required draft forces also increase with the tillage depth (Awad-Allah *et al.*, 2009).

Many recent investigations into the effects of vibrations have been motivated by the increasing possibilities of applying engineered vibrations. For example, Soeharsono and Sateiawan (2010).

Niyamapa and Salokhe (2000b) conducted experimental investigations into vibrating tillage tools and sandy loam soil; they concluded that the dry bulk density tends to increase with oscillating frequency. In their study, the dry bulk density increased by approximately 5.3 to 13.8, 17 to 20% and 5% at frequencies of 8.7, 13.9 and 0 Hz, respectively. On the other hand, it slightly decreased when the oscillating amplitude was increased from 59 to 77 mm.

The application of vibrations leads to a decrease in the required force and this becomes more apparent as the cutting depth increases. However, at shallow depths (0.01 m), the effects of vibrations are negligible due to the low soil resistance and the need to overcome the inertia forces of the blade masses (Awad-Allah *et al.*, 2009). Further, other experiments have been conducted in a soil bin by Niyamapa and Salokhe (2000a).

In this research, the force requirements and pressure distributions when using vibratory tillage tools have been studied and compared certain parameters such as vibrations and tillage depths and soil physics properties such as the bulk density and total porosity of the main equipments used in primary tillage systems-moldboard and disk plows-for tillage operations. A mathematical model (Rayleigh method) is used to compare the two plows under vibration conditions.

MATERIALS AND METHODS

Present research was conducted over three months from July 01, 2010 to September 01, 2010. For present experiment, A tractor Mighty Antar (Z81; Thornycroft) was used with 4 cylinders and 80 hp. Further, as the tillage equipment, we used a suspended moldboard plow with three shanks and a suspended disk plow with three disks (Mechanical Industries Company, Iraq); their technical specifications are listed in Table 1.

The core sample method was used to estimate the bulk density of the soil. Soil samples were first taken and then dried in an oven at 105°C for 24 h. The bulk density was then calculated using bulk density equation (Miller and Donahue, 1990).

The total porosity was estimated mathematically by applying the values of the real density and bulk density of soil in total porosity equation (Miller and Donahue, 1990).

Table 1: Technical Specifications of plows

Moldboard plow	Specifications	Disk plow	Specifications
Model	113	Model	131
No. of shanks	3	No. of disks	3
Total length	2390 mm	Total length	2250 mm
Total width	1130 mm	Total width	1150 mm
Total height	1190 mm	Total height	1350 mm
Total weight	370 kg	Total weight	465 kg
Weight of all the shanks	69.5 kg	Weight of all disks	102 kg

The soil resistance force to cutting and consistency is influenced by the width and depth of the tillage. This force was calculated using the following equation:

$$F_{RM} = BP \times RS \times D \text{ (kg f)}$$

Here, F_{RM} is the soil resistance force to cut and consistency (kg f); R_S, the soil resistivity of soil (kg cm^{-2}) and D, tillage depth (cm).

The natural frequency of the tillage equipments (moldboard and disk plows) was estimated using the Rayleigh method (Thomson, 1997). The actual load was estimated by distributing the mass for both tillage equipments in accordance with the Rayleigh method (Ozkose and Bagdatli, 2010) and then calculating the vertical forces that are equivalent to the soil resistance force to cut and consistency; the results are listed in Table 2.

Y represents the dimensions of the mass whose natural frequency is to be measured and it is obtained from the following equation:

$$\{y\} = [H]^* \{W\} \quad (1)$$

where, H is a matrix transformed using the following equation:

$$[H] = \begin{pmatrix} \delta_{ii} & \delta_{ij} & \delta_{ik} \\ \delta_{ji} & \delta_{jj} & \delta_{jk} \\ \delta_{ki} & \delta_{kj} & \delta_{kk} \end{pmatrix} \quad (2)$$

δ_{ki}, δ_{ii}, δ_{ki} are matrices estimated from the following three equation:

$$\delta_{ki} = \frac{Wb^2(3c-b)}{6EI}; \delta_{ii} = \frac{Wb^3}{3EI}; \delta_{ki} = \frac{Wb^2(3c-b)}{6EI} \quad (3)$$

where, a, b and c are constants for moldboards plow or disk plow (m) (Fig. 1), E; Young's modulus (modulus of elasticity; 207 GPa) and I; second moment of area (m^4).

As an example, consider the following calculations:

$$\delta_{33} \text{or} \delta_{kk} = \frac{Wb^3}{3EIeq} = \frac{1 * 0.4^3}{3EIeq} = \frac{0.064}{3EIeq} \quad (4)$$

Table 2: The effects of plows type on soil resistance force to cut and consistency without Vertical forces and with Vertical forces

		With vertical forces	
Plows	Without vertical forces	D1 (20-25 cm)	D2 (15-20 cm)
Moldboard plow	1079	948	543
	1177	850	445
	1373	654	240
Disk plow	1506	711	469
	1275	942	700
	1781	432	195

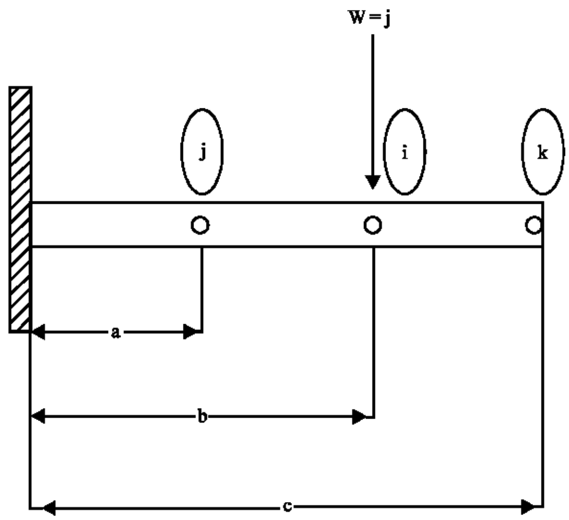

Fig. 1: Tillage equipment with a vibrating cantilever beam

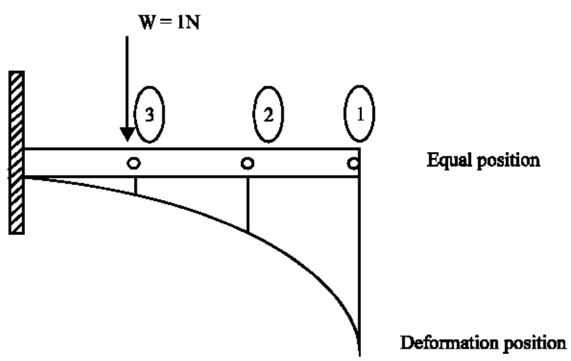

Fig. 2: Deflected beam shape after application of load

$$[H] = \frac{1}{3EIeq}\begin{pmatrix} \delta_{11} & \delta_{12} & \delta_{13} \\ \delta_{21} & \delta_{22} & \delta_{23} \\ \delta_{31} & \delta_{32} & 0.064 \end{pmatrix} \tag{5}$$

By performing similar calculations for the other terms, The obtain final results are as follows:

$$[H] = \frac{1}{3EIeq}\begin{pmatrix} 5.832 & 2.601 & 0.399 \\ 2.601 & 1.330 & 0.230 \\ 0.399 & 0.231 & 0.064 \end{pmatrix} \tag{6}$$

$$\{y\} = [H]*\{W\}$$

The actual load is:

$$\{W\} = \begin{Bmatrix} 948 \\ 850 \\ 654 \end{Bmatrix} N$$

$$\begin{Bmatrix} y_1 \\ y_2 \\ y_3 \end{Bmatrix} = \frac{1}{3EIeq}\begin{pmatrix} 5.832 & 2.601 & 0.399 \\ 2.601 & 1.335 & 0.231 \\ 0.399 & 0.231 & 0.064 \end{pmatrix}\begin{Bmatrix} 948 \\ 850 \\ 654 \end{Bmatrix} = \begin{Bmatrix} 3864763*10^{-9} \\ 1810960*10^{-9} \\ 298438*10^{-9} \end{Bmatrix} m$$

From the lumped masses procedure:

$$\omega_n = \sqrt{\frac{g\sum_{i=1}^{3} W_i y_i}{\sum_{i=1}^{3} W_i y_i^2}} = \sqrt{\frac{9.81\left[(948*(3864763*10^{-9}))+(850*(1810960*10^{-9}))+(654*(298438*10^{-9}))\right]}{948*(3864763*10^{-9})^2+850*(1810960*10^{-9})^2+654*(298438*10^{-9})^2}} \quad (7)$$

$$\omega_n = \sqrt{\frac{9.81*(3.66+1.54+0.195)}{0.014+(2.78*10^{-3})+(5.82*10^{-5})}} = 57 \text{ rad sec}^{-1}$$

RESULTS AND DISCUSSION

Bulk density: Bulk density and actual speed have a direct correlation with each other (Table 3), this is because as the speed increases, the coefficient of soil fragmentation by the momentum of the plow shank increases. This, in turn, leads to an increase in the cracking of earth mounds that micronize and fill the pores, thereby reducing the size and increasing the bulk density (Saxton *et al*., 1986).

Further, from Table 3, the bulk density for the moldboard plow (M) is higher than that for the disc plow (D). This is because of the difference in their mechanical design; in particular, the blade and actual tillage width of the shanks are different (Srivastava *et al*., 2006). Moreover, the bulk density for the highest tillage depth is more than that for the lowest tillage depth because the porosity increases with the depth, which, in turn, increases the density (Jabro *et al*., 2000; Tsimba *et al*., 1999).

Total porosity: The total porosity decreased as the speed increased (Table 4). Increasing the speed increases the coefficient of soil fragmentation due to the greater momentum of the plow shank and this, in turn, increases the cracking of the earth mounds, micronization and filling of the pores. Further, the porosity of the disk plow is higher than that of the moldboard plow because the moldboard plow has a higher bulk density and bulk density is inversely proportional to porosity.

Furthermore, as the depth increases, the porosity decreases since the fragmentation of the soil increases and this causes higher filling of the pores in the soil and reduction in the porosity (Abu-Hamdeh, 2002).

Table 3: The effects of tillage depth, plows type and different speeds on bulk density (g cm^{-3})

		Speed (km h^{-1})			
Depth	Plow	1.5	3	4	Average
D1	M	1.26	1.52	1.79	1.52
	D	1.05	1.48	1.83	1.45
	Average	1.155	1.50	1.81	
D2	M	1.23	1.20	1.60	1.34
	D	1.21	1.16	1.55	1.30
	Average	1.22	1.18	1.57	

M = Moldboard plow, D = Disc plow

Table 4: The effects of tillage depth ,plows type and different speeds on total porosity%

		Speed (km h^{-1})			
Depth	Plow	1.5	3	4	Average
D1	M	52.49	42.83	32.43	42.58
	D	60.51	44.34	31.18	45.34
	Average	56.50	43.58	31.80	
D2	M	53.50	54.88	39.83	49.40
	D	54.37	56.37	41.70	50.81
	Average	55.93	55.62	40.76	

M = Moldboard plow, D = Disc plow

Table 5: The effects of tillage depth, plows type and different speeds on soil resistance force to cut and consistency (kg f)

		Speed (km h^{-1})			
Depth	Plow	1.5	3	4	Average
D1	M	413.33	620.00	826.67	620
	D	451.37	677.60	903.47	
	Average	288.85	433.53	578.05	
D2	M	330.67	496.00	661.33	496
	D	402.87	604.30	805.73	604
	Average	366.77	550.15	733.53	

M = Moldboard plow, D = Disc plow

Table 6: The effects of tillage depth, plows type and different speeds on vibration (rad sec^{-1})

		Speed (km h^{-1})			
Depth	Plow	1.5	3	4	Average
D1	M	38.00	57	76.00	57
	D	32.00	48	64.00	48
	Average	28.83	36	48.00	
D2	M	49.33	74	98.67	74
	D	41.33	62	82.67	62
	Average	45.33	68	90.67	

M = Moldboard plow, D = Disc plow

Soil resistance force to cut and consistency: The soil resistance force to cut and consistency increased with the actual speed (Table 5) because an increase in the speed decreases the draft force that has an inverse relationship with the force (Spektor and Katz, 1985).

Table 5 also shows that the moldboard plow exhibited better results than the disk plow and has lower values of the soil resistance force to cut and consistency. This is because of the differences between the mechanical designs of the two plows; the width and angle of the shank in the moldboard plow reduce the force. Finally, Table 5 indicates that the soil resistance force increased with the depth since the required draft forces increase with the tillage depth.

Vibration: Table 6 shows that vibrations increased with the actual speed because the draft force decreased; the vibration is inversely proportional to the draft force (Schmidt and Tondl, 2009).

Further, the vibrations of the moldboard plow are higher than that of the disk plow because of the differences in their masses and mechanical designs (De-Silva, 2007; Kelly, 1996). Finally, the results show that increasing the depth reduces the vibration; this can be attributed to the low soil resistance as compared to the force required to overcome the inertial forces of the vibrating masses.

CONCLUSIONS

We conducted a study in order to compare two types of plows (moldboard and disk plows) in terms of certain parameters such as vibrations and soil physical properties such as bulk density. Increasing the speed (1.5, 3 and 4 km h^{-1}) increased the coefficient of soil fragmentation, thereby reducing the soil porosity (53.93, 55.62 and 40.76%, respectively) and increasing the bulk density (1.22, 1.18 and 1.57 g cm^{-3}, respectively). Moreover, increasing the speed reduced the draft forces and increased soil resistance force to cut and consistency (366.77, 550.15 and 733.53 kg f, respectively) and vibrations (45.33, 68, 90.67 rad sec^{-1}, respectively).

The shape and angle of the disk in a disk plow caused an increase in the number of soil pores (45.34, 50.81%), thereby decreasing bulk density (1.45, 1.30 g cm^{-3}, respectively) in contrast, the width and angle of the plow shank of a moldboard plow led to the lowest value of the soil resistance force to cut and consistency (620, 496 kg f) possible. On the other hand, the vibration was minimum in the case of disc plows (48, 62 rad sec^{-1}). Note that this is compatible with the general rule of vibration-the more weight, the less the vibration.

Further, increase in depth reduced the size of the pores (50.10, 43.96%) of the soil; this, in turn, increased the bulk density (1.30, 1.48 g cm^{-3}, respectively). On the other hand, an increase in the depth decreased the draft force, which increased the soil resistance force to cut and consistency (550.15, 648.8 kg f, respectively); vibrations also decreased (68, 52.5 rad sec^{-1}, respectively) since the soil resistance was lower than the force required to overcome the inertia forces of the vibrating masses.

Therefore, this study have experimentally compared the performance of moldboard and disk plows in terms of their vibrations.

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